TEXT-BOOK OF GEOLOGY

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STRATIGRAPHICAL GEOLOGY
(CONTINUED)

PART III. MESOZOIC OR SECONDARY

THOUGH no geologist now admits the abrupt lines of division which were at one time believed to mark off the limits of geological systems and to bear witness to the great terrestrial revolutions by which these systems were supposed to have been terminated, nevertheless the influence of the ideas which gave life to these banished beliefs is by no means extinct. The threefold division of the stratified rocks of the terrestrial crust into Primary, Secondary, and Tertiary, or, as they are now called, Palæozoic, Mesozoic, and Cainozoic, is a relic of those ideas. This threefold arrangement is retained, however, not because each of these great periods of geological time is thought to have been separated by any marked geological or geographical episode from the period which preceded or that which followed it, but because, classification and subdivision being necessary in the acquisition of knowledge, this grouping of the earth's stratified formations into three great series is convenient. In our survey of the older members of these formations we have come to the end of the first series of fossiliferous systems, and are about to enter upon the consideration of the second. But we find no indication in the rocks of any general break in the continuity of the processes of sedimentation and of life which we have seen to be recorded among the Palæozoic rocks. On the contrary, so insensibly do the Palæozoic formations in many places merge into the Mesozoic, that not only can no sharp line be drawn between them, but it has even been proposed to embrace the strata at the top of the one series and the base of the other as parts of a single continuous system of deposits.

Nevertheless, when we look at the Mesozoic rocks as a whole, and contrast them with the Palæozoic rocks below them, certain broad distinctions readily present themselves. Whereas in the older series mechanical sediments form the prevalent constituents, piled up in masses of graywacke, sandstone, conglomerate, and shale often many thousands of feet in thickness, in the newer series limestones play a much more conspicuous part. Again, while in the Palæozoic formations a single kind of sediment may continue monotonously persistent for many hundreds or even thousands of feet of vertical depth, in the Mesozoic series, though thick accumulations of one kind of material, especially limestone, are locally developed, there is a much more general tendency toward frequent alternations of different kinds of sedimentary material, sandstones, shales, and limestones succeeding each other in rapid interchange. Another contrast between the two series is supplied by the very different extent to which they have suffered from terrestrial disturbances. Among the Palæozoic rocks it is the rule for the strata to have been thrown into various inclined positions, to have been dislocated by faults, and in many regions to have been crumpled, pushed over each other, and even metamorphosed. The exceptions to this rule are so few that they are always signalized as of special interest. Among the Mesozoic rocks, on the contrary, the original stratification-planes have usually been little deranged, faults are generally few and trifling, and it is for the most part only along the flanks or axes of great mountain-chains that extreme dislocation and disturbance can be observed. A further distinction is to be found in the relation of the two series to volcanic activity. We have seen in the foregoing chapters that every period of Palæozoic time has been marked somewhere in the Old World by volcanic eruptions, that in certain regions, such as that of the British Isles, there has been an abundant outpouring of volcanic material again and again in successive geological periods within the same limited area, and thus that masses of lava and tuff thousands of feet in thickness, and sometimes covering hundreds of square miles in extent, have been thrown out at the surface. But in the European area, with some trifling exceptions at the beginning, the whole of the Mesozoic ages appear to have been unbroken by volcanic eruptions. The felsites, rhyolites, porphyrites, diabases, basalts, and other lavas and eruptive rocks so plentiful among the Primary formations are generally absent from the Secondary series.

But perhaps the most striking, and certainly the most interesting, contrast between the rocks of the older and the newer series is supplied in their respective organic remains. The vegetable world undergoes a remarkable transformation. The ancient preponderance of cryptogamic forms now ceases. The antique types of Sigillaria, Stigmaria, Lepidodendron, Calamites, and their allies disappear from the land, and their places are taken by cycads and conifers, while eventually the earliest monocotyledons come as the vanguard of the rich flora of existing time. Nor are the changes less marked in the animal world. Such ancient and persistent types as the graptolites and trilobites had now wholly vanished. The crinoids, that grew so luxuriantly over the sea-floor in older time, now flourished in greatly diminished numbers, while the urchins, which had previously occupied a very subordinate position, took their place as the most conspicuous group of the Echinoderms. The brachiopods, which from the remotest time had filled so prominent a place among the mollusks, now rapidly diminished in number and variety. Among the cephalopods the Palæozoic type of the Orthoceratites was succeeded by the Mesozoic type of the Ammonites. But perhaps the most distinctive feature of the fauna was the variety and abundance of reptilian life. The labyrinthodont amphibians were replaced by many new orders, such as the Ichthyosaurs, Plesiosaurs, Ornithosaurs, Deinosaurs, and Crocodiles. It was in Mesozoic time also that the first mammals made their appearance in marsupial forms, which remained the highest types that were reached before the beginning of the Cainozoic periods.

The Mesozoic formations have been grouped in three great divisions, which, though first defined in Europe, are found to have their representative series of rocks and fossils all over the world. The oldest of these is the Trias or Triassic system, followed by the Jurassic and Cretaceous.

Section i. Triassic

It has been already mentioned that the great mass of red-rocks, which in England overlie the Carboniferous system, were formerly classed together as New Red Sandstone, but are now ranged in two systems. We have considered the lower of these under the name of Permian. The general facies of organic remains in that division is still decidedly Palæozoic. Its brachiopods and its plants connect it with the Carboniferous rocks below. Hence it is placed at the close of the long series of Palæozoic formations. When, however, we enter the upper division of the red rocks, though the general lithological characters remain in most of Europe very much as in the lower group, the fossils bring before us the advent of the great Mesozoic flora and fauna. This group therefore is put at the base of the Mesozoic or Secondary series, though in some regions, as in England, no very satisfactory line of demarcation can always be drawn between Permian and Triassic rocks. The term Trias was suggested by F. von Alberti in 1834, from the fact that in Swabia, and throughout most of Germany, the group consists of three well-marked subdivisions.[1] But the old name, New Red Sandstone, is familiarly retained by many geologists in England. The word Trias, like Dyas, is unfortunately chosen, for it elevates a mere local character into an importance which it does not deserve. The threefold subdivision, though so distinct in Germany, disappears elsewhere.

§ 1. General Characters

As the term Trias arose in Germany, so the development of the Triassic rocks in that and adjoining parts of Europe has been accepted as the normal type of the system. There can be little doubt, however, that though this type is best

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[1] "Beitrag zu einer Monographie des Bunten Sandsteins, Muschelkalks, und Keupers und die Verbindung dieser Gebilde zu einer Formation," Stuttgart, 1834, p. 324. Thirty years later the same observer published his "Ueberblick über die Trias," 1864, and gave a synopsis of the Triassic literature of that interval.

known, and has been traced in detached areas over the centre and west of Europe, from Saxony and Franconia to the north of Ireland, and from Basel to the Germanic plain, reappearing even among the Eastern States of North America, it must be looked upon as a local phenomenon. This assertion commends itself to our acceptance, when we reflect upon the nature of the strata of the central European Triassic basins. These rocks consist for the most part of bright red sandstones and clays or marls, often ripple-marked, sun-cracked, rain-pitted, and marked with animal footprints. They contain layers, nodules, or veinings of gypsum, beds (and scattered casts of crystals) of rock-salt, and bands or massive beds of limestone, often dolomitic. Such an association of materials points to isolated basins of deposit, or salt-lakes or inland seas, to which the outer sea found occasional access, and in which the water underwent concentration, until its gypsum and salt were thrown down. That the intervals of diminished salinity, during which the sea renewed, and perhaps maintained, a connection with the basins, were occasionally of some duration, is shown by the thickness and fossiliferous nature of the limestones.

It is evident, however, that in this, as in all other geological periods, the prevalent type of sedimentation must have been that of the open sea. The thoroughly marine or pelagic equivalents of the red rocks of the basins have now been traced over a far wider portion of the earth's surface. In the Alps and thence eastward through the Carpathian Mountains and southern Russia into the heart of Asia and northern India, as well as southward into Italy and Spain, the deposits of the open Triassic sea are well developed. Masses of limestone and dolomite, attaining sometimes a thickness of several thousands of feet, are there replete with a characteristically marine fauna. The same fauna has been detected over a wide region of the north of Asia from Spitzbergen to Japan, the western regions of North and South America, in New Zealand, and in Southern Africa.

LIFE.—The flora of the Triassic period appears to have been closely similar to that of the Permian. It consisted mainly of ferns (some of them arborescent), equisetums, conifers, and cycads. Among the ferns, a few Carboniferous genera (Sphenopteris, Pecopteris, Cyclopteris) still survive, together with Glossopteris, Tæniopteris, Caulopteris, and other old genera, but new forms have appeared (Anomopteris, Acrostichites, Clathropteris, Lepidopteris, Merianopteris, Neuropteridium [Crematopteris], Sagenopteris). The earliest undoubted horsetail reeds occur in this system. Here they are represented by the two genera Equisetum (Fig. 377) and Schizoneura. The latter genus died out in the Jurassic period, but the former is still represented by twenty-five living species. The conifers are represented by Voltzia, the cypress-like or spruce-like twigs of which are specially characteristic organisms of the Trias (Fig. 378), and by Albertia. But the most distinctive feature in the flora of the earlier Mesozoic ages was the great development of cycadaceous vegetation. The most abundant genus is Pterophyllum; others are Nilssonia, Zamites, Podozamites, Ptilophyllum, Otozamites. So typical are these plants that the

Fig. 377.—Equisetum columnare, Brongn. (½).

Mesozoic formations have been classed as belonging to the "Age of Cycads." Calcareous algæ (Gyroporella, etc.) abounded in the open seas of the time and contributed to the growth of limestone reefs.

The fauna is exceedingly scanty in the red sandy and marly strata of the central European Trias, and comparatively poor in forms, though often abundant in individuals,

Fig. 378.—Voltzia heterophylla, Brongn.

in the calcareous zones of the same region. From the Alpine development, a much more varied suite of organisms has been disinterred. Some of the Alpine limestones are full of foraminifera (Orbulina, Globigerina), others contain numerous calcareous sponges (Eudea, Verticellites, Peronella, etc.). Corals abound in some localities in the same rocks, occasionally forming true reefs. Echinoderms are plentiful among the limestones, particularly crinoid-stems, of which these rocks are in some cases almost wholly composed. One of the most characteristic fossils of the Muschelkalk is the Encrinus liliiformis (Fig. 379). Species of urchins (Cidaris) are common in the Alpine Trias. An

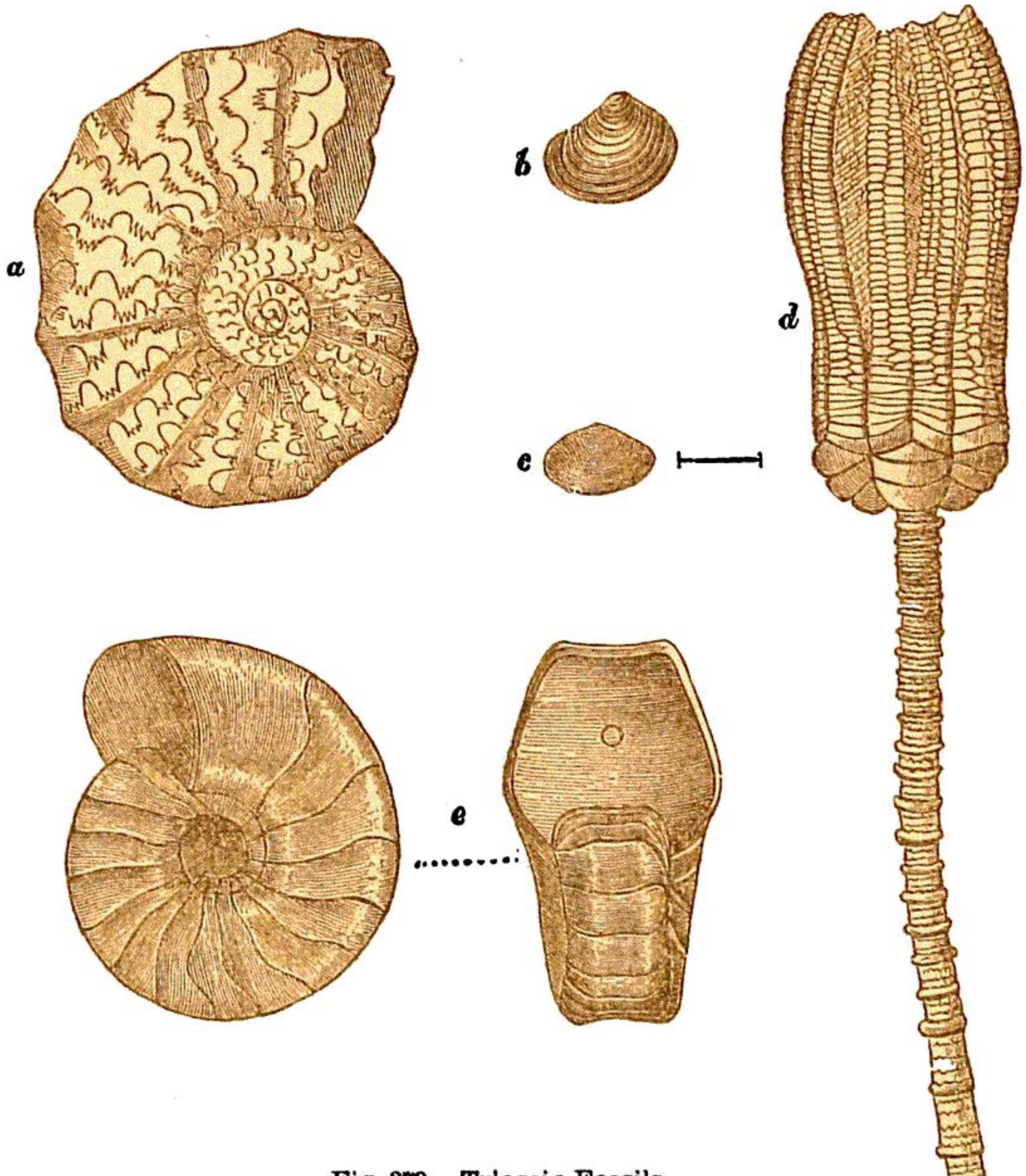

Fig. 379.—Triassic Fossils.
a, Ceratites nodosus, De Hann.; *b*, Estheria minuta, Goldf. ($\frac{4}{1}$); *c*, Pullastra arenicola, Strickland (nat. size and enlarged); *d*, Encrinus liliiformis, Schloth. (nat. size); *e*, Nautilus bidorsatus, Schloth. ($\frac{1}{3}$).

abundant fossil in some of the upper Triassic and Rhætic shales is the little phyllopod Estheria (Fig. 379, *b*). Long-tailed decapods, like our living shrimps and prawns, were well represented (Penæus, Æger, Pemphyx, etc.). The brachiopods, while showing some resemblances to those of

Palæozoic time, present on the whole a great contrast to these in their comparatively diminished numbers, and in the final disappearance of some of the ancient genera. Thus Athyris and Retzia, which survived from Upper Silurian into Triassic time, then disappeared; Cyrtina, which began in the Devonian period, likewise died out in the Triassic seas, while its contemporary Spiriferina continued to flourish until the time of the Lias. Although species of Spiriferina, Athyris, and Retzia are common, the two most conspicuous genera of brachiopods are Terebratula and Rhynchonella, and they continued to hold this position during the whole of the Mesozoic ages.

While the brachiopods were waning, the lamellibranchs were taking a more prominent place in the molluscan fauna, and in the Triassic seas they had already established the predominance which they have maintained down to the present day. One of the most distinctively Triassic genera is Myophoria, of which there is a great abundance and variety of species. Pecten, Daonella, Hinnites, Monotis, Lima, Gervillia, Anoplophora, Avicula, Cardium, Cardita, Megalodon, Nucula, Cassianella, Pullastra (Fig. 379, *c*), likewise occur throughout the system. Among gasteropods we find representatives of some Palæozoic types (Naticopsis, Loxonema, Macrocheilus, Murchisonia), together with genera characteristic of Secondary time, and some of which even continue to live now (Turritella, Cerithium, Chemnitzia, Solarium).

In no feature is the contrast between the palæontological poverty of the German and the richness of the Alpine Trias so marked as in the development of cephalopods in the respective regions. In the former area the nautili are represented chiefly by a few species of Nautilus (N. bidorsatus,

Fig. 379, *e*), and the Ammonites by species of Ceratites (C. nodosus, Fig. 379, *a*; C. semipartitus). In the Alpine limestones, however, there occurs a profusion of cephalopod forms, among which a remarkable commingling of Palæozoic and Mesozoic types is noticeable. The genus Orthoceras, so typical of the Palæozoic rocks, has never yet been met with in the German Triassic areas; but it appears in the Alpine Trias in species which do not differ much from those of the older formations. Associated with it are many forms of the ancient and still surviving type of the Nautilus. It is especially interesting amid these examples of the persistence of primeval forms to notice the advent of the earliest precursors of types which played a conspicuous part in the animal life of later periods. Thus the family of the Belemnites, which appeared so prominently among the denizens of the Mesozoic seas, had its earliest known forms in the open waters of Triassic time (Aulacoceras, Atractites). Though the earliest Ammonites had appeared long before, it was not until Triassic time that this great order began to assume the importance which it maintained all through the Mesozoic ages. So long as only the German type of the Trias had been studied this early development was not known. But now besides the Ceratites, which also ranged into the opener Triassic waters, we have become acquainted with a remarkable variety of ammonoid types (Arcestes, Didymites, Halorites, Tropites, Rhabdoceras, Ptychites, Sageceras, Trachyceras, Pinacoceras, Lobites, Cladiscites, Megaphyllites).

The fishes of the Triassic period include teeth and spines of elasmobranchs (Hybodus, Acrodus), scales, teeth, or exoskeletons of ganoids (Gyrolepis, Dapedius, Semionotus, Lepidotus, Nephrotus, Saurichthys, Eugnathus) and teeth of the dipnoan genus Ceratodus.

One of the distinctive palæontological features of the Trias is the remarkable assemblage of amphibian and reptilian remains found in it. The ancient order of Labyrinthodonts still flourished; numerous prints of their feet have been observed on surfaces of sandstone beds, and the bones of some of them have been found (Trematosaurus, Mastodonsaurus, etc.). The rhynchocephalous reptiles, which are now almost extinct, first appear in Permian, and are well represented in Triassic rocks. Bones, and sometimes even nearly entire skeletons, of several have been discovered, the most important genera being Telerpeton, Hyperodapedon, and Rhynchosaurus. It is noteworthy that while these various forms are by no means abundant in the Triassic system generally, they have been obtained in considerable numbers from one or two localities. In Britain the most prolific deposit for them is the pale sandstone of Elgin, in the north of Scotland, formerly believed to be Upper Old Red Sandstone. This rock contains the remains chiefly in the form of empty casts. Besides the small lizard, Telerpeton, described by Mantell in 1852, as well as the larger possibly allied form Hyperodapedon, the sandstone has recently yielded a number of new forms of Anomodonts which present a curious resemblance to those found in the South African deposit to be immediately referred to. These skulls and skeletons have been skilfully worked out and described by Mr. E. T. Newton of the Geological Survey.[2] One of them, Gordonia, was nearly allied to Dicynodon (Owen), Geikia was closely related to Ptychognathus, while Elginia was a remarkable many-horned animal distantly allied to Pareiasaurus (Owen). The South African formation, to which allusion has been

[2] Phil. Trans. 1893.

made, is known as the "Karoo beds," which, extending over a vast region in the south of the continent, have furnished an interesting assemblage of vertebrate remains. Among these there occur Labyrinthodonts (Micropholis, Petrophryne, Saurosternon), Anomodonts (Tapinocephalus, Pareiasaurus, Anthodon), and a large number of genera belonging to a remarkable carnivorous order, the Theriodonts, distinguished by having three sets of teeth, like those of carnivorous mammals (Lycosaurus, Tigrisuchus, Cynodracon, etc.). There were likewise examples of Dicynodonts, characterized by having no teeth, or by a single tusk-like pair, the jaws being probably prolonged into a horny beak. The limbs of these creatures were well developed, and the animals probably walked on the land (Dicynodon, Oudenodon, etc.).[3] The earliest deinosaurs yet known occur in this system (Thecodontosaurus, Teratosaurus, Palæosaurus, Cladyodon, Plateosaurus [Zanclodon], Ammosaurus, Anchisaurus, etc.).[4] These long-extinct types of reptilian life presented characters in some measure intermediate between those of the ostriches and true reptiles, and their size and unwieldiness gave them a resemblance to the elephants and rhinoceroses of modern times. They appear to have walked mainly on their strong hind legs, the prints of their hind feet occurring in great abundance among the red sandstones of Connecticut. Many of them had three bird-like toes, and left footprints quite like those

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[3] Owen's "Catalogue of Fossil Reptilia of South Africa," Brit. Museum, 1876.

[4] See on deinosaurs of the Trias, Huxley, Q. J. Geol. Soc. xxvi. 32. In the year 1877, a slab of the "Stubensandstein" near Stuttgart was obtained, in which were twenty-four individuals of "a mailed bird-lizard," named Aëtosaurus, probably a deinosaur with lacertilian characters. O. Fraas, Jahrb. Ver. Nat. Würtemberg, xxxiii. 1877. For the Triassic deinosaurs of Connecticut see Marsh, Amer. Journ. Sci. xxxvii. 1889, p. 331; xlii. 1891, p. 267; xliii. 1892, p. 542; xlv. 1893, p. 169.

of birds. Others had four or even five toes, and attained an enormous size, for a single footprint sometimes measures twenty inches in length.

The ichthyosaurs and plesiosaurs, which played so foremost a part in the reptilian life of Mesozoic time, had their Triassic forerunners (Ichthyosaurus, Nothosaurus, Simosaurus, Neusticosaurus). Of higher grade were the earliest types of crocodiles, the remains of which have been detected in Triassic rocks. They belong to an extremely generalized type, and appear to have been widely distributed. Stagonolepis occurs among the other reptilian remains at Elgin,[5] while Phytosaurus (Belodon) has been obtained in Germany, India, and North America.

It has been supposed that evidence of the existence of Triassic birds is furnished by the three-toed footprints above referred to. But probably these are mostly, if not entirely, the tracks of deinosaurs, the absence of two pairs of prints in each track being accounted for by the bird-like habit of the animals in the use of their hind feet in walking. One of the most noteworthy facts in the palæontology of the Trias is the occurrence in this system of the first relics of mammalian life. These consist of detached teeth and lower jaw-bones, referred to small marsupial animals allied to the Myrmecobius, or Banded Ant-eater of New South Wales. The European genus is Microlestes (Hypsiprymnopsis). In the Trias of North Carolina an allied form has been described under the name of Dromatherium.

§ 2. Local Development

Britain.[6]—Triassic rocks occupy a large area of the low

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[5] On the Crocodilian remains of the Elgin Sandstone see Huxley, Quart. Journ. Geol. Soc. 1859; Mem. Geol. Surv. Monograph iii. 1877.

[6] See E. Hull, "Permian and Triassic Rocks of England," Geological Survey Memoirs, 1869; H. B. Woodward, Geol. Mag. 1874, p. 385; "Geology of East

plains in the centre of England, ranging thence northward along the flanks of the Carboniferous tracts to Lancaster Bay, and southward by the head of the Bristol Channel to the southeast of Devonshire. They have been arranged in the following subdivisions:

Rhætic[7]	Penarth beds.—Red, green, and gray marls, black shales, and "White Lias"—20 feet or less up to 150 feet.
Upper Trias or Keuper	Upper Keuper or New Red Marl.—Red and gray shales and marls, with beds of rock-salt and gypsum—800 to 3000 feet. Lower Keuper Sandstone.—Thinly laminated micaceous sandstones and marls (waterstones), passing downward into white, brown, or reddish sandstones, with a base of conglomerate or breccia—150 to 250 feet.
Lower Trias or Bunter (1000 to 2000 feet)	Upper Mottled Sandstone.—Soft bright red and variegated sandstones, without pebbles—200 to 700 feet. Pebble-beds.—Harder reddish-brown sandstones with quartzose pebbles, passing into conglomerate; with a base of calcareous beccia—60 to more than 1000 feet. Lower Mottled Sandstone.—Soft bright red and variegated sandstone, without pebbles—80 to 650 feet.

Like the Permian red rocks below, the sandstones and marls of the Triassic series are almost barren of organic remains. Extraordinary differences in the development of their several members occur, even within the limited area of England, as may be seen from the subjoined table, which shows the variations in thickness from northwest to southeast:

		Lancashire and W. Cheshire.	Staffordshire	Leicestershire and Warwickshire
		Feet	Feet	Feet
Keuper	Red marl . . .	3000	800	700
Keuper	Lower Keuper sandstone	450	200	150
Bunter	Upper mottled sandstone	500	50–200	absent
Bunter	Pebble-beds . . .	500–750	100–300	0–100
Bunter	Lower mottled sandstone	200–500	0–100	absent

Somerset and Bristol Coal-fields," Mem. Geol. Survey, 1876; Ussher, Q. J. Geol. Soc. xxxii. 367; xxxiv. 459; Geol. Mag. 1875, p. 163; Proc. Somerset. Arch. Nat. Hist. Soc. xxxv. 1889; Etheridge, Q. J. Geol. Soc. xxvi. 174; A. Irving, Geol. Mag. 1874, p. 314; 1887, p. 309; Quart. Journ. Geol. Soc. 1888, p. 149; W. T. Aveline, op. cit. 1877, p. 380; J. G. Goodchild, Trans. Cumberl. Westmorel. Assoc. xvii. 1891–92.

[7] The term "Rhætic" is derived from the Rhætian Alps, where the rocks so named are well developed. "Bunter" and "Keuper" are terms borrowed from Germany; the first was taken by Werner from the variegated (German, bunt) colors of the strata, the second is a local miner's term.

Hence we observe that, while toward the northwest the Triassic rocks attain a maximum depth of 5200 feet, they rapidly come down to a fifth or sixth of that thickness as they pass toward the southeast. Southwestward, however, they swell out in Devon and Somerset to probably not less than 2500 or 3000 feet.[8] Recent borings in the southeastern counties show the Trias to be there generally absent.[9] The main source of supply of the sediment which formed the material of the Triassic deposits probably lay toward the north or northwest. The pebble-beds, besides local materials, contain abundant rolled pebbles of quartz, which have evidently been derived from some previous conglomerate, probably from some of the Old Red Sandstone masses now removed or concealed. The Trias rests with a more or less decided unconformability on the rocks underneath it, so that, although the general physical conditions as regards climate, geography, and sedimentation, which prevailed in the Permian period, still continued, terrestrial movements had, in the meanwhile, taken place, whereby the Permian sediments were generally upraised and exposed to denudation. Hence the Trias rests now on Permian, now on Carboniferous, and sometimes even on Cambrian rocks. Moreover, the upper parts of the Triassic series overlap the lower, so that the Keuper groups repose successively on Permian and Carboniferous rocks.

The Bunter series is singularly devoid of organic remains. The rolled fragments in the pebble-beds have yielded fossils at Budleigh Salterton, on the southern coast of Devonshire, proving that Silurian and Devonian rocks were exposed within the area from which the materials of these strata were derived. The peculiar quartzites of the Budleigh Salterton pebbles do not seem to have come from any British rocks now visible, but rather to have been derived from the northwest of France.[10] A marked characteristic of the Bunter series in central England is its capacity for holding water, whence it is an important source of water-supply.

At the base of the Keuper series, in the region of the

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[8] Ussher, Q. J. Geol. Soc. xxxii. 392.

[9] Red strata in the deep boring at Richmond are believed by Prof. Judd to be Triassic. Mr. Whitaker regards as Trias similar rocks found under Kentish Town and Crossness near London.

[10] For an account of their included fossils see Davidson, Palæontograph. Soc. 1881.

Mendip Hills, a remarkable littoral breccia or conglomerate occurs. Over Carboniferous Limestone it consists mainly of limestone, and is precisely like "brockram" (p. 1402), but in the slaty tracts of Devonshire, the fragments are of slate, porphyry, granite, etc. Its matrix being sometimes dolomitic, it has been called the Dolomitic conglomerate; but it occasionally passes into a magnesian limestone. It represents the shore deposits of the Trias salt-lake or inland sea, and, as it lies on many successive horizons, we see that the conditions for its formation persisted during the subsidence by which the Mendips and other land of this region were gradually depressed and obliterated under the red sandstones and marls (see Figs. 219, 220, 221).[11] The Dolomitic conglomerate averages 20 feet in thickness, but here and there rises into cliffs 40 or 50 feet high. It has yielded two genera of deinosaurs (Palæosaurus, Thecodontosaurus).[12] Some geologists have regarded this band of rock as an English representative of the German Muschelkalk. But the manner in which it ascends along what was the margin of the Triassic land shows it to be a local base occupying successive horizons in the red rocks. There is no equivalent of the Muschelkalk in Britain, unless the middle division of the Devonshire Trias can be so regarded.[13]

The lower Keuper group is composed of red and white sandstones with occasional lenticular bands of coarser material, and like the corresponding strata in the Bunter group, is generally unfossiliferous, but has furnished many amphibian footprints. The surfaces of the sandstone-beds are likewise impressed with rain-drops and are marked with desiccation-cracks and ripple-marks, suggestive of flat shores exposed to the air.

In the upper Keuper group the sediments were generally muddy and now appear as red and variegated marls with occasional partings of sandstone or bands of dolomite or gypsum. Among these strata are beds of rock-salt varying from a few inches to more than 100 feet in thickness. The marly character of the upper Keuper is a distinguishing feature of the group from the south of Scotland to the south of Devonshire, and from Antrim to the east of Yorkshire. Throughout this wide area cubical casts of salt (chloride

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[11] De la Beche, Mem. Geol. Survey, i. p. 240. H. B. Woodward, "Geology of East Somerset and Bristol Coal-fields," Mem. Geol. Survey, 1876, p. 53.

[12] Etheridge, Q. J. Geol. Soc. xxvi. 174.

[13] Ussher, op. cit. xxiv. p. 469.

of sodium) are not infrequent, though this substance is only workable at a few places (Antrim, Cheshire, Middlesbrough[14]). The salt is chiefly obtained by dissolving the material underground and pumping up the brine, very little being now actually mined. The rock-salt as it occurs intercalated in the marls is a crystalline substance, usually tinged yellow or red from intermixture of clay and peroxide of iron, but is tolerably pure in the best parts of the beds, where the proportion of chloride of sodium is as much as 98 per cent. Through the bright red marls with which the salt is interstratified there run thin seams of rock-salt, also bands of gypsum, somewhat irregular in their mode of occurrence, sometimes reaching a thickness of 40 feet and upward.

The paucity of organic remains in the English Keuper indicates that the conditions for at least animal life must have been extremely unfavorable in the waters of the ancient Dead Sea wherein these red rocks were accumulated. The land possessed a vegetation which, from the fragments yet known, seems to have consisted in large measure of cypress-like coniferous trees (Voltzia, Walchia), with calamites on the lower more marshy grounds. The red marl group contains in some of its layers numerous valves of the little crustacean Estheria minuta, and a solitary species of lamellibranch, Pullastra arenicola. A number of teeth, spines, and sometimes entire skeletons of fish have been obtained (Dipteronotus cyphus, Palæoniscus superstes, Hybodus Keuperi, Acrodus minimus, Sphenonchus minimus, etc.). The bones, and still more frequently the footprints, of labyrinthodont and even of saurian reptiles occur in the Keuper beds—Labyrinthodon (4 species), Cladyodon Lloydii, Hyperodapedon, Palæosaurus, Zanclodon (Teratosaurus), Thecodontosaurus, Rhynchonosaurus, and footprints of Cheirotherium. The remains of the small marsupial Microlestes have likewise been discovered in the highest beds sometimes taken as the base of the Rhætic series.

At the top of the Keuper marl certain thin-bedded strata form a gradation upward into the base of the Jurassic system. As their colors are gray, blue, and black, and contrast with the red and green marls below, they were formerly classed without hesitation in the Jurassic series. Egerton,

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[14] T. Hugh Bell on salt deposits of Middlesbrough, Proc. Cleveland Inst. Engin., Session 1882–83.

however, showed that, from the character of the fish remains found in the "bone-bed" of the black shales, they had more palæontological affinity with the Trias than with the Lias. Subsequent research, particularly among the Rhætian Alps and elsewhere on the Continent, brought to light a great series of strata of intermediate characters between the previously recognized Trias and Lias. These results led to renewed examination of the so-called beds of passage in England (Penarth beds),[15] which were found to be truly representative of the massive formations of the Tyrolese and Swiss Alps. They are therefore now known as Rhætic (sometimes as Infra-Lias), and are usually classed as the uppermost member of the Trias, but offering evidence of the gradual approach of the physical geography and characteristic fauna and flora of the Jurassic period.

The Rhætic (Penarth) beds occur as a continuous though thin band at the top of the Trias, throughout the British area. They extend from the coast of Yorkshire across England to Lyme Regis on the Dorsetshire shores.[16] They occur in scattered patches up the west of England, and on both sides of the Bristol Channel, and they may be detected even in the north of Scotland. Their thickness, on the average, is probably not more than 50 feet, though it rarely increases to 150 feet. In the southwest of England, they consist of the following subdivisions in descending order:

White Lias—composed of an upper hard limestone (Sun-bed or Jew-stone, 6 to 18 inches), with Modiola minima and Ostrea liassica; and a lower group of pale limestones (10 to 20 feet) with the same fossils and Cardium phillipianum (rhæticum), Monotis decussata. The Cotham Stone or Landscape Marble (4 to 8 inches) is a hard compact limestone, with dendritic markings, lying at the base of these calcareous strata.

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[15] So named from their being well developed in the cliffs of Penarth on the Glamorganshire coast. Bristow, Brit. Assoc. 1864, sects. p. 50; Geol. Surv. Vertical Sections, sheets 47, 48.

[16] Strickland, Proc. Geol. Soc. iii. part ii. p. 585; H. W. Bristow, Geol. Mag. i. 1864, p. 236; T. Wright, Quart. Journ. Geol. Soc. xvi. p. 374; C. Moore, op. cit. xvi. p. 483; xxiii. p. 459; xxxvii. pp. 67, 459; W. B. Dawkins, xx. p. 396; E. B. Tawney, xxii. p. 69; P. B. Brodie, p. 93; F. M. Burton, xxiii. p. 315; W. J. Harrison, xxxii. p. 212; P. M. Duncan, xxiii. p. 12; J. W. Davis, xxxvii. p. 414; E. Wilson, xxxviii. p. 451; H. B. Woodward, "Geology of E. Somerset and Bristol Coal-fields," Mem. Geol. Survey, p. 69; Proc. Geol. Assoc. x. 1888.

At Aust it has yielded elytra of Coleoptera, wings of insects, and scales, and perfect specimens of the fishes Legnonotus cothamensis, Pholidophorus Higginsi.

Black paper-shales (10 to 15 feet), finely laminated and pyritous, with selenite and fibrous calcite ("beef") and one or more seams of ferruginous and micaceous sandstone (bone-bed) containing remains of fish and saurians. Some of the shales yield Avicula (Cassianella) contorta, Cordium phillipianum (rhæticum), Pecten valoniensis (= Avicula contorta zone).

Green and gray Marls (20 to 30 feet), with alabaster, celestine, and sometimes pseudomorphs of rock-salt; generally unfossiliferous, but yielding Microlestes. These Marls form properly the top of the Trias, the bone-bed above serving as a convenient base for the Rhætic beds.

A bone-bed similar to that in the foregoing section reappears on the same horizon in Hanover, Brunswick, and Franconia. Among the reptilian fossils are some precursors of the great forms which distinguished the Jurassic period (Ichthyosaurus and Plesiosaurus). The fishes include Acrodus minimus, Ceratodus altus (and five other species), Hybodus minor, Nemacanthus monilifer, etc. Some of the lamellibranchs (Fig. 380) are specially characteristic; such are Cardium phillipianum (rhæticum), Avicula (Cassianella) contorta, Pecten valoniensis, and Pullastra arenicola (Fig. 379).

Central Europe.—The Trias is one of the most compactly distributed geological formations of Europe. Its main area extends as a great basin from Basel down to the plains of Hanover, traversed along its centre by the course of the Rhine, and stretching from the flanks of the old high grounds of Saxony and Bohemia on the east across the Vosges Mountains into France, and across the Moselle to the flanks of the Ardennes. This must have been a great inland sea, out of which the Harz Mountains, and the high grounds of the Eifel, Honsdrück, and Taunus probably rose as islands. To the westward of it, the Palæozoic area of the north of France and Belgium had been raised up into land.[17] Along the margin of this land, red conglomerates, sand-

[17] This land, according to MM. Cornet and Briart, rose into peaks 16,000 to 20,000 feet high! Ann. Soc. Geol. Nord. iv.

stones, and clays were deposited, which now appear here and there reposing unconformably on the older formations. Traces of what were probably other basins occur eastward in the Carpathian district, in the west and southeast of France, and over the eastern half of the Spanish peninsula. But these areas have been considerably obscured, sometimes by dislocation and denudation, again by the overlap of more recent accumulations. In the region between Marseilles and Nice, Triassic rocks cover a considerable area. They

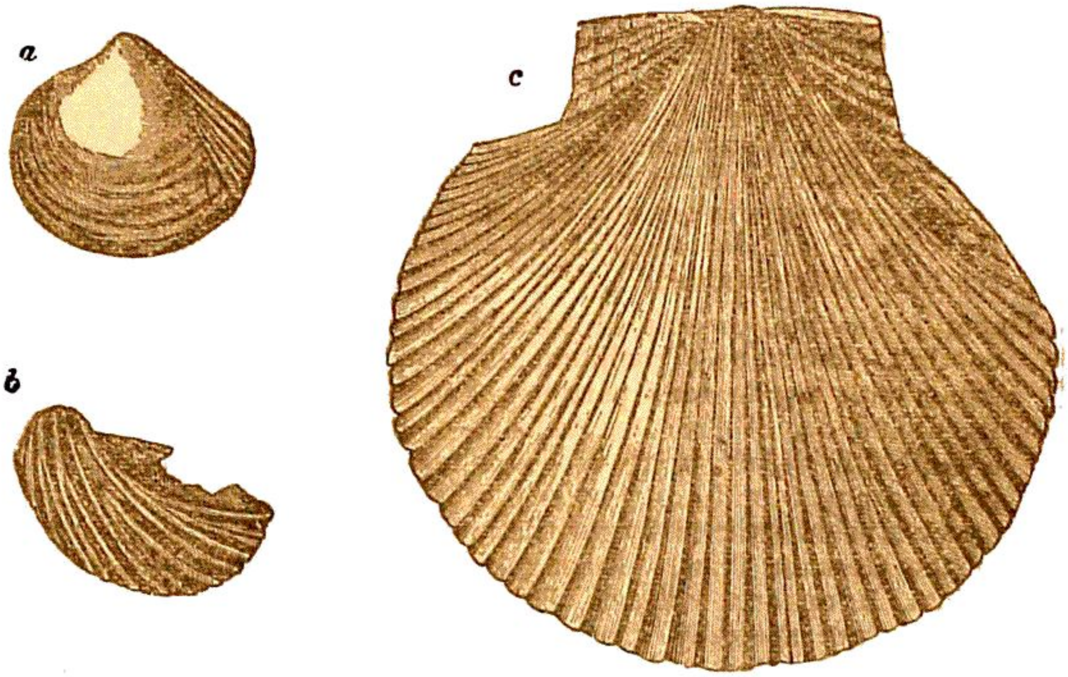

Fig. 880.—Rhætic Fossils.
***a*, Cardium phillipianum (rhæticum, Merian,); *b*, Avicula (Cassianella) contorta, Portlock; *c*, Pecten valoniensis, Defrance.**

contain feeble representatives of the Grès bigarré or Bunter beds, and of the Marnes irisées or Keuper division, separated by a calcareous zone believed to be the equivalent of the Muschelkalk of Germany. Their highest platform, the Rhætic or Infra-Lias, contains a shell-bed abounding in Avicula contorta, and is traceable throughout Provence.[18]

In the great German Triassic basin[19] the deposits are as shown in the subjoined table:

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[18] Hébert, Bull. Soc. Geol. France (2e ser.) xix. p. 100. Dieulafait, Ann. Sci. Geol. i. p. 337.

[19] E. Weiss, Zeitsch. Deutsch. Geol. Ges. xxı. 1869, p. 837; C. W. Gümbel, "Geognostische Beschreibung des Königreichs Bayern," iii. 1879, chap. xv.; F. Roemer, "Geologie von Oberschlesien," 1870, p. 122; E. W. Benecke, "Ueber die Trias in Elsass-Lothringen und Luxemburg," Abh. Geol. Specialkarte Elsass-Lothr. i. part iv. 1877; G. Meyer, Mittheil. Com. Geol. Landes-

Rhætic.

Rhætic (Rhät, Infra-Lias).—Gray sandy clays and fine-grained sandstones, containing Equisetum, Asplenites and cycads (Zamites, Pterophyllum), sometimes forming thin seams of coal—Cardium phillipianum (rhæticum), Avicula (Cassianella) contorta, Estheria minuta, Nothosaurus, Trematosaurus, Belodon and Microlestes antiquus.[20*]

Keuper.

Keupermergel, Gypskeuper.—Bright red, green and mottled marls, with an underlying set of beds of gypsum and rock-salt. In some places where sandstones appear they contain numerous plants, Equisetum columnare, Pterophyllum, etc., and labyrinthodont and fish remains[21*] —300 to 1000 feet.

Lettenkohle, Kohlenkeuper.—Gray sandstones and dark marls and clays, with abundant plants, sometimes forming thin seams of an earthy hardly workable coal—Lettenkohle—about 230 feet. The plants include, besides those above mentioned, the conifers Araucarioxylon thuringicum, Voltzia heterophylla, etc. A few shells have been obtained from this group, especially from a band of dolomite at its upper limit, Lingula tenuissima, Myophoria Goldfussi, M. transversa, Anoplophora, Gervillia. Some of the shales are crowded with small phyllopod crustacea: Estheria minuta, also Bairdia. Remains of fish—Acrodus, Hybodus, Ceratodus—and of the Mastodonsaurus Jægeri and Nothosaurus have been obtained.

Muschelkalk.

Upper Limestone, capable of subdivision into two groups, a lower hard encrinite limestone (Trochitenkalk) and an upper group of thin limestone with argillaceous partings, known as the Nodosus group from the abundance of Ceratites nodosus—200 to 400 feet. In some regions a third still higher group of dolomites and limestones is called the Trigonus group from the prevalence in it of Trigonodus Sandbergeri. The upper Muschelkalk is by far the most abundantly fossiliferous division of the German Trias. Among its fossils, Nautilus bidorsatus, Lima striata, Myophoria vulgaris, Trigonodus Sandbergeri and Terebratula vulgaris are specially characteristic, with Encrinus liliiformis in the lower and Ceratites nodosus in the upper part of the rock. Some parts of the lower limestones are almost wholly made up of crinoid stems.

Middle Limestone and Anhydrite, consisting of dolomites with anhydrite, gypsum and rock-salt. Nearly devoid of organic remains, though bones and teeth of saurians have been found—200 to 400 feet.

Lower Limestone, Wellenkalk, consisting of limestones and dolomites, Wellendolomite, with in the upper part bands of porous limestone known as Schaumkalk—160 to 500 feet. This zone is on the whole poor in fossils, save in the limestone bands, some of which form a lower zone full of Encrinus liliiformis, while a higher zone is characterized by Myophoria orbicularis. The upper portion of the limestone, however, is highly fossiliferous, and has yielded a number of brachiopods (Spiriferina fragilis, S. hirsuta, Athyris trigonella, Terebratula vulgaris, T. angusta), numerous lamellibranchs, especially the widespread genus Myophoria, (M. vulgaris, elegans, cardissoides), Gervillia costata, Monotis Alberti, and some ammonites (Beneckeia, Ceratites, etc.).

Untersuch. i. part i. 1886; H. Bücking and E. Schumacher, op. cit. ii. part ii. 1889; E. W. Benecke and L. van Wervecke, op. cit. iii. part i. 1890; and the Jahrbuch of the Prussian Geological Survey. Detailed measured sections of the Muschelkalk and Lettenkohle in Franconia are given by F. v. Sandberger, Verh. Phys. Med. Ges. Würzburg, xxvi. 1892, No. 7. S. Passarge, "Das Röth im östlichen Thüringien," Jena, 1891.

* For foot-notes see next page.

Bunter.

Upper (Röth).—Red and green marls, with gypsum in the lower part, and sometimes beds of rock-salt—250 to 300 feet. Occasional bands of dolomite, Rhizocorallium dolomite of Thuringia, yield a number of fossils: Rhizocorallium jenense, probably a sponge, Myophoria costata, M. vulgaris, Gervillia socialis, Myacites mactroides, the Ammonite Beneckeia tenuis. The Myophoria is specially characteristic. The plants of this stage consist chiefly of Voltzia, with ferns and horse-tails: Anomopteris, Equisetum.

Middle.—Coarse-grained sandstones, 1000 feet, sometimes incoherent, with wayboards of Estheria-shale; amphibian footprints and remains of labyrinthodonts.

Lower.—Fine reddish argillaceous false-bedded sandstone, Grès des Vosges, several hundred feet thick, often micaceous and fissile, with occasional interstratifications of dolomite and of the marly oolitic limestone called "Rogenstein." Fossils extremely scarce; Estheria minuta occurs in some layers.

The Bunter division, in the north and centre of Germany, lies conformably on and passes insensibly into the Zechstein. Except in the dolomite beds of the Röth, it is usually barren of organic remains. The plants already known include Equisetum arenaceum, one or two ferns, and a few conifers, Albertia and Voltzia. The lamellibranch Myophoria costata is found in the upper division all over Germany. Numerous footprints occur on the sandstones, and the bones of labyrinthodonts as well as of fish have been obtained.

In the Vosges, the Bunter (Grès bigarré, Vosgian) consists of (1) a lower coarse red unfossiliferous sandstone (Grès des Vosges) resting conformably on the red Permian sandstone and marked by the frequent crystalline condition of its quartz-grains (crystalline sandstone, p. 232); also by its quartz-conglomerates, which occasionally reach a thickness of more than 1600 feet; (2) an upper series of red sandstones, surmounted by marls, forming the Grès bigarré, and containing among other fossils Voltzia, Albertia, Equisetum, arenaceum, Myophoria, Nothosaurus Schimperi, Menodon plicatus, Odontosaurus Voltzii, Mastodonsaurus waslenensis. The Muschelkalk in the same region is a compact gray limestone capable of subdivision into three zones, as in Ger-

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[20]* The Avicula contorta zone (see Dr. A. von Dittmar, "Die Contorta-Zone," Munich, 1864) ranges from the Carpathians to the north of Ireland and from Sweden to the hills of Lombardy. In northern and western Europe, it forms part of a thin littoral or shallow-water formation, which over the region of the Alps expands into a massive calcareous series, that accumulated in a deeper and clearer sea. It is well developed also in northern Italy. See Stoppani, "Geologie et Paleontologie des Couches à Avicula Contorta en Lombardie," Milan, 1881.

[21]* It is deserving of notice that while in the pelagic or Alpine facies of the Trias fish remains are on the whole scarce, and only occur in numbers at a few places, they are widely distributed and tolerably abundant throughout the German Trias. See O. Jaekel, Abhand. Geol. Specialkart. Elsass-Lothr. iii. Heft iv. 1889.

many, while the Keuper (Marnes irisées) presents a characteristic assemblage of bright red and green mottled argillaceous marls.[22]

Scandinavia.[23]—Though fragmentary remains of the terrestrial flora that clothed the land which surrounded the German Triassic inland sea not infrequently occur, it is on the north side of the basin that the most abundant traces have been recovered of the vegetation of this period. Above reddish saliferous rocks, presumably Triassic, there come in southern Sweden certain light gray and yellow strata, which, from the occurrence of Avicula contorta and other fossils in them, are assigned to the Rhætic stage, though possibly their higher members may be Jurassic. They attain in some places a thickness of 500 to 800 feet, and cover about 250 square miles. They have been divided into a lower freshwater group, with workable coal-seams, but no marine fossils, and an upper marine group, with only poor coals, but with numerous marine organisms (Ostrea, Pecten, Avicula, etc.). In the coal-bearing strata clay-ironstones occur, and seams of fire-clay underlie the coals. Nathorst and Lundgren have brought to light 150 species of plants from these beds—a larger number than the whole of the Triassic flora of other countries. At Bjuf they include 36 species of ferns, 36 cycads, 15 conifers, and 1 monocotyledon. The subjoined grouping of the Swedish Triassic rocks has been given by Lundgren:

	Arieten-Lias.
	Cardinia Lias.
Younger Rhætic	Zone of *Nilssonia polymorpha.*
Rhætic . .	Pullastra bed.
	Zone of *Thaumatopteris Schenki.*
	Zone of *Equisetum gracile.*
	Zone of *Lepidopteris Ottonis.*
Older Rhætic .	Zone of *Camptopteris spiralis.*
	Keuper.

Alpine Trias.[24]—In the western Alps, certain lustrous schists, with gypsum, anhydrite, dolomite and rock-salt, lie

[22] Benecke, Abhandl. Specialkarte Elsass-Lothringen, 1877; Lepsius, Z. Deutsch. Geol. Ges. 1875, p. 83.

[23] See Hébert, Ann. Sci. Geol. 1869, No. 1; Bull. Soc. Geol. France (2), xxvii. 1870, p. 366; Memoirs of the Geological Survey of Sweden, especially Nathorst "Om Floran Skånes Kolförande Bildningar," 1878, 1879; E. Erdmann, "Beskrifning till Kartbladet Helsingborg," 1881, p. 42; G. Lindström, op. cit. "Kartbladet Engelholm," 1880; also Nathorst, "Bidrag till Sveriges fossila Flora," K. Vet. Akad. Handl. Stockholm, xiv. xvi.; Lundgren, Geol. Fören. Stockholm Förh. 1880.

[24] See F. von. Richthofen, "Geognostische Beschreibung der Umgegend

underneath the Jurassic series, and are referred to the Trias. On the Italian side, they swell out to great proportions, reaching a thickness of more than 13,000 feet along the line of the Mont Cenis Tunnel. Traced through Piedmont, they are found to play an important part in the structure of the northern Apennines, where they contain the celebrated statuary marbles of Carrara (p. 1043). They have undergone, in these mountainous tracts, extensive metamorphism, the original shales or marls being changed into lustrous schists, and the limestones into crystalline marbles. But even in this altered condition Triassic fossils have been found in them.

Already in Triassic time a notable distinction had been established between the geographical conditions of the regions now marked by the eastern and western Alps. The line of division between the two areas may be said to coincide generally with that ancient line of N.E. and S.W. disturbance known as the "Rhine-Ticino fault." To the west the Triassic deposits point to varying conditions of lagoons and inland seas. Eastward, however, the corresponding deposits attain an enormous development, and are now recognized as presenting a record of the deeper water or pelagic conditions of the Triassic period. As Mojsisovics has remarked, what England and North America are for the Palæozoic formations in general, what Bohemia is for the Silurian system, what the Jura Mountains are for the Jurassic deposits, the eastern Alps are for the Trias.[25] Special interest attaches to the Trias of the eastern Alps from the great thickness of its limestones and their thoroughly marine fauna, with a commingling of Palæozoic and Mesozoic types intercalated between the Permian and Jurassic systems. It would appear that during the deposition of these limestones the central core of crystalline and Palæozoic rocks of the

von Predazzo," etc. Gotha, 1860; Gümbel, "Geog. Beschreib. des Bayerisch. Alpen," 1861; Stur, "Geologie der Steiermark," 1871; E. von Mojsisovics, Jahrb. Geol. Reichsanstalt, Vienna, 1869, 1874, 1875, 1880; Abhandl. Geol. Reichsanstalt, vi. 1875, p. 82; Verhandl. Geol. Reichsanstalt, 1866, 1875, 1879; and "Dolomitriffe Südtirols und Venetiens," 1878; E. Süss, "Die Entstehung der Alpen," 1875; also memoirs by Von Hauer, Laube, Süss, Stache, Stur, Toula, Bittner, and others in the Jahrb. Geol. Reichsanstalt; Von Hauer's "Geologie," p. 358 *et seq.*; Miss M. Ogilvie, Quart. Journ. Geol. Soc. xlix. 1893, p. 1. The fossils are described by Benecke, Geol. Palæontol. Beitr. vol. ii.; Mojsisovics, Abhandl. k. k. Geol. Reichsanst. vii. x.; Bittner, op. cit. vol. xiv.; G. L. Laube, Denksch. Akad. Wien, xxiv.–xxx.; numerous other memoirs are cited by Mojsisovics in his "Dolomitriffe."

[25] "Die Dolomitriffe," p. 39.

Alpine chain rose as an island that stretched from the Engadine eastward into Austria. North of this old insular tract the Triassic strata are on the whole somewhat sandy, the accumulation of limestone there having been frequently interrupted by inroads of sand or silt. On the south side the deposition of limestone and dolomite went on more continuously, though interfered with occasionally by submarine volcanic eruptions. Some of the dolomite masses may have been coral-reefs; Mojsisovics even believes that in the conglomeratic portions he can detect traces of the breaker-action by which the reefs were ground down, while the thin marls were deposited in lagoons, or in the inner channels between the reefs and the land. But it is specially deserving of notice that corals were not the only agents in the accumulation of reef-like masses in this region. Alike in the dolomites and the massive limestones calcareous sea-algæ occur so abundantly as to show that they grew up into wide reefs, which, judging from what is known of the distribution of such organisms at present, show that the Triassic sea in these tracts did not exceed 200 fathoms in depth. Though organisms of higher grade are often associated with these reef-building plants, they occur most frequently in the thin-bedded marls and shales at definite horizons in the series of strata.

Having regard to the lithology and palæontology of the Alpine Trias, Mojsisovics proposed some years ago to regard the system in the eastern Alps as pointing to the existence of two great marine "provinces." The larger of these lay over the sites of North and South Tyrol, Lombardy, and Carinthia, and stretched far to the east. To this area the able Austrian investigator gave the name of the "Mediterranean province." To the other, which occupied a limited tract on the northeast slopes of the Austrian Alps, extending from the Salzkammergut into Hungary, he gave the designation of "Juvavian province" (from the old Roman name of Salzburg). Though the Triassic deposits of these two regions were geologically contemporaneous, they inclose remarkably different assemblages of organic remains, insomuch that the palæontological zones which can be determined in the one have not been found to hold good in the other. In no respect is this independence more strongly shown than in the great contrast presented by the Ammonites of the two areas. The Juvavian province has yielded a Triassic cephalopodous fauna far outrivalling in variety and interest that of any other tract. It was for a long time believed that the cephalopods were quite distinct in the two regions, Phylloceras, Didymites, Halorites, Tropites, Rhabdoceras, and Cochloceras being regarded as the dominant and distinctive genera of the Juvavian province, while Lytoceras, Sagaceras, and Ptychites were equally characteristic of the Mediterranean province.[26] The progress of research, however, has shown that the so-called Juvavian province can no longer be strictly maintained, for the type of rocks and fossils on which it was based have been found in the midst of the Mediterranean. Nevertheless it remains true that the peculiar lithological and palæontological features, as well as the complicated structure, of the district of the Salzkammergut have up to the present time interposed very great difficulties in the way of the institution of any exact comparison between the Triassic succession in that area and in other parts of the Alpine region. The table on p. 1446, compiled from the results of the latest researches, shows the contrasted grouping of the Triassic formations on the two sides of the eastern Alps, and their distinction from those of the German inland sea, between which and the Alpine basins there seem to have been only occasional and brief intervals of connection.[27]

1. Bunter.—The base of the Alpine Trias shades down into the Permian formations (Bellerophon limestone, Groden sandstone), and consists of the group of red sandy micaceous shales known as the Werfen beds (from Werfen in the Salzburg), which form a tolerably persistent horizon. Among the fossils in the upper part are Naticella costata, Turbo rectecostatus, Trigonia costata, Monotis aurita, and the ammonites Tirolites (Ceratites) cassianus, Dalmatinus idrianus, D. muchianus, Trachyceras Licanum, Norites caprilensis. Some of these organisms occur so abundantly as to form entire beds. Corals, echinoderms, and brachiopods (except Lingula) are absent. In the lower part of the group Monotis Clarai is especially abundant. The presence here

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[26] Mojsisovics has recently modified his previously published opinions regarding the order of the Triassic formations in the Salzkammergut, Sitzb. Akad. Wien, 1892, p. 780. The views of this observer, however, regarding the succession of the strata are not everywhere accepted among the geologists of Austria. For a recent critique on this subject see A. Bittner, Jahrb. k. k. Geol. Reichsanst. vol. xlii. 1892, p. 387.

[27] In the preparation of my account of the Alpine Trias I have been greatly aided by Miss M. M. Ogilvie, whose intimate acquaintance with this geological system in the eastern Alps is well shown in her paper already cited. The table on next page has been entirely drawn up by her.

			In the Northern Alps.		In the Southern Alps.	
German Trias.[1]	Stages according to Mojsisovics.	Alpine Fossil Zones.	Bavarian and North Tyrol.	Upper and Lower Austria.	Lombardy Alps.	Carinthian Alps and S. Tyrol.
Rhætic beds.	Rhætic Stage.	1. *Megalodon scutatus* and *Avicula contorta.*	Dachstein Lime-stone. Kössen beds. Main Dolomite. | Dachstein and Coral-reef Limestone.	Dachstein Limestone or Kössen beds.	Kössen beds (Arzzarola beds). Main Dolomite.	Dachstein Dolomite.
	Juvavian Stage.	2. *Turbo solitarius* and *Avicula exilis.*		Dachstein Limestone or Dolomite. | Hallstadt (Salzkammergut) development of limestones, dolomites, &c., with lenticular fossiliferous intercalations.		
Keuper. { Upper or Gypskeuper. Lower Keuper (Lettenkohle).	Carinthian Stage.	3. *Trachyceras aonoides.*	Raibl beds. { "Ostrea" horizon. "Cardita crenata" horizon.	Opponitz Limestone. Lunz Sandstone.	Raibl beds (Gorno and Dossena beds).	Raibl beds. { Torer beds. Dolomite. Fisch-schiefer. | Raibl beds.
Muschelkalk. { Upper and Middle Limestones.		4. *Trachyceras aon.*	Wetterstein Limestone. Partnach beds. | Wetterstein or Reef Limestone.	Partnach beds.	Esino Limestone.	"Erz-führende Dolomit" of Raibl. | Cassian beds. | Schlern Dolomite.
	Noric Stage.	5. *Trachyceras Archelaus* and *Halobia Lommeli.*				
		6. *Trachyceras Curionii.*		Reifling Limestone.	"Halobia" Shales or Prezzo Limestones.	Wengen beds. Buchenstein beds.
Lower Limestones (Wellenkalk).		7. *Ceratites trinodosus.* 8. *Ceratites binodosus* and *Terebratula vulgaris.*	Alpine Muschelkalk.	Guttenstein Limestone.	Muschelkalk (Recoaro Limestone).	Muschelkalk (Virgloria Limestone). | Mendola Dolomite.
Buntor. { Röth horizon. Middle and Lower Bunt-sandstones.		9. *Myophoria costata* and *Tirolites cassianus.*	"Myophoria" beds or Reichenhall Limestone with beds of salt, gypsum, &c. Werfen beds.		Röth Werfen beds.	Werfen beds { Campil beds. Seis beds.

[1] For a comparison between the Trias of Germany and that of the Alps, see Wöhrmann, *Jahrb. k. k. Geol. Reichsanst.* 1889, p. 181. A useful summary will be found in Fraas' 'Scenerie der Alpen,' p. 146.

of Trigonia costata, a characteristic form of the German Roth, serves to mark the relation of the Werfen beds to the Triassic series of the German area.

2. Muschelkalk.—It is above the position of the Werfen beds that the Alpine Trias begins to manifest great lithological differences, not only in the two provinces on the northern and southern sides of the Alps, but even within the confines of each province. The general character of these differences is expressed in the foregoing table. Yet, with some notable exceptions, the palæontological zones can be distinguished. The lower Muschelkalk of the eastern Alps consists in its inferior portion of sedimentary deposits which are largely argillaceous, while the upper part is composed of limestones and dolomites arranged in lenticular reef-like masses. The lower argillaceous division varies in its palæontological character. Mojsisovics distinguishes three facies, the lowest in which lamellibranchs predominate (Recoaro), and which shows a close lithological and palæontologial relation to the German Muschelkalk, followed by one with brachiopods and land-plants, and that by a third with cephalopods (Dont, Val Inferna and Brags). The calcareous group sometimes resembles in lithological character the German Wellenkalk, but in certain places it assumes the aspect of reefs. Among the most important fossils of the Alpine Lower Muschelkalk some are common to this stage in Germany, such as Spiriferina Mentzeli, S. hirsuta, Rhynchonella securtata, Terebratula vulgaris, T. angusta, Myophoria vulgaris, Pecten discites, Encrinus gracilis, Ceratites trinodosus. But there remains a large number of peculiar forms, especially the abundant ammonites (Ptychites, Trachyceras, numerous species, Lytoceras). The Upper Muschelkalk is generally a dark gray to black limestone, but sometimes (Salzkammergut) is red and like a marble. Among the typical fossils are Daonella Sturi, D. parthanensis, Orthoceras campanile, Nautilus Pichleri, Ptychites gibbus, Arcestes Bramantei, Ægoceras megalodiscus, Ceratites (Trachyceras) trinodosus, and other genera.

3. Noric Stage.—It was at the close of the deposition of the Alpine Muschelkalk and the beginning of the Noric stage that the two great biological provinces above referred to were finally established. The general grouping of the formations in each area and the striking difference they present even within the same area are best understood from the inspection of such a table as that given above. On the southern side of the Alps two groups in this stage have

been recognized: (1) the Buchenstein beds, consisting of flaggy and nodular limestones, with hornstone concretions. These strata have not yet been found in the northern Alps. Among their fossils are Orthoceras Bockhi, Arcestes trompianus and other species, Ptychites angusto-umbilicatus, Sageceras Zsigmondyi, Lytoceras, cf. wengenense, Trachyceras Curionii, T. Reitzi and other species, Spiriferina Mentzeli, Daonella Taramellii, and other species. (2) The Wengen beds comprise all the strata lying between the Buchenstein beds and the base of the St. Cassian group. Their most important material consists of a dark sandstone with shaly partings, derived chiefly from volcanic detritus. In South Tyrol and in Carinthia sheets of lava and tuff lie at the base of this group, and thicken out round the centres of eruption. With these interbedded igneous rocks are associated bosses and dikes of augite-porphyry and melaphyre. A characteristic feature of the Wengen beds is the great development of reefs formed by calcareous algæ (Gyroporella, including Diplopora), and built up into enormous masses of limestone and dolomite with corals, large Naticas, and Chemnitzias. Among the characteristic fossils of the Wengen beds are Trachyceras Archelaus, and numerous other species, Arcestes tridentinus, Pinacoceras daonicum, Halobia Lommeli, with in some places remains of land-plants—Equisetites arenaceus, Calamites arenaceus, Neuropteris several species, Sagenopteris, Pecopteris, Thinnfeldia, Pterophyllum, Tæniopteris, Voltzia.

4. Carinthian Stage.—The geographical distribution of the two marine provinces lasted beyond the early part of this stage. The separation between these areas gradually disappeared, and some of their peculiar ammonites began to migrate from the one territory to the other. In the southern area Mojsisovics has noted three distinct Carinthian groups: (1) the St. Cassian beds, consisting of brownish calcareous marls, limestones, and oolites. This group has long been celebrated for the astonishing abundance and variety of its organic remains. The Echinoderms are particularly prominent. Abundant also are the species of Halobia (Daonella) (H. cassiana and H. Richthofeni). Corals abound in the neighborhood of the dolomite-reefs, and the coral banks, like the beds of echinoderms, can be traced laterally into these reefs. The St. Cassian beds are represented in other parts of the Alps by fossiliferous limestones (Marmolata and Esino limestones in South Tyrol and Lombardy, Wetterstein limestone in North Tyrol) and nearly

unfossiliferous dolomites (Schlern dolomite in South Tyrol, "Erzfuhrende Dolomit" of Carinthia) of the "reef-type" of Mojsisovics. Out of the large series of fossils the following may be mentioned here—Trachyceras aon, species of Arcestes, Lobites Orthoceras, Nautilus, Bactrites, Gervillia angusta, Koninckina Leonardi, Rhynchonella semiplecta, Encrinus cassianus, Pentacrinus propinquus, Cidaris dorsata. (2) The Raibl beds mark the close of the separation of the two provinces, for they range from the one into the other. They consist of dark bituminous marly strata, with lenticular beds and thick reef-like masses of limestone, and frequently with gypsum and rauchwacke. Their fauna, distinguished by the large number of littoral lamellibranchs, includes Trigonia Kefersteini, Cardita Gumbeli, Corbula Rosthorni, Halobi rugosa, Gervillia bipartita, Megalodus carinthiacus, Chemnitzia eximia, Nautilus Wulfeni, Trachyceras anoides. The Lunz sandstones, which belong to this horizon, have yielded numerous land-plants, comprising many species of Pterophyllum and forms of Equisetites, Calamites, Neuropteris, Alethopteris, etc. (3) The beds comprising the zone of Avicula exilis and Turbo solitarius show a return of the dolomitic condition of earlier parts of the system. These conditions had already set in during the deposition of the Raibl beds, but they reached their full development during the accumulation of the next group, when masses of dolomite ranging up to nearly 4000 feet in thickness were laid down. This group of rocks, though placed by Mojsisovics in the Carinthian stage, is by other authors considered to be Rhætic. In North Tyrol it is known as the Main Dolomite (Hauptdolomit), in the Salzkammergut as the lower part of the Dachstein limestone, which forms an important feature in the scenery of the district. These rocks everywhere present a great contrast to the strata below them in their poverty of organic remains: Some of their most prominent fossils are casts of Megalodus (M. Gumbeli, M. complanatus, M. Mojsvári, etc.), and remains of calcareous algæ (Gyroporella). The bituminous Seefeld beds of the North Tyrol have yielded many fishes (Semionotus, Lepidotus, Pholidophorus) and remains of plants.

Until recently, according to Mojsisovics, the order of superposition of the rocks in the Hallstadt area was misinterpreted. He now believes that the Hallstadt marble does not form a continuous mass overlying the Zlambach beds, but that the latter, instead of underlying the Hallstadt rock, actually lie within it. He has grouped a section of the Hallstadt series as a separate stage under the name of "Juvavian." It consists at the base of red and variegated lenticular seams of limestone with Sagenites Giebeli. Then follow red lenticular limestones with gasteropods (zone of Cladiscites ruber). It is here that the Zlambach beds come in with their Choristoceras Haueri. They are succeeded by gray limestone with Pinacoceras Metternichi, and this by seams of limestone carrying Cyrtopleurites bicrenatus.[28] This whole series, comprising several palæontological zones, is regarded by Mojsisovics as the equivalent in time of the Main Dolomite.

5. Rhætic Stage.—Two distinct facies of this stage are developed in the eastern Alps, but the unity of the deposits over the whole region is shown by the presence of the characteristic Avicula contorta. The Kossen beds are a marly, highly fossiliferous group of strata, marking probably the shallower water, while the upper Dachstein limestone into which they merge may indicate the opener sea. Süss has distinguished a series of "facies" in this group, the lowest (Swabian) marked by the preponderance of lamellibranchs, the next (Carpathian) by the abundance of Terebratula gregaria and Plicatula intusstriata; the Hauptlithodendron-limestone—a thick mass of coral limestone; the Kossen facies includes the dark brachiopod limestones with shaly partings, while the Salzburg facies is recognized by the prominence of its cephalopods (Choristoceras Marshi, Ægoceras planorboides).

The Kossen beds are most fully developed in the northern Alps, more particularly in Bavarian and North Tyrol, thinning out toward Salzkammergut, while the dolomitic facies of Dachstein limestone predominates in the southern Alps, the fossiliferous marly facies only appearing in the Lombardy Alps. The occurrence of the fossiliferous Rhætic beds in the Alps gave not only the first clew to the identity in time of the Triassic beds in Alpine and extra-Alpine regions, but it has proved of the greatest importance in tracing the zonal parallelism of the Triassic succession within the Alps themselves. As has been said, a great thickness of wholly unfossiliferous dolomitic and gypsiferous rock sometimes occurs in the western Alps, and it would be impossible to assign a Triassic age to any part of this series were it not for the presence of well-known

[28] Mojsisovics, Sitzb. Akad. Wien, 1892, p. 769.

Rhætic fossils in the beds immediately succeeding them. Again, the same fossils give undoubted evidence of the gradual submersion of the island of older crystalline and Palæozoic rock in the Triassic sea of the eastern Alps. Rhætic fossils are found on the Radstadter Tauer and on the Stubey Mountains in the central chain of the Alps.

The intrusive volcanic rocks of the celebrated districts of Predazzo and Monzoni in South Tyrol are referred by some authors to Lower, by others to Upper Triassic time. At Predazzo there is a core of orthoclase porphyry and tourmaline granite with an envelope of syenite, by which, among the now familiar phenomena of contact-metamorphism, the Triassic limestones have been in places converted into marble. Similar phenomena are presented at Monzoni, where a central boss of augite-syenite, traversed by veins of gabbro, melaphyre, etc., cuts across the Triassic strata (ante, p. 1001).

The Triassic rocks of the Alps have participated in the great earth-movements to which this chain of mountains owes its structure, and they consequently present remarkable cases of dislocation, inversion, and even of metamorphism. Thus the Triassic formations of the Radstadter Tauer in the Tyrol cannot be separated from the calc-mica schist of that district, and Prof. Suss regards this schist as an altered Triassic limestone.[29]

Spitzbergen.—Since the Alpine type of the Trias has been recognized as that of the open sea, it has been traced far and wide over the Old World, northward into the Arctic Circle, eastward across Asia to Australasia, and along the eastern borders of the Pacific Ocean. In northern Siberia, at the mouth of the River Olenek, and in Spitzbergen, Triassic strata have been found with a characteristic marine fauna, including the following genera of cephalopods: Dinarites, Ceratites, Sibirites, Prosphingites, Popanoceras, Monophyllites, Xenodiscus, Meekoceras, Hungarites, Ptychites, Pleuronautilus, Nautilus, and Atractites; also species of Pseudomonotis, Oxytoma, Avicula, Pecten, Gervillia, Cardita, Lingula, Spiriferina, and Rhynchonella, together with remains of fish and reptiles (Acrodus spitzbergensis, Ichthyosaurus polaris, I. Nordenskioldii).[30]

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[29] Anzeiger Akad. Wien, No. xxiv. 20th Nov. 1890.

[30] A. E. Nordenskiöld, Geol. Mag. 1876, p. 741; A. Bittner and A. Teller, Mem. Acad. St. Petersbourg, vol. xxxiii.; Mojsisovics, Verhandl. k. k. Geol. Reichsanst. 1886, No. 7.

Asia.—The Trias has a wide extension in this continent. In the old district of Mysia, Asia Minor, dark shales and limestones inclose undoubted Triassic forms such as Arcestes, Nautilus, and Halobia.[31] Strata with Ceratites and Orthoceras occur in Beloochistan, and in the Salt Range of the Punjab. In northern Kashmir and western Thibet a well-developed succession of Triassic formations appears among the Himalayan ranges, sometimes exceeding 4000 feet in thickness. It contains many of the same species of fossils as occur in the Alpine Trias. Some of its forms are Ammonites floridus, A. diffusus, Halobia Lommeli, Monotis salinaria, Megalodus triqueter. The researches of Mr. Griesbach have added much to our materials for a comparison between these Himalayan Triassic rocks and their representatives in Europe. At the base of these formations in the Himalayan regions lies a group of strata, the Otoceras beds, with a cephalopodan fauna poor in species but rich in individuals (Xenodiscus, Meekoceras, Otoceras, Prosphingites). These are followed by another lower Trias member, with a large assemblage of cephalopods resembling that of the Ceratite beds of the Salt Range, which are regarded by Waagen as homotaxial with the Bunter sandstone of Europe. The horizon of the Muschelkalk is represented by rocks in which there is a blending of the palæontological characters of the Arctic and Mediterranean types of this formation. Three upper Triassic groups have been recognized. Of these the lowest, consisting of black Daonella limestone, contains forms of Arcestes, Entomoceras, and Arpadites, the middle contains small ammonites of the genera Sibirites, Heraclites, and Halorites, while the highest group may be compared with the zone of Tropites subbullatus, at the base of the Carinthian stage of the eastern Alps.[32] The freshwater Karharbári beds, near the base of the Gondwána series of peninsular India, contain a Bunter assemblage of plants, including Voltzia heterophylla and Albertia (near A. speciosa);[33] also several cycads (Glossozamites, Zamia) and a number of ferns (Neuropteris, Gangamopteris, Glossopteris, Sagenopteris). It has been already observed that some of these types, which were believed to be exclusively Mesozoic, occur in Australia associated with a Carboniferous Limestone

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[31] Neumayr, Sitzb. Akad. Wien, 1887.

[32] Mojsisovics, Sitzb. Akad. Wien, ci. 1892, p. 372.

[33] Medlicott and Blanford's "Geology of India," pp. xlvi. 114. C. L. Griesbach, Mem. Geol. Surv. India, vol. xxiii.

fauna (ante, p. 1389). The Tálchir group contains bowlder-beds that may indicate glacial action in Triassic or Permian time. The Damuda group, which comprises nearly all the coal-fields of the Indian peninsula, contains a remarkable flora, distinguished by the abundance of ferns (Glossopteris, Gangamopteris, Sagenopteris, Tæniopteris, etc.), and by its mingled Palæozoic and Mesozoic characters. The Panchet group, crowning the lower Gondwána system, is composed of sandstones with bands of red clay, the whole having a thickness of 1800 feet, and yielding the Rhætic ferns Pecopteris concinna and Cyclopteris pachyrhachis, the Triassic and Rhætic genus of horsetail Schizoneura; the labyrinthodonts Gonioglyptus and Pachygonia, allied to Triassic forms, together with Dicynodon, Epicampodon, etc.[34]

Australia.—In New South Wales a group of yellowish-white sandstones (Hawkesbury beds) about 1000 feet thick lies unconformably upon the coal-bearing strata referred to the Permian period. This group forms the picturesque cliffs around the coast of Port Jackson, and has furnished the building-stone for the principal public buildings in Sydney. It has yielded a large number of plants (Phyllotheca, Sphenopteris, Neuropteris, Thinnfeldia—common, Odontopteris, Alethopteris, Macrotæniopteris, Podozamites, and Walchia); also the fishes Palæoniscus antipodeus, Myriolepis Clarkei, Cleithrolepis granulatus, and labyrinthodonts, but no marine shells. At Gosford, near the base of the Hawkesbury beds, in a thin seam of gray shale, a large collection of fishes has been obtained. The animals seem to have lived in some land-locked lake or estuary, and to have been killed in large numbers by the sudden silting up of the water with coarse sand and gravel. They belong to at least six genera, four of which occur in the European Trias. Of these four, two (Dictyopyge and Semionotus) are typically Triassic, while the third (Belonorhynchus) commonly ranges to the Lias, and the fourth (Pholidophorus) is best developed in the Jurassic system. The fifth genus (Pristisomus) is new, but scarcely higher in rank than Semionotus, while the sixth (Cleithrolepis) has only been definitely recognized in the Stromberg beds of South Africa, the age of which may be Triassic or Lower Jurassic.[35] On the Hawkesbury sand-

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34 "Geology of India," p. 131.

35 A. S. Woodward, Mem. Geol. Surv. N. S. Wales, Palæontology, No. 4, 1890, p. 54.

stones, perhaps unconformably, lies a group of shales (Wianamatta beds) with abundant plants, chiefly ferns, sometimes aggregated into thin seams of coal (Thinnfeldia, Odontopteris, Pecopteris, Macrotæniopteris, Phyllotheca, and Unio and Unionella). These two groups of strata are with some hesitation referable to the Trias.[36]

New Zealand.—Under the name of Trias, Sir J. Hector groups a great thickness of strata divisible into three series. (1) The Oreti series—a thick mass of green and gray tuff-like sandstones and breccias, with a remarkable conglomerate (50 to 400 feet thick) containing bowlders of crystalline rocks sometimes 5 feet in diameter, found both in the North and South Islands; fossils, chiefly Permian and Triassic, but with a Pentacrinus like a Jurassic species. (2) Above these beds lies the Wairoa series, containing Monotis salinaria, Halobia Lommeli, etc., and also plants, as Dammara, Glossopteris, Zamites, etc. (3) The Otapiri series, which, from the commingling of fossils nearly allied to Jurassic species with others which are Triassic and some even Permian, and from the presence of many forms identical with those of the Rhætic formations of the Alps, is assigned to the Upper Trias or Rhætic division.[37]

Africa.—In South Africa the "Karoo beds" spread over a wide area of country, consisting of nearly horizontal incoherent sandy materials, from which the remarkable assemblage of amphibian and reptilian remains already referred to has been obtained. The similarity of the fossils in these rocks and in those which are assigned to the Triassic series in India and Australia deserves to be specially remarked.

North America.—Rocks which are regarded as equivalent to the European Trias cover a large area in North America. On the Atlantic coast, they are found in Prince Edward Island, New Brunswick, and Nova Scotia; in Connecticut, New York, Pennsylvania, and North Carolina; in Honduras and along the chain of the Andes into Brazil and the Argentine Republic. Spreading also over an enormous extent of the Western Territories, they cross the Rocky Mountains into California and British Columbia. They consist mainly of

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[36] C. S. Wilkinson, "Notes on Geology of New South Wales," Sydney, 1882, p. 53. O. Feistmantel, Mem. Geol. Surv. N. S. Wales, Palæontology, No. 3, 1890; R. Etheridge jun. op. cit. No. 1, 1888.

[37] "Handbook of New Zealand," p. 33. F. W. Hutton, Quart. Journ. Geol. Soc. 1885, p. 202.

red sandstones, passing sometimes into conglomerates, and often including shales and impure limestones. But an important distinction may be drawn between the system as developed in the eastern and central parts of the continent, on the one hand, and along the Pacific slope on the other. In the former wide region, the rocks, evidently laid down in inland basins, like those of the same period in central Europe, are remarkably barren of organic remains. Their fossil contents include remains of terrestrial vegetation, with footprints and other traces of reptilian life, but with hardly any indications of the presence of the sea. This is the German type of the system.

The fossil plants of the Triassic rocks in the valley of the Connecticut and New Jersey present a general facies like that of the European Triassic flora. Among them are horse-tails (Equisetum, Schizoneura), cycads (Pterophyllum [some European species], Zamites, Otozamites, Sphenozamites, Nilssonia polymorpha, Dioonites), ferns (Pecopteris, Neuropteris, Tæniopteris, Clathropteris) and conifers (Cheirolepis).[38] In Virginia, where two distinct Mesozoic floras have been preserved, the older appears to be not more ancient than the Rhætic stage. So abundant is the vegetable matter in the sandy strata of the series as to form seams of workable coal, one of which is sometimes 26 feet thick. The plants include species of Equisetum, Schizoneura, Macrotæniopteris, Acrostichites, Cladophlebis, Lonchopteris, Clathropteris, Pterophyllum, Ctenophyllum, Podozamites, Cycadites, Zamiostrobus, Baiera, Cheirolepis, etc. Again in North Carolina a coal-bearing formation occurs with a similar flora, 41 per cent of the plants being also found in Virginia.[39]

The fauna of the North American Triassic rocks is remarkable chiefly for the number and variety of its vertebrates. The labyrinthodonts are represented by footprints, from which upward of fifty species have been described. Saurian footprints have likewise been recognized; in a few cases their bones also have been found. Some of the vertebrates had bird-like characteristics, among others that of three-toed hind feet, which produced impressions exactly like those of birds (p. 1432). But, as already remarked, it

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[38] J. S. Newberry, Monographs of U. S. Geol. Survey, vol. xvi. 1888, and Amer. Journ. Sci. xxxvi. 1888, p. 342.

[39] W. M. Fontaine, Monogr. U. S. Geol. Surv. vol. vi. 1883. The younger Mesozoic flora of Virginia is probably Neocomian (postea, Sect. iii. § 1).

is by no means certain that what have been described as "ornithichnites" were not really made by deinosaurs. The small insectivorous marsupial (Dromatherium) above referred to, found in the Trias of North Carolina, is the oldest American mammal yet known.

On the Pacific slope, however, a very different development of the Trias occurs. The Alpine or pelagic type of the system is here seen. The strata are estimated to attain a thickness of sometimes as much as 14,000 or 15,000 feet. Like the Alpine formations, they include a mingling of such Palæozoic genera as Spirifer, Orthoceras, and Goniatites, with characteristically Secondary forms as ammonites (Ceratites, Haidingeri, Ammonites ausseanus, etc.) and bivalves of the genera Halobia, Monotis, Myophoria, etc.

Section ii. Jurassic

This great series of fossiliferous rocks, first recognized by William Smith in the geological series in England, received originally the name of "Oolitic" from the frequent and characteristic oolitic structures of many of its limestones. Lithological names being, however, objectionable, the term "Jurassic," applied by the geologists of France and Switzerland to the great development of the rocks among the Jura Mountains, has now been universally adopted to embrace both Lias and Oolites.

§ 1. General Characters

Jurassic rocks have been recognized over a large part of the world. But they do not present that general uniformity of lithological character so marked among the Palæozoic systems. The suite of rocks changes as it passes from England across France, and is replaced by a distinctly different type in Northern Germany, and by another in the Alps. If we trace the system further into the Old World we find it presenting still another aspect in northwestern

India, while in America the meagre representatives of the European development have again a facies of their

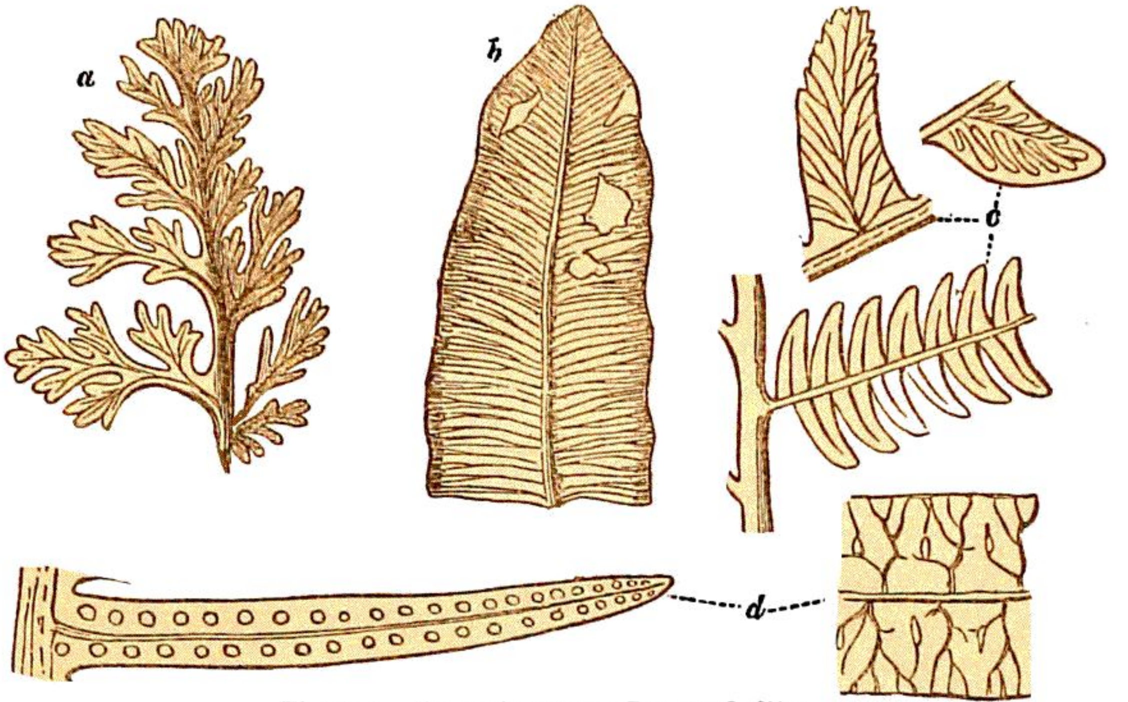

Fig. 381.—Jurassic Ferns (Lower Oolite).
a, Sphenopteris trichomanoides, Brongn.; *b*, Tæniopteris major, Lindl. and Hutt. (⅜); *c*, Pecopteris dentata, Lindl. and Hutt. (nat. size and mag.); *d*, Phlebopteris polypodioides, Brongn. (nat. size and mag.).

own. Hence no generally applicable petrographical characters can be assigned to this part of the geological record.

The flora of the Jurassic period, so far as known to us, was essentially gymnospermous.[40] The Palæozoic forms of vegetation traceable up to the close of the Permian system are here absent. Equisetums, so common in the Trias, are still abundant, one of them (E. arenaceum) attaining gigantic proportions. Ferns likewise continue plentiful, some of the chief genera being Alethopteris, Sphenopteris,

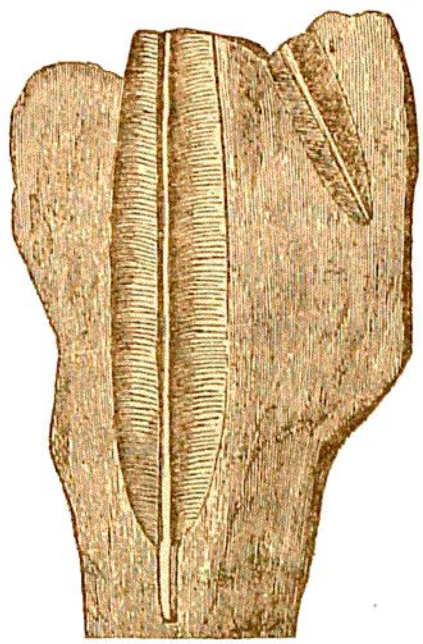

Fig. 382.—Jurassic Fern—Tæniopteris vittata, Brongn. (⅙).

[40] The entire known Jurassic flora of Britain, up to the top of the Portlandian stage, comprises between 60 and 70 genera and about 200 species—doubtless a mere fragment of the whole flora of the period.

Phlebopteris, Oleandridium, and Tæniopteris (Figs. 381, 382). The cycads (Fig. 383), however, are the dominant forms, in species of Zamites, Pterophyllum, Anomozamites, Nilssonia (Pterozamites), Dioonites, Podozamites, Sphenozamites, Glossozamites, Otozamites, Cycadites, Bucklandia (Clathraria), Bennettites, Mantellia (Cycadites and Cycadoidea), Zamiostrobus (Cycadeostrobus), Beania, Cycadospadix,

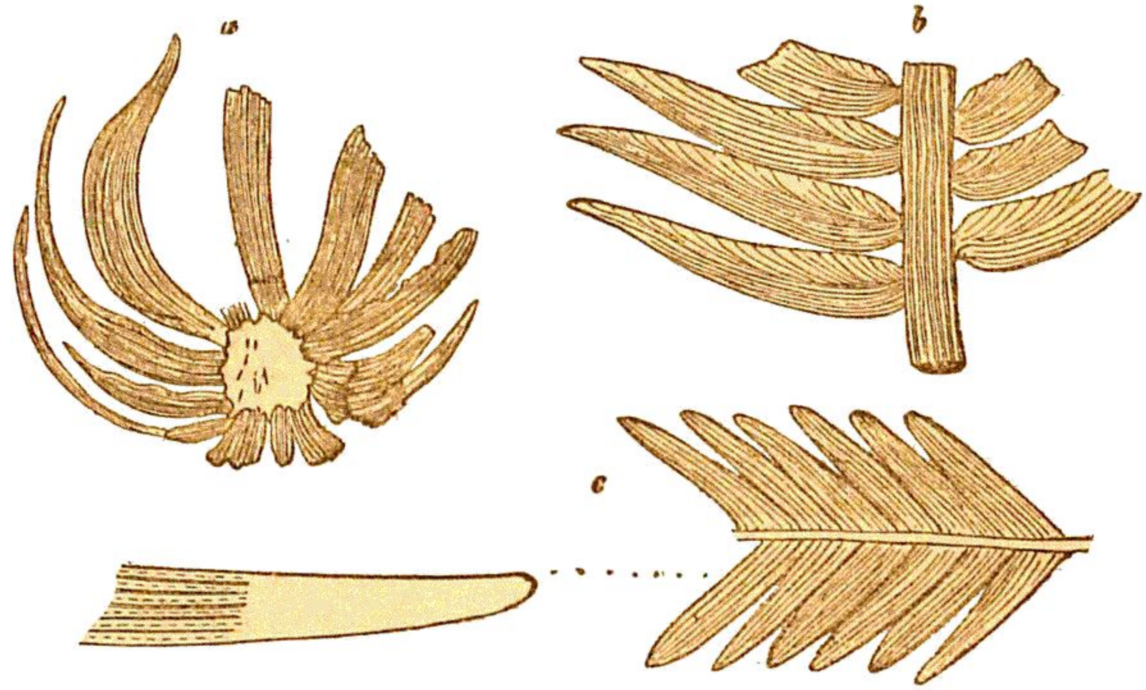

Fig. 383.—Jurassic Cycads (Lower Oolites).

a, Williamsonia (Zamia) gigas, Carr (½); *b*. Otozamites lanceolatus, Lindl. and Hutt. (½); *c*, Williamsonia hastula, Bean. (nat. size and mag.).

Cycadinocarpus. Williamsonia is by some botanists placed with the cycads, by others with the dicotyledons or with the monocotyledons. Conifers also are found in some numbers, particularly Araucarians of the genera Pachyphyllum (Walchia) and Araucaria; also Pinites, Peuce, Brachyphyllum, and Thuyites. This flora appears to have flourished luxuriantly even as far north as Spitzbergen, where the large number of cycads gives an almost tropical aspect to the Jurassic vegetation of this Arctic island.[41]

[41] O. Heer, K. Svensk. Vet. Akad. Handl. xiv. No. 5, p. 1.

The Jurassic fauna[42] presents a far more varied aspect than that of any of the preceding systems. Owing to the intercalation of fresh-water, and sometimes even terrestrial, deposits among the marine formations, traces of the life of the lakes and rivers, as well as of the land itself, have been to some extent embalmed, besides the preponderant marine forms. The conditions of sedimentation have likewise been favorable for the preservation of a succession of varied phases of marine life. Prof. Phillips directed attention to the remarkable ternary arrangement of the English Jurassic

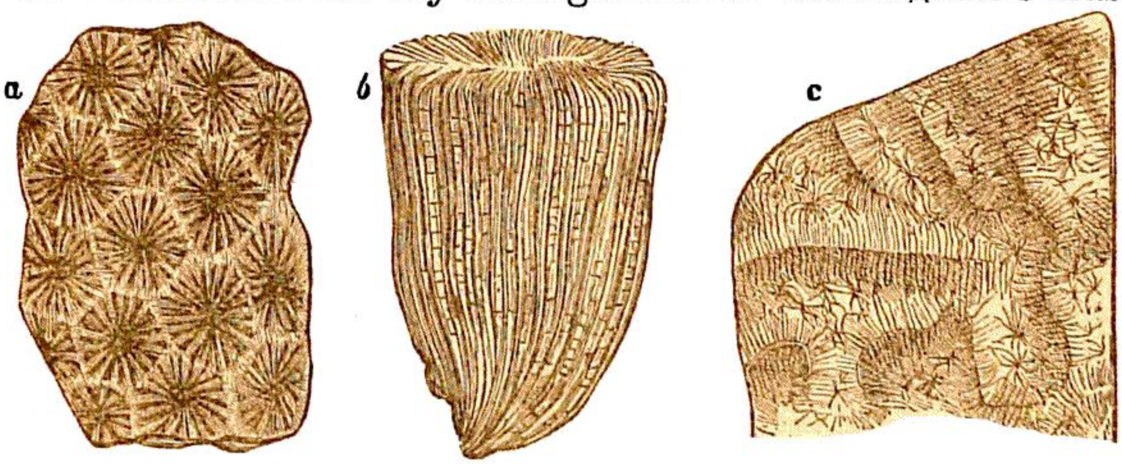

Fig. 384.—Jurassic Corals (Middle Oolite).
a, Isastræa helianthoides, Goldf.; *b*, Montlivaltia dispar, Phill.; *c*, Comoseris irradians, M. Edw.

series.[43] Argillaceous sediments are there succeeded by arenaceous, and these by calcareous, after which the argillaceous once more recur. These changes are more or less local in their occurrence, but five repetitions of the succession are to be traced from the top of the Lias to the top of the Portlandian stage. Such an alternation of sediments points to interrupted depression of the sea-bottom.[44] It permitted the growth and preservation of different kinds of

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[42] The total Jurassic fauna of Britain up to the top of the Portlandian stage was estimated in 1882 to include 450 genera and 4297 species, which is likewise but a small proportion of the whole original fauna. Etheridge, Q. J. Geol. Soc. 1882, Address.

[43] "Geology of Oxfordshire," etc. p. 393.

[44] Ante, p. 870.

marine organisms in succession over the same areas—at one time sand-banks, followed by a growth of corals, with abundant sea-urchins and shells, and then by an inroad of fine mud, which destroyed the corals, but in which, as it sank to the bottom, the abundant cephalopods and other mollusks of the time were admirably preserved.

A characteristic feature of the Jurassic fauna is the

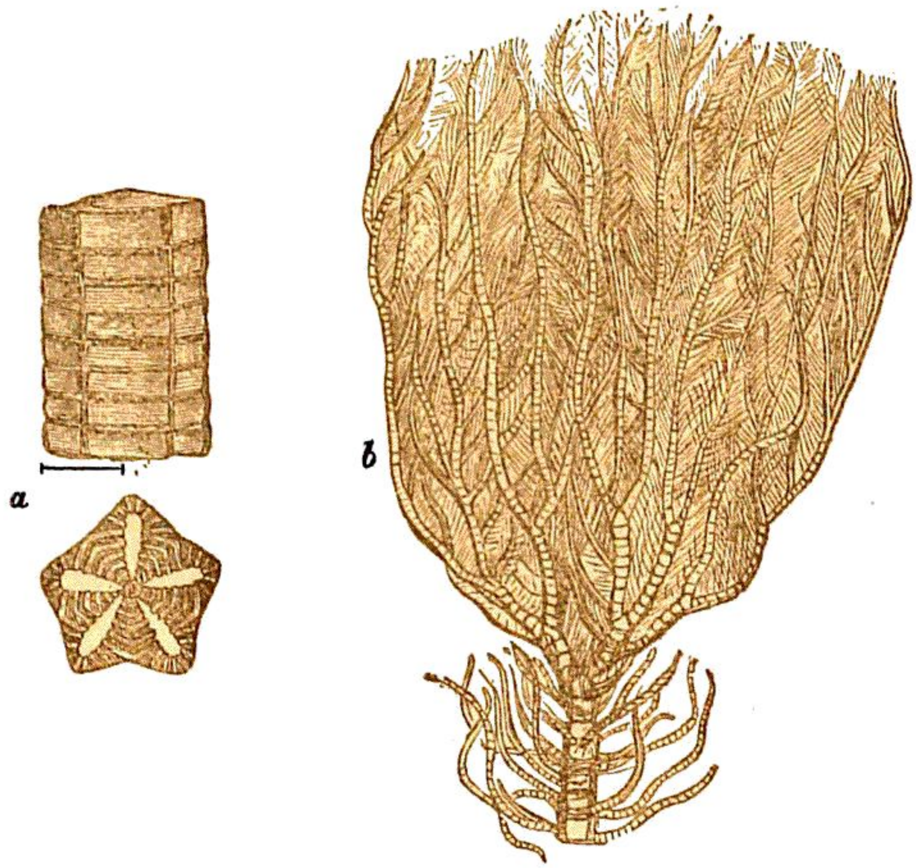

Fig. 385.—Lias Crinoids.
a, Pentacrinus basaltiformis, Goldf. (side view and end view of part of stem); *b*, Extracrinus briareus, Mill. (½).

abundance of its beds or banks of coral. During the time of the Corallian formation, in particular, the greater part of Europe appears to have been submerged beneath a coral sea. Stretching through England from Dorsetshire to Yorkshire, these coral accumulations have been traced across the Continent from Normandy to the Mediterranean, over the east of France, through the whole length of the Jura Mountains, and along the flank of the Swabian Alps.

The corals belonged to the genera Isastræa, Thamnastræa, Thecosmilia, Calamophyllia, Montlivaltia, etc. (Fig. 384). In the Jurassic seas generally echinoderms were abundant, particularly crinoids of the genera Pentacrinus, Extracrinus (Fig. 385), and Apiocrinus. Among these the multiplication of identical or nearly identical parts reaches a climax in the Extracrinus briareus, which is estimated to have possessed no fewer than 600,000 distinct ossicles. There were likewise several forms of star-fishes, but it is in the great profusion of echinoids that the echinoderms now begin to be distinguished. Among these the genera Acrosalenia, Cidaris (Fig. 386), Hemicidaris, Echinobrissus, Hemi-

Fig. 386.—Jurassic Urchin.—Cidaris florigemma, Phill. (½) Corallian.

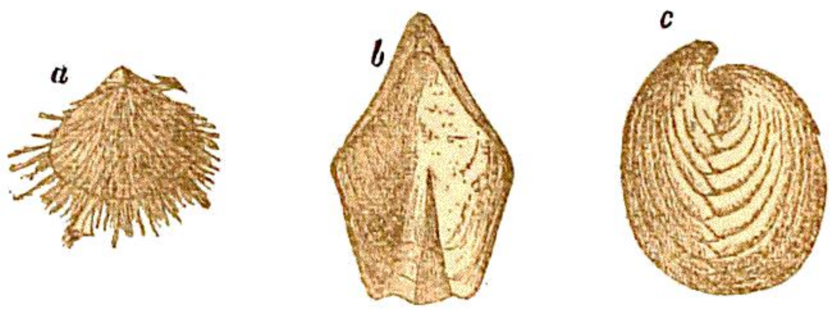

Fig. 387.—Oolitic Brachiopods.
a, Rhynchonella spinosa, Schloth. (½), Lower Oolite; *b*, Terebratula Phillipsii, Mor. (½), Lower Oolite; *c*, Rhynchonella pinguis, Rœm. Middle Oolite.

pedina, Pseudodiadema, Clypeus, Pygaster, and Pygurus were conspicuous. Polyzoa of creeping, foliaceous and dendroid types abound on many horizons in the Jurassic system. They include some extinct forms, but also some (Diastopora, Alecto) which have survived to the present time. They occur plentifully in the Pea-grit beds of the Inferior Oolite near Cheltenham, and Forest Marble near Bath, and still more abundantly near Metz and near Caen.[45] The brachiopods continue to decrease in importance compared to the prominence they enjoyed in Palæozoic time. So far as

[45] F. D. Longe, Geol. Mag. 1881, p. 23. The genus Alecto seems to range back to Lower Silurian times.

known, they are chiefly species of Rhynchonella and Terebratula (Fig. 387). The last of the ancient group of Spirifers (Spiriferina) and of the genus Leptæna (Koninckella, Fig. 388) disappear in the Lias, while Waldheimia, a still living genus, now takes its place. Among the lamellibranchs (Figs. 389–392) some of the more abundant genera are Avicula, Pseudomonotis, Aucella, Posidonomya, Gervillia, Ostrea, Gryphæa, Exogyra, Lima, Pecten, Pinna, Astarte, Cardinia, Cardium, Gresslya, Hippopodium, Modiola, Myacites, Cyprina, Isocardia, Pholadomya, Goniomya,

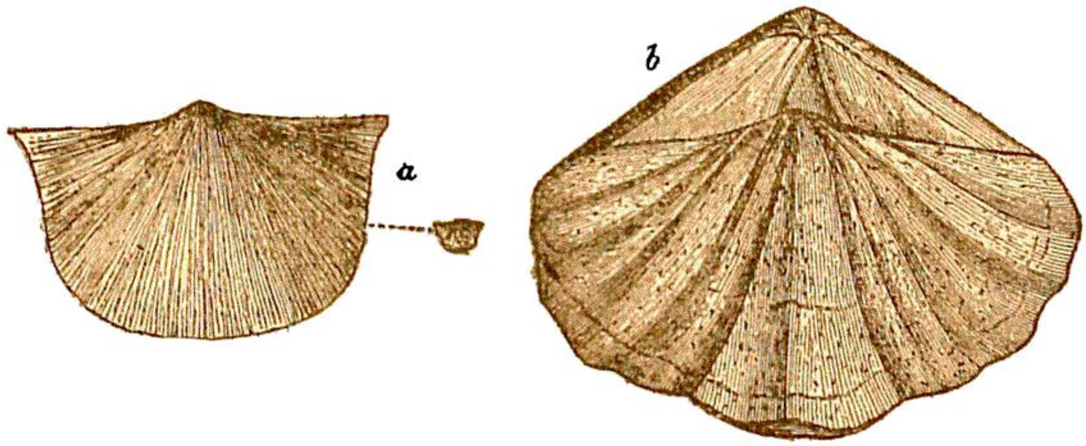

Fig. 388.—Lias Brachiopods.
a, Leptæna (Koninckella) Moorei, Dav. (nat. size and enlarged); *b*, Spiriferina Walcottii, Sby.

and Trigonia. Some of these genera, particularly the tribe of oysters, are specially characteristic: Gryphæa, for example, occurring in such numbers in some of the Lias limestones as to suggest for these strata the name of "Gryphite Limestone," and again in the so-called "Gryphite Grit" of the Inferior Oolite. Different species of Trigonia,[46] a genus now restricted to the Australian seas, are likewise distinctive of horizons in the middle and upper part of the system. Many of the most abundant gasteropods (Fig. 393) belong to

[46] This genus affords an instructive example of the remarkable changes of form which some genera of shells have undergone. See Lycett's monograph on Trigonia, Palæontograph. Soc.

still living genera, as Pleurotomaria, Cerithium, and Natica. But the most important element in the molluscan fauna was undoubtedly supplied by the cephalopods. In particular,

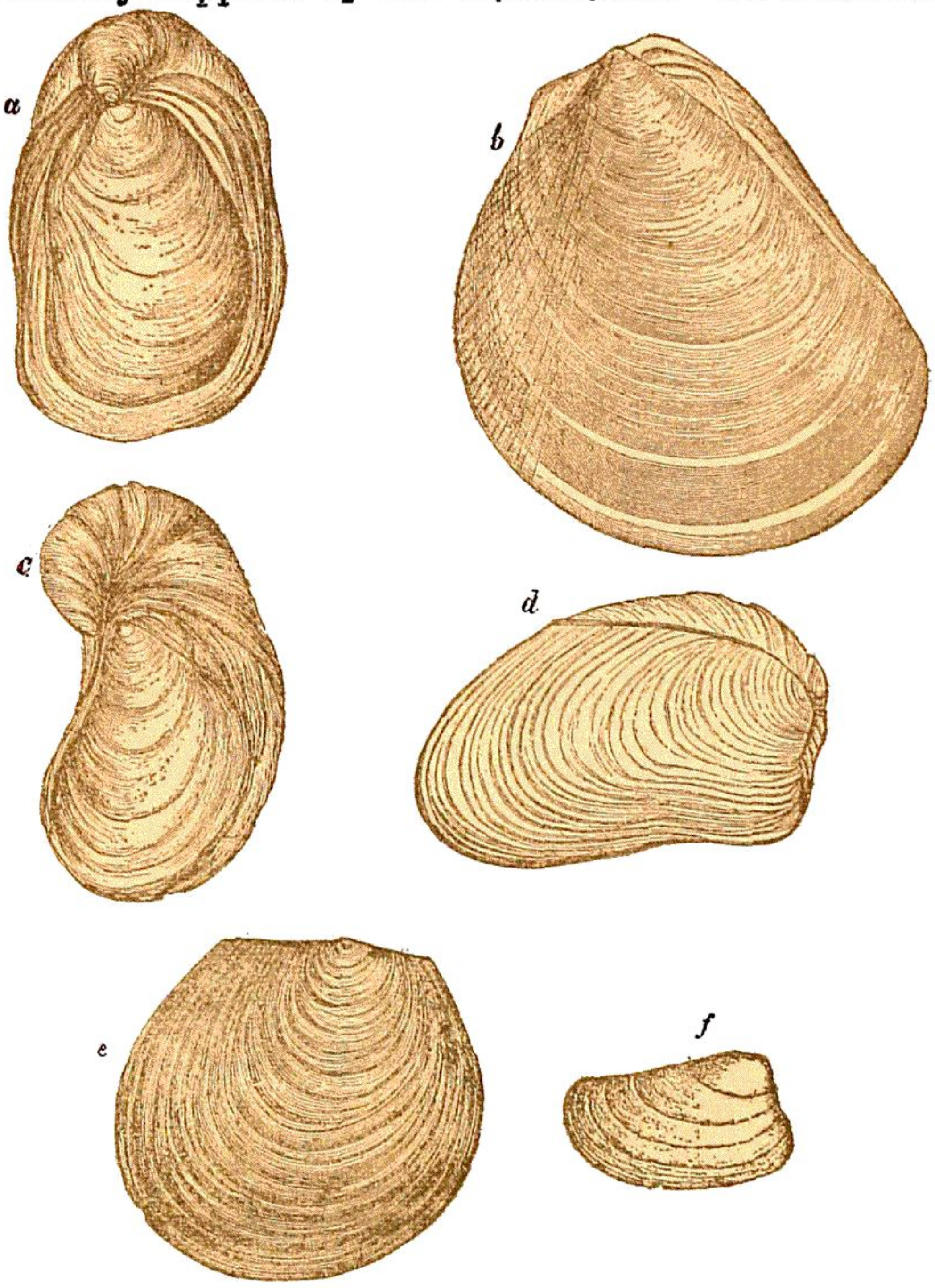

Fig. 389.—Liassic Lamellibranchs.

a, Gryphæa cymbium, Lam. (1/3); *b*, Lima gigantea, Sby. (1/3); *c*, Gryphæa arcuata, Lam. (incurva, Sby. (2/3); *d*, Hippopodium ponderosum, Sby. (1/2); *e*, Posidonomya Bronnii, Goldf. (nat. size); *f*, Nucula Hammeri, Defr.

the tetrabranchiate tribes of Ammonites attained an extraordinary exuberance, both in number of individuals and in variety of form (see Figs. 405–409). These organisms possess a great importance to the geologist, for their limited vertical range makes them extremely valuable in marking successive life-zones. The whole Jurassic system has been

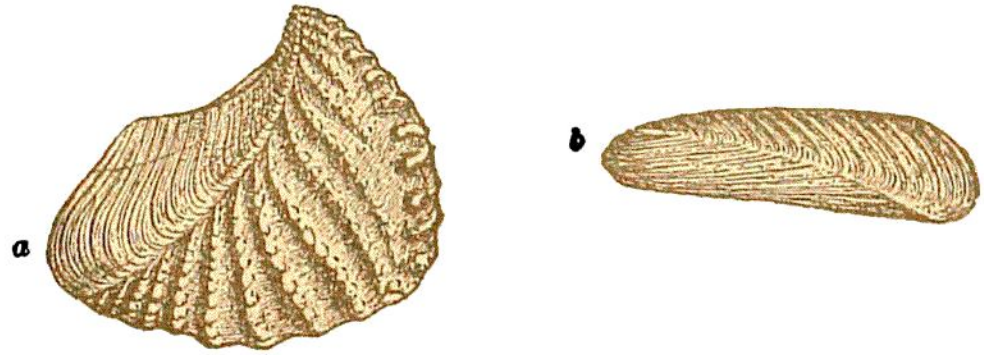

Fig. 390.—Lower Oolitic Lamellibranchs.
a, Trigonia navis, Lam. (½); *b*, Modiola (Mytilus) sowerbyana, D'Orb. (½).

divided into a series of platforms, each characterized by some predominant species or group of Ammonites. The ammonoid families which had previously existed seem to have in great measure died out, and a new and still richer series took their place at the close of the Triassic period.

Fig. 391.—Middle Oolitic Lamellibranchs.
a, Ostrea hastellata, Schloth. (½); *b*, Trigonia clavellata, Syb. (½).

The old comprehensive genus Ammonites has now been broken up into many families and genera. In the older part of the Jurassic system the genera Arietites, Ægoceras, Amaltheus, Lytoceras, Phylloceras, and Stephanoceras are characteristic. Higher up, besides some of these genera, we find Cosmoceras, Harpoceras, and Aspidoceras, and in the upper parts Perisphinctes and Oppellia. The dibranchiate division was likewise represented by species of cuttle-fish (Teudopsis, Beloteuthis, Sepia, but particularly Belemnites, Fig. 394). The Belemnites are the preponderating type, and, like the Ammonites, though in a less degree, their specific forms serve to mark life-zones.

No contrast can be more marked than between the

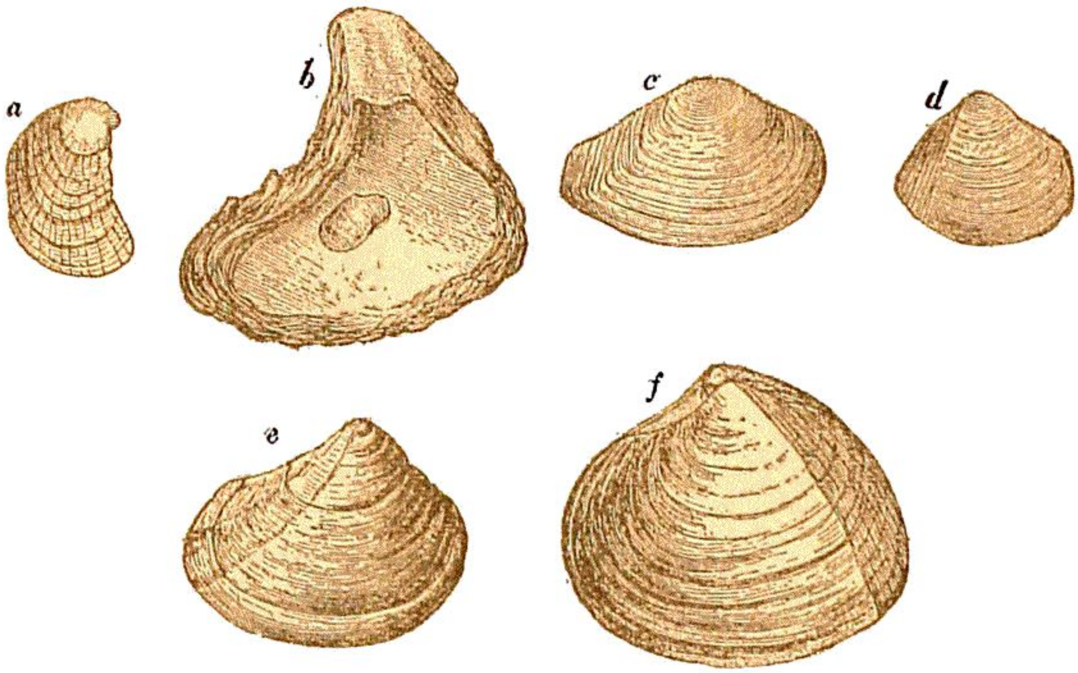

Fig. 392.—Upper Oolitic Lamellibranchs.
a, Exogyra (Ostrea) virgula, D'Orb.; *b*, Ostrea deltoidea, Sby. (1/4); *c*, Astarte hartwellensis, Sby. (1/3); *d*, Cardium striatulum, Sby. (1/2); *e*, Trigonia gibbosa, Sby. (1/2); *f*, Cardium dissimile, Sby. (1/3).

crustacean fauna of the Jurassic and that of the older systems. The ancient trilobites and eurypterids, as remarked by Phillips, are here replaced by tribes of long-tailed ten-footed lobsters and prawns, and of representatives of our modern crabs (Æger, Eryon).[47]

Here and there, particularly in the Jurassic series of England and Switzerland, thin bands occur containing the remains of terrestrial insects (Fig. 395). The neuropterous

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[47] For an account of the Jurassic decapods of North Germany see G. Krause, Zeitsch. Deutsch. Geol. Ges. 1891, p. 171.

forms predominate, including remains of dragon-flies and mayflies. There are also cockroaches and grasshoppers. The elytra and other remains of numerous beetles have been obtained belonging to still familiar types (Curculionidæ, Elateridæ, Melolonthidæ). A wing (Palæontina oolitica) disinterred from the Stonesfield Slate was originally believed to be the oldest known trace of a butterfly, but it is now considered to belong to the hemiptera. A few dipterous insects have been detected even as low down as the Lias toward the base of the system.[48]

In no department of the animal kingdom was the advent

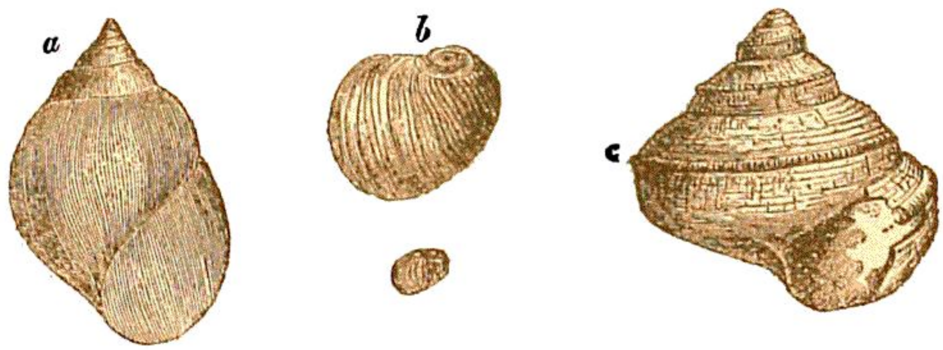

Fig. 393.—Jurassic Gasteropods.
a, Natica hulliana, Lyc. (Lower Oolite); *b*, Nerita costulata, Desh. (Lower Oolite, nat. size and mag.); *c*, Pleurotomaria reticulata, Sow. (Kimeridge clay, ½).

of Mesozoic time more marked than among the fishes. The Palæozoic types, with their heterocercal tails, nearly died out. The sharks and rays were well represented by species of Acrodus and Hybodus, while the ganoids appeared in numerous, mostly homocercal genera, such as Dapedius, Æchmodus, Mesodon, Gyrodus, Lepidotus, Pholidophorus, Pachychormus, Caturus, Leptolepis, Megalurus.[49]

The most impressive feature in the life of the Jurassic period was the abundance and variety of the reptilian

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[48] A. G. Butler, Geol. Mag. x. 1873, p. 2; i. 2d ser. 1874, p. 446. Scudder, Bull. U.S. Geol. Surv. No. 71, 1891, p. 175, and authorities there cited.

[49] For a list of Liassic fishes, see memoir by H. E. Sauvage, Ann. Sciences Geol. vi. 1875.

forms. Mesozoic time, as already remarked, has been termed the "Age of Reptiles," and it was especially during the Jurassic period that the maximum development of reptilian types, with the final disappearance of the ancient order of labyrinthodonts and the rise and growth of new orders of reptiles which have long since been extinct, was reached. The first true turtles seem to have made their

Fig. 394.—Jurassic Belemnites.

a, Belemnites paxillosus, Schloth. (Lias. ½); *b*, B. irregularis, Schloth. (Lias and Lower Oolite, nat. size); *c*, B. hastatus, Blainv. (Middle Oolite, ½).

appearance during this period. Numerous fragments of lacertilians have been obtained. The bones of various crocodilian genera occur, such as Teleosaurus, Steneosaurus, Mystriosaurus, and Goniopholis. Teleosaurus, found in the Yorkshire Lias and the Stonesfield Slate, was a true carnivorous crocodile, measuring about 18 feet in length, and is judged by Phillips to have been in the habit of venturing more freely to sea than the gavial of the Ganges or the crocodile of the Nile. Of the long-extinct reptilian types, one of the most remarkable was that of the enaliosaurs or sea-lizards. One of these, the Ichthyosaurus (Fig. 396, *a*), was a creature with a fish-like body, two pairs of strong swimming paddles, probably a vertical tail-fin, and a head joined to the body without any distinct neck, but furnished with two large eyes, having a ring of bony plates round the eyeball, and with teeth that had no distinct sockets. Some of the skeletons

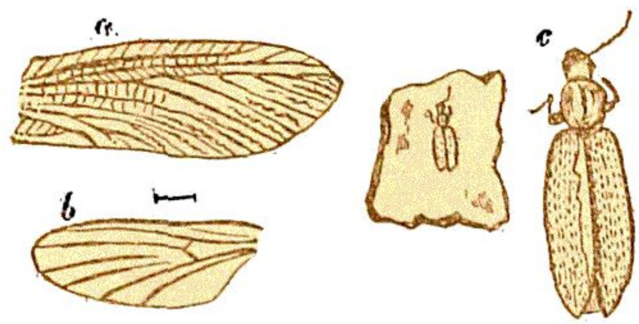

Fig. 395.—Insects, Purbeck Beds.

a, *b*, Wings of Neuropterous Insects (*Corydalis*) (nat. size and mag.); *c*, *Carabus elongatus* (nat. size and mag. Brodie, "Foss. Insects," pl. ii. and v.)

of this creature exceed 24 feet in length. Contemporaneous with it was the Plesiosaurus (Fig. 396, *b*), distinguished by its long neck, the larger size of its paddles, the smaller size of its head, and the insertion of its teeth in special sockets, as in the higher saurians. These creatures seem to have haunted the shallow Liassic seas, and, varying in species with the ages, to have survived till toward the close of Mesozoic time.[50] The genus Pliosaurus, related to the last-named, was distinguishable from it by the shortness of its neck and the proportionately large size of its head. Another extraordinary reptilian type was that of

[50] On the distribution of the Plesiosaurs see a table by G. F. Whidborne, Q. J. Geol. Soc. 1881, p. 480.

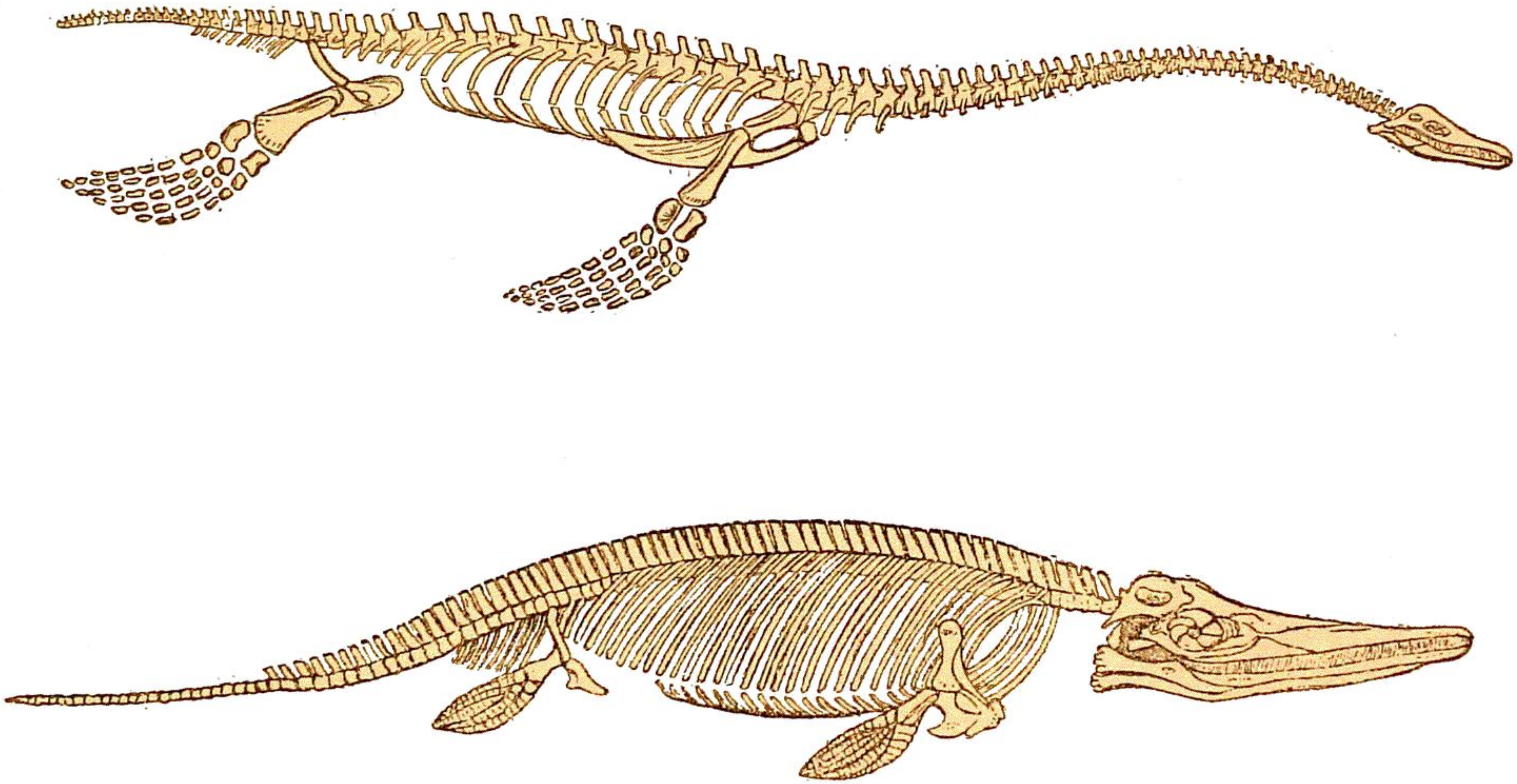

Fig. 396.—Jurassic Enaliosaurs or Sea-lizards.
a, Ichthyosaurus communis, Conyb. (restored by Conybeare and Cuvier); *b*, Plesiosaurus dolichodeirus, Conyb. (restored by Conybeare).

the pterosaurians or flying reptiles, which were likewise peculiar to Mesozoic time. These huge, winged, bat-like creatures had large heads, teeth in distinct sockets, eyes like the Ichthyosaurus, one finger of each fore-foot prolonged to a great length, for the purpose of supporting a membrane for flight, and bones, like those of birds, hollow and air-filled.[51] The best-known genus, Pterodactylus (Scaphognathus, Fig. 397), had a short tail and jaws furnished from end to end with long teeth. Others were Dimorphodon, distinguished especially by long anterior and short hinder teeth, and by the length of its tail, and Rhamphorhynchus (Figs. 398, 399, 400, 401), also possessing a long tail, with a caudal membrane, and having formidable jaws, which may have terminated in a horny beak. These strange harpy-like creatures were able to fly, to shuffle on land, or perch on rocks, perhaps even to dive in search of their prey. The long slender teeth which some of them possessed probably indicate that the creatures lived on fish. Lastly, the most colossal living beings of Mesozoic time, and, indeed, so far as we know, of any time, belonged to the ancient order of Deinosaurs, which now attained their maximum development. In these animals, which appeared

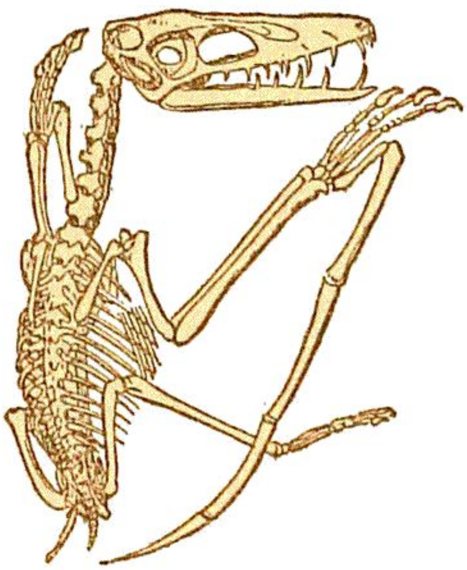

Fig. 397.—Jurassic Pterosaur. Scaphognathus (Pterodactylus) crassirostris, Goldf. (Middle Oolite).

[51] See Marsh on wings of Pterodactyles, Amer. Journ. Sci. April, 1882. The remarkable specimen of Rhamphorhynchus (R. Münsteri) from the Solenhofen Slate, described by this author (Figs. 399, 400, 401), possessed a long tail, the last sixteen short vertebræ of which supported a peculiar caudal membrane which, kept in an upright position by flexible spines, must have been an efficient instrument for steering the flight of the creature. I am indebted to the kindness of Prof. Marsh for the three figures which illustrate this structure.

in the earliest Mesozoic ages, ordinary reptilian characters (as already remarked) were united to others, particularly in the hinder part of the skeleton, like those of birds. It was during the Jurassic period that the Deinosaurs reached their culmination in size, variety, and abundance. The most important European Jurassic genera are Compsognathus, Megalosaurus (Fig. 398), and Cetiosaurus. In Compsognathus, from the Solenhofen Limestone, the bird-like affinities are strikingly exhibited, as it possessed a long

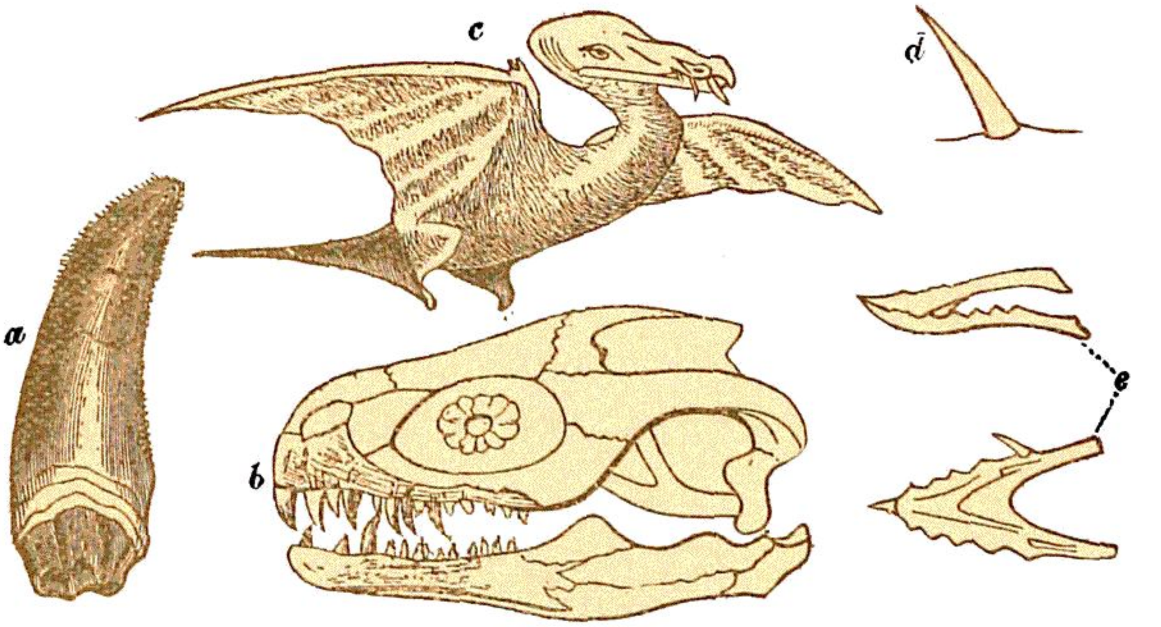

Fig. 398.—Jurassic Deinosaur and Pterosaur.

a, Megalosaurus Bucklandi (Meyer), tooth (½); *b*, Megalosaurus, restoration of head, after Owen ($\frac{1}{20}$); *c*, Rhamphocephalus Bucklandi (Goldf.), restoration after Phillips (compare Fig. 401); *d*, Do. tooth (nat. size); *e*, Do. jaw (½).

neck, small head, and long hind limbs on which it must have hopped or walked. The Megalosaurus of the Stonesfield Slate is estimated to have had a length of 25 feet, and to have weighed two or three tons. It frequented the shores of the lagoons, walking probably on its massive hind legs, and feeding on the mollusks, fishes, and perhaps the small mammals of the district. Still more gigantic was the Cetiosaurus, which, according to Phillips, probably reached, when standing, a height of not less than 10 feet and a length of 50 feet. It seems to have been a marsh-loving or river-side animal, living on the ferns, cycads, and conifers among which it dwelt.

But these monsters of the Old World were surpassed in

Fig. 399.—Jurassic Pterosaur.

Rhamphorhynchus Munsteri, Goldf. (¼). The animal lies upon its back, and the under surface of the wing-membrane is exposed. The caudal membrane is shown of nat. size in Fig 400.

dimensions by some discovered in the Jurassic formations of Colorado. Of these, Brotosaurus was distinguished by its relatively short body, long neck and tail, and remarkably small head. Its legs and feet were massive, with solid bones, and made footprints each measuring about a square yard in area. Its length is estimated at 50 feet or more, and its weight, when alive, at more than 20 tons. In habit it was more or less amphibious, probably feeding on aquatic

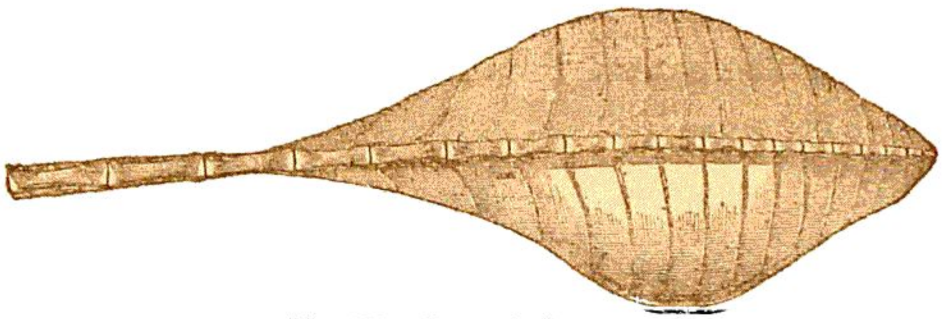

Fig. 400.—Jurassic Pterosaur.
Rhamphorhynchus Munsteri, Goldf. Caudal extremity (nat. size).

plants or other succulent vegetation. The small head and brain and slender neural cord indicate a stupid, slow-moving reptile.[52] Stegosaurus had a remarkably small skull with short massive jaws, very short, powerful fore-limbs, with comparatively long and slender hind-limbs. But its most

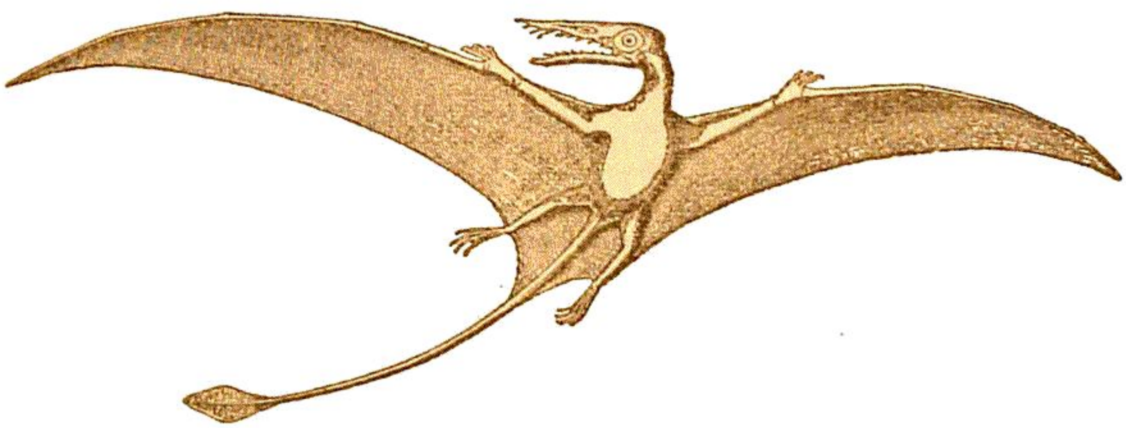

Fig. 401.—Jurassic Pterosaur.
Rhamphorhynchus Munsteri (1/7), restored by Marsh.

singular character was the possession of numerous dermal spines, some of great size and power, and many bony plates of various sizes and shapes, some of them more than 3 feet in diameter. Thus armed as well as protected, it must have

[52] Marsh, Amer. Journ. Sci. xxvi. 1883, p. 81.

been one of the most uncouth monsters that haunted the waters of the time. Yet it was itself herbivorous, and appears to have been more or less aquatic in habit.[53] But the most colossal of all these forms, and, indeed, the most gigantic creature yet known, was that to which Professor Marsh has given the name of Atlantosaurus. It was built on so huge a scale that its femur alone is more than 8 feet

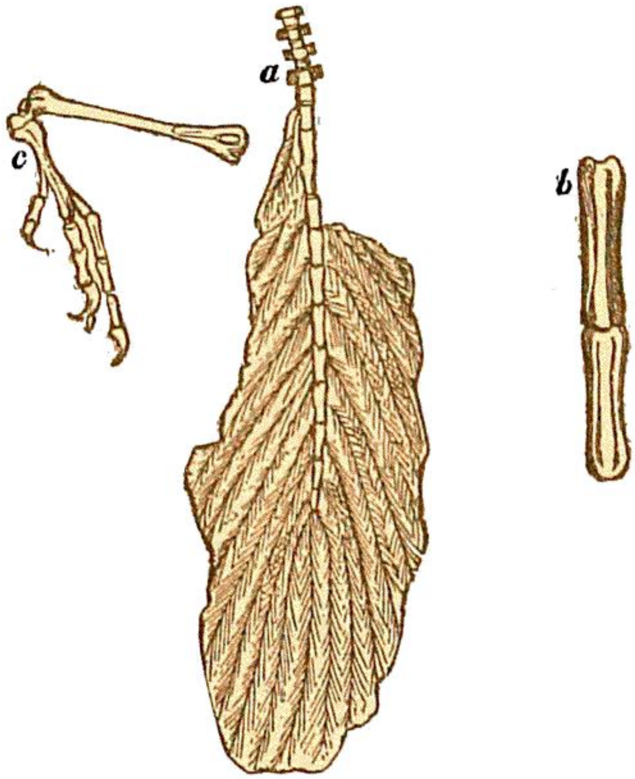

Fig. 402.—Bird (Archæopterix macrura, Owen)—Solenhofen Limestone (Middle Jurassic).

a, Tail and Tail-feathers (¼); *b*, caudal vertebræ (nat. size); *c*, foot (¼).

high, the corresponding bone of the most gigantic elephant looking like that of a dwarf, when put beside this fossil. The whole length of the animal is supposed to have been not much short of 100 feet, with a height of 30 feet or more. Contemporaneous with these huge creatures, however, there existed in Jurassic time in North America diminutive forms having such strong avian affinities that

[53] Marsh, op. cit. xix. 1880, p. 258.

their separate bones cannot be distinguished from those of birds. Professor Marsh, who has brought these interesting forms to light, regards them as having been in some cases probably arboreal in habit, with possibly at first no more essential difference from the birds of their time than the absence of feathers.[54]

The oldest known bird, Archæopteryx (Fig. 402), comes from the Solenhofen Limestone in the Upper Jurassic series —a rock which has been especially prolific in the fauna of the Jurassic period. This interesting organism, which was rather smaller than a crow, united some of the characters of reptiles with those of a true bird. Thus it possessed biconcave vertebræ, a well-ossified broad sternum, and a long lizard-like tail, each vertebra of which bore a pair of quill-feathers. The three wing-fingers were all free and each ended in a claw, and there appear to have been four toes to each foot, as in most of our common birds. The jaws carried true teeth, as in the toothed birds found in the Cretaceous rocks of Kansas.[55] Remains of birds have also been obtained from the Upper Jurassic rocks (Atlantosaurus-beds) of Wyoming Territory in Western America. The best preserved of these has been named by Marsh Laopteryx, which he believes to have possessed teeth and biconcave vertebræ.[56]

The most highly organized animals of which the remains have been discovered in the Jurassic system are small mar-

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[54] For Prof. Marsh's descriptions of Jurassic Deinosaurs see Amer. Journ. Sci. xvi. 1878, p. 411; xvii. 1879, p. 86; xviii. 1880; xix. 1880, p. 253; xxi. 1881, p. 417; xxii. 1881, p. 340; xxiii. 1882, p. 81; xxvi. 1883, p. 81; xxvii. 1884, p. 161; xxxiv. 1887, p. 413; xxxvii. 1889, pp. 323, 331; xxxix. 1890, p. 415; xlii. 1891, p. 179; xliv. 1892, p. 347.

[55] See Marsh, Amer. Journ. Sci. Nov. 1881, p. 337; Geol. Mag. 1881, p. 485; Carl Vogt, Rev. Sci. Sept. 1879; Seeley, Geol. Mag. 1881, pp. 300, 454; W. Dames, Sitzb. Berlin Akad. xxxviii. 1882, p. 817; Geol. Mag. 1882, p. 566; 1884, p. 418.

[56] Amer. Journ. Sci. xxi. 1881, p. 341; also xxii. p. 337.

supials. Two horizons in England have furnished these interesting relics—the Stonesfield Slate and the Purbeck beds. The Stonesfield Slate has yielded the remains of five genera —Amphitylus, Amphilestes, and Phascolotherium (Fig. 403), probably insectivorous, the latter being related to the living American opossums; Amphitherium, resembling most

Fig. 403.—Marsupial from the Stonesfield Slate.
Phascolotherium Bucklandi, Broderip: *a*, teeth, magnified; *b*, jaw, nat. size.

closely the Australian Myrmecobius; and Stereognathus, which Owen was disposed to think was rather a placental, hoofed, and herbivorous form. Higher up in the English Jurassic series another interesting group of mammalian remains has been obtained from the Purbeck beds, whence upward of twenty species have been exhumed belonging to

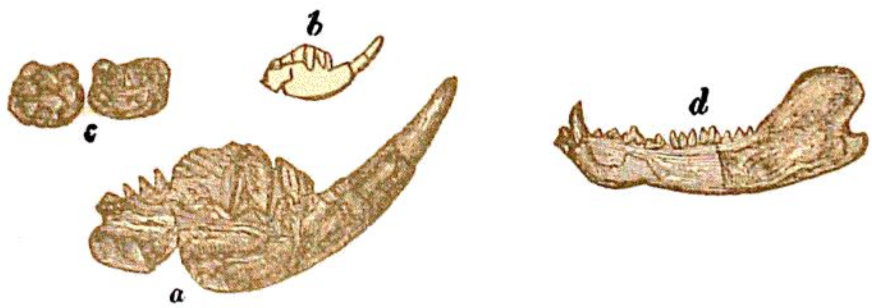

Fig. 404.—Marsupials from the Purbeck Beds.
***a*, Jaw of Plagiaulax minor, Falconer (?); *b*, same, (nat. size); *c*, Molar (?), *d*, Triconodon mordax (Triacanthodon serrula) Owen (nat. size).**

eleven genera (Spalacotherium, Amblotherium, Peralestes, Achyrodon, Kurtodon, Peramus, Stylodon, Bolodon, Triconodon, Triacanthodon, Fig. 404), of which some appear to have been insectivorous, with their closest living representatives among the Australian phalangers and American opossums, while one, Plagiaulax, resembling the Australian kangaroo-rats (Hypsiprymnus), is held by Owen to have been a carnivorous form.[57] A still more varied and abundant assemblage of mammalian remains has been exhumed from the Jurassic rocks of the western regions of the United States (see Sect. ii. § 2).

GEOGRAPHICAL DISTRIBUTION.—The Jurassic system covers a vast area in Europe. Beginning at the west, remnants of it occur in the far north of Scotland. It ranges across England as a broad band from the coasts of Yorkshire to those of Dorset. Crossing the Channel, it encircles with a great ring the Cretaceous and Tertiary basin of the north of France, whence it ranges on the one side southward down the valleys of the Saone and Rhone, and on the other round the old crystalline nucleus of Auvergne to the Mediterranean. Eastward, it sweeps through the Jura Mountains (whence its name is taken) up to the high grounds of Bohemia. It forms part of the outer ridges of the Alps on both sides, rises along the centre of the Apennines, and appears here and there over the Spanish peninsula. Covered by more recent formations, it underlies the great plain of northern Germany, whence it ranges eastward and occupies large tracts in central and eastern Russia. Some years ago, Neumayr, following up the early generalization of L. von Buch, showed that three distinct geographical regions of deposit, marking diversities of climate, can be made out among the Jurassic rocks of Europe.[58] (1) The Mediterranean prov-

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[57] See Falconer, Q. J. Geol. Soc. xiii. 261; xviii. 348; Owen, "Monograph of Mesozoic Mammals," Palæontograph. Soc. 1871; "Extinct Mammals of Australia," 1877.

[58] Neumayr, "Jura-Studien," Jahrb. Geol. Reichsanstalt, 1871, pp. 297, 451; Verhandl. Geol. Reichsanst. 1871, p. 165; 1872, p. 54; 1873, p. 288. "Ueber climatische Zonen während der Jura- und Kreidezeit," Denksch. Wien. Akad. xlvii. 1883, p. 277. "Die geographische Verbreitung der Juraformation," op. cit. l. 1885, p. 57. In these memoirs the student will find much

ince, embracing the Pyrenees, Alps, and Carpathians, with all the tracts lying to the south. One of the biological characters of this area was the great abundance of Ammonites belonging to the groups of Heterophylli (Phylloceras) and Fimbriati (Lytoceras), and the presence of forms of Terebratula of the family of T. diphya (janitor). (2) The central European province, comprising the tracts to the north of the Alpine ridge, including France, England, Germany, and the Baltic countries, and marked by the comparative rarity of the Ammonites just mentioned, which are replaced by others of the genera Aspidoceras and Oppellia, and by abundant reefs and masses of coral. (3) The boreal or Russian province, comprising the middle and north of Russia, Petschora, Spitzbergen, and Greenland. The life in this area was less varied than in the others; in particular, the widely distributed species of Oppellia and Aspidoceras of the middle-European province are absent, as well as large masses of corals, showing that in Jurassic times there was a perceptible diminution of temperature toward the north.

Neumayr subsequently extended these three provinces into homoiozoic zones or belts stretching round the globe, and showing the probable distribution of climate and life during Jurassic and early Cretaceous times. (1) The Boreal Zone descends as far as lat. 46° in North America, whence it bends northeastward, coming as high as lat. 63° in Scandinavia; but then taking a remarkable bend toward the southeast across Russia, the Kirghiz Steppes and Turkestan into Tibet, about lat. 29° N. and long. 85° E. This curious projection is explained by the fact that the fauna of the Juras-

interesting speculation regarding zoological distribution, organic progress and vicissitudes of climate during the Jurassic and Neocomian periods. The last memoir contains two successive maps of Jurassic geography.

sic rocks of Tibet, Kashmir and Nepal, though peculiar, has greater affinities with that of the boreal than with that of more southern zones. The boreal zone is divisible, as far as yet known, into three provinces, the Arctic, Russian and Himalayan. (2) The North Temperate Zone reaches to about lat. 33° in North America. In Europe its limits are more precisely defined. It extends from Lisbon across the Spanish table-land to the west end of the Pyrenees, thence across the south of France and along the north side of the Alps to the north end of the Carpathians, bending southward so as to keep to the north of the Black Sea and Caucasus, and then striking southeastward into the Himalaya chain, where it is nearly cut off by the extension of the Boreal Zone just mentioned. In this zone four provinces have been recognized—the middle European, Caspian, Punjab and Californian. (3) The Equatorial Zone extends southward to the southern end of Peru, and does not include the extreme southern coasts of South Africa and Australia, which with the remaining part of South America lie in the South Temperate Zone. In the Equatorial Zone, seven provinces are more or less clearly defined: the Alpine, Mediterranean, Crim-Caucasian, Ethiopian, Columbian, Caribbean (?), and Peruvian. The South Temperate Zone is allowed four provinces: the Chilean, New Zealand (?), Australian, and Cape.

By carefully collecting and collating the evidence furnished by the discovery of Jurassic rocks in all parts of the world, Neumayr believed himself warranted to give a sketch of the probable geographical distribution of sea and land during the Jurassic period, and even to reduce the data to the form of maps. He thought there was sufficient proof of the existence of three great oceans partly coincident with those still existing—the Arctic Ocean, the Pacific Ocean, and the Antarctic Ocean. A central Mediterranean stretched across the narrow part of the American continent, and traversing what is now the North Atlantic, swept all over central and southern Europe, the present Mediterranean Sea, and the north of Africa. It joined the Arctic Ocean in the Russian plain, sent various arms into Asia, and passing across central India stretched southward to the Antarctic Ocean. A long and wide branch extended between Africa and a supposed mass of land connecting southern Africa, Madagascar, and southern India. The chief terrestrial areas of the period, according to Neumayr, were the African-Brazilian continent, extending across the southern Atlantic; the Chinese-Australian continent, extending from the north of China over the southeast of Asia to Tasmania and New Zealand; the Nearctic continent, extending from southeastern Greenland and Iceland across the North Atlantic to the Gulf of Mexico; the Scandinavian island, the European Archipelago, consisting of numerous insular tracts dotted over the Jurassic sea from Ireland on the west to southern Russia on the east; the Turanian island, lying to the east of the Caspian; and the Ural island, on the site of the Ural Mountains. But much of this geography rests on slender evidence. One of the most remarkable facts pointed out by Neumayr is the extent of the overlap of upper Jurassic rocks upon lower members of the system. He showed that the Lias was not deposited over an enormous part of the earth's surface, which nevertheless sank beneath the sea wherein later parts of the Jurassic series were laid down.

§ 2. Local Development

Britain.[59]—The stratigraphical succession of the Jurassic rocks was first worked out in England by William Smith, in whose hands it was made the foundation of stratigraphical geology. The names adopted by him for the subdivisions he traced across the country have passed into universal use, and though some of them are uncouth English provincial names, they are as familiar to the geologists of other countries as to those of England.

The Jurassic formations stretch across England in a varying band from the mouth of the Tees to the coast of Dorsetshire. They consist of sands, sandstones and limestones interstratified with softer clays and shales. Hence they give rise to a characteristic type of scenery—the more durable and more porous beds standing out as long ridges, sometimes even with low cliffs, while the clays underlie the level spaces between. Arranged in descending order, the following subdivisions of the English Jurassic system are generally recognized:

Formations or Series.	Groups or Stages.	Sub-groups or sub-stages.	Maximum thicknesses
			Feet.
Upper or Portland Oolites.	Purbeckian .	Upper fresh-water beds Middle marine beds Lower fresh-water beds	360
	Portlandian .	Portland Stone	70
		Portland Sands	150
	Kimeridgian .	Kimeridge Clay	600
Middle or Oxford Oolites.	Corallian .	Coral Rag, Coralline Oolite, and Calcareous Grit	250
	Oxfordian .	Oxford Clay and Kellaways Rock	600

[59] For British Jurassic rocks the student's attention may be specially called to Phillips' "Geology of Oxford and the Thames Valley"; Tate and Blake's "Yorkshire Lias"; Hudleston's "Yorkshire Oolites," in Geol. Mag. 1880–84, and Proc. Geol. Assoc. vols. iii. to v.; Memoirs published by the Palæontographical Society, particularly Morris and Lycett's "Mollusca from Great Oolite"; Davidson's "Tertiary, Oolitic, and Liassic Brachiopoda"; Wright's "Oolitic Echinodermata" and "Lias Ammonites"; Owen's "Mesozoic Reptiles"; "Mesozoic Mammals," "Wealden and Purbeck Reptiles"; Hudleston's "British Jurassic Gasteropoda"; Buckman's "Inferior Oolite Ammonites." The Memoirs of the Geological Survey comprise some important works on this subject, such as Hull's "Geology of Cheltenham"; Judd's "Geology of Rutland," etc.; H. B. Woodward's "Jurassic Rocks of England and Wales (Yorkshire excepted)"; C. Fox-Strangway's "Jurassic Rocks of Yorkshire," etc. Further information will be found in the Address by Mr. Etheridge, Q. J. Geol. Soc. 1882; in Woodward's "Geology of England and Wales"; and in other memoirs cited below. See also Oppel's "Juraformation England's Frankreichs und Deutschlands," 1856; Quenstedt's "Der Jura," 1858.

Lower Oolites.	Great or Bath Oolite group	Cornbrash. This forms a persistent band at the top of the lower or variable (marine and estuarine) group	25
		Bradford Clay and Forest Marble	160
		Great or Bath Oolite, with Stonesfield Slate	130
	Fuller's Earth	Fuller's Earth	150
	Inferior Oolite	Cheltenham beds (thick estuarine series of Yorkshire, representing the whole succession up to the base of the Cornbrash)	270
		Northampton Sands ("Dogger" of Yorkshire)	160
		Midford Sands (passage beds)	
Lias.	Upper Lias		400
	Marlstone		350
	Lower Lias		900

Although these names appear in tabular order, as expressive of what is the predominant or normal succession of strata, considerable differences occur when the rocks are traced across the country, especially in the Lower Oolites. Thus the Inferior Oolite consists of marine limestones and marls in Gloucestershire, but chiefly of massive estuarine sandstones and shales in Yorkshire. These differences help to bring before us some of the geographical features of the British area during the Jurassic period.

The LIAS[60] consists of three stages or groups, well marked by physical and palæontological characters.[61] In the Lower member, numerous thin blue and brown limestones, with partings of dark shale, are surmounted by similar shales with occasional nodular limestone bands. The Middle Lias consists of argillaceous and ferruginous limestones (Marlstone) with underlying micaceous sands and clays. In some of the midland counties, but more especially in Yorkshire, this subdivision is remarkable for containing a thick series of beds of earthy carbonate of iron (Ironstone series), which has been extensively worked in the Cleveland district. The Upper stage is composed of clays and shales with nodules of limestone, surmounted by sandy deposits, which are perhaps best classed with the Inferior Oolite. In Yorkshire it consists of about 240 feet of gray and black shale, in the upper part of which lies a dark band full of pyritous "doggers" (ironstone concretions) and blocks of jet, which are ex-

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60 This word, now so familiar in geological literature, was adopted by William Smith, who found it given by the Somerset quarrymen to the "layers" of argillaceous limestone forming a part of the series of rocks to which the term is now applied.

61 The English Lias is fully described by Mr. H. B. Woodward in his monograph in the Memoirs of the Geological Survey above cited.

tracted for the manufacture of ornaments. This jet appears to have been originally water-logged fragments of coniferous wood.[62]

These three stages are subdivided into the following zones according to distinctive species of Ammonites, though the zones are not so definite in nature as in palæontological lists:[63]

Upper Lias	2.	Zone of Ammonites	(Stephanoceras) communis.
	1.	"	(Harpoceras) serpentinus.
Middle Lias	2.	"	(Amaltheus) spinatus.
	1.	"	" margaritatus.
Lower Lias	10.	"	(Ægoceras) Henleyi.
	9.	"	(Amaltheus) Ibex.
	8.	"	(Ægoceras) Jamesoni.
	7.	"	(Arietites) raricostatus.
	6.	"	(Amaltheus) oxynotus.
	5.	"	(Arietites) obtusus.
	4.	"	" Turneri.
	3.	"	" Bucklandi.
	2.	"	(Ægoceras) angulatus.
	1.	"	" planorbis.

resting conformably on *Avicula contorta* beds (p. 1438).

The organic remains of the British Lias now include nearly 300 genera and more than six times that number of species. The plants comprise leaves and other remains of cycads (Palæozamia, Otozamites), conifers (Pinites, Clathropteris, Peuce), ferns (Alethopteris, etc.), and mares' tails (Equisetites). These fossils serve to indicate the general character of the flora, which seems now to have been mainly cycadaceous and coniferous, and to have presented a great contrast to the lycopodiaceous vegetation of Palæozoic times. The occurrence of land-plants dispersedly throughout the English Lias shows also that the strata, though chiefly marine, were deposited within such short distance from shore, as to receive from time to time leaves,

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[62] C. Fox-Strangways, Mem. Geol. Survey, "Scarborough and Whitby," 1882, p. 21.

[63] Wright on Liassic Ammonites, Palæontograph. Soc. and Q. J. Geol. Soc. xvi. 374; C. H. Day, op. cit. xix. p. 278; Etheridge, op. cit. xxxviii. (Address), As the zones are not generally defined by lithological features they cannot be satisfactorily mapped. On the maps of the Geological Survey the base of the Middle Lias is perhaps not drawn uniformly at one palæontological horizon; but it generally corresponds with the base of the Margaritatus zone. See Judd. "Geology of Rutland," pp. 45, 89.

seeds, fruits, twigs, and stems from the land. Further evidence in the same direction is supplied by the numerous

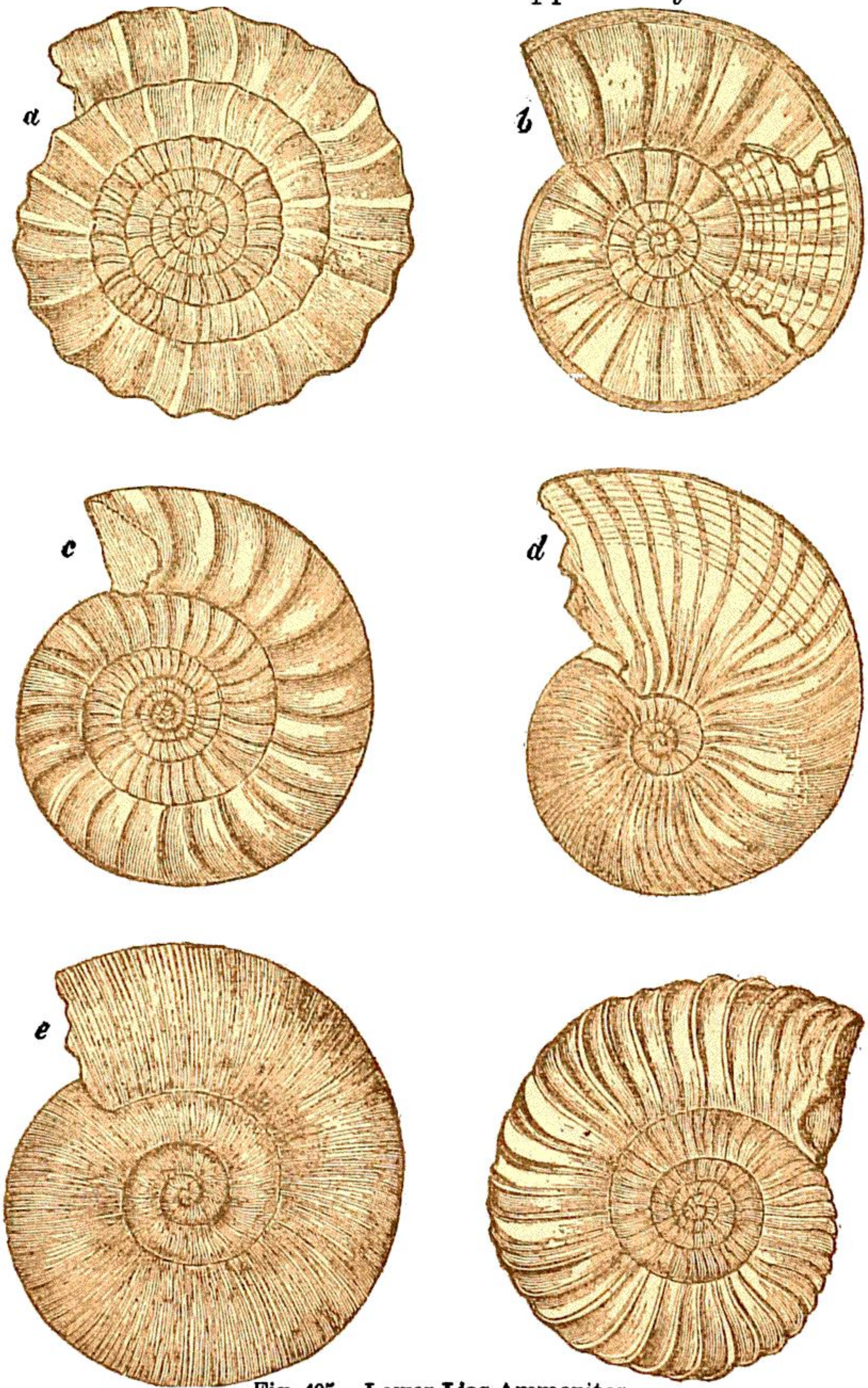

Fig. 405.—Lower Lias Ammonites.

a, Ammonites (Arietites) raricostatus, Zeit. (2/3); *b*, A. (A.) obtusus, Sby. (1/2); *c*, A. (A. Bucklandi, Sby. (1/6); *d*, A. (Amaltheus) oxynotus, Quenst. (2/3); *e*, A. (Ægoceras) planorbis, Sby.; *f*, A. (Æ.) angulatus, Schloth. (1/3).

insect remains, which have been obtained principally from the Lower Lias. These were, no doubt, blown off the land and fell into shallow water, where they were preserved in the silt on the bottom. The Neuroptera are numerous, and include several species of Libellula. The coleopterous forms comprise a number of herbivorous and lignivorous beetles (Elater, Buprestites, etc.). There were likewise representatives of the orthopterous, dipterous, and palæodictyopterous orders. These relics of insect life are so abundant in some of the calcareous bands that the latter are known as insect-beds.[64] With them are associated remains of terrestrial plants, cyprids, and mollusks, sometimes marine, sometimes apparently brackish-water. The marine life of the period has been abundantly preserved, so far at least as regards the comparatively shallow and juxta-littoral waters in which the Liassic strata were accumulated.[65] Foraminifera abounded on some of the sea-bottoms, the genera Cristellaria, Dentalina, Marginulina, Frondicularia, Polymorphina, and Planularia being the more important. Corals, though on the whole scarce, abound on some horizons (Astrocœnia, Thecosmilia, Isastræa, Montlivaltia, Septastræa, etc.). The crinoids were represented by thick growths of Extracrinus and Pentacrinus. There were brittle-stars, starfishes, and sea-urchins (Ophioglypha, Uraster, Luidia, Hemipedina, Cidaris, Acrosalenia)—all generically distinct from those of the Palæozoic periods. The annelids were represented by Serpula, Vermilia, and Ditrupa. Among the crustacea, the more frequent known genera are Eryon (entirely Liassic), Glyphæa (from Lower Lias to Kimeridge clay), and Eryma. The brachiopods are chiefly Rhynchonella, Waldheimia, Spiriferina, Thecidium, and Terebratula. Spiriferina is the last of the Spirifers, and with it are associated the last forms of Leptæna, of which five Liassic species are known from English localities (Fig. 388). Of the lamellibranchs a few of the most characteristic genera are Pecten, Lima, Avicula, Gryphæa, Gervillia, Ostrea, Plicatula, Mytilus, Cardinia, Leda, Cypricardia, Astarte, Pleuromya, Hippopodium, and Pholadomya. Gasteropods, though usually rare in such muddy strata as the greater part of the Lias,

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[64] Brodie, Proc. Geol. Soc. 1846, p. 14; Q. J. Geol. Soc. v. 31; "History of Fossil Insects," 1846. See Scudder, Bull. U. S. Geol. Survey. No. 71, 1891, pp. 98–236, for a list of all known Mesozoic insects, and references to the authorities for the description of each species.

[65] See R. Tate, "Census of Lias Marine Invertebrata," Geol. Mag. viii. p. 4.

occasionally occur, but most frequently in the calcareous zones. The chief genera are Cerithium, Turbo, Trochus, Pleurotomaria, Chemnitzia, and Turritella. The cephalopods, however, are the most abundant and characteristic shells of the Lias; the family of the Ammonites numbers upward of 300 species in the British Lias. Many of these are the same as those that have been found in the Jurassic series of Germany, and they occupy on the whole the same relative horizons, so that over central and western Europe it has been possible to group the Lias into the various zones given in the table (p. 1482). Of the genus Nautilus about ten species have been found. The dibranchiate cephalopods are represented by more than 60 species of the genus Belemnites.

From the English Lias numerous species of fishes have been obtained. Some of these are known only by their teeth (Acrodus), others by both teeth and spines (Hybodus). The ganoids are frequently found entire; Dapedius, Pholidophorus, Æchmodus, Pachycormus, Eugnathus, and Leptolepis are the most frequent genera. But undoubtedly the most remarkable palæontological feature in this group of strata is the number and variety of its reptilian remains. The genera Ichthyosaurus, Plesiosaurus, Dimorphodon, Scelidosaurus, Teleosaurus, and Steneosaurus have been recovered, in some cases the entire skeleton having been found with almost every bone still in place. The two genera first mentioned are especially frequent, and more or less perfect skeletons of them are to be seen in most public museums.

The Lias extends continuously across England from the mouth of the Tees to the coast of Dorsetshire. It likewise crosses into South Wales. Interesting patches occur in Shropshire and at Carlisle, far removed from the main mass of the formation. A considerable development of the Lias stretches across the island of Skye, and skirts adjoining tracts of the west of Scotland, where the shoreline of the period is partly traceable; while small portions of the lower division of the formation are exposed on the foreshore of the east of Sutherland, near Dunrobin. In the north of Ireland, also, the characteristic shales appear in several places from under the Chalk escarpment.

The Lower Oolites lie conformably upon the top of the Lias, with which they are connected by a general similarity of organic remains, and by about 45 species which pass up into them from the Lias. In the southwest and centre of England they chiefly consist of shelly marine limestones, with clays and sandstones; but, traced north-

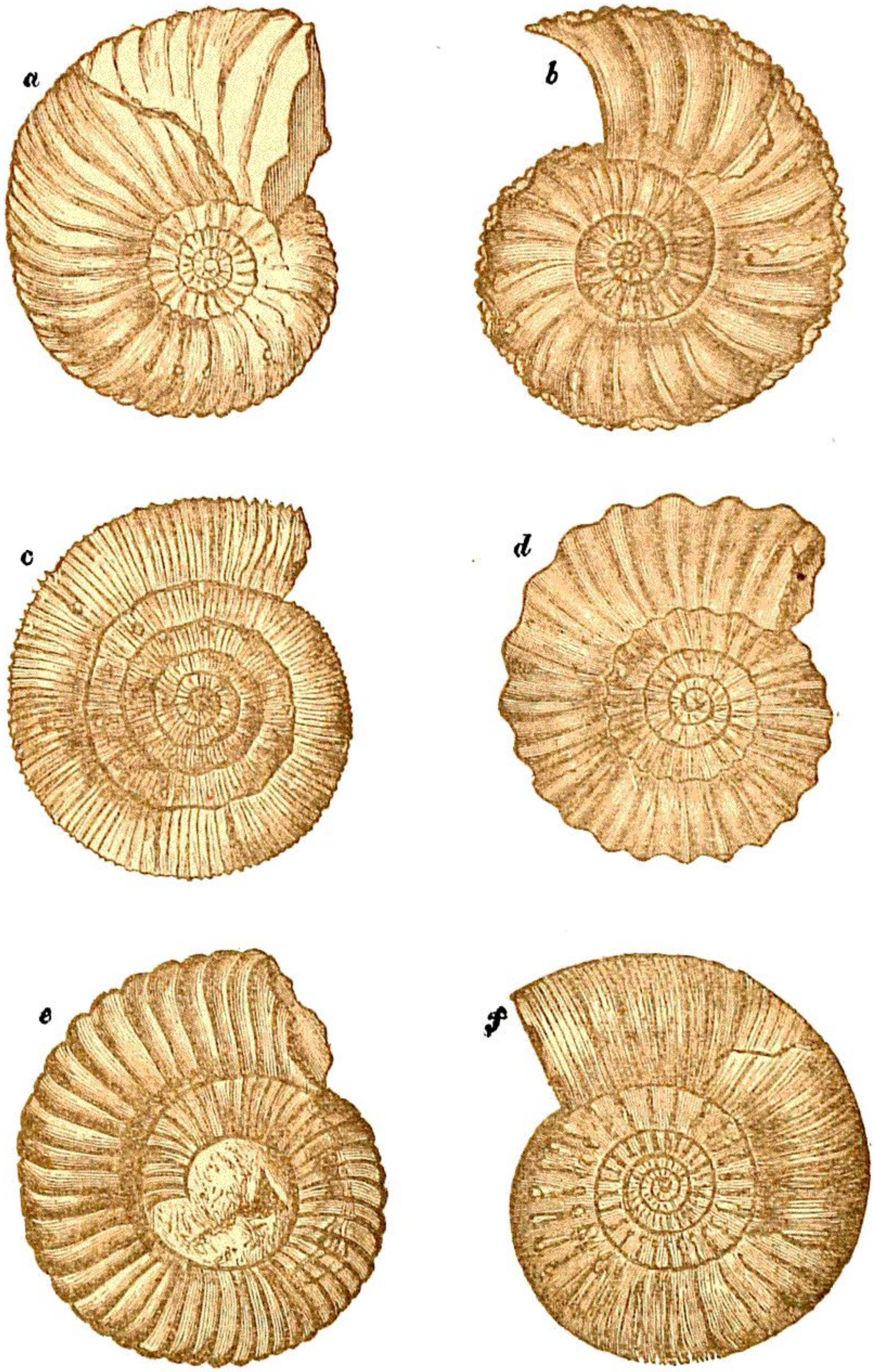

Fig. 406.—Middle and Lower Lias Ammonites.

a, Ammonites (Amaltheus) margaritatus, Mont. (⅓); *b*, A. (A.) spinatus, Brug. (⅓); *c*, A. (Ægoceras) Davœi, Sby. (½); *d*, A. (Æ.) capricornus, Schloth. (½); *e*, A. (Æ.) Jamesoni, Sby. (⅓); *f*, A. (Æ.) brevispina, Sby. (⅓).

ward into Northampton, Rutland, and Lincolnshire, they contain not only marine limestones, but a series of strata indicative of deposit in the estuary of some river descending from the north, for, instead of the abundant cephalopods of the truly marine and typical series, we meet with fresh-water genera such as Cyrena and Unio, estuarine or marine forms such as Ostrea and Modiola, thin seams of lignite, thick and valuable deposits of ironstone, and remains

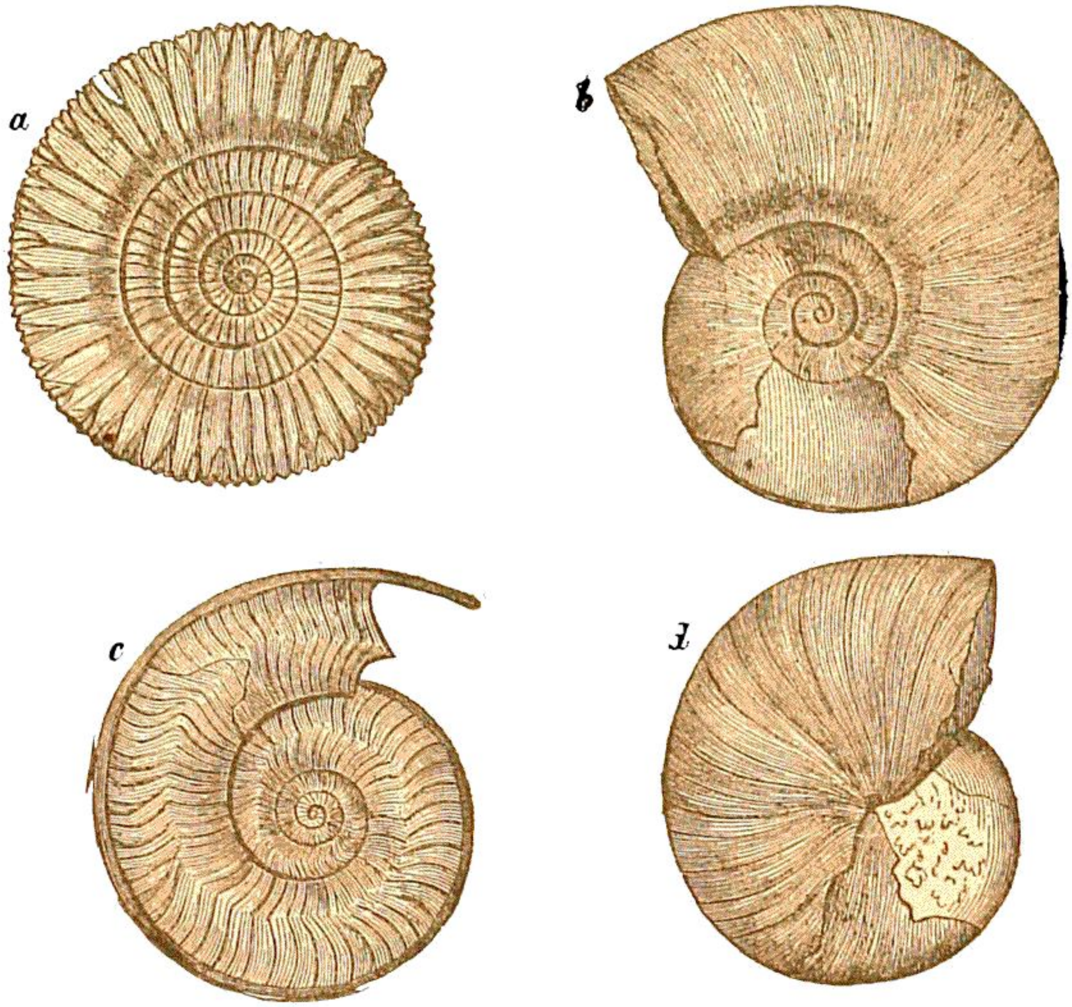

Fig. 407.—Upper Lias Ammonites.

a, Ammonites (Stephanoceras) communis, Sby. ($\frac{2}{3}$); *b*, A. (Lytoceras) jurensis, Zieten ($\frac{1}{12}$); *c*, A. (Harpoceras) serpentinus, Reinecke ($\frac{1}{4}$); *d*, A. (Phylloceras) heterophyllus, Sby. ($\frac{1}{8}$).

of terrestrial plants. These indications of the proximity of land become still more marked in Yorkshire, where the strata (800 feet thick) consist chiefly of sandstones, shales with seams of ironstone and coal, and occasional horizons containing marine shells. It is deserving of notice that the Cornbrash, at the top of the Lower Oolite in the typical Wiltshire district, though rarely 20 feet thick, runs across the country from Devonshire to Lincolnshire and Yorkshire. Thus a distinctly defined series of beds of an estuarine character is in the north homotaxially representative of the marine formations of the southwest. At the close of the Lower Oolitic period the estuary of the northern tract was submerged, and marine deposits were laid down across England.

The English Lower Oolites show considerable local variation in their subdivisions. They are typically developed in the southwestern counties, but the limestones and clays pass laterally into sands. The lowest group, that of the Midford Sands, is sometimes placed with the Lias. It consists of yellow micaceous sands, with some concretionary sandstone and sandy limestone, and ranges from 25 to 200 feet in thickness. A ferruginous limestone at the top contains so many Ammonites, Belemnites, and Nautili, that it has been called the "Cephalopoda bed." Two Ammonite zones may be recognized in this group, viz.:

Zone of Ammonites (Harpoceras) **opalinus**.
" " (Lytoceras) **jurensis**.

Among the other characteristic fossils are Ammonites aalensis, A. hircinus, A. radians, A. variabilis, Belemnites compressus, B. irregularis, Gresslya abducta, Trigonia formosa, Gervillia Hartmanni, Rhynchonella cynocephala, R. plicatella, etc.

The Inferior Oolite (Bajocian) attains its maximum development in the neighborhood of Cheltenham, where it has a thickness of 264 feet, and consists of calcareous freestone and ragstone or grit. It presents a tolerably copious suite of invertebrate remains, which resemble generically those of the Lias. The corals include species of Isastræa, Montlivaltia, and other genera. The crinoids are represented by Pentacrinus; the star-fishes by species of Astropecten, Goniaster, Solaster, and Stellaster; the sea-urchins by species of Acrosalenia, Cidaris, Hemipedina, Clypeus, Pygaster, etc. The predominance of Rhynchonella and Terebratula over the rest of the brachiopods become still more marked. Lima, Ostrea, Pecten, Pinna, Astarte, Cucullæa, Myacites, Mytilus, Pholadomya, Trigonia are the most common genera of lamellibranchs. The gasteropods are abundant, especially in the genera Pleurotomaria, Alaria, Trochus, Turbo, Nerinæa, Cerithium, and Pseudomelania. Ammonites, Nautili, and Belemnites are of frequent occurrence. Palæontologically the Inferior Oolite has been subdivided into the following zones in descending order:[66]

- Zone of Ammonites (Cosmoceras) Parkinsoni (A. subradiatus, Terebratula globata, Rhynchonella subtetrahedra, etc.).
- Zone of Ammonites (Stephanoceras) humphriesianus (A. Blagdeni, A. Martinsii, Waldheimia carinata, etc.).
- Zone of Ammonites (Harpoceras) Murchisonæ, with sub-zone of A. Sowerbyi in upper part (A. concavus, Terebratula fimbria, T. simplex, T. plicata, etc.).

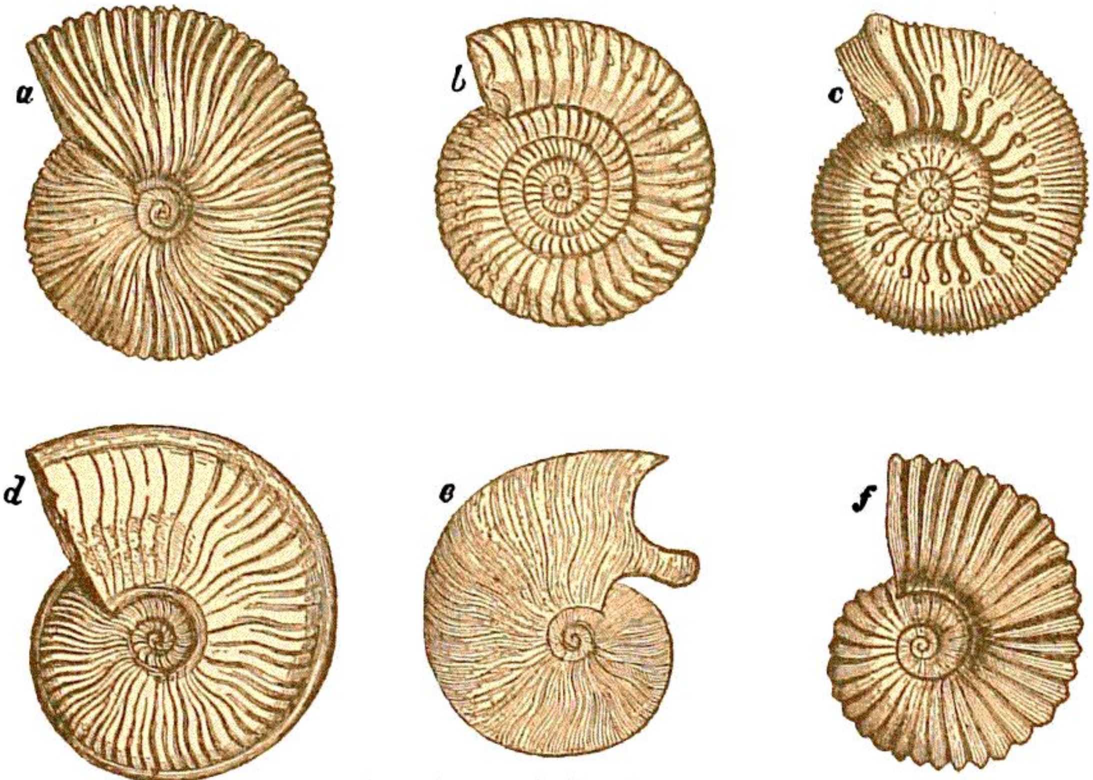

Fig. 408.—Lower Oolite Ammonites.

a, Ammonites (Stephanoceras) macrocephalus, Schloth. (1-3); *b*, A. (Cosmoceras) Parkinsoni, Sby. (1-6); *c*, A. (Stephanoceras) humphriesianus, Sby. (1-5); *d*, A. (Harpoceras) Murchisonæ, Sby. (1-3); *e*, A. (Harpoceras) opalinus, Rein (1-2); *f*, A. (Lytoceras) torulosus, Ziet. (1-3).

The component strata of the group are subject to great variations in thickness and lithological character. The thick marine series of Cheltenham is reduced in a distance of 30 or 40 miles to a thickness of a few feet. The limestones pass into sandy strata, so that in parts of Northamptonshire the whole of the formations between the Upper Lias Clay and

[66] On the Ammonites of these zones, see S. S. Buckman, Q. J. Geol. Soc. 1881, p. 588.

the Great Oolite consist of sands with beds of ironstone, known as the Northampton Sand. The higher portions of the sandy series contain estuarine shells (Cyrena) and remains of terrestrial plants. In Yorkshire the Great Oolite series disappears (unless its upper part is represented by the Upper Estuarine series of that district) while the Inferior Oolites swell out into a great thickness and are composed of the following subdivisions in descending order:[67]

		Feet.
Inferior Oolite or "Bajocian."	Upper Estuarine series, shales and sandstones resting on a thick sandstone (Moor Grit) . . . . more than	200
	Scarborough or Gray Limestone series, consisting of gray calcareous and siliceous bands with shaly partings (Belemn. giganteus, Amm. humphriesianus, Amm. Blagdeni, etc.) . . .	3–100
	Middle Estuarine series, chiefly shales with three or four beds of sandstone full of plant-remains. This is the chief coal-bearing zone of the Lower Oolites. A few thin coal-seams occur, only two of which have been found worth working; none of them exceeds 18 inches or 2 feet in thickness	50–100
	Millepore bed, a ferruginous or calcareous grit passing into a sandy limestone (Ammonites Sowerbyi)	10–40
	Lower Estuarine series, consisting of an upper group of false-bedded ferruginous sandstones with carbonaceous matter, separated by some ironstone bands from a lower group of carbonaceous shales and sandstones with thin coal-seams	300
	Dogger—ferruginous sandstone and sandy ironstone passing down into the Jurensis-beds (Midford Sands) (Ceromya bajociana, Amm. Murchisonæ, A. aalensis, etc.)	40–95

A tolerably abundant fossil flora has been obtained from these Yorkshire beds. With the exception of a few littoral fucoids, all the plants are of terrestrial forms. Among them are more than 50 species of ferns (Pecopteris, Sphenopteris, Phlebopteris, and Tæniopteris being characteristic). Next in abundance come the cycads, of which above 20 species are known (Otozamites, Zamia, Pterophyllum, Cycadites). Coniferous remains are not infrequent in the form of stems or fragments of wood, as well as in occasional twigs with attached leaves (Araucarites, Brachyphyllum, Thuyites, Peuce, Walchia, Cryptomerites, Taxites).

The Fuller's Earth is an argillaceous deposit which, extending from Dorsetshire to the neighborhood of Bath and

[67] Phillips' "Geology of Yorkshire," Hudleston, Geol. Mag. 1880, p. 246; 1882, p. 146; Proc. Geol. Assoc. iii. iv. v. C. Fox-Strangways, "Geology of Scarborough and Whitby," Mem. Geol. Surv. 1882. The fullest account of the Jurassic rocks of Yorkshire will be found in the volumes by Mr. Fox-Strangways in the series on "The Jurassic Rocks of Britain," in the Memoirs of the Geol. Survey, 1892.

Cheltenham, attains a maximum depth of nearly 150 feet, but dies out in Oxfordshire, and is absent in the eastern and northeastern counties. Among its more abundant fossils are Ammonites subcontractus, Goniomya literata, Ostrea acuminata, Rhynchonella varians, and Waldheimia ornithocephala; but most of its fossils occur also in the Great and Inferior Oolite. The conditions for marine life over the muddy bottom on which this deposit was laid down would appear to have been unfavorable. Thus few gasteropods are known from the Fuller's Earth. The beds of economic fuller's earth are worked at Midford and Wellow near Bath; their detergent properties are due to physical characters rather than chemical composition.

The Great Oolite (Bathonian) consists, in Gloucestershire and Oxfordshire, of three sub-groups of strata; (*a*) lower sub-group of thin-bedded limestones with sands, known as the Stonesfield Slate; (*b*) middle sub-group of shelly and yellow or cream-colored, often oolitic limestones, with partings of marl or clay—the Great Oolitic proper; (*c*) upper sub-group of clays and shelly limestones, including the Bradford Clay, Forest Marble, and Cornbrash. These subdivisions, however, cease to be recognizable as the beds are traced eastward. The Bradford Clay of the upper sub-group soon disappears, and the Forest Marble, so thick in Dorsetshire, thins away in the north and east of Oxfordshire, the horizon of the group being represented in Bedfordshire, Northamptonshire, and Lincolnshire, by the "Great Oolite Clays" of that district. The Cornbrash, however, is remarkably persistent, retaining on the whole its lithological and palæontological characters from the southwest of England to the borders of the Humber. The limestones of the middle sub-group can be traced from Bradford-on-Avon to Lincolnshire. The lower sub-group, including the Stonesfield Slate, is locally developed in parts of Gloucestershire and Oxfordshire, and passes into the "Upper Estuarine series" of the Midland counties.[68]

The fossils of the Stonesfield Slate are varied and of high geological interest. Among them are about a dozen species of ferns, the genera Pecopteris, Sphenopteris, and Tæniopteris being still the prevalent forms. The cycads are chiefly species of Palæozamia, and the conifers of Thuyites. With these drifted fragments of a terrestrial vegetation there occur

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[68] Judd's "Geology of Rutland," Mem. Geol. Surv.

remains of beetles, dragon-flies, and other insects which had been blown or washed off the land. The waters were tenanted by a few brachiopods (Rhynchonella concinna and Terebratula), by lamellibranchs (Gervillia acuta, Pholadomya acuticosta, Lima, Ostrea gregaria, Pecten, Astarte, Modiola, Trigonia, etc.), by gasteropods (Natica, Nerita, Patella, Trochus, etc.), by a few ammonites (A. gracilis) and belemnites (B. fusiformis, B. bessinus), and by elasmobranch and ganoid fishes, of which about 50 species are known (Ceratodus, Ganodus, Hybodus, Lepidotus, Pholidophorus, Pycnodus, etc.). The reptiles comprise representatives of turtles, with species of Plesiosaurus, Cetiosaurus, Teleosaurus, Megalosaurus, and Rhamphocephalus. But the most important organic relics from this geological horizon are the marsupial mammalia already referred to.

The fauna of the Great Oolite proper is distinguished, among other characteristics, by the number and variety of its corals (including the genera Isastræa, Cyathophora, Thamnastræa). The echinoderms, which rank next to the ammonites in stratigraphical value, are well represented. Among the regular echinoids the most frequent forms are Hemicidaris, Acrosalenia, Pseudodiadema, and Cidaris. The irregular echinoids are represented by species of Echinobrissus, Clypeus, Pygurus, etc.; the asteroids by Astropecten and Goniaster; the crinoids by Apiocrinus, Millericrinus, and Pentacrinus. Polyzoa are abundant (Diastopora, Heteropora). The brachiopods are represented by species of Terebratula, Rhynchonella, Waldheimia, Terebratella, Crania, etc. Of the whole British Jurassic lamellibranchs, numbering about 100 genera and nearly 1400 species, more than half the genera, and about one-fifth of the species, are found in the Great Oolite. Specially conspicuous are the genera Pecten, Lima, Ostrea, Avicula, Astarte, Modiola, Pholadomya, Trigonia, Cardium, Arca, Tancredia. The characteristic gasteropods of the Great Oolite include Actæonina, Nerinæa, Nerita, Purpuroidea, Brachytrema, Patella. Species of ammonite peculiar to the Great Oolite are Am. arbustigerus, A. discus (passes to Cornbrash), A. gracilis, A. micromphalus, A. morisea, A. subcontractus, and A. Waterhousei. Characteristic likewise are Nautilus Baberi, N. dispansus, N. subcontractus, Belemnites aripistillum, and B. bessinus. Of the fishes, the genera most abundant in species are Mesodon, Ganodus, Hybodus, and Strephodus, with Acrodus, Lepidotus, Pholidophorus, etc. The reptilian remains include the crocodilians Teleosaurus and Steneosaurus, Plesiosaurus, the pterosaur Rhamphocephalus, and the deinosaurs Megalosaurus, Cetiosaurus, and Cardiodon.

The Forest Marble varies greatly in thickness and lithological character. In the north of Dorsetshire it is estimated to be 450 feet thick, but it rapidly diminishes northward, the limestone bands being usually not more than 30 feet thick. It lies sometimes on the Great Oolite, sometimes on the Fuller's Earth. Its lower portion becomes a gray marly clay near Bradford-on-Avon, about 10 feet thick, and this argillaceous band has been separately designated the Bradford Clay. The Forest Marble contains a much diminished fauna. Among the forms peculiar to it are the echinoderms Apiocrinus elegans, Astropecten Huxleyi, A. Phillipsii, Hemicidaris alpina. The Bradford Clay of Wiltshire has long been well known for its pear-encrinites (Apiocrinus Parkinsoni), which are found at the bottom of the clay with their base attached to the top of the Great Oolite limestone.

The Cornbrash (a name given by W. Smith) consists of earthy limestones, which when freshly broken are blue and compact, but which under the influence of the weather break up into rubbly material. It varies from 5 to 40 feet in thickness, yet in spite of this insignificant development it is one of the most persistent bands in the English Jurassic system. It is rich in echinoderms, lamellibranchs, and gasteropods. Among its common and characteristic species are Echinobrissus *clunicularis*, *Holectypus* depressus, Glyphæa rostrata, Hippothoa Smithii, Hinnites gradus, Lima rigidula, Ostrea flabelloides, Pecten vagans, Cardium latum, Leda rostralis, Myacites uniformis, Trigonia cassiope, Actæonina scarburgensis, Ceritella costata. Its ammonites are A. discus and A. macrocephalus, the last-named ranging up into the Kellaways Rock and Oxford Clay.[62]

The Great Oolite series in the northeast of Scotland consists mainly of sandstones and shales, with some coal-seams which were formerly worked at Brora in Sutherland. In Skye and Raasay the formation consists of a very thick estuarine series, with abundant oysters, Trigonias, Anomias, Cyrenas, Hydrobrias, Cyprids, and remains of land-plants.

The MIDDLE or OXFORD OOLITES are composed of two distinct groups: (1) the Oxfordian, and (2) the Corallian.

(1) Oxfordian, divisible into two sub-groups: (*a*) a lower division of calcareous abundantly fossiliferous sand-

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[62] Etheridge, Q. J. Geol. Soc. 1882, Address, p. 202.

stone, known, from a place in Wiltshire, as the Kellaways Rock (Callovian). This rock-division, from 5 to more than 80 feet thick, may be traced from Wiltshire through Bedfordshire to Lincolnshire, and attains a considerable importance in Yorkshire. It contains about 200 species of fossils, of which one-third are found in lower parts of the Jurassic series, and nearly the same proportion passes upward into higher zones. Among its characteristic forms are Avicula inæquivalvis, Gryphæa bilobata, Lima notata, Ostrea archetypa, O. striata, Anatina versicostata, Cardium subdissimile, Corbis lævis, Lucina lyrata, Trigonia complanata, T. paucicostata, Alaria arsinoe, Cerithium abbreviatum, Pleurotomaria arenosa. The distinctive ammonite of this stage is A. calloviensis, which gives its name to a zone. Numerous

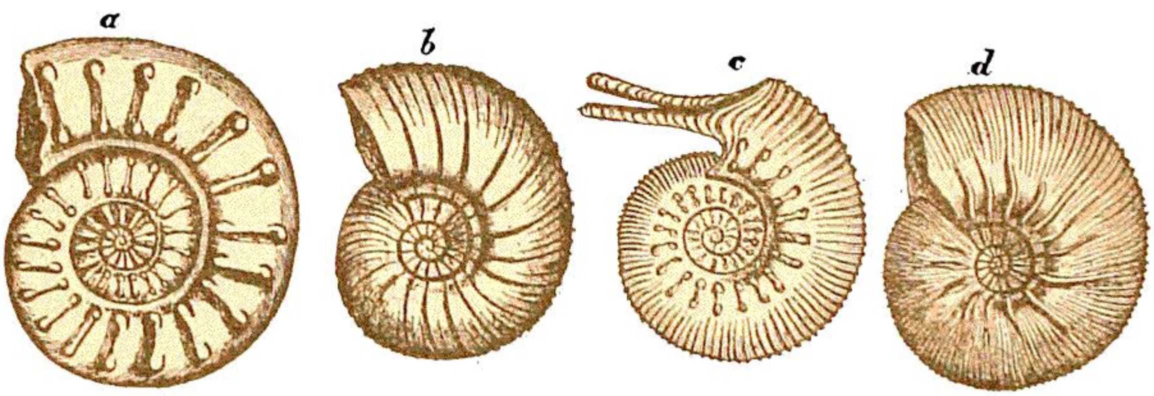

Fig. 409.—Middle Oolite Ammonites.

a, Ammonites (Aspidoceras) perarmatus, Sby. (1-2); *b*, A. (Amaltheus) Lamberti, Sby.; *c*, A. (Cosmoceras) Jason, Zeit. (1-3); *d*, A. (Cosmoceras) calloviensis, Sby. (1-2).

other species of ammonites occur, including A. modiolaris, A. gowerianus, A. auritulus, A. Bakeriæ, A. Baugieri, A. Eugenii, A. flexicostatus, A. fluctuosus, A. goliathus, A. lalandianus, A. Lonsdalie, A. planula, A. tatricus, A. Vernoni; also Ancyloceras calloviense, Nautilus calloviensis, and Belemnites Owenii.

(*b*) The Oxford Clay—so called from the name of the county through which it passes in its course from the coast of Dorsetshire to that of Yorkshire—consists mainly of layers of stiff blue and brown clay, attaining a thickness of from 300 to 600 feet. From the nature of its material and the conditions of its deposit, this rock is deficient in some forms of life which were no doubt abundant in neighboring areas of clearer water. Thus there are no corals, hardly any species of echinoderms, no polyzoa, and less than a dozen species of brachiopods. Some lamellibranchs are abundant, particularly Gryphæa dilatata and Ostrea (both forming sometimes wide oyster-beds), Lima, Avicula, Pecten, Astarte, Trigonia (clavellata, elongata, irregularis), Nucula (N. nuda, N. Phillipsii)—the whole having a great similarity to the assemblages in the clayey beds of the Lower Oolite. The gasteropods are not so numerous as in the calcareous beds below, but belong mostly to the same genera. The ammonites, especially of the Ornati, Dentati, Flexuosi, and Armati groups, are plentiful—A. cordatus, A. Duncani, A. Elizabethæ (Jason), A. Lamberti, A. oculatus, A. ornatus, A. athleta being characteristic. Two ammonite zones have been determined in this part of the group, viz.:

Zone of Amm. cordatus (A. Lamberti, etc.)
" " Jason (A. ornatus, A. athleta, etc.)

The belemnites, which also are common, include B. hastatus (found all the way from Dorsetshire to Yorkshire) and B. puzosianus. The fishes include the genera Aspidorhynchus, Hybodus, Ischyodus, and Lepidotus. The reptilian genera Ichthyosaurus, Murænosaurus, Plesiosaurus, and Megalosaurus have been noted.

(2) Corallian, traceable with local modifications from the coast of Dorset to Yorkshire. The name of this group is derived from the numerous corals which it contains. According to the exhaustive researches of Messrs. Blake and Hudleston,[70] this group when complete consists of the following subdivisions:

6. Supra-Corallian beds—clays and grits, including the Upper Calcareous Grit of Yorkshire, and the Sandsfoot clays and grits of Weymouth. 5. Coral Rag, a rubbly limestone composed mainly of masses of coral—sub-zone of Cidaris florigemma. 4. Coralline Oolite, a massive limestone in Yorkshire, but dying out southward and reappearing in the form of marl and thin limestone. 3. Middle Calcareous Grit, probably peculiar to Yorkshire.	Zone of Amm. plicatilis.
2. Lower or Hambleton Oolite, not certainly recognized out of Yorkshire. 1. Lower Calcareous Grit.	" " perarmatus.

The corals are found in their positions of growth, forming massive coral-banks in Yorkshire (Thamnastræa, Isas-

[70] "On the Corallian Rocks of England," Q. J. Geol. Soc. xxxiii. p. 260.

træa, Thecosmilia, Rhabdophyllia [Fig. 384], etc.). Numerous sea-urchins occur in many of the beds, particularly Cidaris florigemma (Fig. 386), also Pygurus, Pygaster, Hemicidaris, etc. Brachiopods are comparatively infrequent. The lamellibranchs are still largely represented by species of Avicula, Lima, Ostrea, Pecten, and Gryphæa (Ostrea gregaria being specially numerous). Nearly all the species of gasteropods are peculiar to or characteristic of the Corallian stage. The distinctive ammonites are A. ancepsalbus, A. babeanus, A. Bergeri, A. cadonensis, A. decipiens, A. rupellensis, A. plicatilis, A. perarmatus, A. pseudocordatus, A. retroflexus, A. Williamsoni.

The UPPER or PORTLAND OOLITES bring before us the records of the closing epochs of the long Jurassic period in England. They are divisible into three groups: (1) Kimeridgian, at the base; (2) Portlandian, and (3) Purbeckian.

(1) Kimeridgian, so named from the clay at the base of the Upper Oolites, well developed at Kimeridge, on the coast of Dorsetshire, whence it is traceable continuously, save where covered by the Chalk, into Yorkshire. It consists of dark bluish-gray shale or clay, which in Dorsetshire is in part bituminous and can be burned. According to Mr. J. F. Blake it may be subdivided into two sub-groups:

(*a*) Upper Kimeridgian, consisting of paper-shales, bituminous shales, cement stone, and clays, characterized by a comparative paucity of species of fossils but an infinity of individuals; perhaps 650 feet thick in Dorsetshire, but thinning away or disappearing in the inland counties. This zone is fairly comparable with the "Virgulian sub-stage" of foreign authors.

(*b*) Lower Kimeridgian, blue or sandy clay with calcareous "doggers," representing the "Astartian sub-stage" of foreign geologists. This is the great repository of the fossils of this group.[71]

Among the more common fossils are numerous foraminifera (Pulvulina pulchella, Robulina Münsteri), also Serpula tetragona, Discina latissima, Exogyra virgula (Fig. 392), E. nana, Astarte supracorallina, Thracia depressa, Corbula Deshayesii, Cardium striatulum (Fig. 392). Upward of 20 species of ammonite occur only in this stage; among them

[71] J. F. Blake, "On the Kimeridge Clay of England," Q. J. Geol. Soc. xxxi.

are A. accipitris, A. alternans, A. Beaugrandi, A. flexuosus, A. Kapfii. A. lallerianus, A. mutabilis, A. Thurmanni, A. triplex. Among the belemnites are B. abbreviatus, B. excentricus, B. explanatus, B. nitidus. The Kimeridge Clay derives its chief palæontological interest from the fact that it has supplied the largest number of the Mesozoic genera and species of reptiles yet found in Britain. The huge deinosaurs are well represented by Bothriospondylus, Cetiosaurus, Cryptodraco, Gigantosaurus, Iguanodon (Camptosaurus), Megalosaurus, Omosaurus; the pterosaurs by Pterodactylus; the plesiosaurs by Plesiosaurus and Pliosaurus; the ichthyosaurs by Ichthyosaurus and Ophthalmosaurus; chelonians by Enaliochelys and Pelobatochelys; and crocodilians by Dakosaurus, Steneosaurus, and Teleosaurus.[72]

In the sea-cliffs of Speeton, Yorkshire, a thick group of clays occurs, the lower part of which contains Kimeridgian fossils, while the higher portions are unmistakably Cretaceous. Traces of a representative of the Kimeridge Clay, and possibly of the Portlandian, above, are found even as far north as the east coast of Cromarty and Sutherland, at Eathie and Helmsdale.

(2) Portlandian, so named from the Isle of Portland, where it is typically developed. This group, resting directly on the Kimeridge Clay, consists of two divisions, the Portland Sand and Portland Stone. At Portland, according to Mr. J. F. Blake, it presents the following succession of beds in descending order:[73]

Portland Stone.	Shell limestone (Roach), containing casts of Cerithium portlandicum (very abundant), Sowerbya, Dukei, Buccinum naticoides, and casts of Trigonia.
	"Whit-bed"—Oolitic Freestone, the well-known Portland stone (Ammonites giganteus).
	"Curf," another calcareous stone, Ostrea solitaria.
	"Base-bed," a building stone like the whit-bed, but sometimes containing irregular bands of flint.
	Limestone, "Trigonia bed": Trigonia gibbosa, Fig. 392, Perna mytiloides.
	Bed, 3 feet, consisting of solid flint in the upper and rubbly limestone in the lower flat.
	Band, 6 feet, containing numerous flints: Serpula gordialis, Ostrea multiformis.
	Thick series of layers of flints irregularly spaced: Ammonites boloniensis, Trigonia gibbosa, T. incurva.
	Shell-bed abounding in small oysters and serpulæ: Ammonites pseudogigas, A. triplex, Pleurotomaria rugata, P. Rozeti, Cardium dissimile, Fig. 392, Trigonia gibbosa, T. incurva, Pleuromya tellina.

[72] Etheridge, Q. J. Geol. Soc. 1882, Address, p. 221.
[73] Q. J. Geol. Soc. xxxvi. p. 189.

Portland Sand.
- Stiff blue marl without fossils, 12 to 14 feet.
- Liver-colored marl and sand with nodules and bands of cement stone—26 feet: Mytilus autissiodorensis, Pecten solidus, Cyprina implicata, Ammonites biplex, etc.
- Oyster-bed, 7 feet, composed of Exogyra bruntrutama.
- Yellow sandy beds—10 feet: Cyprina implicata, Arca.
- Sandy marl, at least 30 feet, passing down into Kimeridge Clay: Ammonites biplex, Lima boloniensis, Pecten Morini, Avicula octavia, Trigonia incurva, T. muricata, T. Pellati, Rhynchonella portlandica, Discina humphriesiana.

Among Portlandian fossils a single species of coral (Isastræa oblonga) occurs; echinoderms are scarce (Acrosalenia Königi, etc.), there are also few brachiopods. The most abundant fossils are lamellibranchs, the best represented genera being Trigonia (T. gibbosa, T. incurva), Astarte, Mytilus, Pecten, Lima, Perna, Ostrea, Cyprina, Lucina (L. portlandica), Cardium (C. dissimile), Pleuromya. The most frequent gasteropod is Cerithium portlandicum. The ammonites include A. giganteus, pseudogigas, boloniensis, gravesianus, pectinatus. Fish are represented by Gyrodus, Hybodus, Ischyodus, and Pycnodus, and some of the older Jurassic reptilian genera (Steneosaurus, Plesiosaurus, Pliosaurus, Cetiosaurus, Megalosaurus) still appear, together with the crocodile Goniopholis.[74]

(3) Purbeckian.—This group, so named from the Isle of Purbeck, where best developed, is usually connected with the foregoing formations, as the highest zone of the Jurassic series of England. But it is certainly separated from the rest of that series by many peculiarities, which show that it was accumulated at a time when the physical geography and the animal and vegetable life of the region were undergoing a remarkable change. The Portland beds were upraised before the lowest Purbeckian strata were deposited. Hence, a considerable stratigraphical and palæontological break is to be remarked at this line. The sea-floor was converted partly into land, partly into shallow estuaries. The characteristic marine fauna of the Jurassic seas nearly disappeared from the area. Fresh-water and brackish-water forms characterize the great series of strata which reaches up to the Neocomian stage, and might be termed the Purbeck-Wealden series.

The Purbeckian group has been divided into three sub-

[74] J. F. Blake, op. cit. and Etheridge, op. cit. Damon's "Geology of Weymouth," 1884.

groups. Of these, the lowest (95 to 160 feet) consists of fresh-water limestones and clays, with layers of ancient soil ("dirt beds") containing stumps of the trees which grew in them; the middle comprises 50 to 150 feet of strata with some marine fossils, while the highest (50 to 60 feet) shows a return of fresh-water conditions. Among the indications of the presence of the sea is an oyster-bed (Ostrea distorta) 12 feet thick, with Pecten, Modiola, Avicula, Thracia, etc. The fresh-water bands contain still living genera of lacustrine and fluviatile shells (Paludina, Limnæa, Planorbis, Physa, Valvata, Unio, Cyrena). Numerous fishes, placoid and ganoid, haunted these Purbeck waters. Many insects, blown off from the adjacent land, sank and were entombed and preserved in the calcareous mud. These include coleopterous, orthopterous, hemipterous, neuropterous, and dipterous forms (Fig. 395). Remains of several reptiles, chiefly chelonian, but including the Portlandian crocodile Goniopholis, and likewise some interesting dwarf crocodiles (Theriosuchus is computed to have been only 18 inches long), have also been discovered. The most remarkable organisms of this group of strata are the mammalian forms already noticed (p. 1474), which occur almost wholly as lower jaws, in a stratum about 5 inches thick, lying near the base of the Middle Purbeck sub-group, these being the portions of the skeleton that would be most likely first to drop out of floating and decomposing carcasses.

The zone of Belemnites lateralis in the Speeton Clay of the Yorkshire coast and the Spilsby Sandstone of Lincolnshire, are considered by Prof. A. Pavlow and Mr. G. W. Lamplugh to represent in part the Purbeck and Portland beds of the southern districts.[75]

France and the Jura.—The Jurassic system is here symmetrically developed in the form of two great connected rings. The southern ring incloses the crystalline axis of the centre and south; the northern and larger ring encircles the Cretaceous and Tertiary basin and opens toward the Channel, where its separated ends point across to the continuation of the same rocks in England. But the structure of the two areas is exactly opposite, for in the southern area the oldest rocks lie in the centre and the Jurassic strata dip outward, while in the northern region the youngest formations lie in the centre and the Jurassic beds dip inward below them.

[75] Bull. Soc. Imp. des Nat. Moscou, 1891.

Where the two rings unite in the middle of France they send a tongue down to the Bay of Biscay. On the eastern side of the country the Jurassic system is copiously developed, and extends thence eastward through the Jura Mountains into Germany.

The subdivisions of the Jurassic system in the north and northwest of France belonging to what has been termed the Anglo-Parisian basin, resemble generally those established in England. But in the southern half of the country, and generally in the Mediterranean province, the facies departs considerably both lithologically and palæontologically from the English type, more particularly as regards the Upper Jurassic rocks. The following table gives in descending order a summary of the distribution of the Jurassic system in France:[76]

10. Portlandian, separated into two sub-stages. At the base lie sands and clays, equivalents of the Portland sands, or "Bononian" with Ammonites (Stephanoceras) portlandicum, A. gigas, and Ostrea expansa. Higher up come sands and calcareous sandstones corresponding to the Portland stone, with Trigonia gibbosa and Perisphinctes transitorius. The Purbeckian is marked by Corbula inflexa. The stage is best developed along the coast near Boulogne-sur-mer, where it is composed of about 75 feet of clays, sands, and sandstones, with Acrosalenia Koenigi, Perna Bouchardi, Echinobrissus Brodiei, Cardium Pellati, Trigonia radiata, T. gibbosa, T. incurva, etc. At the top lies a bed of limestone containing Cyrena Pellati, Cardium dissimile, and covered by a travertin with Cypris, which may represent the Purbeck beds. Far

[76] For a detailed account of the development of the Jurassic rocks of France, see De Lapparent's "Geologie," 3d edition, 1893; also A. d'Orbigny's "Paleontologie Française—Terrains Oolithiques," 1842–50; D'Archiac, "Paleontologie de la France," 1868, and "Paleontologie Française, continuée par une reunion de Paleontologistes—Terrain Jurassique," in course of publication; Hébert, "Les Mers anciennes et leurs Rivages, dans le Bassin de Paris," 1857 (a most interesting and valuable essay), and numerous papers in Bull. Soc. Geol. France; Monographs by Loriol, Cotteau, Pellat, Royer, Tombeck; Gosselet's "Esquisse," cited ante, p. 1222; J. F. Blake, Q. J. Geol. Soc. 1881, p. 497, gives a bibliography for N. W. France, and Barrois (Proc. Geol. Assoc.) gives a summary of results for the Boulonnais. For the last named district consult also Pellat, Bull. Soc. Geol. France, viii. 1879; Douvillé et Rigaux, op. cit. xix. 1891, p. 819. Rigaux, "Notice Geologique sur le Bas Boulonnais," Boulogne-sur-mer, 1892.

to the south, in Charente, some limestones containing Portlandian fossils are covered by others with Corbula inflexa, Physa, Paludina, etc., possibly Purbeck. Fresh-water limestones, gypsiferous marls and dolomites (about 200 feet), and containing Corbula forbesiana, Physa wealdiana, Valvata helicoides, Trigonia gibbosa, etc., occur in the Jura, round Pontarlier and near Morteau, in the valley of the Doubs.

The Upper Jurassic rocks of southern France and the southern flanks of the Alps, or what has been termed the Mediterranean basin, present a facies so different from that which was originally studied in England, northern France, and Germany that much difficulty was for many years experienced in the correlation of the deposits, and much discussion has arisen on the subject. From the researches of Oppel, Benecke, Hébert, and later writers, the true meaning of the southern facies is now better understood. It appears that the divisions ranging above the Oxfordian are represented in the southern area by a singularly uniform series of limestones, indicative of long unbroken deposition in deeper water, and unvaried by those oscillations and occasional terrestrial conditions which are observable further north. The name of Tithonian was given by Oppel to this more uniform suite of strata, which were marked by the mixed character of their cephalopods, and by their peculiar perforated brachiopods of the type of Terebratula diphya (janitor).[77] Around Grenoble, the massive limestones resting upon some marls with species belonging to the zone of Ammonites tenuilobatus, contain Terebratula diphya associated with ammonites closely linked with Neocomian types. In the Basses Cevennes, the limestones attain a thickness of from 1200 to 1400 feet. At their base lie marls and marly limestones containing Ammonites macrocephalus, A. transversarius and A. cordatus. A band of bluish limestone with bituminous marls (65 feet), belonging to the zone of A. bimammatus, represents the Corallian. Some gray limestones (260 feet), with A. polyplocus, contain fossils of the zone of A. tenuilobatus, equiva-

[77] For a study of the Tithonian fauna see A. Toucas, Bull. Soc. Geol. France, xviii. 1890, p. 560.

lent to the Sequanian stage. These are succeeded by a massive limestone (330 feet) with Terebratula diphya (janitor) and Amm. transitorius, and this by a compact white limestone (500–650 feet) with Terebratula moravica (Repellini), Cidaris glandifera, corals, etc. At the top lie some limestones (200 feet) with Terebratula diphyoides and many ammonites (A. Calypso, A. privasensis, A. berriasensis, etc.).

9. Kimeridgian=Kimeridge Clay, divided in central and northern France into the following sub-stages in ascending order: 1, Sequanian or Astartian (Ostrea deltoidea, zone of Ammonites tenuilobatus); 2, Pterocerian (Pterocera Oceani, zone of Amm. acanthicus); 3, Virgulian (Exogyra virgula). In Normandy, the Corallian clays with Diceras arietinum are covered by other clays with Ostrea deltoidea (Sequanian), and nodular limestone with Pterocera Oceani (Pterocerian), followed by blue clays and lumachelles with Exogyra virgula (Virgulian). In the Pays de Bray, these various strata are 330 to 400 feet thick, and are surmounted by calcareous marls, sandstone and limestone (115–160 feet) containing Ostrea catalaunica, Anomia lævigata, Hemicidaris Hofmanni, Echinobrissus Brodiei, Ostrea bruntrutana, and representing the Bononian sub-stage. The coast-section near Boulogne-sur-mer exposes a series of clays, sands, and sandstones (180 feet), from which a large series of characteristic fossils has been obtained, and which, as the type section of the Bononian beds, indicate a local littoral deposit in the upper part of the Kimeridge Clay.

In the French Ardennes, the Sequanian, Pterocerian, and Virgulian sub-stages are composed of a succession of marls and limestones (500–560 feet), the Sequanian marls and lumachelles being marked by Ostrea deltoidea, etc., the Pterocerian limestones by Waldheimia humeralis, Pterocera ponti, etc., and the Virgulian marls by immense numbers of Exogyra virgula. In the Meuse and Haute Marne, a group of compact limestones, more than 500 feet thick (Calcaires de Barrois), with Ammonites (Stephanoceras) gigas, etc., represents the Bononian sub-stage. In Yonne, the Sequanian sub-stage consists of oolites and contains a reef of coral full of bunches of Septastræa, Montlivaltia, etc. Toward the Jura, this sub-stage (200 feet thick) consists of limestones and marls (Astarte minima); the Pterocerian is well developed, and shows its characteristic fossils; while the Bononian comprises the so-called "Portlandian" limestones of the Jura, its upper part becoming the yellow or red unfossiliferous "Portlandian dolomite." In the department of the Jura, the Pterocerian sub-stage contains a coral-reef, more than 300 feet thick, near Saint Claude, and further south another occurs at Oyonnax. In the same region, the Virgulian sub-stage, composed of bituminous shales and thin lithographic limestones, has yielded numerous fishes, reptiles, and abundant cycads and ferns. The position of these beds is fixed by the occurrence of the Exogyra virgula below them, and of the Bononian limestones with Nerinæa and Amm. gigas above them. From what we said above under the Portlandian stage, it will be seen that the Kimeridgian appears in a totally different aspect in the Mediterranean basin, being there composed of thick limestones with a mixed assemblage of ammonites, and characterized in the higher parts by the appearance of Terebratula diphya.

8. Corallian, divisible into (*a*) Argovian, or zone of sponges and Amm. canaliculatus; (*b*) Glyptician, or zone of Glyptichus hieroglyphicus, and (*c*) Diceratian, or zone of Diceras arietinum. The sub-stages *b* and *c* comprise the zone of Amm. bimammatus. In Normandy, the stage presents a lower assise (Trouville oolite, or zone of Amm. Martelli) composed of marly and oolitic limestone and black clays (Echinobrissus scutatus, Trigonia major, etc.), and an upper coral-rag with Cidaris florigemma and a dark marl with Exogyra nana; the whole passing laterally into clays (Havre). In the Ardennes, an argillaceous marl (with Phasianella striata) represents the Argovian division, and is surmounted by a mass of coral limestone (400–420 feet). In Haute Marne, the Corallian beds attain a thickness of 330 feet, but are mainly formed of marls, the coral beds or reefs dwindling down in that direction. Southward, in Burgundy, massive limestones with corals reappear, with lithographic and oolitic limestones. To the east also, in the district of Besançon, the stage is represented by 130 to 200 feet of coral-limestone with compact and oolitic bands, and some-

times with calcareous marls that abut against the sides of what were formerly coral-reefs. Some horizons in the Corallian stage are marked by the occurrence of remains of ferns and other land-plants (Saint Mihiel, in Lorraine; Dept. of Indre).

7. Oxfordian, divisible into (*a*) Callovian, with zones of Amm. macrocephalus, and A. anceps, and (*b*) Oxfordian, with zones A. Lamberti, A. Mariæ, A. cordatus. This stage is well exposed on the coast of Calvados, between Trouville and Dives, where it attains a thickness of 330 feet, and is divisible into a lower sub-group of marls (Dives) with Amm. Lamberti, a middle sub-group of clays (Villiers) with A. Mariæ, and an upper sub-group of clays with A. cordatus. It is likewise displayed in the Boulonnais. Northeastward, in the Ardennes, the Callovian sub-stage appears as a pyritous clay (25–30 feet) with oolitic limonite, the Oxfordian as a series of clays, marls, argillaceous sandstone (full of gelatinous silica and locally known as gaize) and oolitic ironstone. In the Côte-d'Or, the fossils of the Callovian and Oxfordian beds are mingled in the same strata. Round Poitiers, the Callovian division is upward of 100 feet thick. Eastward it dwindles down toward the Jura, but is recognizable there under the Oxfordian pyritous marls (330 feet).

6. Bathonian (Grande Oolithe) may be divided into a lower sub-stage (Vesulian) with the zone of Ostrea acuminata and Amm. ferrugineus, and an upper (Bradfordien) with the zones of Rhynchonella decorata and Waldheimia digona (Amm. aspidoides). In Normandy, it consists of (*a*) a lower group of strata which at one part are the Port-en-Bessin marls (100 feet or more) and at another the famous Caen stone, so long used as a building material, and which from its saurian and other remains may be paralleled with the Stonesfield Slate; (*b*) granular limestone (Ranville), bryozoan limestone, with some of the fossils of the Bradford Clay. In the Ardennes, the Fuller's Earth is represented by some sandy limestones, lumachelles, and granular limestone, with Ostrea acuminata, Amm. Parkinsoni, Belemnites giganteus, etc.; the Great Oolite by a massive limestone (160–200 feet) with Cardium pes-bovis, Purpura minax, followed by

150–180 feet of limestones, with numerous fossils (Rhynchonella decorata, R. elegantula, Ostrea flabelloides, etc.). The limestones are replaced eastward by marly and sandy beds. In the Côte-d'Or, the stage is largely developed, and is divided into three sub-stages: (*a*) Lower (115 feet), limestones and marls with zones of Homomya gibbosa, Terebratula Mandelslohi, Pholadomya bucardium; (*b*) Middle (196 feet), white limestones and oolites with zone of Amm. arbustigerus, Purpura glabra and echinoderms; (*c*) Upper (82 feet), limestones and marls with Eudesia cardium, Waldheimia digona, Pernostrea Pellati, Pentacrinus Buvignieri, and with land-plants in one of the zones.[78]

5. B a j o c i a n (Oolithe Inférieure) is well developed in the department of Calvados, the name of the stage being taken from Bayeux. Its thickness is 60–80 feet, and it consists of: 1, Lower limestone (Amm. Murchisonæ); 2, limestone with numerous ferruginous oolites, fossils abundant and well preserved (Amm. humphriesianus, A. Sowerbyi, A. Parkinsoni, etc.); 3, Upper white oolite with abundant brachiopods, sponges and urchins (Amm. Parkinsoni, Terebratula Phillipsi, Stomechinus bigranularis, etc.). In the French Ardennes, the stage presents a lower group of marls (32 feet) with Amm. Murchisonæ, A. Sowerbyi, etc., followed by an upper limestone (30–130 feet) with Amm. Blagdeni, A. subradiatus, Belem. giganteus, etc. Toward Lorraine, this limestone becomes charged with corals, some parts being true reefs. North of Metz, the stage is mostly limestone, and reaches a thickness of 330 feet. In Burgundy, the stage is chiefly a crinoidal limestone (100 feet), capping boldly the Liassic marls. In the Jura, it attains a thickness of upward of 300 feet, and consists chiefly of limestone. In Southern France, it swells out to great proportions, reaching in Provence a thickness of 950 feet, where it consists of the following assises in ascending order: 1, Amm. Murchisonæ; 2, A. Sauzei; 3, A. humphriesianus; 4, A. niortensis.

4. T o a r c i a n (from Thouars=Upper Lias). In Lorraine, this stage (330–370 feet thick) consists of a lower series of marls followed by sandstone and an oolitic brown

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[78] For a study of the gasteropods of this zone in France see M. Cossmann, Mem. Geol. Soc. France (3), tome iii. No. 3, 1885.

ironstone containing Ammonites opalinus, A. insignis, Belemnites abbreviatus. This ironstone is traceable from the Ardèche to Luxembourg. In the Ardennes, the stage includes a lower series of marls and clays (300 feet) with Amm. serpentinus, a middle marl containing Amm. radians, A. bifrons, and an upper limonite (Longwy) with Amm. opalinus, Ostra ferruginea, Trigonia navis. In Yonne and Côte-d'Or, it consists of the following members in ascending order: 1, marls with Posidonia and lumachelle with Amm. serpentinus (15–30 feet); 2, marls with A. complanatus (26 feet); 3, marls with Turbo subduplicatus (12–20 feet); 4, blue marls with Cancellophycus liassicus (25–30 feet). Near St. Amand, Cher, the stage consists of nearly 200 feet of marls and clays with seven recognizable zones. In the Haute Marne, it is nearly as thick. In the Rhone basin, it consists of a lower group of limestones with Pecten æquivalvis, and an upper group of ferruginous beds, including an important seam of oolitic ironstone, and containing the zones of Amm. bifrons and A. opalinus. In Provence, it reaches a thickness of 950 feet, and in this region the whole Liassic subdivisions attain the great depth of 2300 feet. In Normandy, the Toarcian stage is only about 20 feet thick, but shows the characteristic ammonite zones.

3. Liassian (=Middle Lias and Lower Lias, in part). In Lorraine, where this stage reaches a thickness of 230 to 260 feet, it consists of the following three assises in ascending order: 1, limestones (Ammonites Davœi) and marls; 2, marls (A. margaritatus); 3, sandstones (Gryphæa regularis). In the French Ardennes, it is 360 feet thick, and comprises: 1, sandy clay with Amm. planicosta, Gryphæa regularis, Plicatula spinosa; 2, marl with Belemnites clavatus, Amm. capricornus; 3, ferruginous limestone with Amm. spinatus, Bel. paxillosus. Westward this stage becomes almost wholly marly. In Yonne and Côte-d'Or, it is divisible into three assises, in the following ascending order: 1, Belemnite limestone of Venarey (40 feet), comprising the zones of (*a*) Amm. Valdani, (*b*) A. venarensis, (*c*) A. Henleyi, (*d*) A. Davœi; 2, micaceous and pyritous marls, about 200 feet; 3, nodular limestone with large gryphites, comprising the zones of (*a*) Amm. zetes,

(*b*) Pecten æquivalvis, (*c*) Amm. acanthus. Near St. Amand, Cher, the stage consists of nearly 300 feet of marls and marly limestone, with the zones of (*a*) Gryphæa regularis, (*b*) Amm. raricostatus, (*c*) A. ibex, (*d*) A. Davœi, (*e*) A. margaritatus, (*f*) A. spinatus. In the Rhone basin, it varies up to 340 feet in thickness, but in Provence it expands to nearly 900 feet, the lower half composed chiefly of limestones and the upper half of marls. In Normandy, it is chiefly belemnite limestone, 50 to 65 feet thick.

2. Sinemurian (= Lower Lias). This stage (Lias à gryphées) is typically developed at Semur, Côte-d'Or (whence its name), where it consists of nodular gryphite limestone with marly bands (23–26 feet) and is divisible into three zones, which, counting from below, are marked respectively by: 1, Ammonites rotiformis; 2, A. Bucklandi; 3, A. stellaris. Near St. Amand, Cher, it is composed of about 15 feet of marly limestone, which represent only its upper part. In the Haute Marne and Jura it is a limestone with curved gryphites, and ranges from 15 to 25 feet in thickness. In the basin of the Rhone it is a calcareous formation, 20 to 25 feet thick, containing the zones of Ammonites Davidsoni, A. stellaris, A. oxynotus, and A. planicosta. Further south, it swells out in Provence to 275 feet, and is separable into a lower group with Amm. Bucklandi, and a higher with Belemnites acutus, Amm. bisulcatus. In Normandy, it is about 100 feet thick, and comprises clays and marly gryphite limestones (Ammonites bisulcatus), surmounted by gryphite limestones and clays (Belemnites brevis, Waldheimia cor.).

1. Hettangian (= Infra-Lias), marly and shelly limestones with Ammonites planorbis, etc. (corresponding to the Angulatus and Planorbis zones at the base of the Lias), resting conformably on the sandstones, marls, and bone-bed of the Avicula contorta zone or Rhætic group. In Lorraine, this stage is only 13 feet thick. In Luxembourg, the lower or Planorbis zone is composed of dark clays alternating with bands of fetid limestone (10–40 feet). The upper or Angulatus zone, consisting mostly of sandstone (200 feet), is well seen at Hettange, whence the name. This zone becomes less sandy as it advances into Belgium, where it forms

the Marne de Jamoigne. The Hettangian stage of Burgundy is thin, and is composed of a lower Lumachelle de Bourgogne (Ostrea irregularis, Cardinia Listeri, Ammonites Burgundiæ) and an upper marly limestone known as "Foie de Veau" (Ammonites Burgundiæ, A. moreanus). In the basin of the Rhone, the Planorbis zone is about 40 feet thick, and the Angulatus zone 20 to 26 feet. In Cotentin, the stage is divisible into a lower sub-group of marls (Mytilus minutus, Corbula Ludovicæ) and an upper sub-group of limestones (Cardinia concinna, Pecten valoniensis).

One of the most interesting features of the Lias in the northern or Jura part of Switzerland is the insect-beds at Schambelen in the Canton Aargau. The insects are better preserved and much more varied than in the English Lias, and include representatives of Orthoptera, Neuroptera, Coleoptera (upward of 100 species of beetles), Hymenoptera, and Hemiptera. About half of the beetles are wood-eating kinds, so that there must have been abundant woodlands on the Swiss dry land in Liassic time.[79]

Germany.—In northwestern Germany the subjoined classification of the Jurassic system has been adopted:[80]

Upper or White Jura[80] (Malm).

- Purbeck group—Serpulit, a limestone 160 feet thick, and Münder Mergel, a series of red and green marls, with dolomite and gypsum, at least 1000 feet thick—forming a transition between the Purbeck and Portland groups.
- Eimbeckhäuser Plattenkalke and zone of Amm. gigas, equivalent to the English Portland group: Corbula, Modiola, Paludina, Cyrena.
- Kimeridge group, Upper, with Exogyra virgula = Virgulian; Middle or Pterocera beds (Pterocerian); Lower (Astartian, Upper Sequanian), with Nerinæa beds and zone of Terebratula humeralis.[81]
- Corallian, with Cidaris florigemma, corals, Pecten varians, Ostrea rastellaris, Nerinæa visurgis.
- Oxfordian, with Gryphæa dilatata, Amm. perarmatus, A. cordatus.
- Clays with Amm. ornatus, A. Jason, A. Lamberti, A. anceps, A. athleta = "Ornatus clays." This stage is usually included by German geologists in the Middle Jura.

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[79] Heer, "Urwelt der Schweiz," p. 82.

[80] Heinr. Credner, Ober. Jura in N. W. Deutschland, 1863. See also the works of Oppel and Quenstedt quoted on p. 1481, and K. von Seebach's Der Hannoversche Jura, 1864. Brauns' Unter. Mittl. und Ober. Jura, 1869, 1871, 1874. O. Fraas, "Geognostische Beschreibung von Württemberg, Baden und Hohenzollern," Stuttgart, 1882; Th. Engel, "Geognostischer Wegweiser durch Württemberg," Stuttgart, 1883.

[81] Struckmann, N. Jahrb. 1881 (ii.) p. 102.

Middle or Brown Jura (Dogger).	Upper 20–100 ft.	Clays, shales, and ferruginous oolite with at the top the zone of Amm. (Macrocephalites) macrocephalus, equivalent to the Callovian or Kellaways rocks, and at the bottom that of Amm. Parkinsoni.
	Middle 50 ft.	"Bifurcatus-schichten" with Amm. (Cosmoceras) bifurcatus. These "Bifurcatus beds," with the Hauptrogenstein above them, including the zones of Oppellia fusca and O. aspidoides, form the Bathonian stage.[82]
		"Coronatus-schichten," clays with Amm. (Stephanoceras) humphriesianus, A. Blagdeni, A. Braikenridgei, and many corals of the genera Montlivaltia, Thecosmilia, Cladophyllia, Isastræa, Confusastræa and Thamnastræa.[83]
		Ostrea limestone with Ostrea Marshi, O. eduliformis, Trigonia costata.
		Clays with Belemnites giganteus.
	Lower up to 500 ft.	Shales, sandstones and ironstones, with Inoceramus polyplocus, Amm. (Harpoceras) Murchisonæ, Pecten personatus.
		Clays and shales with Amm. (Harpoceras) opalinus, A. torulosus, Trigonia navis.
Lower or Black Jura (Lias).	Upper 30 ft.	Gray marls with Amm. (Lytoceras) jurensis (Jurensis-Mergel), A. (Harpoceras) radians.
		Bituminous shales (Posidonien-Schiefer) with Amm. lythensis, A. communis, A. bifrons, Posidonia Bronni.
	Middle 80–100 ft.	Clays with Amm. spinatus, A. (Amaltheus) margaritatus, Belemnites paxillosus.
		Marls and limestones with Amm. capricornus, A. Davœi.
		Dark clays and ferruginous marls with A. brevispina, A. Jasoni, A. ibex, A. Jamesoni, Terebratula numismalis.
	Lower 100–115 ft.[84]	Clays with Amm. obtusus (Turneri), A. Oxynotus, A. raricostatus (Oxynotenlager).
		Oil shales and Pentacrinus beds resting on gryphite limestone with Amm. (Arietites) Bucklandi, A. Conybeari, Gryphæa arcuata, Lima gigantea, Spiriferina Walcotti (Arietenschichten).
		Sandstones with Amm. angulatus (Angulatenschichten), Cardinia Listeri.
		Dark clays, sandy layers and limestone with Amm. planorbis (psilonotus) Psilonotenkalk.

In lithological characters the German Lower or Black Jura presents many points of resemblance to the English Lias. Some of the shales in the upper division are so bituminous as to be workable for mineral oil. With the general succession of organisms also, so well worked out by Oppel, Quenstedt, and others, the English Lias has been found to agree closely.

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[82] For an account of the fauna of this stage in the upper Rhenish lowland see A. O. Schlippe, Abhand. Geol. Specialkart. Elsass-Lothr. IV. Heft. iv. 1888.

[83] G. Meyer, "Korallen des Doggers," Abhand. Geol. Specialkart. Elsass-Lothr. IV. Heft v. 1888.

[84] For an account of this stage see J. A. Stuber, Abhandl. Geol. Specialkart. Elsass-Lothr. V. ii. 1893.

The Dogger or Brown Jura represents the Lower Oolite of England and the Etages Bajocien and Bathonien of France. Its lower division consists mainly of dark clays and slates, passing up in Swabia into brown and yellow sandstones with oolitic ironstone.[86] The central group in northern Germany differs from the corresponding beds in England, France, and southern Germany by the great preponderance of dark clays and ironstone nodules. The upper group consists essentially of clays and shales with bands of oolitic ironstone, thus presenting a great difference to the massive calcareous formation on the same platform in England and France.

The Malm, or Upper or White Jura corresponds to the Middle and Upper Oolites of England, from the base of the Oxford clay upward, with the equivalent formations in France. It is upward of 1000 feet thick, and derives its name from the white or light color of its rocks contrasted with the dark tints of the Jurassic strata below. It consists mainly of white limestones in many varieties; other materials are dolomite and calcareous marl. Its lower (Oxfordian) group is essentially calcareous, but with some of the fossils which occur in the Oxford clay, *e.g.* Ammonites ornatus and Gryphæa dilatata. The massive limestones with Cidaris florigemma are the equivalents of the Corallian. The Kimeridge group presents at its base beds equivalent to part of the Sequanian or Astartian sub-stage of France (Astarte supracorallina, Natica globosa, etc.), with such an abundance and variety of the gasteropod genus Nerinæa that the beds have been named the "Nerineen-Schichten." Above these come strata with Pterocera Oceani (Pterocerian), marking the central zone of the Kimeridgian stage. Higher still lie compact and oolitic limestones with Exogyra virgula (Virgulian). At the top some limestones and marly clays yield Ammonites giganteus (Portlandian). The most important member of the German Kimeridgian stage is undoubtedly the limestone long quarried for lithographic stone at Solenhofen, near Munich. Its excessive fineness of grain has enabled it to preserve in the most marvellous perfection the remains of a remarkably varied and abundant fauna both of the sea and land. Besides skeletons of fishes (Aspidorhynchus, Lepidotus, Megalurus), cephalopods show-

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[86] For a detailed stratigraphical and palæontological account of the Lower Dogger of German Lorraine see W. Branco, Abhand. Geol. Specialkart. Elsass-Lothr. II. Heft ii. 1879.

ing casts of their soft parts, crabs with every part of the integument in place, and other denizens of the water, there lie the relics of a terrestrial fauna washed or blown into the neighboring shallow lagoons—dragon-flies with the lace-work of their wings, and other insects; the entire skeletons of Pterodactyle and Rhamphorhynchus, in one case with the wing membrane preserved (Figs. 399, 400, 401), and the remains of the earliest known bird, Archæopteryx (pp. 1474, 1475). The upper Jurassic series is well developed in Hanover, where it has been carefully studied by C. Struckmann. The Portland group has been shown by him to contain eighty-five species of fossils, one-half of which are lamellibranchs, and to include the characteristic ammonites A. gigas, portlandicus, Gravesianus, giganteus.[86] The German Purbeck group attains an enormous development in Westphalia (1650 feet), where, between limestones full of Corbula, Paludina, and Cyclas, pointing to fresh-water deposition, there occur beds of gypsum and rock-salt.

Alps.—The Jurassic system in the Alps is developed under a different aspect from its varied characters in central and western Europe. It there includes massive reddish limestones or marbles like those of the Trias of the same region. Indeed it would seem that the pelagic conditions under which the Triassic limestones were deposited had not entirely passed away when the Jurassic formations came to be laid down. The Lias is well represented in the Alps under several distinct types. At the western end of the chain in the region north and south of Briançon it consists of crystalline, often brecciated limestones, generally full of lamellibranchs, sometimes of corals. In Dauphiné it is made up of marly non-crystalline limestones distinguished by the number of their ammonites and belemnites, and sometimes reaching, according to Lory, a thickness of more than 6000 feet. Southward in Provence the limestones are especially rich in brachiopods and crinoids.[87] In the Tyrol and eastern Alps the Lias presents still other lithological and palæontological characters. A distinguishing feature is the prominence of red and variegated marbles, also the abundance of genera of ammonites which are for the most

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[86] "Der Obere Jura der Umgegend von Hanover," 1878; Palæontolog. Abhand. (Dames u. Kayser) I. i. 1882; Zeitsch. Deutsch. Geol. Ges. 1887, p. 32.

[87] Haug, "Les Chaines subalpines," Bull. Carte Geol. France, No. 21, 1891; Lory, Bull. Soc. Geol. France (3), ix.

part feebly represented in central and western Europe, some of the conspicuous forms being species of Phylloceras, Lytoceras, Amaltheus, Oxynoticeras, Arietites, Psiloceras, and Schlotheimia. At Adneth, in Salzburg, this facies has been long studied. In the Hierlatz Mountains of the Salzkammergut the Lias is represented by massive white and pink limestones with abundant brachiopods. Yet with these calcareous deposits there are also developed along the southern borders of Bohemia and eastward in Hungary, sandy and argillaceous strata containing so much vegetation as to afford in some places beds of coal.[88] The Alpine Lias, in spite of these variations of character and organic contents, shows here and there some of the distinctive ammonite zones, so that it can be placed in comparison with that of the rest of Europe. It lies conformably on and passes down into the Rhætic series.

The equivalents of the English Lower Oolites or "Middle Jura" of the Continent have been detected in both the western and eastern Alps, but are not well developed there. In the west, where they are about 1300 feet thick, they consist of limestones, shales, and clays with calcareous nodules, which form regular alternations. Ammonites, especially of the genera Phylloceras and Lytoceras, abound, together with Posidonia. The zones of Amm. (Harpoceras) Murchisonæ, A. (Harpoceras) concavus, A. (Sonninia) Sowerbyi, A. (Sonninia) Romani, A. humphriesianus (Cœloceras subcoronatum), A. (Parkinsonia) Parkinsoni, and A. (Oppellia) fuscus have been recognized.[89]

The Oxfordian and Corallian divisions of the Jurassic system, or Callovian, Oxfordian, and Sequanian formations are in general feebly represented in the Alpine region; but the Upper Oolites or Kimeridgian and Portlandian series attain a large development. It is this higher part of the system which in the Alps specially presents the Tithonian facies already referred to. Above the zone of Ammonites (Oppellia) tenuilobatus (Aspidoceras acanthicum) comes a mass of strata consisting of a lower group of reddish well-bedded limestones so full of Terebratula diphya (janitor) as to be named the "Diphya-limestone"; and of an upper thick-bedded or massive light-colored limestone (Stramberg limestone, from Stramberg in Moravia). The limestones are often crowded with cephalopods, of which a large number

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[88] Neumayr, Abhand. k. k. Geol. Reichsanst. 1879.
[89] Haug, Bull. Cart. Geol. France, No. 21, 1891.

of species, many of them peculiar, have been noticed (Amm. [Phylloceras] ptychoicus, A. volanensis, A. hybonotus, A. transitorius, A. lithographicus, A. steraspis). The presence of some of these in the Portlandian rocks of Germany serves to place all these Alpine limestones at the very top of the Jurassic system. About a dozen species of fossils pass up from them into the Cretaceous rocks. The shales or impure shaly limestones are sometimes full of the curious cephalopod-appendages known as Aptychus (Aptychus-beds). Some of the more massive limestones are true coral-reefs. Many of the limestone escarpments of the Alps (Hochgebirgskalk) are referable to the Terebratula diphya beds. In some places they are overlain by the Diphyoides-beds (with Terebratula diphyoides), elsewhere they pass insensibly upward into the so-called Biancone—a white compact siliceous limestone containing Cretaceous cephalopods. The Diphya-limestone, with its peculiar fossils, appears to range from the Carpathians through the Alps and Apennines (where it occurs as a marble) into Sicily.[90]

Sweden.—The coal-bearing Rhætic series developed in Scania and referred to on p. 1442, is followed by a series of marine strata, in which a number of the ammonite-zones of the Lower and Middle Lias have been recognized as high as that of Amm. margaritatus.[91] Similar strata are found on the island of Bornholm. These Scandinavian deposits and those in the north of Scotland mark the northern and western limits of the Jurassic system in Europe.

Russia.—Jurassic formations spread over a larger area in Russia than in any other part of Europe, for they sweep northward over a vast breadth of territory to the White Sea, and extend eastward into Asia. Yet in this wide area it is only the upper half of the system which appears. The Lias and the stages below the Callovian are absent. The fauna of these Russian Jurassic formations is so peculiar, and for a long time yielded so few species found elsewhere in Europe,

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[90] In the voluminous literature of this subject the following works may be consulted: Oppel, Z. Deutsch. Geol. Ges. xvii. 1865, 535; Neumayr, Abh. Geol. Reichsanstalt, v.; Zittel, Paläont. Mittheil. Mus. Bayer.; Hébert, Bull. Soc. Geol. France, ii. (2) p. 148, xi. (3) p. 400; E. W. Benecke, "Trias und Jura in den Südalpen," 1866; "Geognostisch. Paläontologische Beiträge," 8vo, Munich, 1868; C. Moesch, "Jura in den Alpen, Ostschweiz," 1872; E. Fraas, "Scenerie der Alpen." See also the "Jura-studien," etc. of Neumayr, already cited, p. 1477, and the papers of Favre, Loriol, Renevier and others.

[91] J. C. Moberg, Sverig. Geol. Undersökn. Stockholm, 1888.

that it was difficult to correlate these rocks with those of better known regions. More sedulous research, however, has now in large measure removed this difficulty, and shown that some of the recognized life-zones of western Europe can be detected in Russia.[92] At the bottom lies (1) the Callovian stage, consisting of clays, divided into—*a.* Lower with Amm. (Cosmoceras) calloviensis, A. gowerianus; *b.* Middle with Amm. (Cosmoceras) Jason, A. (Stephanoceras) coronatus; *c.* Upper with Amm. (Quenstedticeras) Lamberti, A. (Cosmoceras) Duncani. (2) Oxfordian, composed of dark sandy clays and divided into—*a.* Lower with Amm. (Cardioceras) cordatus, A. (Card.) vertebralis, A. (Perisphinctes) plicatilis, A. (Aspidoceras) perarmatus; *b.* Upper with Amm. (Cardioceras) alternans, A. (Perisphinctes) Martelli. (3) Volgian, consisting of green, brown, and dark sandstones and sands. The lower part of this group contains Amm. (Perisphinctes) virgatus, A. (Perisph.) Pallasi, Belemnites absolutus, B. magnificus, Aucella Pallasi, A. mosquensis, and the higher part yields Belemnites mosquensis, Holcostephanus Blaki, and many species of the lamellibranch Aucella. The group is correlated by Pavlow with the Portlandian stage of western Europe. At the top a number of species pass up into the Neocomian series.[93]

North America.—So far as yet known, rocks of Jurassic age play but a subordinate part in North American geology. Perhaps some of the red strata of the Trias belong to this division, for it is difficult, owing to paucity of fossil evidence, to draw a satisfactory line between the two systems. Strata containing fossils believed to represent those of the European Jurassic series have been met with in recent years during the explorations in the western domains of the United States. They occur among some of the eastern ranges of the Rocky Mountains (Colorado; Black Hills, Dakota; Wind River Mountains; Uinta Mountains; Wahsatch range, etc.), as well as in the Sierra Nevada, California, and other localities on the western side of the watershed. They have been recognized far to the north, beyond the great region of Azoic and Palæozoic rocks, in the Arctic portion of the continent. They have been met with also in South America, where

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[92] Neumayr, Geogn. Palaeontol. Beiträge, 1876, vol. ii.; Nikitin, Neues Jahrb. 1886, ii. p. 205; Mem. Acad. St. Petersbourg, 1881; Pavlow, Bull. Soc. Geol. France, xii. 1884; Bull. Soc. Nat. Moscou, 1889, 1891.

[93] Pavlow, Bull. Soc. Nat. Moscou, 1891.

they appear to range far southward into the Argentine Republic.[94] The fossils include species of Pentacrinus, Monotis, Gryphæa, Trigonia, Lima, Ammonites (Amaltheus, Arietites, Cardioceras), and Belemnites.

The American Jurassic rocks, though a few European species appear to occur in them, have not yet been satisfactorily correlated with the subdivisions of the system in Europe. The younger members of the series are probably best developed. In these strata as exposed in Wyoming, Utah, Dakota, and Colorado great discoveries of vertebrate remains have been made. Prof. Marsh has brought to light from the upper Jurassic strata of Colorado the remarkable series of reptilian forms already referred to which have given a wholly new interest and importance to the Jurassic rocks of America. Among remains of fish (Ceratodus), tortoises, pterodactyles, and crocodilians, he has recognized the bones of herbivorous deinosaurs (Atlantosaurus, Brontosaurus, Stegosaurus, Morosaurus, Apatosaurus), together with the carnivorous Creosaurus and the curious ostrich-like Laosaurus. With this rich and striking reptilian fauna are associated the remains of many genera of small mammals which have been named by Prof. Marsh Allodon, Ctenacodon, Dryolestes, Stylacodon, Asthenodon, Laodon, Diplocynodon, Docodon [Enneodon], Menacodon, Tinodon, Triconodon, Priacodon, Paurodon.[95]

Asia.—In India, as already stated, the upper part of the enormous Gondwána system is possibly referable to the Jurassic period. In Cutch, however, a marine series of strata occurs containing a representation of the European Jurassic system from the Inferior Oolite up to the Portland group inclusive. These rocks attain a thickness of 6300 feet, of which the lower half is chiefly marine and the upper mainly fresh-water. Among the zones recognized by Stoliczka were those of Ammonites macrocephalus, A. anceps, and A. athleta of the Kellaways (Callovian) group; A. Lamberti, A. cordatus, A. transversarius of the Oxford clay; A. tenuilobatus of the Kimeridge group.[96]

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[94] O. Behrendsen has found Lower and Middle Lias, and higher Jurassic beds on the eastern slopes of the Argentine Cordilleras. Zeit. Deutsch. Geol. Gesell. xliii. 369, 1891.

[95] Marsh, Amer. Journ. Sci. xv. 1878, p. 459; xviii. 1879, pp. 60, 215, 396; xx. 1880, p. 235; xxi. 1881, p. 511; xxxiii. 887, p. 237; Geol. Mag. 1887, pp. 241, 289.

[96] Medlicott and Blanford's "Geology of India," p. 253. Waagen, Palæont. Indica, 1875.

Australasia.—The existence of Jurassic rocks in Queensland and western Australia has been demonstrated by the discovery of recognizable Jurassic species and others closely allied to known Jurassic forms.[97] In Queensland above the Permo-Carboniferous rocks comes the Burrum formation, a great series of coal-bearing rocks, with Sphenopteris, Thinnfeldia, Alethopteris, Tæniopteris, Podozamites, Otozamites, Baiera, and a few animal remains, including species of Corbicula and Rocellaria. This group is followed by another sandy and conglomeratic series with abundant remains of land-plants and workable coals, forming the valuable Ipswich formation. From these strata a large flora has been collected, together with cyprids, coleoptera, and Unio. From the plant-remains these two formations have been grouped as Jura-Trias.[98] Traces of Jurassic rocks have been found in New Caledonia and the northern end of New Guinea.

In New Zealand a thick series of rocks classed as Jurassic is subdivided as follows:

Mataura series, estuarine, with terrestrial plants (8 species known).

Putakaka series, marlstones and sandstones passing into conglomerates, and inclosing plant-remains and irregular seams of coal; marine fossils (11 species known) of Middle Oolite facies.

Flag Hill series, with species of Rhynchonella, Terebratula, Spiriferina, etc.

Catlin's River and Bastian series, consisting in the upper part of conglomerates and grits, with obscure plant-remains, and in the lower part of sandstones. Fossils abundant (especially ammonites), and affording means for defining horizons. This division is referred to the Lias.[99]

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[97] Moore, Q. J. Geol. Soc. xxvi. 261. W. B. Clarke, op. cit. xxiii. 7. R. Etheridge jun., "Catalogue of Australian Fossils," 1878.

[98] Jack and Etheridge, "Geology and Palæontology of Queensland," 1892, chaps. xxiii.–xxx.

[99] Hector's "Handbook of New Zealand," p. 31. Compare F. W. Hutton, Quart. Journ. Geol. Soc. 1885, p. 204.

Section iii. Cretaceous

The next great series of geological formations received the name of Cretaceous system, from the fact that, in north-western Europe, one of its most important members is a thick band of white chalk (creta). It presents very considerable lithological and palæontological differences as it is traced over the world. In particular, the white chalk is almost wholly confined to the Anglo-Parisian basin where the system was first studied. Probably no contemporaneous group of rocks presents more remarkable local differences than the Cretaceous system of Europe. These differences are the records of an increasing diversity of geographical conditions in the history of the Continent.

§ 1. General Characters

Rocks.—In the European area, as will be afterward pointed out in more detail, two tolerably distinct areas of deposit can be recognized, each with its own character of sedimentary accumulations, as in the case of the Jurassic system already described. The northern tract includes Britain, the lowlands of central Europe southward into Silesia, Bohemia, and round the Ardennes into the basin of the Seine. The southern region embraces the centre and south of France, the range of the Alps, and the basin of the Mediterranean eastward into Asia. In the northern area, which appears to have been a basin in great measure shut off from free communication with the Atlantic, the deposits are largely of a littoral or shallow-water kind. The basement beds, usually sands or sandstones, sometimes conglomerates, are to a large extent glauconitic (greensand). The marked diffusion of glauconite, both in the sandstones and marls, is one of the distinctive characters of this series of rocks. Another feature is the abundance of soluble silica (sponge-spicules), more particularly in the formation called the Upper Greensand, and in the Lower Chalk of many parts of the south and southeast of England and the north of France. In Saxony and Bohemia, the Cretaceous system consists chiefly of massive sandstones, which appear to have accumulated in a gulf along the southern margin of the northern basin. Considerable bands of clay, occurring on different platforms among the European Cretaceous rocks, are often charged with fossils, sometimes so well preserved that the pearly nacre of the shells remains, in other cases incrusted or replaced by marcasite. Alternations of soft sands, clays, and shales, usually more or less glauconitic, are of frequent occurrence in the lower parts of the system (Neocomian and older Cenomanian). The calcareous strata assume sometimes the form of soft marls, which pass into glauconitic clays, on the one hand, and into white chalk, on the other. The white chalk itself is a pulverulent limestone, mainly composed of fragmentary shells and foraminifera. Its upper part shows layers of flints, which are irregular lumps of dark-colored, somewhat impure chalcedony, disposed for the most part along the planes of bedding, but sometimes in strings and veins across them. The flints frequently inclose silicified fossils, especially sponges, urchins, brachiopods, etc. (see pp. 247, 289). The chalk, in some places, becomes a hard dull limestone, breaking with a splintery fracture. Nodular phosphate of lime or phosphatic chalk, occurring on different horizons in the system, is extensively worked as a source of artificial manure in the

Upper Chalk of Belgium.[100] It has been found also in the north of France, and at Taplow, near Maidenhead, in England.[101]

The terrestrial vegetation of the period has in different places been aggregated into beds of coal. These occur in northwestern Germany among the Wealden deposits, where they are mined for use; also to a trifling extent in the Wealden series of England; they are likewise found in the Cenomanian series of Saxony and the Senonian of Magdeburg. The upper Cretaceous (Laramie) rocks of the Western Territories of the United States consist largely of sandstones and conglomerates, among which are numerous important seams of coal. Beds of concretionary brown iron-ore are present in the Cretaceous series of Hanover, and similar deposits were once worked in the English Wealden series. In the southern European basin, where the conditions of deposit appear to have been more those of an open sea freely communicating with the Atlantic, the most noticeable feature is the massiveness, compactness, and persistence of the limestones over a vast area. These rocks, often crowded with hippuritids, from their extent and organic contents, indicate that, during Cretaceous times, the Atlantic stretched across the south of Europe and north of Africa, far into the heart of Asia, and may not impossibly have been connected across the north of India with the Indian Ocean.

LIFE.—The Cretaceous system, both in Europe and North America, presents successive platforms on which the land-vegetation of the period has been preserved, though most of the strata contain only marine organisms. This ter-

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[100] Cornet, Quart. Journ. Geol. Soc. xlii. p. 325; Renard et Cornet, Bull. Acad. Roy. Belg. xxi. 1891, p. 126.

[101] A. Strahan, Quart. Journ. Geol. Soc. xlvii. 1891, p. 356.

restrial flora possesses a great interest, for it includes the earliest known progenitors of the abundant dicotyledonous angiosperms of the present day. In Europe, during the earlier part of the Cretaceous period, it appears to have closely resembled the vegetation of the previous ages, for the same genera of ferns, cycads, and conifers, which formed

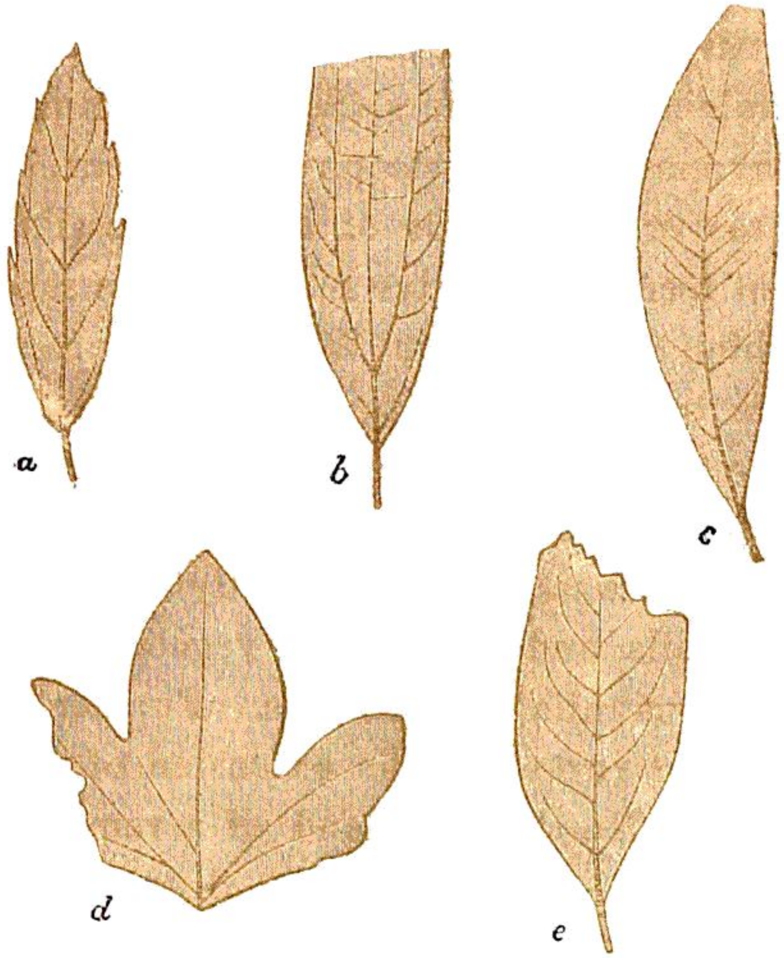

Fig. 410.—Cretaceous Plants.

***a*, Quercus rinkiana (2-3); *b*, Cinnamomum sezannense (2-3); *c*, Ficus atavina (2-3); *d*, Sassafras recurvata (2-3); *e*, Juglans arctica (1-2).**

the Jurassic woodlands, are found in the rocks. Yet that angiosperms must have already existed is made certain by the sudden appearance of numerous forms of that class, at the base of the Upper Cretaceous formations in Saxony and Bohemia, whence forms of Acer, Alnus, Credneria, Cunninghamites, Salix, etc., have been obtained. Still more varied and abundant is the dicotyledonous flora preserved in the Upper Cretaceous formations in Westphalia, from which 53 species of dicotyledonous plants have been obtained, belonging to the genera Populus, Myrica, Quercus, Ficus, Credneria, Viburnum, Aralia, Eucalyptus, etc., besides algæ, ferns, cycads, conifers, and various monoctyledons (Fig. 410).[102] Another rich Cretaceous flora is found in the corresponding beds at Aix-la-Chapelle. It includes numerous ferns (Gleichenia, Lygodium, Danæites, Asplenium, Pteridoleimma), conifers (Sequoia, Cunninghamites), Caulinea, Dryophyllum, Myricophyllum, Ficus, Laurophyllum, and three or four kinds of screw-pine (Pandanus).[103] The prevalent forms which give so modern an aspect to this flora, and which occur also in Westphalia, are Proteaceæ, many of them being referred to genera still living in Australia or at the Cape of Good Hope. These interesting fragments indicate that the climate of Europe, at the close of the Cretaceous period, was doubtless greatly warmer than that which now prevails, and nourished a vegetation like that of some parts of Australia or the Cape. Further information has been afforded regarding the extension of this flora by the discovery in North Greenland of a remarkable series of fossil-plants, of which Heer has described nearly 200 species, including more than 40 kinds of ferns, with club-mosses, horse-tail reeds, cycads (Cycas, Podozamites, Otozamites, Zamites), conifers (Baiera, Ginkgo, Juniperus, Thuyites, Sequoia, Dammara, Pinus, etc.), monocotyledons (Arundo, Potamogeton, etc.), and many dicotyledons, in-

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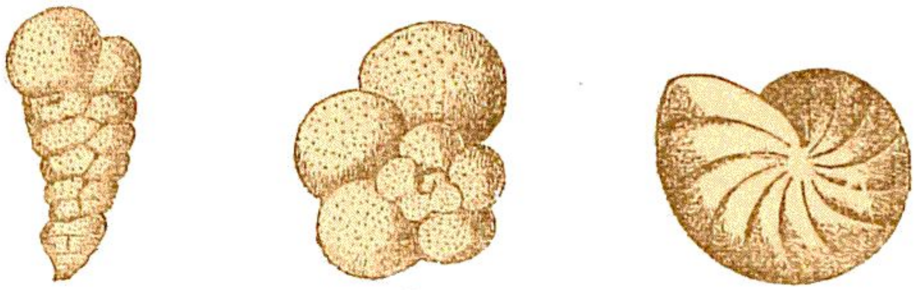
[102] Hosius and Von der Marck, "Die Flora der Westfälischen Kreideformation," Palæontographica, xxvi. 1880, p. 125. The total flora described by these observers is made up of 85 species from the Upper and 20 species from the Lower Cretaceous beds.

[103] T. Lange, Zeitsch. Deutsch. Geol. Ges. 1890, p. 658; and H. von Dechen, as cited postea, Note 170.

cluding forms of poplar, myrica, oak, fig, walnut, plane, sassafras, laurel, cinnamon, ivy, aralia, dogwood, magnolia, eucalyptus, ilex, buckthorn, cassia and others.[104]

In North America, also, abundant remains of a similar

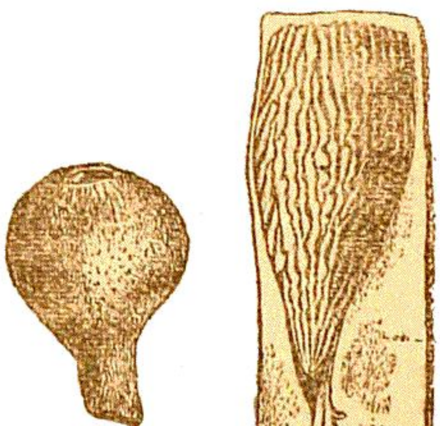


a *b* *c*

Fig. 411.—Cretaceous Foraminifera.

a, Gaudryina pupoides, D'Orb.; *b*, Globigerina cretacea, D'Orb.; *c*, Cristellaria rotulata, D'Orb. (all magnified).

vegetation have been obtained from the Cretaceous rocks of the Western Territories. The Laramie group of strata in particular has yielded a remarkably large and varied flora. Out of more than 100 species of dicotyledonous angiosperms there found, half are related to still living American trees. Among them are species of oak, willow, beech, plane, poplar, maple, hickory, fig, tulip-tree, sassafras, laurel, cinnamon, buckthorn, together with ferns, American palms (sabal, Flabellaria), conifers, and cycads.[105] The "Potomac formation" of Virginia and Maryland has a special interest from its age. It is referred with some probability to the Neocomian period, and it has yielded about 350 species of plants,



a *b*

Fig. 412.—Cretaceous Sponges.

a, Siphonia pyriformis, Goldf. (1-2); *b*, Ventriculites decurrens, var. tenuiplicatus, Smith (1-2).

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[104] "Flora Fossilis Arctica," vols. vi. and vii. 1882–83.

[105] For a synopsis of the Laramie flora see L. F. Ward, 6th Ann. Rep. U. S. Geol. Surv. 1885.

viz. three species of Equiseta, 139 ferns, 22 cycads, and more than 100 conifers. But besides this assemblage, which is distinctly Mesozoic in character, the deposits have furnished no fewer than 29 genera and 75 species of angiosperms. Of these higher forms of vegetation about two-thirds are new, and the more peculiar forms seem to be what are known as "generalized types," indicating the great antiquity of the flora. But among the genera there are found Sassafras, Ficus, Myrica, Bombax, and Aralia.[106]

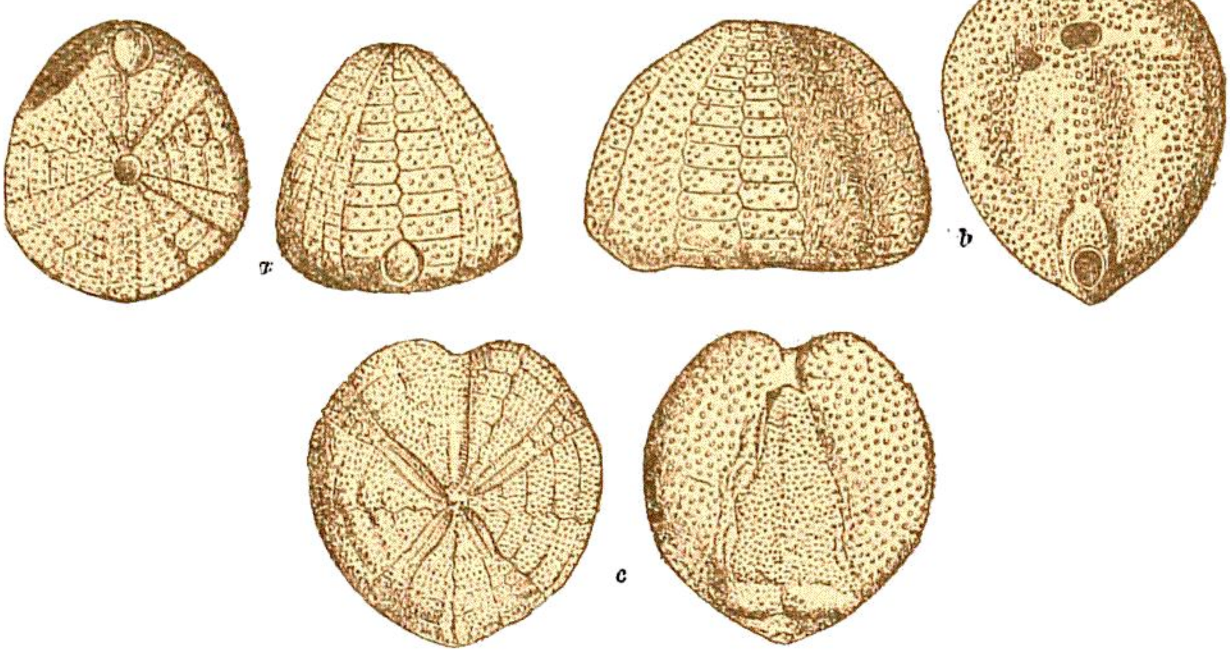

Fig. 413.—Upper Cretaceous Echinoids.

a, Echinoconus conicus, Brey. (=Galerites albo-galerus, Lam.) (2-3); *b*, Ananchytes ovatus (=Echinocorys vulgatus, Leske) (1-2); *c*, Micraster cor-anguinum, Klein (1-2).

The known Cretaceous fauna is tolerably extensive. Foraminifera now reached an importance as rock-builders which they never before attained. Their remains are abundant in the white chalk of the northern European basin, and some of the hard limestones of the southern basin are mainly composed of their aggregated shells. The glauconite grains

[106] W. M. Fontaine, "The Potomac or Younger Mesozoic Flora," Monog. U.S. Geol. Surv. vol. xv. 1889. See also O. Feistmantel, Zeitsch. Deutsch. Geol. Ges. 1888, p. 27.

of many of the greenish strata are the internal casts of foraminiferous shells (see pp. 766, 1081). Some of the more frequent genera are Globigerina, Orbitolina, Nodosaria, Textilaria, and Rotalia (Fig. 411). Calcareous sponges are of frequent occurrence, while siliceous sponges must have swarmed on the floor of the Cretaceous seas, for their siliceous spicules are abundant, and entire individuals are not uncommon.[107] Characteristic genera (Fig. 412) are Ventriculites, Siphonia, Cœloptychium, and Corynella. The formation of flints has been referred to the operation of sponges.

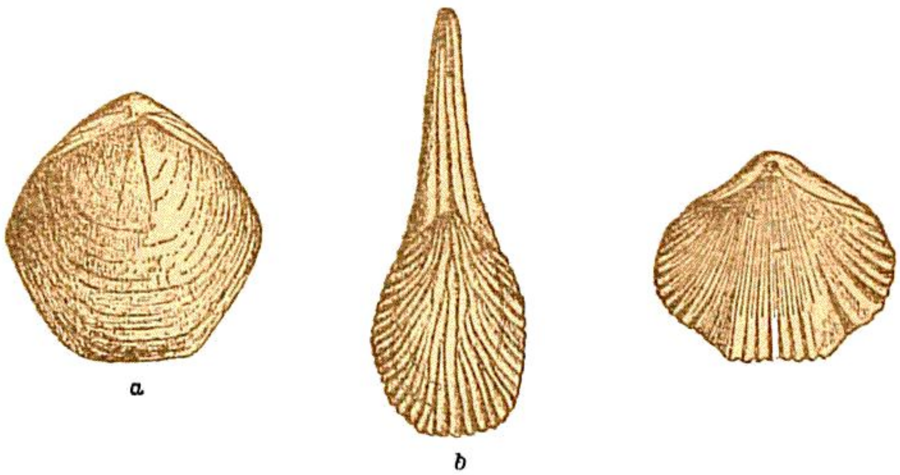

Fig. 414.—Cretaceous Brachiopods.
a, Terebratula carnea, Sow. (2-3); *b*, Terebrirostra lyra, Sow. (2-3); *c*, Rhynchonella plicatilis, var. octoplicata, Sow. (2-3).

Undoubtedly these animals secreted an enormous quantity of silica from the water of the Cretaceous sea, and though the flints are certainly not due merely to their action alone, amorphous silica may have been aggregated by a process of chemical elimination round dead sponges or other organisms (p. 828). Mollusks and urchins have been completely silicified in the Chalk.

[107] See on Sponge spicules, papers by Prof. Sollas, Ann. Mag. Nat. Hist. ser. 5, vi. and memoirs by Dr. G. J. Hinde, "Fossil Sponge Spicules," Munich, 1880; "Cat. of Fossil Sponges, British Museum," 1883; Phil. Trans. vol. clxxvi. p. 403, 1886; "British Fossil Sponges," Pal. Soc. vols. xl. xli. 1887–88. The sponge spicules of the Upper Cretaceous rocks are very generally in the condition of amorphous or colloid silica; those of the Lower Cretaceous are frequently of crystalline silica.

On the whole, corals are not abundant in Cretaceous deposits, though they occur plentifully in the so-called coral limestone of Faxoe. They seem to have been chiefly solitary forms, some of the more characteristic genera being Trochocyathus, Caryophyllia, Trochosmilia, Parasmilia, Micrabacia, and Cyclolites. The rugose corals so abundant

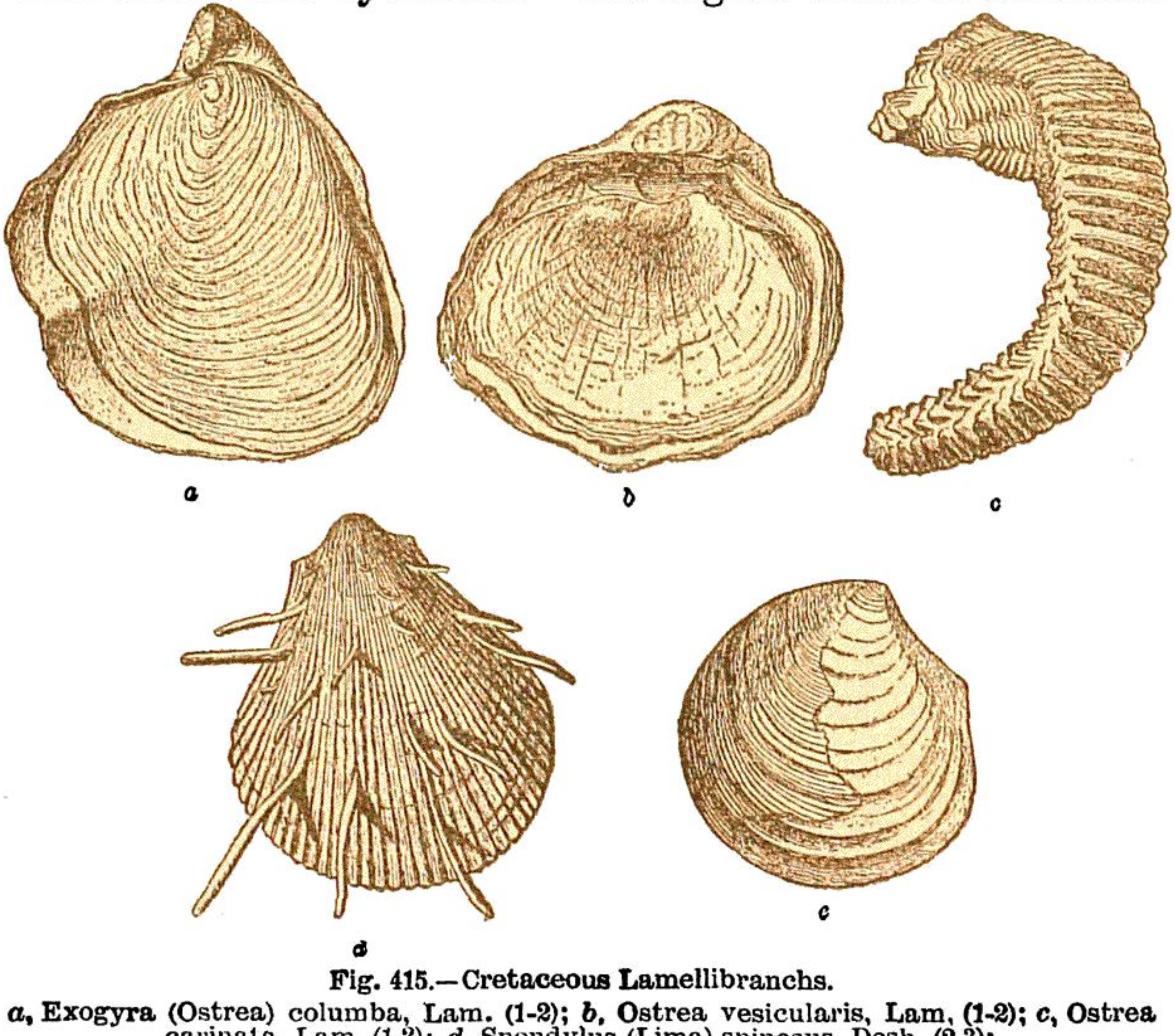

Fig. 415.—Cretaceous Lamellibranchs.
a, Exogyra (Ostrea) columba, Lam. (1-2); *b*, Ostrea vesicularis, Lam, (1-2); *c*, Ostrea carinata, Lam. (1-2); *d*, Spondylus (Lima) spinosus, Desh. (2-3); *e*, Inoceramus Cuvieri, Sow. (young spec.) (1-2).

among Palæozoic rocks are now doubtfully represented by the little Neocomian Holocystis. Sea-urchins are conspicuous among the fossils of the Cretaceous system. A few of their genera are also Jurassic, while a not inconsiderable number still live in the present ocean. One of the most striking results of recent deep-sea dredging is the discovery of so many new genera of echinoids, either identical with, or very nearly resembling, those of the Cretaceous period, and having thus an unexpectedly antique character.[108] Some of the most abundant and typical Cretaceous genera (Fig. 413) are Ananchytes (Echinocorys), Holaster, Toxaster, Micraster, Hemiaster, Hemipneustes, Cardiaster, Pygurus, Echinobrissus (Nucleolites), Echinoconus (Galerites), Discoidea, Cyphosoma, Pseudodiadema, Salenia, Cidaris. A few crinoids have been met with, of which Bourgueticrinus and Marsupites of the Upper Chalk are characteristic.

Polyzoa abound in some parts of the system, especially

Fig. 416.—Cretaceous Lamellibranchs (Hippuritids).
a, Hippurites organisans, Desm. (nat. size); *b*, Caprotina (Requienia) ammonia, D'Orb. (1-3).

in the upper formations (Cellaria, Vincularia, Membranipora, Micropora, Retepora). The brachiopods (Fig. 414) are abundantly represented by species of Terebratula and Rhynchonella, which approach in form to still living species. Other contemporaneous genera were Crania (numerous species), Thecidium, Magas, Terebratella, Lyra (Terebrirostra), Trigonosemus, Terebratulina, and Argiope. Among the most abundant genera of lamellibranchs (Fig. 415) are Inoceramus, Exogyra, Ostrea, Spondylus, Lima,

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[108] A. Agassiz, "Report on Echinoidea," "Challenger" Expedition, vol. iii. p. 25.

Pecten, Perna, Modiola, Trigonia, Isocardia, Cardium, Venus. Inoceramus and Exogyra are specially characteristic, but still more so is the family of Hippuritidæ or Rudistes. These singular forms are entirely confined to

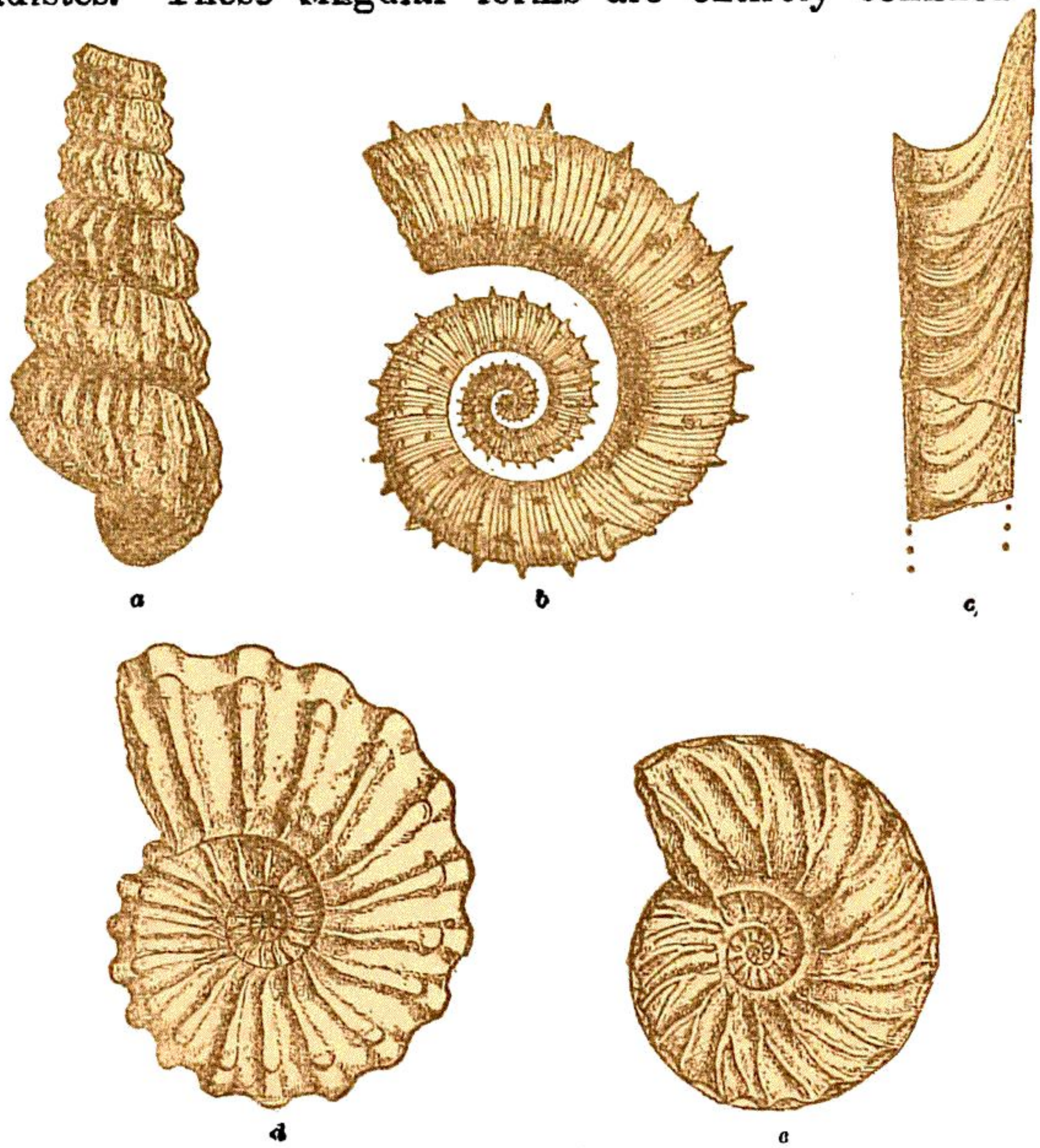

Fig. 417.—Cretaceous Cephalapods.

a, Turrilites costatus, Lam. (½); *b*, Crioceras Emerici, Lev. (¼); *c*, Baculites anceps, Lam. (½); *d*, Ammonites (Acanthoceras) rothomagensis, Brong. (¼); *e*, Ammonites varians, Sow. (⅔).

the Cretaceous system: their most common genera (Fig. 416) being Hippurites, Radiolites, Sphærulites, Caprina, Monopleura, and Caprotina (Requienia).[109] Hence, according to present knowledge, the occurrence of hippuritids in a

[109] For a study of the Rudistes, see the Memoir by H. Douvillé, Mem. Soc. Geol. France (3), i. 1890; ii. 1892.

limestone suffices to indicate the Cretaceous age of the rock. The most common gasteropods belong to the genera Actæonella, Turbo, Solarium, Trochus, Pleurotomaria,

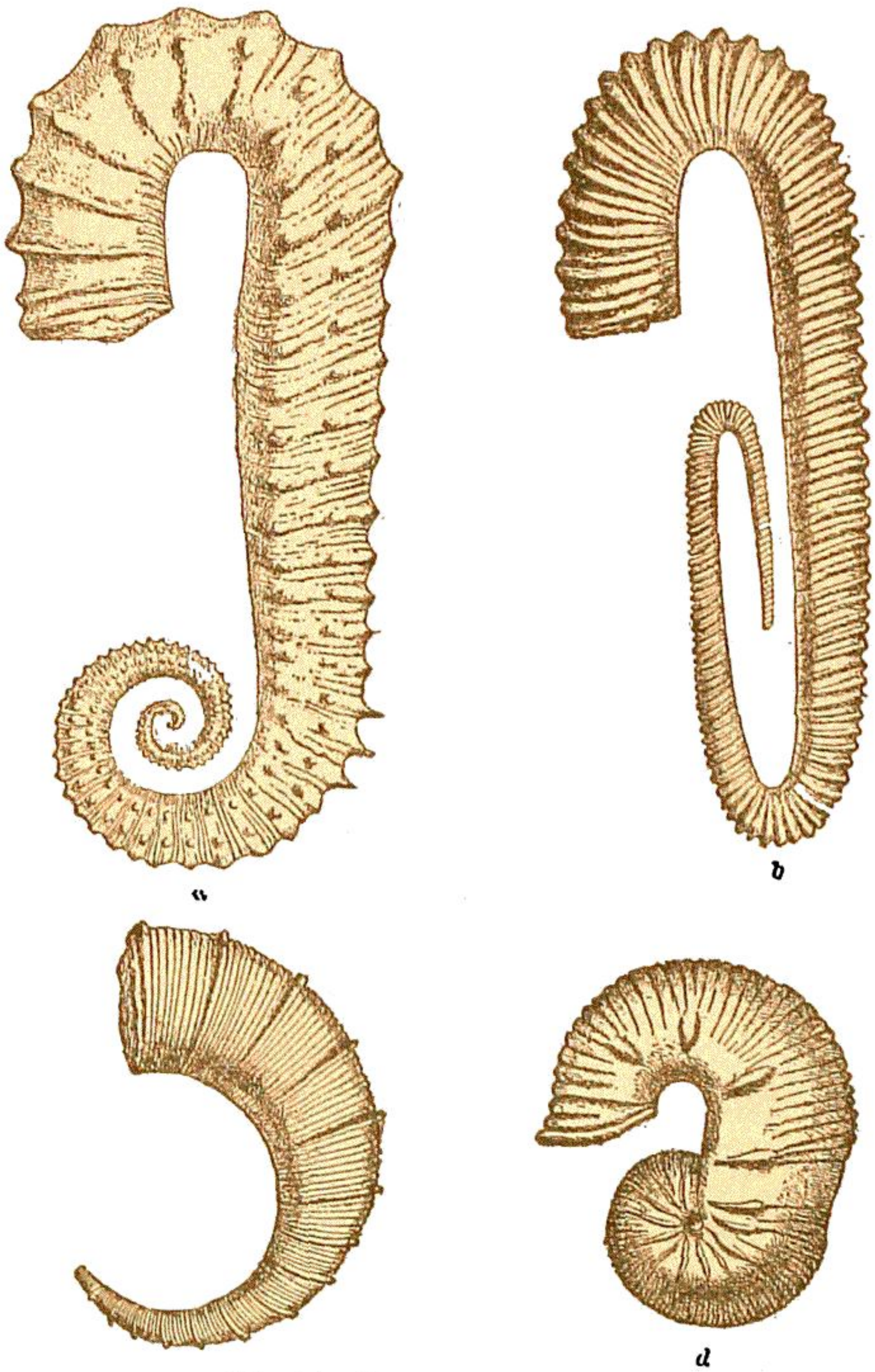

Fig. 418.—Cretaceo Cephalopods.

a, Ancyloceras matheronianus, D'Orb. (⅛); *b*, Hamites attenuatus, Sow. (½); *c*, Toxoceras bituberculatus, D'Orb.; *d*, Scaphites æqualis, Sow.

Cerithium, Rostellaria, Aporrhais, Fusus, Mitra, and Murex. Cephalopods must have swarmed in some of the Cretaceous seas (Figs. 417, 418, 419). Their remains are abundant in the Anglo-Parisian basin and thence eastward, but are comparatively infrequent in the southern Cretaceous area. To the geologist, they have a value similar to those of the Jurassic system, as distinct species are believed to be restricted in their range to particular horizons, which have by their means been identified from district to district. To the student of the history of life, they have a special interest, as they include the last of the great Mesozoic tribes of the Ammonites and Belemnites. These organisms continue abundant up to the top of the Cretaceous system, and then disappear from the European geological record.[110] Never was cephalopodous life so varied as in the Cretaceous period, just before its decline. It included some old Ammonite genera such as Phylloceras, Lytoceras, and Haploceras, some of which had continued even from Liassic time, together with new genera, some resembling old types (Schloenbachia), others which now appeared for the first time. Of these new forms Crioceras (Fig. 417) is an Ammonite with the coils of the shell not contiguous. Scaphites and Ancyloceras have the last coil straightened, and its end bent into a crozier-like shape (Fig. 418). Toxoceras, as its name implies, is merely bent into a bow-like form. Hamites is a long tapering shell, curved round hook-wise upon itself. In Ptychoceras the long tapering shell is bent once and the two parts are mutually adherent. Turrilites (Fig. 417) is a spirally coiled

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[110] No abrupt disappearance of a whole widely-diffused fauna probably ever took place. The cessation of Ammonites with the Cretaceous system in Europe can only mean that in this area there intervened between the deposition of the Cretaceous and Tertiary strata a long interval, marked by such physical revolutions as to extirpate Ammonites from that region. That the tribe continued elsewhere to live on into Tertiary time appears to be proved by the occurrence of some Ammonite remains in the oldest Tertiary beds of California. A. Heilprin, "Contributions to the Tertiary Geology and Palæontology of the United States," Philadelphia, 1884, p. 102.

shell, and Helicoceras resembles it, but has the coils not in contact. Baculites (Fig. 417) is the simplest of all the forms, being a mere straight-chambered shell somewhat like the ancient Orthoceras. These forms, in numerous species, are almost entirely confined to the Cretaceous system, at the summit of which they disappear. The genus Nautilus is found not infrequently in Upper Cretaceous rocks. Another characteristic cephalopod is Belemnitella (Fig. 419), which occurs abundantly in the higher

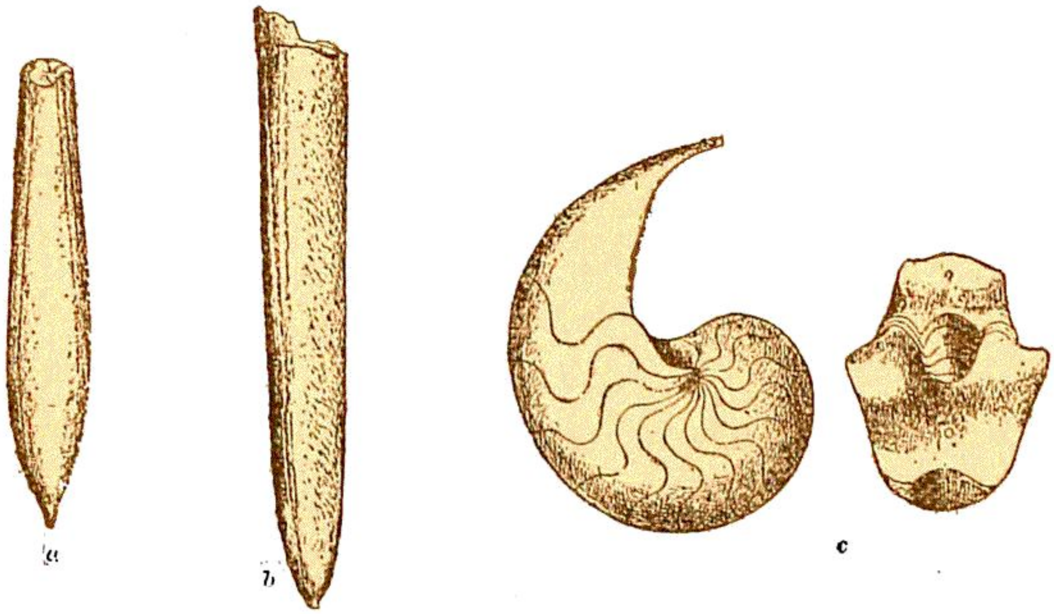

Fig. 419.—Upper Cretaceous Cephalopods.

a, Belemnitella plena (Belemnites plenus), Blainv. (½); *b*, Belemnitella mucronata, Schloth. (½); *c*, Nautilus danicus, Schloth. (½).

parts of the system. The Belemnites are more particularly characteristic of Lower Cretaceous rocks, and belong to Zittel's groups of the "Bipartiti," "Conophori," and "Dilatati."

Vertebrate remains have been obtained in some number from the Cretaceous rocks. Fish are represented by scattered teeth, scales, or bones, sometimes by more entire skeletons. The most frequent genera are Odontaspis,[111]

[111] Odontaspis (Lamna) elegans ranges up to the Rupelian (Oligocene) beds. A. Rutot, Ann. Soc. Geol. Belg. 1875, p. 34.

Lamna, Oxyrhina, Ptychodus, Hybodus, Mesodon (Pycnodus), Sphærodus, and the earliest of the teleostean tribes, which include the vast majority of modern fishes—Protosphyræna, Cimolichthys, Enchodus, Stratodus, Beryx (Fig. 420), Syllæmus, Portheus, etc.

Reptilian life has not been so abundantly preserved in the Cretaceous as in the Jurassic system, nor are the forms so varied. In the European area the remains of Chelonians of several genera (Chelone, Protemys, Platemys) have been recovered. The last of the tribe of deinosaurs died out toward the close of the Cretaceous period. Among the Cretaceous forms of this order are the Megalosaurus and

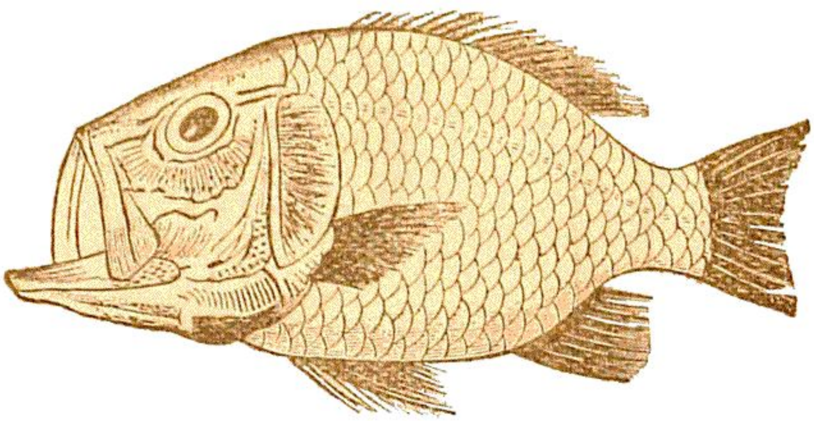

Fig. 420.—Cretaceous Fish.
Beryx lewesiensis (½).

Cetiosaurus, which survived from Jurassic time; likewise Pelorosaurus, Polacanthus, Iguanodon, Hylæosaurus, Hypsilophodon, Ornithopsis. Of these Iguanodon is the most familiar type (Fig. 421). Some of its teeth and bones were first found in the Wealden series of Sussex, but in recent years almost entire skeletons have been disinterred from the ancient alluvium filling up valleys of the Cretaceous period in Belgium, so that its osteology is now well known. Like other deinosaurs, it had many affinities with birds. Palæontologists have differed in opinion as to whether it walked on all fours or erect. M. Dollo, who has had the advantage of working out the structure of the wonderfully perfect Belgium specimens, believes that the animal moved on its hind legs, which are disproportionately longer than

Fig. 421.—Cretaceous Deinosaur (Iguanodon). From the skeleton as restored and erected by MM. de Paw and Dollo in the Brussels Museum.

the fore ones. Its powerful tail obviously served as an organ of propulsion in the water, and likewise to balance the creature as it walked. Its strange fore-limbs, armed with spurs on the digits, doubtless enabled it to defend itself from its carnivorous congeners; it was itself herbivorous.[112] Among Cretaceous rocks the order of Lizards is represented by Coniasaurus, Dolichosaurus, and Leiodon. The gigantic Mosasaurus, placed among lacertilians by Owen, but among "pythonomorphs" by Cope, is estimated to have had a length of 75 feet, and was furnished with fin-like paddles, by which it moved through the water. True crocodiles frequented the rivers of the period, for the remains of several genera have been recognized (Goniopholis, Pholidosaurus, Theriosuchus). The ichthyosaurs and plesiosaurs were still represented in the Cretaceous seas of Europe. The pterosaurs likewise continued to be inhabitants of the land, for the bones of several species of pterodactyle have been found. These remains are usually met with in scattered bones, only found at rare intervals and wide apart. In a few places, however, reptilian remains have been disinterred in such numbers from local deposits as to show how much more knowledge may yet be acquired from the fortunate discovery of other similar accumulations. One of the most remarkable of these exceptional deposits is the hard clay above referred to as filling up some deep valley-shaped depressions in the Carboniferous rocks near Bernissart in Belgium, and which has been unexpectedly encountered at a depth of more than 1000 feet below the surface in mining for coal. These precipitous defiles were

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[112] Mantell's "Illustrations of the Geology of Sussex," 1827. For recent additions to our knowledge, see Dollo, Bull. Mus. Roy. Belgique, ii. 1883. Ann. Sci. Geol. xvi. 1883, No. 6.

evidently valleys in Cretaceous times, in which fine silt accumulated, and wherein carcasses of the reptiles of the times were quietly covered up and preserved, together with remains of the river chelonians and fishes, as well as of the ferns that grew on the cliffs overhead. These deposits have remained undisturbed under the deep cover of later rocks.[113] Again, from the so-called "Cambridge Greensand"—a bed about 1 foot thick lying at the base of the Chalk of Cambridge, and largely worked for the phosphate of lime which is supplied by phosphatic nodules and phosphated fossils—there have been exhumed the remains of several chelonians, the great deinosaur Acanthopholis, several species of Plesiosaurus, 5 or 6 species of Ichthyosaurus, 10 species of Pterodactylus—from the size of a pigeon upward, one of them having a spread of wing amounting to 25 feet—3 species of Mosasaurus, a crocodilian (Polyptychodon), and some others. From the same limited horizon also the bones of at least two species of birds have been obtained.

In recent years the most astonishing additions to our knowledge of ancient reptilian life have been made from the Cretaceous rocks of western North America, chiefly by Professors Leidy, Marsh, and Cope.[114] According to an enumeration made a few years ago by Cope, but which is now below the truth, there were known 18 species of deinosaurs, 4 pterosaurs, 14 crocodilians, 13 sauropterygians or sea-saurians, 48 testudinates (turtles, etc.), and 50 phythonomorphs or sea-serpents. One of the most extraordinary of reptilian types was the Discosaurus or Elasmosaurus—a huge snake-

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[113] E. Dupont, Bul. Acad. Roy. Belg. 2e ser. xlvi. 1878, p. 387.

[114] Leidy, Smithson. Contrib. 1865, No. 192; Rep. U. S. Geol. and Geograph. Survey of Territories, vol. i. 1873; Cope, Rep. U. S. Geol. and Geograph. Survey of Territories, vol. ii. 1875; Amer. Naturalist, 1878 *et seq.*; Marsh, Amer. Journ. Science, numerous papers in 3d series, vols. i.–xlii. 1892.

like form 40 feet long, with slim arrow-shaped head on a swan-like neck rising 20 feet out of the water. This formidable sea-monster "probably often swam many feet below the surface, raising the head to the distant air for a breath, then withdrawing it and exploring the depths 40 feet below without altering the position of its body. It must have wandered far from land, and that many kinds of fishes formed its food is shown by the teeth and scales found in the position of its stomach" (Cope). The real rulers of the American Cretaceous waters were the pythonomorphic saurians or sea-serpents, in which group Cope includes forms like Mosasaurus, whereof more than 40 species have been discovered. Some of them attained a length of 75 feet or more. They possessed a remarkable elongation of form, particularly in the tail; their heads were large, flat, and conic, with eyes directed partly upward. They swam by means of two pairs of paddles, like the flippers of the whale, and the eel-like strokes of their flattened tail. Like snakes, they had four rows of formidable teeth on the roof of the mouth, which served as weapons for seizing their prey. But the most remarkable feature in these creatures was the unique arrangement for permitting them to swallow their prey entire, in the manner of snakes. Each half of the lower jaw was articulated at a point nearly midway between the ear and the chin, so as greatly to widen the space between the jaws, and the throat must, consequently, have been loose and baggy like a pelican's. The deinosaurs were likewise well represented on the shores of the American waters. Among the known forms are Hadrosaurus, a kangaroo-like creature resembling the Iguanodon, and about 28 feet long; Diclonius, an allied form with a bird-like head and spatulate beak, probably frequenting the lakes and wading there for succulent vegetable food, interesting from its occurrence in the Laramie group of beds at the very close of the Cretaceous series; and Lælaps, which probably also walked erect, and resembled the Megalosaurus. Still more gigantic was the allied Ornithotarsus, which is supposed to have had a length of 35 feet. There were also in later Cretaceous time strange horned creatures such as Ceratops which, attaining a length of 25 or 30 feet, had a massive body, a pair of large and powerful horns, and a peculiar dermal armor. Akin to it were various deinosaurs united in the genus Triceratops, so named from the third rhinoceros-like nasal horn. Some of their skulls exceeded 6 feet in length, exclusive of the horny beak, and 4 feet in width, with horn-cores about 3 feet long. Claosaurus was another gigantic deinosaur not unlike the Iguanodon, with remarkably small fore-limbs compared with the massive hind legs.[115] Pterosaurs have likewise been obtained characterized by an absence of teeth (Pteranodonts), and some of which had a spread of wing of 20 to 25 feet.[116] Among the Chelonians one gigantic species is supposed to have measured upward of 15 feet between the tips of the flippers.

The remains of birds have been met with both in Europe and in America among Cretaceous rocks. From the Cambridge Greensand bones of at least two species, referred to the genus Enaliornis, have been obtained. These creatures are regarded by Prof. Seeley as having osteological characters that place them with the existing natatorial birds.[117] From the American Cretaceous rocks nine genera and twenty

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[115] Marsh, on Cretaceous Deinosaurs, op. cit. xxxvi. 1888, xxxviii. xxxix. xli. xlii. xliv. xlv. 1893.

[116] Marsh, on American Cretaceous Pterodactyles, Amer. Journ. Sci. i. 1871, iii. xi. xii. xxi. xxvii. 1884.

[117] Q. J. Geol. Soc. 1876, p. 496

species, represented at present by the remains of about 120 individuals, have been obtained. Among these by far the most remarkable are the Odontornithes, or toothed birds,

Fig. 422.—Cretaceous Bird.[118]
Hesperornis regalis, Marsh ($\frac{1}{10}$).

from the Cretaceous beds of Kansas. Prof. Marsh, who some years ago described these wonderfully preserved forms,

[118] For this restoration and Fig. 423 I am indebted to the kindness of my friend Prof. Marsh.

has pointed out the interesting evidence they furnish of a reptilian ancestry.[119] In the most important and indeed unique genus, named by him Hesperornis (Fig. 422), the jaws were furnished with teeth implanted in a common alveolar groove, as in Ichthyosaurus; the wings were rudimentary or aborted, so that locomotion must have been entirely performed by the powerful hind limbs, with the aid of a broad, flat, beaver-like tail, which no doubt materially helped in steering the creature through the water. It must have been an admirable diver. Its long flexible neck and powerful toothed jaws would enable it to catch the most agile fish, while, as the lower jaws were united in front only by cartilage, as in serpents, and had on each side a joint that admitted of some motion, it had the power of swallowing almost any size of prey. Hesperornis regalis, the type species, must have measured about 6 feet from the point of the bill to the tip of the tail, and presented some resemblance to an ostrich. Of the other genera, Ichthyornis (Fig. 423) and Apatornis were distinguished by some types of structure pointing backward to a very lowly ancestry. They appear to have been small, tern-like birds, with powerful wings but small legs and feet. They possessed reptile-like skulls, with teeth set in sockets, but their vertebræ were biconcave, like those of fishes. There were likewise forms which have been grouped in the genera Graculævus, Laornis, Palæstringa, and Telmatornis. Altogether the earliest known birds present characters of strong affinity with the Deinosaurs and Pterodactyles.[120]

Though mammalian remains had long been known to oc-

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[119] "Odontornithes," being vol. i. of Memoirs of Peabody Museum of Yale College, and also vol. vii. of Geol. Explor. 40th Parallel. "Birds with Teeth," Rep. U. S. Geol. Surv. 1881–82, p. 45.

[120] See Marsh, U. S. Geol. Surv. Report, 1881–82, p. 86.

cur in the Triassic and Jurassic formations, none had been obtained from Cretaceous rocks, and this absence was all the more remarkable from the great abundance and perfect preservation of the reptilian forms in these rocks. But the

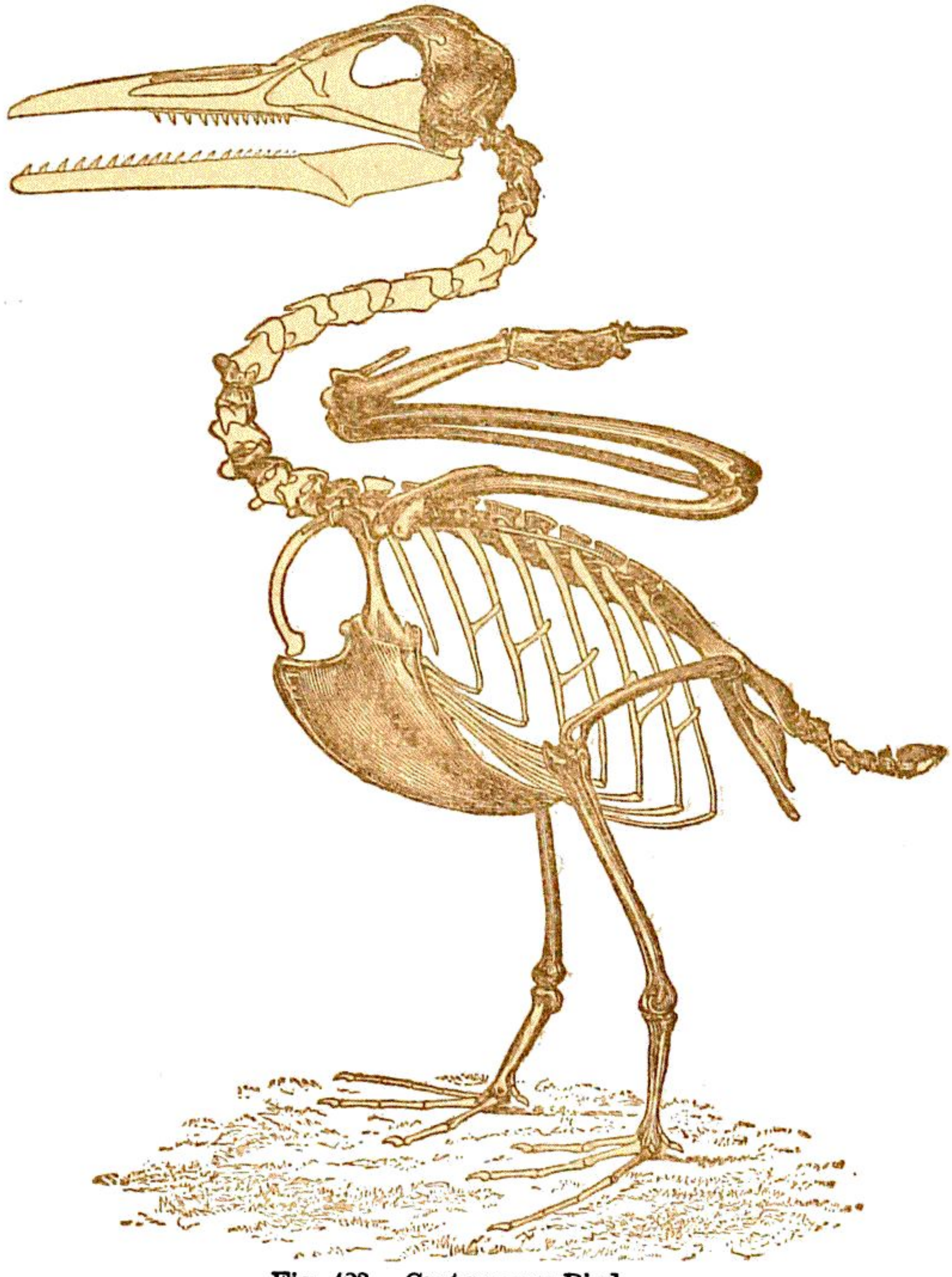

Fig. 423.—Cretaceous Bird.
Ichthyornis victor, Marsh (½).

blank has now been filled by the remarkable discovery in the Upper Cretaceous rocks of Dakota and Wyoming of a large series of jaws, teeth, and different parts of the skeletons of small mammals belonging to many individuals, and including not a few genera and species. They were found associated with remains of deinosaurs, crocodiles, turtles, ganoid fishes, and invertebrate fossils indicating brackish or fresh water conditions. The mammalian forms show close affinities to the Triassic and Jurassic types. There are several distinct genera of small marsupials, others seem to be allied to the monotremes, but there are no carnivores, rodents, or ungulates. The genera proposed for them by Prof. Marsh are Cimolomys, Cimolodon, Nanomys, Dipriodon, Tripriodon, Selenacodon, Halodon, Camptomus, Dryolestes, Didelphops, Cimolestes, Pediomys, Stagodon, Platacodon, Oracodon, and Allacodon.[121] More recently the discovery of a single small tooth in the Wealden series of Hastings is the first trace of mammalian life yet found in the Cretaceous formations of Europe. The specimen has been provisionally referred to the Purbeckian genus Plagiaulax.[122]

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121 Marsh, Amer. Journ. Sci. xxxviii. 1889, pp. 81, 177; xliii. 1892, p. 249.
122 A. Smith Woodward, Nature, xlv. 1891, p. 164.

§ 2. Local Development

The Cretaceous system, in many detached areas, covers a large extent of Europe. From the southwest of England it spreads across the north of France, up to the base of the ancient central plateau of that country. Eastward it ranges beneath the Tertiary and post-Tertiary deposits of the great plain, appearing on the north side at the southern end of Scandinavia and in Denmark, on the south side in Belgium and Hanover, round the flanks of the Harz, in Bohemia and Poland, eastward into Russia, where it covers many thousand square miles, up to the southern end of the Ural chain. To the south of the central axis in France, it underlies the great basin of the Garonne, flanks the chain of the Pyrenees on both sides, spreads out largely over the eastern side of the Spanish table-land, and reappears on the west side of the crystalline axis of that region along the coast of Portugal. It is seen at intervals along the north and south fronts of the Alps, extending down the valley of the Rhone to the Mediterranean, ranging along the chain of the Apennines into Sicily and the north of Africa, and widening out from the eastern shores of the Adriatic through Greece, and along the northern base of the Balkans to the Black Sea, round the southern shores of which it passes in its progress into Asia, where it again covers an enormous area.

A series of rocks covering so vast an extent of surface must needs present many differences of type, alike in their lithological characters and in their organic contents. They bring before us the records of a time when a continuous sea stretched over the centre and most of the south of Europe, covered the north of Africa, and swept eastward to the far east of Asia. There were doubtless many islands and ridges in this wide expanse of water, whereby its areas of deposit and biological provinces may have been more or less defined. Some of these barriers can still be traced, as will be immediately pointed out.

While there is sufficient palæontological similarity to allow a general parallelism to be drawn among the Cretaceous rocks of western Europe, there are yet strongly marked differences pointing to very distinct conditions of life, and probably, in many cases, to disconnected areas of deposit. Having regard to these geographical variations, a distinct northern and southern province, as above stated (p. 1518), can be recognized; but Gümbel has proposed a further grouping into three great regions: (1) the northern province, or area of White Chalk with Belemnitella, comprising England, northern France, Belgium, Denmark, Westphalia, etc.; (2) the Hercynian province, or area of Exogyra columba, embracing Bohemia, Moravia, Saxony, Silesia, and central Bavaria; and (3) the southern province, or area of Hippurites, including the regions of France south of the basin of the Seine, the Alps, and southern Europe.[123]

Britain.[124]—The Purbeck beds bring before us evidence of a great change in the geography of England toward the close of the Jurassic period. They show how the floor of the sea, in which the thick and varied formations of that period were deposited, came to be gradually elevated, and how into pools of fresh and brackish water the leaves, insects, and small marsupials of the adjacent land were washed down. These evidences of terrestrial conditions are followed in the same region by a vast delta-formation, that of the Weald, which accumulated over the south of England, while marine strata were being deposited in the north. Hence two types of Lower Cretaceous sedimentation occur, one where the strata are fluviatile (Wealden), the other where they are marine (Neocomian). The Upper Cretaceous groups, extending continuously from the coasts of Dorsetshire to those of Yorkshire, show that the diversities of sedimentation in Lower Cretaceous time were effaced by a general submergence of the whole area beneath the sea in which the Chalk was deposited. Arranged in descending order, the following are the subdivisions of the English Cretaceous rocks:

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[123] "Geognost. Beschreib. Ostbayer, Grenzgebirg."

[124] Consult Conybeare and Phillips, "Geology of England and Wales," 1822; Fitton, Ann. Philos. 2d ser. viii. 379; Trans. Geol. Soc. 2d ser. iv. 103; Dixon's "Geology of Sussex," edit. T. Rupert Jones, 1878; Phillips' "Geology of Oxford and the Thames Valley"; H. B. Woodward's "Geology of England and Wales," 2d edit. Special papers on the English Cretaceous formations are quoted in subsequent footnotes.

English Stratigraphical Subdivisions.			*Palæontological Zones.*	
Upper Cretaceous.			Danian, wanting.	
Upper Chalk with Flints.	Chalk of Norwich, Studland Bay	Senonian.	Campanian.	Zone of *Belemnitella mucronata*: Horizon of *B. mucronata* alone. " *B. mucronata* and *B. quadrata*.
	Chalk of Brighton, Margate, Bridlington, Salisbury		Santonian.	Zone of *Marsupites ornatus*: " numerous sponges. " *Inoceramus lingua* and few sponges.
	Chalk of Broadstairs, Flamborough Head Chalk of Dover			Zone of *Micraster cor-anguinum*, var. " *M. cor-testudinarium*.
Middle Chalk (without Flints).	Hard nodular Chalk of Dover, &c., "Chalk Rock"	Turonian.	Angoumian.	Zone of *Holaster planus*.
	Chalk without flints, Dover, &c.			" *Terebratulina gracilis*.
	Nodular Chalk of Shakespeare's Cliff, &c., "Melbourne Rock"		Ligerian.	Zone of *Inoceramus labiatus* (*mytiloides*), and *Rhynchonella Cuvieri*.
Lower Chalk.	Grey Chalk of Folkestone, &c., Totternhoe Stone. Chalk Marl. Red Chalk of Norfolk. "Chloritic Marl," Glauconitic Marl.	Cenomanian.	Carentonian.	Zone of *Belemnitella plena* (*Belemnites plenus*). Zone of *Holaster subglobosus*: Horizon of *Ammonites rothomagensis*. " *A. varians*. " *Plocoscyphia mæandrina*.
	Cambridge Greensand		Rothomagian.	Zone of "Craie glauconieuse" of France.
Upper Greensand.	Warminster beds, &c.			" *Pecten asper*.
	Blackdown beds, &c.			" *Ammonites* (*Schlönbachia*) *inflatus*.
Gault.	Upper	Gault.	Albian.	*Ammonites cristatus*, *A. auritus*, *A. lautus*.
	Lower			*Hamites rotundus*.

Lower Cretaceous.

Southern Type. (Fluviatile, and in upper part marine.)		*Northern Type.*[1] (Marine.)		
Lower Greensand.	Sands, clays, limestones, &c., in Kent, Surrey, Sussex, Hampshire.	Below the Red Chalk, at Speeton, on the Yorkshire coast, clays and marls, in apparently continuous sequence, pass down into Neocomian clays and shales (Speeton clay), which are less than 300 feet thick, and shade down into Kimeridge Clay. They are grouped in four zones. Their upper portions are equivalent to the Carstone and Tealby limestone and clay of Lincolnshire, and their lower parts to the Claxby Ironstone and Spilsby Sandstone.	Neocomian (including Urgonian, Aptian, and part of the Albian of French authors).	4. Zone of *Belemnites minimus*, perhaps including equivalents of Lower Gault. 3. Zone of *Belemnites semicanaliculatus* (?) (*B. brunsvicensis*), with *Ammonites Deshayesi*, species of *Crioceras*, *Ancyloceras*, *Hamites*, *Rostellaria Phillipsii*, *Exogyra sinuata*, *Panopæa neocomiensis*, &c.
Wealden.	Weald Clay.			2. Zone of *Belemnites jaculum*, with *Ammonites noricus*, *A. speetonensis*, *A. astierianus*, *Crioceras Duvalii*, *C. puzosianum*, *Rostellaria Phillipsii*, *Exogyra sinuata*, *Pecten cinctus*, *Nucula subangulata*, &c.
	Hastings sands and clays, passing down into Purbeck beds.			1. Zone of *Belemnites lateralis*, with *Amm. gravesianus*, *A. noricus*, *A. rotula*, *Crioceras*, *Exogyra sinuata*, *Panopæa plicata*, *Pecten lens*, *P. cinctus*, *Serpula vertebralis*.

[1] See G. W. Lamplugh, *Quart. Journ. Geol. Soc.* xlv. (1889) p. 575; *Brit. Assoc.* (1890) p. 808; 'Argiles de Speeton et leurs équivalents,' by A. Pavlow and G. W. Lamplugh in *Bull. Soc. Imp. Nat. Moscou*, 1891.

LOWER CRETACEOUS (NEOCOMIAN[125]).—Between the top of the Jurassic system and the strata known as the Gault, there occurs an important series of deposits to which, from their great development in the neighborhood of Neuchâtel in Switzerland, the name of Neocomian has been given. This series, as already remarked, is represented in England by two distinct types of strata. In the southern counties, from the Isle of Purbeck to the coast of Kent, there occurs a thick series of fresh-water sands and clays termed the Wealden series. These strata pass up into a minor marine group known as the Lower Greensand, in which some of the characteristic fossils of the Upper Neocomian rocks occur. The Wealden beds of England therefore form a fluviatile equivalent of the continental Neocomian formations, while the Lower Greensand represents the later marginal deposits of the Neocomian sea, which gradually usurped the place of the Wealden estuary. The second type, seen in the tract of country extending from Lincolnshire into Yorkshire, contains the deposits of deeper water, forming the westward extension of an important series of marine formations which stretch for a long way into central Europe.

Neocomian.[126]—The marine Neocomian strata of England are well exposed on the cliffs of the Yorkshire coast at Filey, where they occur in an argillaceous deposit long known as the "Speeton Clay." This deposit is now shown to contain an interesting continuous section of marine strata from the Kimeridge Clay to the top of the Lower Cretaceous, or even into the Upper Cretaceous series. It has been carefully studied by Mr. Lamplugh and by Professors Pavlow and Nikitin, by whom it has been brought into comparison with the Neocomian rocks of Russia. The lower part of the "Speeton Clay" consists of hard dark bituminous shales with large septarian nodules and many crushed fossils. Among these remains there occur Belemnites Oweni, Ammonites sp., Lingula ovalis, Discina latis-

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[125] Neucomian, from Neucomum, the old name of Neuchâtel in Switzerland.

[126] Fitton, Trans. Geo. Soc. 2d ser. iv. 1837, 103; Proc. Geol. Soc. iv. pp. 198, 208; Q. J. Geol. Soc. i. Consult on marine Neocomian type Young and Bird, "Survey of the Yorkhire Coast," 1828, 2d edit. pp. 58-64; J. Phillips, "Geology of Yorkshire," p. 124. J. Leckenby, Geologist, ii. 1859, p. 9. Judd, Q. J. Geol. Soc. xxiv. 1868, 218; xxvi. 326; xxvii. 207; Geol. Mag. vii. 220; C. J. A. Meyer, Q. J. Geol. Soc. xxviii. 243; xxix. 70. A. Strahan, op. cit. xlii. 1886, p. 486; Mem. Geol. Surv. sheet 84.

sima, Ostrea gibbosa, Lucina minuscula, etc. These strata are referred to the higher part of the Kimeridge Clay. They are succeeded conformably by the "zone of Belemnites lateralis," consisting of dark, pale, and banded clays with the fossils mentioned in the foregoing table. At the base of the zone lies a "coprolite bed," and its top is taken at a "compound nodular bed" rich in fossils (Bel. lateralis, Amm. noricus, A. rotula, Avicula inæquivalvis, Pecten cinctus, etc.). The total thickness of this zone is about 34 feet. It is overlain by the "zone of Belemnites jaculum," consisting likewise of various dark and striped clays and bands of nodules, the whole having a thickness of about 125 feet. While the underlying zone has obvious Jurassic affinities, this zone is unmistakably Lower Cretaceous. The characteristic belemnite ranges through 120 feet of the section with hardly any trace of another species. Ammonites noricus occurs in the lower 30 feet of the zone, and is succeeded by A. speetonensis. An interesting palæontological feature in this zone is the occurrence of abundant tests of Echinospatangus cordiformis, a highly characteristic Neocomian type. The "zone of Belemnites semicanaliculatus (?)" is seldom seen in complete section, owing to the slipping of the cliffs and the detritus on the foreshore. It consists of dark clays 100 feet thick or more. Above it a few feet of mottled green and yellow clays form the top of the Speeton Clay. These strata compose the zone of Belemnites minimus, and contain also B. attenuatus, B. ultimus, Inoceramus concentricus, I. sulcatus, etc. Some of their fossils are found in the Gault, and it has been suggested that they may represent here the Lower Gault, while the Red Chalk above may be the equivalent of the Upper Gault.[127]

In Lincolnshire the marine Neocomian series is likewise developed. Rising to the surface from beneath the Chalk, the highest and lowest strata are chiefly sand and sandstone; the middle portion (Tealby series) clays and oolitic ironstones. According to Mr. Lamplugh, the Spilsby Sandstone and the Claxby Ironstone of this country, forming the base of the Neocomian series and resting on Upper Kimeridge shales, are equivalents of the zone of Belemnites lateralis at Speeton. The Tealby Clay, which overlies them, is regarded as representing the zone of B. jaculum, the Tealby Limestone the zone of B. semicanaliculatus (?),

[127] G. W. Lamplugh, op. cit.

while the Carstone at the top immediately below the Red Chalk is placed on the horizon of the marls with B. minimus.[128] The Carstone ranges into Norfolk, and perhaps represents the entire "Lower Greensand" of central and southern England.

Wealden.—In the southern counties a very distinct assemblage of strata is met with.[129] It consists of a thick series of fluviatile deposits termed Wealden (from the Weald of Sussex and Kent, where it is best developed), surmounted by a group of marine strata ("Lower Greensand"), in which Upper Neocomian fossils occur. It would appear that the fresh-water conditions of deposit, which began in the south of England toward the close of the Jurassic period, when the Purbeck beds were laid down, continued during the whole of the long interval marked by the Lower and Middle Neocomian formations, and only in Upper Neocomian times finally merged into ordinary marine sedimentation. The Wealden series has a thickness of over 2000 feet, and in Sussex and Kent consists of the following subdivisions in descending order:

Weald Clay	1000 feet.
Hastings Sand group composed of—	
3. Tunbridge Wells Sand (with Grinstead Clay) . .	140 to 380 "
2. Wadhurst Clay	120 " 180 "
1. Ashdown Sand (with Fairlight Clays in lower part) .	400 or 500 "

In the Isle of Wight these subdivisions cannot be made out, and the total visible thickness of strata (sandstones, sands, clays, and shales) is only about half of what can be observed on the mainland further east, but the base of the series cannot be seen. Westward at Punfield, on the coast of Dorsetshire, the Wealden strata are exposed on the shore, and are there estimated to be from 1500 to 2000 feet thick. On the whole the Wealden series is thickest toward the west.

The sandy and clayey sediments composing the Wealden series precisely resemble the deposits of a modern delta. That such was really their origin is borne out by their

[128] See A. J. Jukes-Browne, "Geology of East Lincolnshire," in Mem. Geol. Surv. sheet 84, 1887; G. W. Lamplugh, "Argiles de Speeton," Bull. Soc. Imp. Nat. Moscou, 1391.

[129] On the Wealden or fluviatile type consult, besides the works quoted on p. 1543, Mantell's "Fossils of the South Downs," 4to, 1822; Topley, "Geology of the Weald," in Mem. Geol. Surv. 8vo, 1875. Bristow and Strahan, "Geology of the Isle of Wight," 2d edit. 1889, in Mem. Geol. Surv., list of Wealden fossils, p. 258.

organic remains, which include terrestrial plants (Equisetum, Sphenopteris, Alethopteris, Thuyites, cycads, and conifers), fresh-water shells (Unio, 10 species; Cyrena, 5 species; Paludina, Vicarya, Melania, etc.), with a few estuarine or marine forms, as Ostrea, Exogyra, and Mytilus, and ganoid fishes (Lepidotus) like the gar of American rivers. Among the spoils of the land floated down by the Wealden river were the carcasses of huge deinosaurian reptiles (Cetiosaurus, Titanosaurus, Iguanodon, Hylæosaurus, Polacanthus, Megalosaurus, Vectisaurus, Hypsilophodon), long-necked plesiosaurs, and winged pterodactyles. The deltoid formation, in which these remains occur, extends in an east and west direction for at least 200, and from north to south for perhaps 100 miles. Hence the delta may have been nearly 20,000 square miles in area. It has been compared with that of the Quorra; in reality, however, its extent must have been greater than its present visible area, for it has suffered from denudation, and is to a large extent concealed under more recent formations. The river probably descended from the northwest, draining a wide area, of which the existing mountain groups of Britain are perhaps merely fragments.

Lower Greensand.—The Wealden series is succeeded conformably by the group of arenaceous strata which has long been known under the awkward name of "Lower Greensand." This group consists mainly of yellow, gray, white, and green sands, but includes also beds of clay and bands of limestone and ironstone. It has been subdivided in descending order as under:

Folkestone beds (Lower Albian in the upper part)		70 to 100 feet.
Sandgate beds	(Aptian)	75 " 100 "
Hythe beds	(Aptian)	80 " 300 "
Atherfield Clay (Urgonian), resting on Wealden		20 " 60 "

These strata appear to represent the continental series up into the base of the Albian stage. The Atherfield Clay is well developed at Atherfield, on the south coast of the Isle of Wight. It contains an abundant series of fossils, among which are Toxaster complanatus, Terebratula sella, Exogyra (Ostrea) Couloni, Ostrea Leymeriei, Perna Mulleti, Arca Raulini, and others which indicate an Urgonian horizon for this band.[130] In the Hythe beds are found Plicatula

130 For a list of the fossils of the Atherfield Clay and other members of the Lower Greensand in the Isle of Wight. see the Geol. Surv. Mem. on that island cited on the foregoing page.

placunea, Ammonites Deshayesi, A. cornuelianus, Ancyloceras gigas, A. Hilsii, Belemnites semicanaliculatus, Crioceras Bowerbankii. Some of these fossils are found also in the Sandgate beds, while the upper part of the Folkestone beds yields likewise Amm. mamillaris. The Hythe and Sandgate beds may therefore represent the Aptian stage, while the Folkestone subdivision may be regarded as the equivalent of the lower part of the Albian.[131]

Of the total assemblage of fossils from the "Lower Greensand," about 300 in number, only 18 or 20 per cent pass up into the Upper Cretaceous series. This marked palæontological break, taken in connection with a great lithological change, and with an unconformability which in Dorset brings the Gault directly upon the Kimeridge Clay, shows that a definite boundary line can be drawn between the lower and upper parts of the Cretaceous system in England.

UPPER CRETACEOUS.—Three leading lithological groups have long been recognized as constituting the Upper Cretaceous series of England. First, a band of clay termed the Gault; second, a variable and inconstant group of sand and sandstones called the "Upper Greensand"; and, third, a massive calcareous formation chiefly composed of white chalk. But the foreign nomenclature, founded mainly on palæontological considerations, and given in the foregoing table (p. 1544), may now be adopted, as it brings the English Upper Cretaceous groups into recognizable parallelism with their continental equivalents.

Gault[132] (Albian).—A dark, stiff, blue, sometimes sandy or calcareous clay, with layers of pyritous and phosphatic nodules and occasional seams of green sand. It varies from 100 to more than 300 feet in thickness, forming a marked line of boundary between the Upper and Lower Cretaceous rocks, overlapping the latter and resting sometimes even on the Kimeridge Clay. One of the best sections is that of Copt Point, on the coast near Folkestone, where the following subdivisions have been established by Messrs. De Rance and Price:[133]

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131 For explanations of these and the other Cretaceous stratigraphical terms, which have been chiefly founded on the names of continental localities or districts where the several subdivisions are especially well developed, see the footnotes on the succeeding pages.

132 "Gault" is a Cambridgeshire provincial name.

133 C. E. De Rance, Geol. Mag. v. p. 163; i. (2) p. 246; F. G. H. Price, Q. J. Geol. Soc. xxx. p. 342; "The Gault," 8vo, London, 1879.

Upper Greensand.

Upper Gault.

11. Pale gray marly clay, 56 ft. 3 in., characterized by Ammonites (Schlönbachia) rostratus (inflatus), A. Goodhalli, Ostrea frons, Inoceramus Crispii.
10. Hard pale marly clay, 5 ft. 1 in., with Kingena lima, Rostellaria maxima, Plicatula pectinoides, Pecten raulinianus, Pentacrinus Fittoni, Cidaris gaultina.
9. Pale gray marly clay, 9 ft. 4½ in., with Inoceramus sulcatus, Ammonites varicosus, Pholadomya fabrina, Pleurotomaria Gibbsii, Scaphites æqualis.
8. Darker clay, with two lines of nodules and rolled fossils, 9½ in., with Ammonites cristatus, A. Beudanti, Pholas sanctæ-crucis, Mytilus Galliennei, Cucullæa glabra, Cyprina quadrata.

Lower Gault.

7. Dark clay, 6 ft. 2 in., highly fossiliferous, with Ammonites auritus, Nucula bivirgata, N. ornatissima, Aporrhais Parkinsoni, Fusus indecisus, Pterocerus bicarinatum.
6. Dark mottled clay, 1 ft., Ammonites denarius, A. cornutus, Turrilites hugardianus, Necrocarcinus Bechei.
5. Dark spotted clay, 1 ft. 6 in., Ammonites (Hoplites) lautus, Astarte dupiniana, Solarium moniliferum, Phasianella ervyana, numerous corals.
4. Paler clay, 4 in., Ammonites Delaruei, Natica obliqua, Dentalium decussatum, Fusus gaultinus.
3. Light fawn-colored clay, "crab-bed," 4 ft. 6 in., with numerous carapaces of crustaceans (Palæocorystes Stokesii, P. Broderipii), Pinna tetragona, Hamites attenuatus.
2. Dark clay marked by the rich color of its fossils, 4 ft. 3 in., Ammonites auritus, Turrilites elegans, Ancyloceras spinigerum, Aporrhais calcarata, Fusus itierianus, Cerithium trimonile, Corbula gaultina, Pollicipes rigidus.
1. Dark clay, dark greensand and pyritous nodules, 10 ft. 1 in., Ammonites interruptus, Crioceras astierianum, Hamites rotundus.

Lower Greensand.

Mr. Price remarks that, out of 240 species of fossils collected by him from the Gault, only 39 are common to the lower and upper divisions, while 124 never pass up from the lower and 59 appear only in the upper. The lower Gault seems to have been deposited in a sea specially favorable to the spread of gasteropods, of which 46 species occur in that division of the formation. Of these only six appear to have survived into the period of the upper Gault, where they are associated with five new forms. Of the lamellibranch fauna, numbering in all 73 species, 39 are confined to the lower division, four are peculiar to the passage-bed (No. 8), 14 pass up into the upper division, where they are accompanied by 16 new forms. About 46 per cent of the Gault fauna pass up into the upper Greensand.[134]

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134 The foraminifera of the Gault at Folkestone, with reference to the zones here given, have been described by F. Chapman, Journ. R. Micros. Soc. 1891, p. 565; 1892, pp. 321, 749.

Cenomanian.[135]—Under the name of *Upper Greensand* have been comprised sandy strata, often greenish in color, which are now known to belong to different horizons of the Cretaceous series. If the term is to be retained at all, its use must be accompanied with some palæontological indication of the true position of the beds to which it is applied. According to the researches of Dr. C. Barrois, the English Upper Greensand, as originally defined by Berger, Inglefield, Webster, Fitton, and others, has no such distinct assemblage of fossils as might have been supposed from its lithological characters, but appears to be everywhere divisible into two groups: a lower containing Ammonites rostratus (inflatus), and an upper marked by Pecten asper. These strata are well developed in Devonshire and Somerset. There the "Blackdown beds" below, linked with the Gault (of which Godwin-Austen regarded them as a sandy littoral representative), contain a numerous fauna, including Ammonites, Goodhalli, Hamites alternatus, Cytherea parva, Venus submersa, Arca glabra, Trigonia alæformis, Pecten laminosus, Janira quinquecostata, J. quadricostata, J. æquicostata, Exogyra conica, Vermicularia polygonalis; while the "Warminster beds" above correspond to the "zone of Holaster nodulosus" of M. Hébert, and the "zone of Pecten asper" of Dr. Barrois, and contain Ammonites (Schlönbachia) varians, A. Mantelli, A. Coupei, Belemnites ultimus, Pecten asper, Ostrea frons (carinata), Terebratella pectita, Terebratula biplicata, T. squamosa, Rhynchonella compressa, R. latissima, Pseudodiadema Michelini, Peltastes clathratus,

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135 From Cœnomanum, the old Latin name of the town Mans in the department of Sarthe. The old lithological subdivisions of the English Upper Cretaceous groups have been found to be wanting in palæontological precision, and are gradually being supplanted by the terms proposed by D'Orbigny, which have long been in use in France. These terms are here employed, but their equivalents in the old nomenclature will be understood from the table on p. 1544. To M. Hebert geology is mainly indebted for the thorough detailed study and classification to which the Upper Cretaceous formations of the Anglo-Parisian basin have been subjected. In 1874 he published a short memoir, in which the Chalk in Kent was subdivided into zones equivalent to those in the Paris basin, Bull. Soc. Geol. France, 1874, p. 416. Subsequently the same task was taken up and extended over the rest of the English Cretaceous districts, by Dr. Charles Barrois ("Recherches sur le Terrain Cretace superieur de l'Angleterre et de l'Irlande," Lille, 1876). The first English geologist who appears to have attempted the palæontological subdivision of the Chalk was Mr. Caleb Evans, "Sections of Chalk," Lewes, 8vo, 1870; for the Geologists' Association. See also W. Whitaker, "Geology of the London Basin" and "Geolcgy of London," in Geol. Survey Memoirs, and authors there cited. A tolerably full bibliography will be found in Dr. Barrois' volume.

Discoidea subucula, etc. A tolerably abundant series of corals has been obtained from the Devonshire Upper Greensand, no fewer than 21 species having been described.[136]

The so-called Greensand of Cambridge (pp. 1535, 1544), a thin glauconitic marl, with phosphatic nodules and numerous (possibly ice-borne) erratic blocks, was formerly classed with the Upper Greensand, but has recently been shown to be the equivalent of the Glauconitic Marl, forming really the base of the Chalk Marl and lying unconformably upon the Gault, from the denudation of which its rolled fossils have been derived.[137]

Lower Chalk.—The thick calcareous deposit known as the Chalk is classed now in three chief divisions—Lower, Middle, and Upper. Under the name of Lower Chalk are included the groups of the Glauconitic or Chloritic Marl, the Chalk Marl, and the Gray Chalk up to the top of the zone of Belemnitella plena and base of the "Melbourne Rock."

Glauconitic (*Chloritic*) *Marl*.—This name has been applied to a local white, or light yellow, chalky marl lying below the true Chalk, and marked by the occurrence of grains of glauconite (not chlorite) and phosphatic nodules. It varies up to 15 feet in thickness. Among its fossils are Ammonites laticlavius, A. Coupei, A. Mantelli, A. varians, Nautilus lævigatus, Turrilites tuberculatus, Solarium ornatum, Plicatula inflata, Terebratula biplicata. It forms the base of the Holaster subglobosus zone.

Chalk Marl is the name given to an argillaceous chalk forming with the chloritic marl, where the latter is present, the base of the true Chalk formation. This subdivision is well exposed on the Folkestone cliffs, also westward in the Isle of Wight, where a thickness of upward of 100 feet has been assigned to it. Among its characteristic fossils are Plocoscyphia mæandrina, Holaster lævis (var. nodulosus), Rhynchonella Martini, Inoceramus striatus, Lima globosa, Plicatula inflata, Ammonites cenomanensis, A. falcatus, A. Mantelli, A. navicularis, A. varians, Scaphites æqualis, Turrilites costatus.

At Hunstanton in Norfolk, likewise in Lincolnshire and

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[136] On the literature of the Blackdown beds, see W. Downes, Q. J. Geol. Soc. xxxviii. 1882, p. 75, where a list of their fossils is given. The corals are described by P. Martin Duncan, Q. J. Geol. Soc. xxxv. p. 90.

[137] Jukes-Browne, Q. J. Geol. Soc. xxxi. p. 272, xxxiii. p. 485; "Geology of Cambridge," Mem. Geol. Surv. 1881; Geol. Mag. 1877.

Yorkshire, as already (p. 1545) referred to, the "Red Chalk"—a ferruginous, hard, nodular chalk zone (4 feet), lies at the base of the Chalk and rests on the Upper Neocomian "Carstone," the true Gault being there absent, although it occurs a few miles further south.[138] Its proper horizon has been the subject of much discussion; but it probably belongs to the Chalk Marl. Bands of red and yellow chalk occur in the lower parts of the Chalk above the horizon of the "Red Chalk" in Lincolnshire and Suffolk.[139]

Gray Chalk.—The lower part of the Chalk has generally a somewhat grayish tint, often mottled and striped. In Bedfordshire and adjoining counties a band of hard gray sandy chalk, from 6 to 15 feet thick, containing 8 per cent of silica and in places much glauconite, is known as the Totternhoe Stone,[140] and forms the base of the Gray Chalk, which as a stage comprises the palæontological zones of Holaster subglobosus and Belemnitella plena. It attains its fullest development along the shore-cliffs of Kent, where it has a thickness of about 200 feet. According to Mr. F. G. H. Price,[141] it is there divisible into five beds or sub-stages. Of these the lowest, 8 feet thick (= lower part of the Ammonites varians zone), contains among other fossils Discoidea subucula, Pecten Beaveri, Ammonites varians; the second bed (11 feet) contains many fossils, including Ammonites rothomagensis, A. Mantelli, A. lewesiensis (= part of A. varians zone); the third bed (2 feet 9 inches), also abundantly fossiliferous, contains among other forms Peltastes clathratus, Hemiaster Morrisii, Terebratula rigida, Rhynchonella mantelliana, Ammonites rothomagensis, A. varians; this and the two underlying beds are regarded as comprising the zone of Ammonites rothomagensis and A. varians; the fourth sub-stage, or zone of Holaster subglobosus (148 feet), contains among its most characteristic fossils Discoidea cylindrica, Holaster subglobosus, Goniaster mosaicus, and in its upper part Belemnitella plena; the fifth bed, or zone of Belemnitella plena, consisting of yellowish-white gritty chalk (4 feet), forms a well-defined band between the Gray Chalk and the overlying lower subdivision of the White

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138 See Whitaker, Geol. Mag. 1883, p. 22; Proc. Geol. Assoc. viii. No. 3, 1883, p. 133. This author gives a full description and bibliography of the Red Chalk in Proc. Norwich Geol. Soc. i. part vii. 1883, p. 212.

139 A. J. Jukes-Browne, Geol. Mag. 1887, p. 24.

140 For the list of fossils of this bed in Norfolk and Suffolk see Jukes-Browne and W. Hill, Quart. Journ. Geol. Soc. 1887, p. 575.

141 Q. J. Geol. Soc. xxiii. p. 436.

Chalk (Turonian); it contains few fossils, among which are Belemnitella plena, Hippurites (Radiolites) Mortoni, Ptychodus.

In Cambridgeshire the Chalk Marl is covered by a band of harder stone (Totternhoe Stone), passing up into sandy and then nearly pure white chalk, and these strata, equivalents of the Chalk Marl and Gray Chalk, are probably separated by a palæontological and stratigraphical break from the next overlying (Turonian) member of the series.[142] According to the original classification of M. Hébert, this zone of Belemnitella plena is placed at the base of the Turonian group; by Dr. Barrois it is made the summit of the Cenomanian. The latter view receives support from traces of a break and denudation above this zone in England.

Middle Chalk, Turonian.[143]—This division comprises the "Lower White Chalk without flints," and is marked off at the base by a band of hard yellow and white nodular chalk, locally known in Cambridgeshire as "rag," and termed by geologists the Melbourne Rock. It is about 8 or 10 feet thick, and forms a convenient band in mapping out the subdivisions of the Chalk. It contains Rhynchonella Cuvieri, Terebratulina striata, Inoceramus Cuvieri, Spondylus striatus, Ammonites peramplus, etc.[144]

The White Chalk of England and northwest France forms one of the most conspicuous members of the great Mesozoic suite of deposits. It can be traced from Flamborough Head in Yorkshire across the southeastern counties to the coast of Dorset. Throughout this long course, its western edge usually rises somewhat abruptly from the plains as a long winding escarpment, which from a distance often reminds one of an old coast-line. The upper half of the deposit is generally distinguished by the presence of many nodular layers of flint. With the exception of these inclosures, however, the whole formation is a remarkably pure white pulverulent dull limestone, meagre to the touch, and soiling the fingers. Composed mainly of crumbled foraminifera, urchins, mollusks, etc., it must have been accumulated in a sea tolerably free from sediment, like some of

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142 A. J. Jukes-Browne, Geol. Mag. 1880, p. 250. See also the same author in "Geology of the Neighborhood of Cambridge" (Mem. Geol. Surv.), and Quart. Journ. Geol. Soc. 1886, p. 216; 1887, p. 544.

143 From Touraine, where the marly chalk is well developed.

144 W. Hill and A. J. Jukes-Browne, Quart. Journ. Geol. Soc. 1886, p. 216; op. cit. 1887, p. 580.

the foraminiferal ooze of the existing sea-bed. There is, however, no evidence that the depth of the water at all approached that of the abysses in which the present Atlantic globigerina-ooze is being laid down. Indeed, the character of the foraminifera, and the variety and association of the other organic remains, are not like those which have been found to exist now on the deep floor of the Atlantic, but present rather the characters of a shallow-water fauna.[145] Moreover, the researches of M. Hébert have shown that the Chalk is not simply one continuous and homogeneous deposit, but contains evidence of considerable oscillations, and even perhaps of occasional emersion and denudation of the sea-floor on which it was laid down. The same observer believed that enormous gaps occur in the Upper Cretaceous series of the Anglo-Parisian basin, some of which are to be supplied from the centre and south of France (postea, p. 1564).

Following the modern classification, we find that the old subdivision of "Chalk without flints" agrees on the whole with the Turonian section of the system. This division, as above remarked, appears in some places to lie unconformably upon the members below it, from which it is further separated by a marked zoological break. Nearly all the Cenomanian species now disappear, save two or three cosmopolitan forms. The echinoderms and brachiopods are entirely replaced by new species.[146] Not only is the base of the Turonian group defined by a stratigraphical hiatus, but its summit is marked by the "Nodular Chalk" of Dover and the hard Chalk-rock, which appear to indicate another stratigraphical break in what was formerly believed to be an uninterrupted deposit of chalk. The three Turonian palæontological zones, so well established in France, are also traceable in England. As exposed in the splendid Kent cliffs, the base of the English beds is formed by a well-marked band (32 feet) of hard gritty chalk, made up of fragments of Inocerami and other organisms.[147] Fossils are here

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[145] Dr. J. Gwyn Jeffreys shows that the mollusca of the Chalk indicate comparatively shallow-water conditions; Brit. Assoc. Rep. 1877, Secs. p. 79. See also Nature, 3d July, 1884, p. 215; L. Cayeux, Ann. Soc. Geol. Nord, xix. 1891, pp. 95, 252. For a general account of the origin of the Chalk, with special reference to its minuter organisms, see T. R. Jones, Trans. Hertford. Nat. Hist. Soc. iii. part 5, 1885, p. 143.

[146] Jukes-Browne, Geol. Mag. 1880, p. 250.

[147] For an account of the Middle Chalk of Dover see W. Hill, Quart. Journ. Geol. Soc. 1886, p. 232.

scarce; they include Inoceramus labiatus (which begins here), Rhynchonella Cuvieri, Echinoconus subrotundus, Cardiaster pygmæus. Above this basement bed lies the massive Chalk without flints, full of fragments of Inoceramus labiatus, with I. Cuvieri, Terebratula semiglobosa, Terebratulina gracilis, Echinoconus subrotundus, etc. The lower 70 feet or so include the zone of Inoceramus labiatus, the next 90 or 100 feet that of Terebratulina gracilis, and the upper 50 or 60 feet, containing layers of black flints, that of Holaster planus. At the top comes the remarkably constant band of hard cream-colored limestone known as the "Chalk Rock," varying from a few inches to 10 feet in thickness. Its upper surface is generally well defined, sometimes even suggestive of having been eroded, but it shades down into the Lower Chalk.[148]

Upper Chalk, Senonian[149] (*Upper Chalk with flints*).—This massive formation is composed of white, pulverulent, and usually tolerably pure chalk, with scattered flints, which, being arranged in the lines of deposit, serve to indicate the otherwise indistinct stratification of the mass. It has been generally regarded by English geologists as a single formation, with great uniformity of lithological characters and fossil contents. Mr. Whitaker, however, showed that distinct lithological platforms occur in it, and later researches, especially by MM. Hébert and Barrois, brought to light in it the same zones that occur in the Paris basin. Of these the lowest, or that of the Micrasters (Broadstairs and St. Margaret's Chalk), is most widely spread, the others having suffered most from denudation. It is well exposed along the cliffs of Kent at Dover, and also in the Isle of Thanet. At Margate its thickness has been ascertained by boring to be 265 feet. It contains two zones, in the lower of which the characteristic urchin is Micraster cor-testudinarium, while in the upper it is M. cor-anguinum. Near the top of the Micraster group of beds in the Isle of Thanet[150] lies a remarkable seam of flint about three or four inches thick, forming a nearly continuous floor, which has been traced southward at the top of the cliffs between Deal and Dover. Again, on the coast of Sussex, what may be nearly the same horizon in the Chalk is defined by a corresponding

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148 Whitaker, Mem. Geol. Surv. iv. p. 46; Jukes-Browne, Geol. Mag. 1880, p. 254. A similar band occurs in Normandy.

149 From Sens in the department of Yonne.

150 F. A. Bedwell, Geol. Mag. 1874, p. 16.

band of massive flattened flints. The traces of emersion and erosion observed by M. Hébert in the Paris Chalk are regarded by Dr. Barrois as equally distinct on the English side of the Channel, in the form of surfaces of hardened and corroded chalk. One of these surfaces marks the upper limit of the Micraster group on the Sussex coast, where it consists of a band of yellowish, hardened, and corroded chalk about six inches thick, containing rolled green-coated nodules of chalk.[151] A similar hardened, corroded band forms the same limit in the Isle of Thanet. Among the fossils of the Micraster division the following may be mentioned: Micraster cor-testudinarium, M. cor-anguinum, Cidaris clavigera, Echinocorys vulgaris, Echinoconus conicus, Epiaster gibbus, Terebratulina gracilis, Terebratula semiglobosa, Ostrea vesicularis, Inoceramus involutus.

The middle subdivision, or Margate Chalk, has been named the Marsupite zone by Dr. Barrois, from the abundance of these crinoids. It attains a thickness of about 80 feet in the Isle of Thanet, where it contains few or no flints, and upward of 400 feet in the Hampshire basin, where flints are numerous. Among its fossils are Porosphæria globularis, Bourgueticrinus ellipticus, Marsupites ornatus, M. Milleri, Micraster cor-anguinum, Echinoconus conicus, Echinocorys vulgaris, Cidaris clavigera, C. sceptrifera, Thecidium Wetherelli, Terebratula semiglobosa, Rhynchonella plicatilis, Terebratulina striata, Spondylus (Lima) spinosus, S. dutempleanus, Pecten cretosus, Ostrea vesicularis, O. hippopodium, Inoceramus lingua (and several others), Belemnitella vera, B. Merceyi, Ammonites leptophyllus.

The highest remaining group, or Norwich Chalk, forms the Belemnitella zone so well marked in northern Europe. It attains a thickness of from 100 to 160 feet in the Hampshire basin, is absent from that of London, but reappears in Norfolk, where it attains its greatest development. It is at Norwich a white crumbling chalk with layers of black flints. Among its fossils are Parasmilia centralis, Trochosmilia laxa, Cyphosoma magnificum, Salenia geometrica, Echinocorys vulgaris, Rhynchonella octoplicata, R. limbata, Terebratula carnea, T. obesa, Ostrea lunata, Belemnitella mucronata, B. quadrata.

The uppermost division, or Danian,[152] of the Continental Chalk appears to be absent in England, unless its lower

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151 Barrois, "Terrain Cretace de l'Angleterre," etc. 1876, p. 21.

152 So named from its development in Denmark.

portions are represented by some of the uppermost beds of the Norwich Chalk.

The Cretaceous system is sparingly represented in Ireland and Scotland. Under the Tertiary basaltic plateau of Antrim there lies an interesting series of deposits which in lithological aspect differ greatly from their English equivalents, and yet from their fossil contents can be satisfactorily paralleled with the latter. They are thus arranged:[153]

Hard white limestone	65 to 200 feet	= zone of	Belemnitella mucronata.	Senonian.
" "	13 " 16 "	"	Marsupites.	
Glauconitic (Chloritic) Chalk	3 " 6½ "	"	Micrasters.	
Glauconitic (Chloritic) . sand and sandstone .	3 " 16 "	" "	Holaster planus. Terebratulina gracilis.	Turonian.
Gray marls and yellow sandstones	3 " 30 "	"	Holaster subglobosus.	Cenomanian.
Glauconitic sand . .	6 " 10 "	"	Pecten asper.	

In the west of Scotland, also, relics of the same type of Cretaceous formations have been preserved under the volcanic plateaus of Mull and Morven. They contain the following subdivisions in descending order:[154]

White marly and sandy beds with thin seams of lignite . . .	20 feet
Hard white chalk with Belemnitella mucronata, etc. . . .	10 "
Thick white sandstone with carbonaceous matter	100 "
Glauconitic sands and shelly limestone, Pecten asper, Exogyra conica, Janiro quinquecostata, Nautilus deslongchampsianus, etc. .	60 "

France and Belgium.[155]—The Cretaceous system so extensively developed in western Europe is distributed in large basins, which, on the whole, correspond with those of the

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[153] Barrois, op. cit. p. 216. R. Tate, Q. J. Geol. Soc. xxi. p. 15.

[154] Judd, Q. J. Geol. Soc. xxxiv. p. 736.

[155] The Cretaceous system has been the subject of prolonged study by the geologists of France, and has given rise to considerable differences of nomenclature. The main subdivisions recognized and named by D'Orbigny have been generally adopted. But great diversity of opinion exists as to the names and limits of the lesser groups. There has been a tendency to excessive elaboration of subdivisions. The minor sections of the geological record must always be of but local significance, and it is to be regretted when they are treated as of any higher importance. M. Hebert refrained from burdening geological nomenclature with a long list of new names for local developments of strata, contenting himself with employing D'Orbigny's names for the formations or sections, and subdividing these into upper, middle and lower stages. The student will find some of the rival systems of classification collected by Mr. Davidson, Geol. Mag. vi. 1869.

chief rivers. Thus in France, there are the basins of the Seine or of Paris, of the Loire or of Touraine, of the Rhone or of Provence, and of the Garonne or of Aquitania, including all the area up to the slopes of the Pyrenees. In most cases, these areas present such lithological and palæontological differences in their Cretaceous rocks as to indicate that they may have been to some extent even in Cretaceous times distinct basins of deposit.

A twofold subdivision of the system is followed in France, but with a difference of nomenclature and partly also of arrangement from that in use in England, as shown in the subjoined table:

(See Table on page 1560.)

From this table it will be perceived how marked a lithological difference is traceable between the Cretaceous deposits of the north and south of France. The northern area indeed is linked with that of England, and was evidently a part of the same great basin in which the English Cretaceous rocks were deposited. But in the south, the aspect of the rocks is entirely changed, and with this change there is so marked a difference in the accompanying organic remains as to indicate clearly the separation of the two regions in Cretaceous times.

INFRA-CRÉTACÉ.—Neocomian.[156]—This division is well seen in the eastern part of the Paris basin. The lowest dark marl, resting irregularly on the top of the Portlandian series, indicates the emersion of these rocks at the close of the Jurassic period. It is followed by ferruginous sands, calcareous blue marl, spatangus-limestones, and yellow marls (abounding in Toxaster complanatus, Exogyra Couloni, Pterocera pelagi, Amm. radiatus, etc.), the whole having a thickness of 125 to 140 feet, and representing chiefly the upper or Hauterivian sub-stage. Much more important is the development of the Neocomian deposits in the southern half of France. They present there evidence of deeper water at the time of their formation. The Neuchâtel type (p. 1570) is prolonged into the northern part of Dauphiné, where it is

[156] See D'Archiac, Mem. Soc. Geol. France, 2e ser. ii. p. 1; Raulin, op. cit. p. 219; Ebray, Bull. Soc. Geol. France, 2e ser. xvi. p. 213; xix. p. 184; Cornuel, Bull. Soc. Geol. France, 2e ser. xvi. p. 742; 3e ser. ii. p. 371; Hebert, op. cit. 2e ser. xxiv. p. 323; xxviii. p. 137; xxix. p. 394; Coquand, op. cit. xxiii. p. 561; Rouville, op. cit. xxix. p. 723; Bleicher, op. cit. 3e ser. ii. p. 21; Toucas, op. cit. iv. p. 315.

		Sub-Stages.	N. France and Belgium.	Provence.
Crétacé	Danien.	Garumnien.[1]*	Calcaire pisolitique.	Calcaire à *Lychnus* de Rognac. Craie à lignites de Fuveau.
		Maestrichtien.[2]	Calcaire à Baculites du Cotentin. Craie de Ciply, Maestricht.	Calcaires marneux à *Hemipneustes*.
	Senonien.	Campanien.[3]	Craie de Meudon. Craie de Reims.	Calcaires à grands rudistes. Marnes et calc. à *Hippurites dilatatus*.
		Santonien.[4]	Craie à *Marsupites*. Craie à *Micr. cor-anguinum*. Craie à *M. cor-testudinarium*. Craie à *M. brevis*.	Calcaires à hippurites. Grès à échinides. Calcaires à hippurites. Grès à *Micraster brevis*. Couches à *Hippurites Zurcheri*.
	Turonien.	Angoumien.[5]	Craie à *Micr. breviporus*. Craie à *Tereb. gracilis*.	Calc. à *Hippurites cornuvaccinum* et grès inf. de Mornas. Calc. à *Biradiolites cornupastoris*. Grès d'Uchaux.
		Ligérien.[6]	Craie marneuse à *Inoceramus labiatus*.	Marnes à nucleolites. Calc. à *Amm. nodosoides*.
	Cenomanien.	Carentonien.[7]	Craie à *Belem. plena*. Couche fossilifère de Rouen. Tourtia de Mons.	Calc. à *Caprina adversa* et grès de Mondragon.
		Rothomagien.[8]	Craie glauconieuse à *Pecten asper*. *Amm.* (*Acanthoceras*) *Mantelli*. Gaize supérieure du Bray.	Zone à *Anorthopygus orbicularis*. Zone à *Amm. Mantelli*.
Infra-crétacé			Jura and Haute Marne.	
	Albien.[9]		Sables à *Amm. inflatus* (Vraconnien), Gaize de l'Argonne. Argiles, calcaires sables (*Amm. lautus*, *A. mamillaris*).	Calcaire glauconieux de Clansayes (*Desmoceras*, *Amm. inflatus*). Grès et calcaires de Clars à *Amm. Lyelli*.
	Aptien.[10]		Sables à *Amm. milletianus*. Calcaire, &c., à Plicatules.	Marnes à *Belem. semicanaliculatus*. Argiles à *Amm. Nisus*. Calcaire à *Ancyloceras Matheroni*. Calc. marneux à Plicatules.
	Urgonien.[11]		Marnes à Orbitolines et Calcaires à Ptérocères et à *Requienia Lonsdalei* (Rhodanien). Calcaire à *Requienia ammonia*.	Calcaire à *Requienia Lonsdalei*. Calcaire à *Scaphites Yvani* et *Crioceras*.
	Néocomien.	Hauterivien.[12] (12 metres).	Calcaire jaune (Neuchâtel); Marnes et calc. à Spatangues. Marnes de Hauterive.	Calcaires à *Crioceras Duvali* et *Belemnites pistilliformis*. Marnes et Calcaires marneux à Ammonites ferrugineuses.
		Valenginien.[13] (50-130 metres).	Limonite de Métabief et calcaire roux à *Pygurus rostratus*, *Belemnites pistilliformis*, *B. dilatatus*. Calcaire à *Strombus Sautieri* (*Natica Leviathan*), *Nerinea gigantea*.	

* For footnotes see next page.

seen in a group of limestones, with Exogyra Couloni, etc., in the lower, and Toxaster complanatus, etc., in the upper beds. Southward the limestones are mostly replaced by marls, and the whole at Grenoble reaches a thickness of more than 1600 feet, resting on the upper Jurassic limestones, with Terebratula diphyoides.

Urgonian.—In the typical district of the lower valley of the Durance, this subdivision consists of massive limestones (1150 feet) with Belemnites latus, B. dilatatus, in the lower part; Toxaster complanatus, Exogyra Couloni, Janira atava, etc., in the central thickest portion; and Toxaster ricordeanus, Ancyloceras, Crioceras, etc., in the upper band. The Caprotina limestone of Orgon (whence the name of the type was taken) is a massive white rock, sometimes 1000 feet thick, marked by the abundance of its hippuritids, Requienia (Caprotina) ammonia, R. Lonsdalei, R. gryphoides, gigantic forms of Nerinæa, and corals. In the northern Cretaceous basin, the Urgonian stage appears as a series of sands and clays which in Haute Marne are from 60 to 80 feet thick, and contain Toxaster ricordeanus, etc.

Aptian.—In the typical district round Apt in Vaucluse, this stage consists of a lower group of blue marls (Marnes de Gargas), with Plicatula placunea, Amm. Nisus, A. Dufrenoyi, followed by a marly limestone with Ancyloceras renauxianus, Ostrea aquila. These beds swell out in the Bedoule to a thickness of 650 feet. One of their most distinctive characters is the prominence of the cephalopods of the Ancyloceras (Crioceras) type. In northern France the Aptian stage is chiefly clay, with Plicatula placunea, P. radiola, hence the name "Argile à Plicatules." Near St. Dizier, the lower beds are characterized by Terebratula sella, Ostrea aquila; the middle by Amm. cornuelianus, Ancyloceras Matheroni; the upper by Amm. Nisus, A. Deshayesi.

Albian.[157]—In the eastern part of the Paris basin, this

[157] See, besides the works already cited, Barrois, Bull. Soc. Geol. France, 2e ser. iii. 707; Ann. Soc. Geol. du Nord. ii. p. 1; Renevier, Bull. Soc. Geol. France, 2e ser. ii. 704.

[1] From the Haute Garonne, where the deposits are typically developed.
[2] Well seen at Maestricht.
[3] From Champagne.
[4] From Santonge.
[5] From Angoulême.
[6] From the basin of the Loire.
[7] From the Charente.
[8] From Rouen (Rothomagus).
[9] From the Department of the Aube.
[10] From Apt in Vaucluse.
[11] From Orgon, near Arles.
[12] From Hauterive, on the Lake of Neuchâtel (see p. 1570).
[13] From the Château de Valengin, near Neuchâtel, Switzerland (see p. 1570).

stage consists of a lower green pyritous sandy member (Sables verts), 30 feet thick, covered by an upper argillaceous band which represents the English Gault. These deposits continue the English type round the northern and eastern margin of the Paris basin. They have been found also in deep wells around Paris. In the valley of the Meuse and in the Ardennes, this stage consists of three subdivisions: (1) a lower green sand (Amm. mamillaris), with phosphatic nodules; (2) a brick clay with Amm. lautus, A. tuberculatus; (3) a porous calcareous and argillaceous sandstone known as Gaize, containing a large percentage of silica soluble in alkali (Amm. inflatus, etc.).

The English type of strata from the Weald upward is also prolonged into France. Fresh-water sands and clays (with Unio and Cyrena), found above the Jurassic series in the Boulonnais, evidently represent the Weald, and are covered by dark green clays and sands (with Ostrea aquila), which are doubtless a continuation of the Folkestone beds, and by a thin blue clay which represents the Gault. Again, in the Pays de Bray, to the west of Beauvais, certain sands and clays resting on the Portlandian strata represent the Wealden series, and are followed by others which may be paralleled with the Urgonian, Albian, and Gault.[158]

In Belgium the Cretaceous system is underlain by certain clays, sands, and other deposits belonging to a continental period of older date than the submergence of that region beneath the sea in which were deposited the uppermost Neocomian beds. These scattered continental deposits have been grouped under the name of Aachenian.[159] That at least some part of them belongs to older Neocomian time, and may be coeval with the Weald, may be inferred from the remarkable discovery at Bernissart, already alluded to, where, in a buried system of Cretaceous ravines, the reptilian and ichthyic life of the time has been well preserved (ante, p. 1534).

CRÉTACÉ.—The Upper Cretaceous rocks of France have been the subject of prolonged and detailed study by the geologists of that country.[160] The northern tracts form part

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[158] Wealden deposits have been described as occurring even as far south as the province of Santander, Spain. A. Gonzalerz de Linares, Anal. Soc. Esp. Hist. Nat. vii. 487, 1878.

[159] On the Aachenian deposits see Dumont, "Terrains Cretaces et Tertiaires" (edited by M. Mourlon, 1878), vol. i. pp. 11–52.

[160] Notably by MM. Hebert, Toucas, Coquand and Cornuel. As already stated, considerable differences exist among French and Swiss geologists as to

of the Anglo-Parisian basin, in which the upper Cretaceous rocks of Belgium and England were laid down. The same palæontological characters, and even in great measure the same lithological composition, prevail over the whole of that wide area, which belongs to the northern Cretaceous province of Europe. Apparently only during the early part of the Cenomanian period, that of the Rouen Chalk, did the Anglo-Parisian basin communicate with the wider waters to the south, which were bays or gulfs freely opening to the main Atlantic. In these tracts a notably distinct type of Cretaceous deposits was accumulated, which, being that of the main ocean, covers a much larger geographical area and contains a much more widely diffused fauna than are presented by the more limited and isolated northern basin. There are few more striking contrasts between contemporaneously formed rocks in adjacent areas of deposit than that which meets the eye of the traveller who crosses from the basin of the Seine to those of the Loire and Garonne. In the north of France and Belgium, soft white chalk covers wide tracts, presenting the same lithological and scenic characters as in England. In the centre and south of France, the soft chalk is replaced by hard limestone, with comparatively few sandy or clayey beds. This mass of limestone attains its greatest development in the southern part of the department of the Dordogne, where it is said to be about 800 feet thick. The lithological differences, however, are no greater than those of the fossils. In the north of France, Belgium, and England, the singular molluscan family of the Hippuritidæ or Rudistes appears only occasionally and sporadically in the Cretaceous rocks, as if a stray individual had from time to time found its way into the region, but without being able to establish a colony there. In the south of France, however, the hippurites occur in prodigious quantity, often mainly composing the limestones, hence called hippurite limestone (Rudisten-Kalk). They attained a great size, and seem to have

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the nomenclature and the lines of demarcation between the upper Cretaceous formations, arising doubtless in great part from the varying aspect of the rocks themselves, according to the region in which they are studied. I have followed mainly M. Hebert, whose suggestive memoirs ought to be carefully read by the student. See especially his "Ondulations de la Craie dans le Bassin de Paris," Bull. Soc. Geol. France (2), xxix. 1872, p. 446; (3), iii. 1875, p. 512; and Ann. Sci. Geol. vii. 1876; "Description du Bassin d'Uchaux," Ann. Sci. Geol. vi. 1875; "Terrain Cretace des Pyrenees," Bull. Soc. Geol. France (2), xxiv. 1867, p. 323; (3) ix. 1880, p. 62.

grown on extensive banks, like our modern oyster. They appear in successive species on the different stages of the Cretaceous system, and can be used for marking palæontological horizons, as the cephalopods are employed elsewhere. But while these lamellibranchs played so important a part throughout the Cretaceous period in the south of France, the numerous ammonites and belemnites, so characteristic of the Chalk in the Anglo-Parisian basin, were comparatively rare there. The very distinctive type of hippurite limestone has so much wider an extension than the northern or Chalk type of the upper Cretaceous system that it should be regarded as really the normal development. It ranges through the Alps into Dalmatia, and round the great Mediterranean basin far into Asia.

Cenomanian (Craie glauconieuse).—According to the classification of M. Hébert this stage is composed of two sub-stages: 1st, Lower or Rouen Chalk, equivalent to the Upper Greensand and Gray Chalk of England. In the northern region of France and Belgium this sub-stage consists of the following subdivisions: *a*, a lower assise of glauconitic beds like the English Upper Greensand, containing Ammonites inflatus below and Pecten asper above (Rothomagian sub-stage); *b*, Middle glauconitic chalk with Turrilites tuberculatus, Holaster carinatus, etc., probably equivalent to the English Glauconitic Marl and Chalk Marl; *c*, Upper hard, somewhat argillaceous, gray chalk with Holaster subglobosus; the threefold subdivision of this assise, already given, is well developed in the north of France; *d*, Calcareous marls with Belemnitella plena (Carentonian sub-stage). 2d, Upper or marine sandstone; according to M. Hébert this sub-stage is wanting in the northern region of France, England, and Belgium. In the old province of Maine it consists of sands and marls with Anorthopygus orbicularis, Exogyra (Ostrea) columba, Trigonia, and Ostrea. Further south these strata are replaced by limestones with hippurites (Caprina adversa), which extend up into the Pyrenees and eastward across the Rhone into Provence.[161]

Turonian (Craie marneuse).[162]—This stage presents a

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[161] See a memoir on the Upper Cretaceous Rocks of the basin of Uchaux (Provence) by Hebert and Toucas, Ann. Sciences Geol. vi. 1875.

[162] For a review and parallelism of the Turonian, Senonian, and Danian stages in the north and south of Europe see Toucas, Bull. Soc. Geol. France, 3me ser. x. 1882, p. 154; xi. p. 344; xix. p. 506; for a general description of the formations in the southeast of France, see Fallot, Ann. Sci. Geol. xviii. 1, 1885, and Bull. Soc. Geol. France (3), xiv. 1886, p. 1.

very different facies according to the part of the country where it is examined. In the northern basin, according to M. Hébert, only its lower portions occur, separated by a notable hiatus from the base of the Senonian stage, and consisting of marly chalk with Inoceramus labiatus, I. Brongniarti, Ammonites nodosoides, A. peramplus, Terebratulina gracilis (Ligerian sub-stage). He placed the zone of Holaster planus at the base of the Senonian stage, and believed that in the hiatus between it and the Turonian beds below the greater part of the Turonian stage is really wanting in the north. On the other hand, Dr. Barrois and others would rather regard the zone of Holaster planus as the top of the Turonian stage (Angoumian sub-stage). In the north of France, as in England, it is a division of the White Chalk, containing Ammonites peramplus, Scaphites Geinitzii, Spondylus spinosus, Inoceramus inæquivalvis, Terebratula semiglobosa, Holaster planus, Ventriculites moniliferus, etc. Strata with Inoceramus labiatus, marking the base of the Turonian stage, can be traced through the south and southeast of France into Switzerland. These are overlain by marls, sandstones, and massive limestones with Exogyra columba and enormous numbers of hippurites (Hippurites cornuvaccinum, Radiolites cornu-pastoris, etc.). These hippurite limestones sweep across the centre of Europe and along both sides of the great Mediterranean basin into Asia, forming one of the most distinctive landmarks for the Cretaceous system.

Senonian.—This stage is most fully developed in the northern basin, where it consists mainly of white chalk separable into the two divisions of: 1st, Micraster (Santonian) sub-stage composed of chalk beds, in the lower of which Micraster cor-testudinarium, and in the upper M. cor-anguinum is the prevalent urchin. The same palæontological facies occurs in this and the other group as in the corresponding strata of England already described. 2d, Belemnitella (Campanian) sub-stage, with B. quadrata in a lower zone, and B. mucronata (Meudon Chalk) in a higher. In the south and southeast of France the corresponding beds consist of limestones, sandstones, and marls, with abundant hippurites, and also include some fresh-water deposits and beds of lignite.

Danian.—This subdivision of the Cretaceous system is specially developed in the northern basin. In the Cotentin, a limestone with Baculites anceps, Scaphites constrictus, and other fossils has been paralleled with the Maestricht

Chalk (Maestrichtian sub-stage). In the neighborhood of Paris and in the department of Oise and Marne, a rock long known as the Pisolitic Limestone occurs in patches, lying unconformably on the White Chalk (Garumnian sub-stage). The long interval which must have elapsed between the highest Senonian beds and this limestone is indicated not only by the evidence of great erosion of the chalk previous to the deposit of the limestone, but also by the marked palæontological break between the two rocks. The general aspect of the fossils resembles that of the older Tertiary formations, but among them are some undoubted Cretaceous species. In the southeast of Belgium, the Danian stage is well exposed, resting unconformably on a denuded surface of chalk. In Hainault, it consists of successive bands of yellowish or grayish chalk, between some of which there are surfaces of denudation, with perforations of boring mollusks, so that it contains the records of a prolonged period (Chalk of St. Vaast, Obourg, Nouvelles, Spienne, and Ciply). Among the fossils are Belemnitella mucronata, Baculites Faujasii, Nautilus Dekayi (but no Ammonites, Hamites, or Turrilites), Inoceramus Cuvieri, Ostrea flabelliformis, O. lateralis, O. vesicularis, Crania ignabergensis, Terebratulina striata, Fissurirostra Palissii (characteristic), Radiolites ciplyanus, Eschara several species and in great numbers, Echinocorys vulgatus, Holaster granulosus. The well-known chalk of Maestricht is equivalent to part of these strata, but appears to embrace also a higher horizon containing Hemipneustes striato-radiatus, Crania ignabergensis, Terebratulina striata, Fissurirostra pectiniformis, Ostrea lunata, O. vesicularis, Janira quadricostata, and numerous remains of Mosasaurus and of chelonians, together with Voluta fasciolaria, and other characteristically Tertiary genera of mollusks.[163] Similar strata and fossils occur at Faxoe, Denmark, and in the south of Sweden.[164] The terrestrial flora in the highest Cretaceous series at Aix-la-Chapelle has been already referred to (p. 1522).

The Danian stage is likewise represented in the south of France in some strongly contrasted forms. Toward the west it consists of marly, chloritic, and compact limestones (about 650 feet thick) with a marine fauna, including Nautilus dani-

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[163] Dumont, "Mem. Terrains Cretaces," etc. 1878; Mourlon, "Geol. de la Belgique," 1880.

[164] Hebert, Bull. Soc. Geol. France (3), v. 645; Lundgren, op. cit. x. 1882, p. 456.

cus, Ananchytes, Micraster tercensis, etc. Eastward, however, in Provence there is evidence of a gradual shallowing of the Upper Cretaceous sea in Cenomanian and Turonian time, until that area had become a fluviatile or lacustrine tract, in which during the later stages of the Cretaceous period a mass of fresh-water strata more than 2600 feet thick was accumulated. This enormous development of strata consists of limestones, marls, and lignites.

Germany.—The Cretaceous deposits of Germany, Denmark, and the south of Sweden were accumulated in the same northern province with those of Britain, the north of France, and Belgium, for they present on the whole the same palæontological succession, and even to a considerable extent the same lithological characters. It would appear that the western part of this region began to subside before the eastern, and attained a greater amount of depression beneath the sea. In proof of this statement, it may be mentioned that the Neocomian clays of the north of England extend as far as the Teutoburger Wald, but are absent from the base of the Cretaceous system in Saxony and Bohemia. In northwest Germany, Neocomian strata, under the name of Hils, appear at many points between the Isle of Heligoland (where representatives of part of the Speeton Clay and the Hunstanton Red Chalk occur) and the east of Brunswick, indicative of what was, doubtless, originally a continuous deposit. In Hanover, they consist of a lower series of conglomerates (Hils-conglomerat), and an upper group of clays (Hils-thon). Appearing on the flanks of the hills which rise out of the great drift-covered plains, they attain their completest development in Brunswick, where they attain a total thickness of 450 feet, and consist of a lower group of limestone and sandy marls, with Toxaster complanatus, Exogyra Couloni (sinuata), Ammonites bidichotomus, A. astierianus, and many other fossils; a middle group of dark blue clays with Belemnites brunsvicensis, Ammonites Nisus, Crioceras (Ancyloceras) Emerici, Exogyra Couloni (sinuata), etc., and an upper group of dark and whitish marly clays with Ammonites Martini, A. Deshayesi, A. Nisus, Belemnites Ewaldi, Toxoceras royerianum, Crioceras, etc.[165] Below the Hilsthon in Westphalia, the Harz, and Hanover, the lower parts

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[165] A. von Strombeck, Zeitsch. Deutsch. Geol. Ges. i. p. 462; xii. 20; N. Jahrb. 1855, pp. 159, 644; Judd, Q. J. Geol. Soc. xxvi. p. 343; Vacek, Jahrb. Geol. Reichsanst. 1880, p. 493.

of the true marine Neocomian series are replaced by a massive fluviatile formation corresponding to the English Wealden, and divisible into two groups: 1st, Deister sandstone (150 feet), like the Hastings Sand of England, consisting of fine light yellow or gray sandstone (forming a good building material), dark shales, and seams of coal varying from mere partings up to workable seams of three, and even more than six, feet in thickness. These strata are full of remains of terrestrial vegetation (Equisetum, Baiera, Oleandridium, Lacopteris, Sagenopteris, Anomozamites, Pterophyllum, Podozamites, and a few conifers), also shells of fresh-water genera (Cyrena, Paludina), cyprids, and remains of Lepidotus and other fishes; 2d, Weald Clay (65–100 feet) with thin layers of sandy limestone (Cyrena, Unio, Paludina, Melania, Cypris, etc.).[166] The Gault (Aptian and Albian) of north-western Germany contains three groups of strata. The lowest of these consists of blue clays with Belemnites brunsvicensis, Amm. (Acanthoceras) Martini, A. (Hoplites) Deshayesi, followed by white marl with Belem. Ewaldi. The middle consists of a lower clay with the zone of Ammonites (Acanthoceras) milletianus, and an upper clay with Amm. (Hoplites) tardefurcatus. The highest contains at its base a clay with Belemnites minimus, and at its top the widely diffused and characteristic "Flammenmergel"—a pale clay with dark flame-like streaks, containing the zone of Ammonites (Schlönbachia) inflatus, Amm. (Hoplites) lautus, etc.[167] In the Teutoburger Wald the Gault becomes a sandstone.

The Upper Cretaceous rocks of Germany present the greatest lithological contrasts to those of France and England, yet they contain so large a proportion of the same fossils as to show that they belong to the same period, and the same area of deposit [168] The C e n o m a n i a n stage consists

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[166] W. Dunker, "Ueber den norddeutsch. Wälderthon, u. s. w.," Cassel, 1844; Dunker and Von Meyer, "Monographie der norddeutsch. Wälderbildung, u. s. w.," Brunswick, 1846; Heinrich Credner, "Ueber die Gliederung der oberen Jura und der Wealdenbildung in nordwestlichen Deutschland," Prague, 1863; C. Struckmann, "Die Wealden-Bildungen der Umgegend von Hannover," 1880; A. Schenk on the Wealden Flora of North Germany, Palæontographica, xix. xxiii.

[167] Geol. Mag. vi. 1869, p. 261. A. von Strombeck, Zeitsch. Deutsch. Geol. Ges. xlii. 1890, p. 557.

[168] On the distribution of the Cephalopods in the Upper Cretaceous rocks of north Germany, see C. Schlüter, Zeitsch. Deutsch. Geol. Ges. xxviii. p. 457 (see Geol. Mag. 1877, p. 169), and Palæontographica, xxiv. 123–263, 1876. For the Inocerami, Zeitsch. Deutsch. Geol. Ges. xxix. p. 735.

in Hanover of earthy limestones and marls (Pläner), which traced southward are replaced in Saxony and Bohemia by glauconitic sandstones (Unter-Quader) and limestone (Unter-Plänerkalk). The lowest parts of the formation in the Saxon, Bohemian, and Moravian areas are marked by the occurrence in them of clays, shales, and even thin seams of coal (Pflanzen-Quader), containing abundant remains of a terrestrial vegetation which possesses great interest, as it contains the oldest known forms of hard-wood trees (willow, ash, elm, laurel, etc.). The Turonian beds, traced eastward, from their chalky and marly condition in the Anglo-Parisian Cretaceous basin, change in character, until in Saxony and Bohemia they consist of massive sandstones (Mittel-Quader) with limestones and marls (Mittel-Pläner). In these strata, the occurrence of such fossils as Inoceramus labiatus, I. Brongniarti, Ammonites peramplus, Scaphites Geinitzii, Spondylus (Lima) spinosus, Terebratula semiglobosa, etc., shows their relation to the Turonian stage of the west. The Senonian[169] stage presents a yet more extraordinary variation in its eastern prolongation. The soft upper Chalk of England, France, and Belgium, traced into Westphalia, passes into sands, sandstones, and calcareous marls, the sandy strata increasing southward till they assume the gigantic dimensions which they present in the gorge of the Elbe and throughout the picturesque region known as Saxon Switzerland (Ober-Quader). The horizon of these strata is well shown by such fossils as Belemnitella quadrata, B. mucronata, Nautilus danicus, Marsupites ornatus, Bourgueticrinus ellipticus, Crania ignabergensis, etc.

At Aix-la-Chapelle an exceedingly interesting development of Upper Cretaceous rocks is exposed. These strata, referable to the Senonian stage, consist of a lower group of sands with Belemnitella quadrata and abundant remains of terrestrial vegetation (p. 1522),[170] and an upper group of marl and marly chalk with Belemnitella mucronata, Gryphæa vesicularis, Crania ignabergensis, Mosasaurus, etc.

Switzerland and the Chain of the Alps.[171]—This area is in-

[169] German geologists commence the Senonian with the zone of Belemnitella quadrata, the upper Senonian of Hebert.

[170] For a list of these plants see H. von Dechen, "Geol. Paläont. Uebersicht der Rheinprovinz," etc., 1884, p. 427.

[171] Studer's "Geologie der Schweiz"; Gümbel, "Geognostische Beschreib. Bayer. Alpen," vol. i. p. 517 *et seq.*; "Geognostische Beschreib. des Ostbayer. Grenzegebirg," 1868, p. 697; Jules Marcou, Mem. Soc. Geol. France (2), iii.; P. de Loriol, "Invertebres de l'Étage Neocomien moyen du Mt. Saleve,"

cluded in the southern basin of deposit. In the Jura, and especially round Neuchâtel, Neocomian beds are typically developed. This stage and its two sub-stages have received their names from localities in that region where they are best seen (pp. 0948, 0949). (1) Valenginian—a group of limestones and marls (130–260 feet) with Toxaster Campichei, Pygurus rostratus, Strombus Sautieri (Natica Leviathan), Cidaris hirsuta, Belemnites pistilliformis, B. dilatatus, Ammonites (Oxynoticeras) gevrilianum, etc.; (2) Hauterivian—a mass of blue marls surmounted by yellowish limestones, the whole having a thickness that varies up to 250 feet; Toxaster complanatus, Exogyra Couloni, Janira atava, Perna Mulleti, Nautilus pseudo-elegans, Amm. (Hoplites) radiatus, Amm. (Holcostephanus) astierianus, etc. The Aptian and Albian stages (Gault) are recognizable in a thin band of greenish sandstone and marls which have long been known for their numerous fossils (Perte du Rhone, St. Croix).

In the Alpine region, the Neocomian formation is represented by several hundred feet of marls and limestones, which form a conspicuous band in the mountainous range separating Berne from Wallis, and thence into eastern Switzerland and the Austrian Alps (Spatangenkalk). Some of these massive limestones are full of hippurites of the Caprina group (Caprotinenkalk, with Requienia [Caprotina] Lonsdalei, Radiolites neocomiensis, etc.), others abound in polyzoa (Bryozoenkalk), others in foraminifera (Orbitolitenkalk). The Aptian and Albian stages traceable in the Swiss Jura can also be followed into the Alps of Savoy. In the Vorarlberg and Bavarian Alps their place is taken by calcareous glauconite beds and the Turrilite greensand (T. Bergeri); but in the eastern Alps they have not been recognized. The lowest portions of the massive Caprotina limestone (Schrattenkalk) are believed to be Neocomian, but the higher parts are Upper Cretaceous.

One of the most remarkable formations of the Alpine regions is the enormous mass of sandstone which, under the name of Flysch and Vienna Sandstone, stretches from the southwest of Switzerland through the northern zone of the mountains to the plains of the Danube at Vienna. Fossils are exceedingly rare in this rock, the most frequent

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Geneva, 1861; Renevier, Bull. Soc. Geol. France (3), iii.; A. Favre, *ibid.*; Von Hauer's "Die Geologie der Oesterr. Ungar. Monarchie," 1878, p. 505 *et seq.* E. Fraas, "Scenerie der Alpen."

being fucoids, which afford no clew to the geological age of their inclosing strata. That the older portions in the eastern Alps are Cretaceous, however, is indicated by the occurrence in them of occasional Inocerami, and by their interstratification with true Neocomian limestone (Aptychenkalk). The definite subdivisions of the Anglo-Parisian Upper Cretaceous rocks cannot be applied to the structure of the Alps, where the formations are of a massive and usually calcareous nature. In the Vorarlberg, they consist of massive limestones (Seewenkalk) and marls (Seewenmergel), with Ammonites Mantelli, Turrilites costatus, Inoceramus striatus, Holaster carinatus, etc. In the northeastern Alps, they present the remarkable facies of the Gosau beds, which consist of a variable and locally developed group of marine marls, sandstones, and limestones, with occasional intercalations of coal-bearing fresh-water beds. These strata rest unconformably on all rocks more ancient than themselves, even on older Cretaceous groups. They have yielded about 500 species of fossils, of which only about 120 are found outside the Alpine region, chiefly in Turonian, partly in Senonian strata. Much discussion and a copious literature has been devoted to the history of these deposits.[172] The loosely imbedded shells suggested a Tertiary age for the strata; but their banks of corals, sheets of orbitolite- and hippurite-limestone and beds of marl with Ammonites, Inocerami and other truly Cretaceous forms, have left no doubt as to their really Upper Cretaceous age. Among their subdivisions, the zone of Hippurites cornu-vaccinum is recognizable. From some lacustrine beds of this age, near Wiener Neustadt, a large collection of reptilian remains has been obtained, including deinosaurs, chelonians, a crocodile, a lizard, and a pterodactyle—in all fourteen genera and eighteen species.[173] Probably more or less equivalent to the Gosau beds are the massive hippurite-limestones and certain marls, containing Belemnitella mucronata, Echinocorys vulgaris,

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[172] See among other memoirs, Sedgwick and Murchison, Trans. Geol. Soc. 2d ser. iii.; Reuss, Denkschrift. Akad. Wien, vii. 1; Sitzb. Akad. Wien, xi. 882; Stoliczka, Sitzb. Akad. Wien, xxviii. 482; lii. 1; Zekeli, Abhandl. Geol. Reichsanst. Wien, i. 1 (Gasteropods); F. von Hauer, Sitzb. Akad. Wien, liii. 300 (Cephalopods); "Palæont. Oesterreich," i. 7; "Geologie," p. 516; Zittel, Denkschrift. Akad. Wien, xxiv. 105; xxv. 77 (Bivalves); Bünze, Abhandl. Geol. Reichsanst. v. 1; Gümbel, "Geognostische Beschreib. Bayerisch. Alpen," 1861, p. 517 *et seq.* Redtenbacker, Abhandl. Geol. Reichsanst v. (Cephalopods).

[173] Seeley, Q. J. Geol. Soc. 1881, p. 620.

etc., of the Salzkammergut and Bavarian Alps.[174] The Upper Cretaceous rocks of the southeastern Alps are distinguished by their hippurite-limestones (Rudistenkalk) with shells of the Hippurites and Radiolites groups, while the Lower Cretaceous limestones are marked by those of the Caprina group. They form ranges of bare white, rocky, treeless mountains, perforated with tunnels and passages (Dolinen, p. 623). In the southern Alps white and reddish limestones (Scaglia) have a wide extension.

Basin of the Mediterranean.—The southern type of the Cretaceous system attains a great development on both sides of the Mediterranean basin. The hippurite (Caprotina) limestones of Southern France and the Alps are prolonged into Italy and Greece, whence they range into Asia Minor and into Asia.[175] Cretaceous formations of the same type appear likewise in Portugal, Spain, and Sicily, and cover a vast area in the north of Africa. In the desert region south of Algiers, they extend as wide plateaus with sinuous lines of terraced escarpments.[176]

Russia.—The Cretaceous formations, which are well developed in the range of the Carpathian mountains, sink below the Tertiary deposits in the plains of the Dniester, and rise again over a vast region drained by the Donetz and the Don. They have been studied in central and eastern Russia by the officers of the Russian Geological Survey, who have pointed out the remarkable resemblance between their organic remains and those of the Anglo-French region. There is in particular a close parallelism between them and the English Speeton Clay in their intimate relationship to the Jurassic system below. The Volga group already (p. 1515) referred to is succeeded by typical Neocomian deposits, which are well developed in the district of Simbirsk along the Volga, where they consist of dark clays with sandy layers and phosphatic concretions, divisible into three

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174 See, for this region, Gümbel, who gives a table of correlations for the European Cretaceous rocks with those of Bavaria. "Geognost. Beschreib. Ostbayer. Grenzgeb." pp. 700, 701.

175 For an account of Syrian Cretaceous fossils see R. P. Whitfield, Bull. Amer. Mus. Nat. Hist. iii. 1891, p. 381.

176 Coquand, "Description geol. et paleontol. de la region sud de la province de Constantin," 1862; Rolland, Bull. Soc. Geol. France (3) ix. 508; Peron, op. cit. p. 436; this author has published a valuable memoir on the Geology of Algeria, with a full bibliography, Ann. Sciences Geol. 1883; Zittel, "Beiträge zur Geologie der Libyschen Wüste," 1883.

horizons. The lowest of these yields pyritous ammonites, especially Amm. (Holcostephanus) versicolor, A. (Holcost.) inversus, also Belemnites pseudopanderianus, Astarte porrecta. The middle zone contains septaria inclosing Amm. (Holcost.) Decheni, umbonatus, progredicus, fasciatofalcatus, discofalcatus, Barboti, Inoceramus aucella, Rhynchonella obliterata. The highest zone is almost unfossiliferous near Simbirsk, but its lower layers yield Pecten crassitesta. Deposits of the same type as the Anglo-French Aptian are well developed in the governments of Simbirsk and Saratov, and are characterized by Amm. (Hoplites) Deshayesi and A. (Amaltheus) bicurvatus. The Albian or Gault, which is found in the government of Moscow, and may eventually be traced over a wide area, has yielded a number of ammonites, especially of the genus Hoplites (H. dentatus, talitzianus, Bennettiæ, Engersi, Tethydis, jachromensis, Dutemplei, Haploceras Beudanti). This stage is well developed in the Caucasus, Transcaucasia, and the trans-Caspian region. In the chief Russian Cretaceous area the Cenomanian stage begins with dark clay closely related to the underlying Jurassic series, from the denudation and rearrangement of which it may have been derived. The clay shades upward into sandy, glauconitic, and phosphatic deposits, which gradually assume the condition of chalky marls. These Cenomanian strata appear to have a wide extent at the base of the Upper Cretaceous formations of central Russia. They contain numerous remains of fishes (Ptychodus, Lamna, Odontaspis, Otodus) with bones of ichthyosaurs and plesiosaurs. Ammonites are rare, but Amm. (Schlonbachia) varians occurs, also Belemnitella plena, Exogyra haliotidea, E. conica, Ostrea hippopodium, Janira (Vola) quinquecostata, Pecten laminosus, Rhynchonella nuciformis, etc. Turonian strata have likewise been found over a wide tract in central Russia. The lower bands with Inoceramus (I. russiensis, labiatus, Brongniarti, lobatus aff.) abundant, Belemnitella and Ostrea vesicularis are of constant occurrence in the Cretaceous region of central Russia. In that area, however, the Senonian and higher Cretaceous stages are not well developed, though they assume greater importance in the southern part of the Empire.[177]

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[177] Nitkin, "Les Vestiges de la periode Cretacée dans la Russie centrale," Mem. Com. Geol. Russe, v. No. 2, 1888, p. 165.

India.—The hippurite limestone of southeastern Europe is prolonged into Asia Minor, and occupies a vast area in Persia. It has been detected here and there among the Himalaya Mountains in fragmentary outliers. Southward of these marine strata, there appears to have existed in Cretaceous times a wide tract of land, corresponding on the whole with the present area of the Indian peninsula, but not improbably stretching southwestward so as to unite with Africa. On the southeastern side of this area the Cretaceous sea extended, for near Trichinopoly and Pondicherry a series of marine deposits occurs, corresponding to the European Upper Cretaceous formations, with which it has 16 per cent of fossil species in common. Among these are Amm. (Acanthoc.) rhotomagensis, A. (Pachydiscus) peramplus, and Rhynchonella compressa. The occurrence of Nautilus danicus in the higher sands of Ninnyur probably shows that the Cretaceous system of India reaches as high as the Danian stage.[178] Similar strata with many of the same fossils appear on the African coast in Natal. The most remarkable episode of Cretaceous times in the Indian area was undoubtedly the colossal outpouring of the Deccan basalts (p. 439). These rocks, lying in horizontal or nearly horizontal sheets, attain a vertical thickness of from 4000 to 6000 feet or more. They cover an area estimated at 200,000 square miles, though their limits have no doubt been reduced by denudation. Their oldest portions lie slightly unconformably on Cenomanian rocks, and in some places appear to be regularly interstratified with the uppermost Cretaceous strata. The occurrence of remains of fresh-water mollusks, land-plants, and insects, both in the lowest and highest parts of the volcanic series, proves that the lavas must have been subaerial. This is one of the most gigantic outpourings of volcanic matter in the world.[179]

North America.—The Cretaceous system stretches over a vast portion of the American continent, and sometimes reaches an enormous thickness. Sparingly developed in the eastern States, from New Jersey into South Carolina, it there includes the younger or Neocomian plant-bearing strata of Virginia. It spreads out over a wide area in the

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[178] J. Seunes, Mem. Soc. Geol. France, Paleont. t. ii. fasc. iii. 1891, p. 22.

[179] Medlicott and Blanford, "Geology of India," see ante, pp. 439, 982. The Upper Cretaceous fauna of India is described in Palæontograph. Indica, ser. xiv. 1883.

south, stretching round the end of the long Palæozoic ridge from Georgia through Alabama and Tennessee to the Ohio; and reappearing from under the Tertiary formations on the west side of the Mississippi over a large space in Texas and the southwest. Its greatest development is reached in the Western States and Territories of the Rocky Mountain region, Wyoming, Utah, and Colorado, whence it ranges northward into British America, covering thousands of square miles of the prairie country between Manitoba and the Rocky Mountains, and extending westward even as far as Queen Charlotte Islands, where it is well developed. It has a prodigious northward extension, for it has been detected in Arctic America near the mouth of the Mackenzie River, and in northern Greenland.

The Cretaceous clays and greensand marls of New Jersey have yielded a tolerably ample molluscan fauna, comprising species of Terebratula, Terebratella, Terebratulina, Ostrea, Gryphæa, Exogyra, Anomia, Pecten, Amusium, Spondylus, Plicatula, Mytilus, Modiola, Inoceramus, Trigonia, Unio, Cardita, Crassatella, Cardium, and many other genera.[180] Toward the south over the site of Texas, the Cretaceous sea appears to have been deeper and clearer than elsewhere in the American region, for its presence is recorded chiefly by limestones, among which occur abundant hippurites (Caprotina, Caprina) and foraminfera (Orbitolites).[181] Northward the strata are chiefly sandy, and present alternations of marine and terrestrial conditions, pointing to oscillations which especially affected the Rocky Mountain and western regions. The greatest development of the system is to be seen in the north of Utah and in Wyoming, where it presents a continuous series of deposits unbroken by any unconformability for a thickness of from 11,000 to 13,000 feet. The following table shows the character of these deposits in descending order:

Laramine (Lignitic) group.—Buff and gray sandstones, with bands of dark clays and numerous coal-seams, containing abundant terrestrial vegetation of Tertiary types, land and fresh-water mollusks (Unio, Limnæa, Planorbis, Helix, Pupa, etc.), and remains of fishes (Beryx, Lepidotus), turtles (Trionyx, Emys,

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[180] R. P. Whitfield, Monogr. U. S. Geol. Surv. vol. ix. 1885.

[181] For fossils see "List of Invertebrate Fossils from the Cretaceous Formations of Texas," R. T. Hill, Austin, Texas, 1889.

Compsemys), and reptiles (Crocodilus, Agathaumus, etc.). This group is by some geologists placed among the Tertiary systems, or as a passage series between the Cretaceous and Eocene systems (see p. 1612). Thickness in Green River basin 5000 feet.

On this horizon come the "Ceratops beds" of Wyoming, 3000 feet thick, which rest directly upon the Fox Hills group. They consist of alternating sandstones, shales, and lignites, and are remarkable for the extraordinary number and wonderful preservation of the deinosaurs, mammals, and other forms which they have yielded.[182]

Fox Hills group.—Gray, rusty, and buff sandstones with numerous beds of coal and interstratifications containing a varied assemblage of marine shells (Belemnitella, Nautilus, Ammonites, Baculites, Mosasaurus, etc.). Thickness on the great plains 1500 feet, which in the Green River basin expands to from 3000 to 4000 feet.

Colorado group.—Calcareous shales and clays with a central sandy series, and, in the Wahsatch region, seams of coal as well as fluviatile and marine shells. Thickness east of the Rocky Mountains 800 to 1000 feet, but westward in the region of the Uinta and Wahsatch Mountains 2000 feet. This group was proposed and named by Hayden and Clarence King to include the following sub-groups in the original classification of Messrs. Meek and Hayden in the Missouri region:

Fort Pierre sub-group.—Carbonaceous shales, marls, and clays (Inoceramus Barabini, Baculites ovatus, Scaphites nodosus, Ammonites, Ostrea congesta, etc.).

Niobrara sub-group.—Chalky marls and bituminous limestones (Baculites, Inoceramus deformis, I. problematicus, Ostrea congesta, fish remains).

Fort Benton sub-group.—Shales, clays, and limestones (Scaphites warrenensis, Ammonites, Prionocyclas Woolgari, Ostrea congesta).

Dakota group, composed of a persistent basal conglomerate (which is 200 feet thick and very coarse in the

182 J. B. Hatcher, Amer. Journ. Sci. xlv. 1893, p. 135.

Wahsatch region) overlain with yellow and gray massive sandstones, sometimes with clays and seams of coal or lignite (dicotyledonous leaves in great numbers, Inoceramus, Cardium, etc.). Thickness 400 feet and upward.[183]

The extraordinary palæontological richness of these western Cretaceous deposits has been already referred to. They contain the earliest dicotyledonous plants yet found on this continent, upward of 100 species having been named, of which one-half were allied to living American forms. Among them are species of oak, willow, poplar, beech, elm, dogwood, maple, hickory, fig, cinnamon, laurel, smilax, tulip-tree, sassafras, sequoia, American palm (Sabal), and cycads.[184] The more characteristic marine mollusca are species of Terebratula, Ostrea, Gryphæ, Exogyra, Inoceramus, Hippurites, Radiolites, Ammonites, Scaphites, Hamites, Baculites, Belemnites, Ancyloceras, and Turrilites. Of the fishes of the Cretaceous sea, many species are known, comprising large predaceous representatives of modern or osseous types like the salmon and saury, though cestracionts and ganoids still flourished. But the most remarkable feature in the organic contents of these beds is the extraordinary number and variety of the reptilian remains, to which reference has been already made (p. 1534). Some of the early types of toothed birds also have been obtained from the same important strata (p. 1538).

No question in American geology has given rise to more controversy than the place which should be assigned to the Laramie or Lignitic group, whether in the Cretaceous or Tertiary series.[185] The group consists mainly of lacustrine strata, with occasional brackish-water bands. Somewhere about 140 species of mollusks have been obtained from them which are terrestrial or fresh-water forms, with a few that may be brackish-water. They include numerous species of Ostrea, Anomia, Unio, Corbicula, Corbula, Limnæa, Planorbis, Physa, Helix, Pupa, Goniobasis, Hydrobia, and

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[183] Hayden's Reports of Geographical and Geological Surveys of Western Territories; King's Geological Report of Exploration of 40th Parallel, vol. i.; G. H. Eldridge, Amer. Journ. Sci. xxxviii. 1889, p. 313. J. J. Stevenson, Amer. Geologist, 1889, p. 391.

[184] For an account of the Laramie Flora see L. F. Ward, 6th Ann. Rep. U. S. Geol. Surv. 1885, p. 405. Bull. U. S. Geol. Surv. No. 37, 1887.

[185] For a résumé of the progress of opinion on this subject see Ward, 6th Ann. Rep. U. S. Geol. Surv. 1885, p. 406.

Viviparus.[186] The abundant terrestrial flora resembles in many respects the present flora of North America. A few of the plants are common to the Middle Tertiary flora of Europe, and a number of them have been met with in the Tertiary beds of the Arctic regions. Some of the seams of vegetable matter are true bituminous coals and even anthracites. According to Cope, the vertebrate remains of the Laramie group bind it indissolubly to the Mesozoic formations. Lesquereux, on the other hand, has insisted that the vegetation is unequivocally Tertiary. The former opinion has been maintained by Clarence King, Marsh, and others; the latter by Hayden and his associates in the Survey of the Western Territories. Cope, admitting the force of the evidence furnished by the fossil plants, concludes that "there is no alternative but to accept the result that a Tertiary flora was contemporaneous with a Cretaceous fauna, establishing an uninterrupted succession of life across what is generally regarded as one of the greatest breaks in geologic time." The vegetation had apparently advanced more than the fauna in its progress toward modern types.[187] The Laramie group was disturbed along the Rocky Mountain region before the deposition of the succeeding Tertiary formations, for these lie unconformably upon it. So great have been the changes in some regions, that the strata have assumed the character of hard slates like those of Palæozoic date, if indeed they have not become in California thoroughly crystalline masses. The same mingled marine and terrestrial type of Cretaceous rocks can be followed into California, where the higher parts of the series contain beds of coal. The coast ranges are described by Whitney as largely composed of Cretaceous rocks, usually somewhat metamorphic and sometimes highly so.[188] In the foot-hills, on the eastern slopes of the Rocky Mountains, near the United States and Canadian boundary, the beds are comparatively undisturbed and the coal is bituminous; within the Rocky Mountain area the strata are greatly contorted and the coal is there anthracitic.

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186 C. A. White, "A Review of the Non-Marine Fossil Mollusca of North America," 3d U. S. Geol. Survey Report, 1883; Bull. U. S. Geol. Surv. No. 34, 1886. See the same author's paper on the mingling of an ancient fauna and modern flora in these deposits, Amer. Journ. Sci. (3) xxvi. p. 120.

187 See remarks ante, pp. 1096, 1111. Neumayr (N. Jahrb. 1884, i. p. 74) makes a comparison between the Laramie group and the inter-trappean beds of the Deccan.

188 G. F. Becker, Amer. Journ. Sci. xxxi. 1886, p. 348.

The blending of marine and terrestrial formations, so conspicuous in the Western Territories of the American Union, can be traced northward into British America, Vancouver Island, and the remote Queen Charlotte group, with no diminution in the thickness of the series of strata. The section at Skidegate Inlet in the latter islands is as follows:[189]

Upper shales and sandstones. Few fossils, the only form recognized being Inoceramus problematicus	1,500 feet.
Conglomerates and sandstones (fragments of Belemnites)	2,000 "
Lower shales and sandstones with a workable seam of anthracite at the base (fossils abundant, including species of Ammonites, Hamites, Belemnites, Trigonia, Inoceramus, Ostrea, Unio, Terebratula, etc.)	5,000 "
Volcanic agglomerates, sandstones, and tuffs, with blocks sometimes four or five feet in diameter	3,500 "
Lower sandstones, some tufaceous, others fossiliferous	1,000 "
	13,000 "

Reference has already (p. 1522) been made to the remarkable Cretaceous flora of Greenland. Three horizons of plant-bearing beds have there been met with: (*a*) the Kome beds—dark shales resting on the crystalline rocks, and containing what appears to be a Lower Cretaceous flora; (*b*) the Atane beds—grayish-black shales and sands (Upernivik, Noursoak, Disco, etc.), with Upper Cretaceous plants; (*c*) pale and red clays lying on the Atane beds. Marine fossils found in some of the Upper Cretaceous beds likewise serve to indicate their horizon.[190]

Australasia.—Representatives of the Cretaceous system occupy a vast area in Australia. In Queensland their lower member ("Rolling Downs Formation") is estimated to cover three-fourths of the whole of the colony. This group of strata is found in some districts to pass down conformably into the plant-bearing Jurassic rocks, and elsewhere to lie unconformably on ancient schists, slates, and granites. It has yielded numerous species of foraminifera, brachiopods, lamellibranchs (Ostrea vesiculosa, Pecten, Aucella, Inoceramus, Pinna, Mytilus, etc.), gasteropods, belemnites, ammo-

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[189] G. M. Dawson in Report of Progress of Geol. Surv. Canada, 1878–79; Amer. Journ. Sci. xxxviii. 1889, p. 120; op. cit. xxxix. 1890, p. 180. J. F. Whiteaves, Mesozoic Fossils, vol. i. parts i. iii. in publications of Geol. Survey, Canada. See also Mr. Dawson's Report on Geology and Resources of the Region near the 49th Parallel, British North American Boundary Commission, 1875; Report on Canadian Pacific Railway, Ottawa, 1880.

[190] Heer, "Flora Fossilis Arctica," vi. 1882.

nites of the genera Amaltheus, Schlonbachia, Haploceras, also Hamites, Ancyloceras, Crioceras, and Nautilus; likewise fishes of the genera Lamna, Aspidorhynchus, Belonostomus, and various ichthyosaurs and plesiosaurs. The Upper Cretaceous formations are represented by the "Desert Sandstone," which must have covered at least three-quarters of the colony. It lies on an upturned and denuded surface of the Lower Cretaceous formations and contains land-plants and a marine fauna (Micraster, Rhynchonella, Ostrea, Trigonia, Belemnites).[191]

In New Zealand the "Waipara" formation of Canterbury is believed to represent Upper Cretaceous and possibly some of the older Tertiary horizons. It consists of massive conglomerates (sometimes 6000 to 8000 feet thick), sandstones, shales, brown-coal seams, and ironstones. The plants include dicotyledonous leaves, cones, and branches of araucarians and leaves and twigs of Dammara. Among the shells no cephalopods nor any of the widespread hippurites have yet been found. With the remains of fishes (Odontaspis, Lamna, Hybodus) occur numerous saurian bones, which have been referred to species of Plesiosaurus, Mauisaurus, Polycotylus, etc.[192] According to the work of the Geological Survey Department of New Zealand, the Cretaceous system consists of a lower group (500 feet) of green and gray incoherent sandstones, in which beds of bituminous coal occur on the west coast (Lower Greensand), surmounted by a mass of strata (2000 to 5000 feet) which appears to connect the Cretaceous and Tertiary series. The upper part of the group (consisting of marls, greensand, limestone and chalk with flints) is thoroughly marine in origin, with Ancyloceras, Belemnites, Rostellaria, Plesiosaurus, Leiodon, etc. The lower portion, which is capped by a black grit with marine fossils, contains the most valuable coal-deposits of New Zealand. The plants include dicotyledonous and coniferous forms closely allied to those still living in the country.[193]

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191 R. I. Jack and E. Etheridge, "Geology of Queensland," chaps. xxxi.–xxxiv.

192 Etheridge, Q. J. Geol. Soc. xxviii. 183, 340; Owen, Geol. Mag. vii. 49; Hector, Trans. New Zealand Inst. vi. p. 333; Haast, "Geology of Canterbury and Westland," p. 291; Hutton and Ulrich, "Geology of Otago," p. 44.

193 Hector, "Handbook of New Zealand," 1883, p. 29.

PART IV. CAINOZOIC OR TERTIARY

The close of the Mesozoic periods was marked in the west of Europe by great geographical changes, during which the floor of the Cretaceous sea was raised partly into land and partly into shallow marine and estuarine waters. These events must have occupied a vast period, so that, when sedimentation once more became continuous in the region, the organisms of Mesozoic time (save low forms of life) had, as a whole, disappeared and given place to others of a distinctly more modern type. In England, the interval between the Cretaceous and the next geological period represented there by sedimentary formations is marked by the abrupt line which separates the top of the Chalk from all later accumulations, and by the evidence that the Chalk seems to have been in some places extensively denuded before even the oldest of what are called the Tertiary formations were deposited upon its surface. There is evidently here a considerable gap in the geological record. We have no data for ascertaining what was the general march of events in the south of England between the eras chronicled respectively by the Upper Chalk and the overlying Thanet beds. So marked is this hiatus, that the belief was long prevalent that between the records of Mesozoic and Cainozoic time one of the great breaks in the geological history of the globe intervenes.

Here and there, however, in the continental part of the Anglo-Parisian basin, traces of some of the missing evidence are obtainable. Thus, the Maestricht shelly and polyzoan limestones, with a conglomeratic base, contain a mingling of true Cretaceous organisms with others which are characteristic of the older Tertiary formations. The common Upper Chalk crinoid, Bourgueticrinus ellipticus, occurs there in great numbers; also Ostrea vesicularis, Baculites Faujasii, Belemnitella mucronata, and the great reptile Mosasaurus; but associated with such Tertiary genera as Voluta, Fasciolaria, and others. At Faxoe, on the Danish island of Seeland, the uppermost member of the Cretaceous system (Danian) contains, in like manner, a blending of well-known Upper Chalk organisms with the Tertiary genera (Cypræa, Oliva, and Mitra). In the neighborhood of Paris also, and in scattered patches over the north of France, the Pisolitic Limestone, formerly classed as Tertiary, has been found to include so many distinctively Upper Cretaceous forms as to lead to its being relegated to the top of the Cretaceous series, from which, however, it is marked off by the decided unconformability already described. These fragmentary deposits are interesting, in so far as they help to show that, though in western Europe there is a tolerably abrupt separation between Cretaceous and Tertiary deposits, there was nevertheless no real break between the two periods. The one merged insensibly into the other; but the strata which would have served as the chronicles of the intervening ages have either never been deposited in the area in question, or have since been in great measure destroyed. In southern Europe, especially in the southeastern Alps, and probably in other parts of the Mediterranean basin, no sharp line can be drawn between Cretaceous and Eocene rocks. These deposits merge into each other in such a way as to show that the geographical changes of the western region did not extend into the south and southeast. In North America, also, on the one side (pp. 1530, 1578), and in New Zealand on the other, there is a similar effacement of the hard and fast line which was once supposed to separate Mesozoic and Tertiary formations.

The name Tertiary, given in the early days of geology, before much was known regarding fossils and their history, has retained its hold on the literature of the science. It is often replaced by the terms "Cainozoic" (*recent life*), or "Neozoic" (*new life*), which express the great fact that it is in the series of strata comprised under these designations that most recent species and genera have their earliest representatives. Taking as the basis of classification the percentage of living species of mollusca found by Deshayes in the different groups of the Tertiary series, Lyell proposed a scheme of arrangement which has been generally adopted. The older Tertiary formations, in which the number of still living species of shells is very small, he named Eocene (*dawn of the recent*), including under that title those parts of the Tertiary series of the London and Paris basins wherein the proportion of existing species of shells was only 3½ per cent.[1] The middle Tertiary beds in the valleys of the Loire, Garonne, and Dordogne, containing 17 per cent of living species, were termed Miocene (*less recent*), that is, containing a minority of recent forms. The younger Tertiary formations of Italy were included under the designation Pliocene (*more recent*), because they contained a majority, or from 36 to 95 per cent, of living species. This newest series, however, was further subdivided into Older Pliocene (35 to 50 per cent of living species) and Newer Pliocene (90 to 95 per cent). A still later group of deposits was termed Pleistocene (*most recent*), where the shells all belonged to living species, but the mammals were partly

[1] Some palæontologists, however, doubt whether any older Tertiary species, except of foraminifera or other lowly organisms, is still living.

extinct forms. This classification, though somewhat artificial, has, with various modifications and amplifications, been adopted for the Tertiary groups, not of Europe only, but of the whole globe. The original percentages, however, often depending on local accidents, have not been very strictly adhered to. The most important modification of the terminology in Europe has been the insertion of another stage or group termed Oligocene, proposed by Beyrich, to include strata that were formerly classed partly as Upper Eocene and partly as Lower Miocene.[2]

Some writers, recognizing a broad distinction between the older and the younger Tertiary deposits of Europe, have proposed a classification into two main groups: 1st, Eocene, Older Tertiary or Palæogene, including Eocene and Oligocene; and, 2d, Younger Tertiary or Neogene, comprising Miocene and Pliocene. This subdivision has been advocated on the ground that, while the older deposits indicate a tropical climate, and contain only a very few living species of organisms, the younger groups point to a climate approaching more and more to that of the existing Mediterranean basin, while the majority of their fossils belong to living species.[3]

The Tertiary periods witnessed the development of the present distribution of land and sea and the upheaval of most of the great mountain-chains of the globe. Some of the most colossal disturbances of the terrestrial crust, of which any record remains, took place during these periods. Not only was the floor of the Cretaceous sea upraised into low

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[2] Boyd Dawkins has proposed to use the fossil mammalia as a basis of classification (Q. J. Geol. Soc. 1880, p. 379), but his scheme does not essentially differ from that in common use founded on molluscan percentages.

[3] Hörnes, Jahrb. Geol. Reichsanst. 1864, p. 510.

lands, with lagoons, estuaries, and lakes, but throughout the heart of the Old World, from the Pyrenees to Japan, the bed of the early Tertiary or nummulitic sea was upheaved into a succession of giant mountains, some portions of that sea-floor now standing at a height of at least 16,500 feet above the sea.

During Tertiary time also there was an abundant manifestation of volcanic activity. After a long quiescence during the succession of Mesozoic periods, volcanoes broke forth with great vigor both in the Old and the New World. Vast floods of lava were poured out, and a copious variety of rocks was produced, ranging from highly basic to rhyolites, quartz-felsites, and granites.

The rocks deposited during these periods are distinguished from those of earlier times by increasingly local characters. The nummulitic limestone of the older Tertiary groups is indeed the only widespread massive formation which, in the uniformity of its lithological and palæontological characters, rivals the rocks of Mesozoic and Palæozoic time. As a rule, Tertiary deposits are loose and incoherent, and present such local variations, alike in their mineral composition and organic contents, as to show that they were mainly accumulated in detached basins of comparatively limited extent, and in seas so shallow as to be apt from time to time to be filled up or elevated, and to become in consequence brackish or even fresh.[4] These local characters are increasingly developed in proportion to the recentness of the deposits.

The climate during Tertiary time underwent in the northern hemisphere some remarkable changes. Judging from

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[4] The peculiar characters of the Tertiary rocks of the Western Territories of North America are, however, displayed over areas which in Europe would be regarded as enormous.

the terrestrial vegetation preserved in the strata, we may infer that in England the climate of the oldest Tertiary periods was of a temperate character,[5] but that it became during Eocene time tropical and subtropical, even in the centre of Europe and North America. It then gradually grew more temperate, but flowering plants and shrubs continued to live even far within the Arctic Circle, where, then as now, unless the axis of the earth has meanwhile shifted, there must have been six sunless months every year. Growing still cooler, the climate passed eventually into a phase of extreme cold, when snow and ice extended from the Arctic regions far south into Europe and North America. Since that time, the cold has again diminished, until the present thermal distribution has been reached.

With such changes of geography and climate, the plant and animal life of Tertiary time, as might have been anticipated, is found to have been remarkably varied. Entering upon the Tertiary series of formations, we find ourselves upon the threshold of the modern type of life. The ages when lycopods, ferns, cycads, and yew-like conifers were the leading forms of vegetation, have passed away, and that of the dicotyledonous angiosperms—the hardwood trees and evergreens of to-day—now succeeds them, but not by any sudden extinction and re-creation; for, as we have seen (p. 1520), some of these trees had already made their appearance in Cretaceous times. The hippurites, inocerami, ammonites, belemnites, baculites, turrilites, scaphites, and other mollusks, which had played so large a part in the molluscan life of the later Secondary periods, now cease. The great reptiles, too, which, in such wonderful variety of type, were

[5] J. S. Gardner in "Geology of the Isle of Wight," Mem. Geol. Surv. 1889, p. 106.

the dominant animals of the earth's surface, alike on land and sea, ever since the commencement of the Lias, now waned before the increase of the mammalia, which advanced in augmenting diversity of type until they reached a maximum in variety of form and in bulk just before the cold epoch referred to. When that refrigeration passed away and the climate became milder, the extraordinary development of mammalian life that preceded it is found to have disappeared also, being only feebly represented in the living fauna at the head of which man has taken his place.

Section i. Eocene

§ 1. General Characters

Rocks.—In Europe and Asia the most widely distributed deposit of this epoch is the nummulitic limestone, which extends from the Pyrenees through the Alps, Carpathians, Caucasus, Asia Minor, Northern Africa, Persia, Beloochistan, and the Suleiman Mountains, and is found in China and Japan. It attains a thickness of several thousand feet. In some places it is composed mainly of foraminifera (Nummulites and other genera); but it sometimes includes a tolerably abundant marine fauna. Here and there it has assumed a compact crystalline marble-like structure, and can then hardly be distinguished from a Mesozoic or even Palæozoic rock. Enormous masses of sandstone occur in the eastern Alps (Vienna sandstone, Flysch), referred partly to the same age, but seldom containing any fossils save fucoids (p. 1570). The most familiar European type of Eocene deposits, however, is that of the Anglo-Parisian and Franco-Belgian area, where are found numerous thin local beds of usually soft and uncompacted clay, marl, sand, and sandstone, with hard and soft bands of limestone, containing alternations of marine, brackish, and fresh-water strata. This type of sedimentation evidently indicates more local and shallower basins of deposit than the wide Mediterranean sea, which stretched across the heart of the Old World in early Tertiary time.

LIFE.—The flora of Eocene time has been abundantly preserved on certain horizons. In the English Eocene groups, a succession of several distinct floras has been ob-

Fig. 424.—Eocene Plants.
a, Sabal oxyrhachis, Heer (reduced); *b*, Petrophiloides Richardsoni; *c*, Nipa Burtini, Brongn. sp. (½).

served, those of the London Clay and Bagshot beds being particularly rich. The plants from the London Clay indicate a warm climate.[6] They include species of Callitris, Solenostrobus, Cupressinites, Sequoia, Salisburia, Agave, Smilax, Amomum, Nipa (Fig. 424), Magnolia, Nelumbium, Victoria, Hightea, Sapindus, Eucalyptus, Cotoneaster, Prunus, Amygdalus, Faboidea, etc. Proteaceous plants like the living Australian Petrophila and Isopogon have been asserted to occur in the Lower Eocene vegetation, but their

[6] Ettingshausen, Proc. Roy. Soc. xxix. 1879, p. 388.

occurrence is not yet proved; the so-called Petrophiloides is now regarded as an alder (Fig. 424).[7] During Middle Eocene time in the umbrageous forests of evergreen trees—laurels, cypresses, and yews—there grew species of ferns (Lygodium, Asplenium, etc.), also of many of our familiar trees besides those just mentioned, such as chestnuts, beeches, elms, poplars, hornbeams, willows, figs, planes, and maples. The subtropical character of the climate was shown by clumps of Pandanus, with here and there a fan-

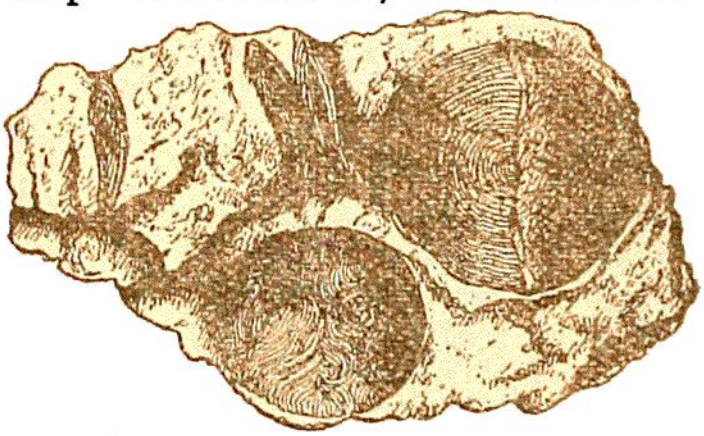

Fig. 425.—Nummulitic Limestone (⅔).

palm (Fig. 424) or feather-palm, a tall aroid or a towering cactus.[8]

The Eocene fauna of western and central Europe presents similar evidence of tropical or subtropical conditions. Especially characteristic are foraminifera of the genus Nummulites, which occur in prodigious numbers in the nummulite limestone (Fig. 425), and also occupy different horizons in the English and French Eocene basins. The assemblage of mollusca is very large, most of the genera being still living, though many of them are confined to the warmer seas of the globe (Figs. 426, 427).

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[7] J. S. Gardner, op. cit. p. 108.

[8] J. S. Gardner, "British Eocene Flora," Palæontograph. Soc. 1879; L. Crié, "Recherches sur la Vegetation de l'Ouest de la France à l'Epoque Tertiaire," Ann. Sciences Geol. ix. 1877; Ettingshausen, Proc. Roy. Soc. xxx. 1880, p. 228; Comte de Saporta, "Le Monde des Plantes," 1879, p. 207.

Characteristic forms are Belosepia, Nautilus, Cancellaria, Fusus, Pseudoliva, Oliva, Voluta, Conus, Mitra, Cerithium, Melania, Turritella, Rostellaria, Pleurotoma, Cypræa, Natica, Scala, Corbula, Cyrena, Cytherea (Meretrix), Chama, Lucina.[9] Fish remains are not infrequent in some of the clays, chiefly as scattered teeth (Fig. 428) and otoliths. The living tropical siluroid genus Arius has been found in these deposits. Some of the more common genera are Lamna, Odontaspis, Myliobates, Aetobates, Pristis, Phyllodus.

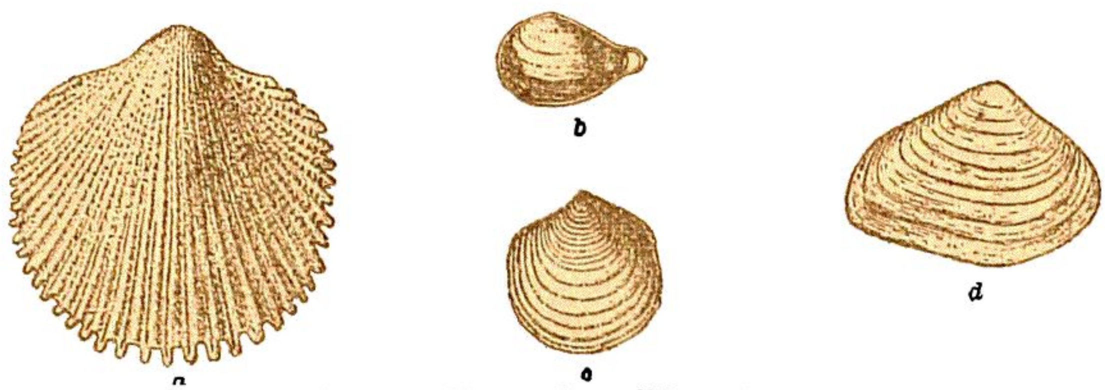

Fig. 426.—Eocene Lamellibranchs.
a, Cardium porulosum, Lam.; *b*, Corbula regulbiensis, Mor.; *c*, Lucina squamula, Desh.; *d*, Cyrena cuneiformis, Sow. (⅔).

The Eocene reptiles present a singular contrast to those of Mesozoic time. They consist largely of tortoises and turtles, with crocodiles and sea-snakes. It is suggestive to find remains of siluroid fish, crocodiles, and chelonians, preserved in deposits of Eocene age, for the assemblage is like what may now be met with in tropical seas of the present time. An interesting series of remains of birds has been obtained from the English Eocene beds. These include Argillornis longipennis (perhaps representative of, but larger than, the modern albatross), Dasornis, and Gastornis (somewhat akin to the extinct Dinornis of New Zealand), Halcyornis toliapicus, Lithornis vulturinus, Macror-

[9] For a list of British Eocene and Oligocene mollusca consult the volume by R. B. Newton, one of the series of Catalogues issued by the British Museum.

nis tanaupus, Odontopteryx toliapicus (a bird with bony tooth-like processes to its large beak). From the upper Eocene beds of the Paris basin ten species of birds have been obtained, including forms allied to the buzzard, osprey, hawk, nuthatch, quail, pelican, ibis, flamingo, and

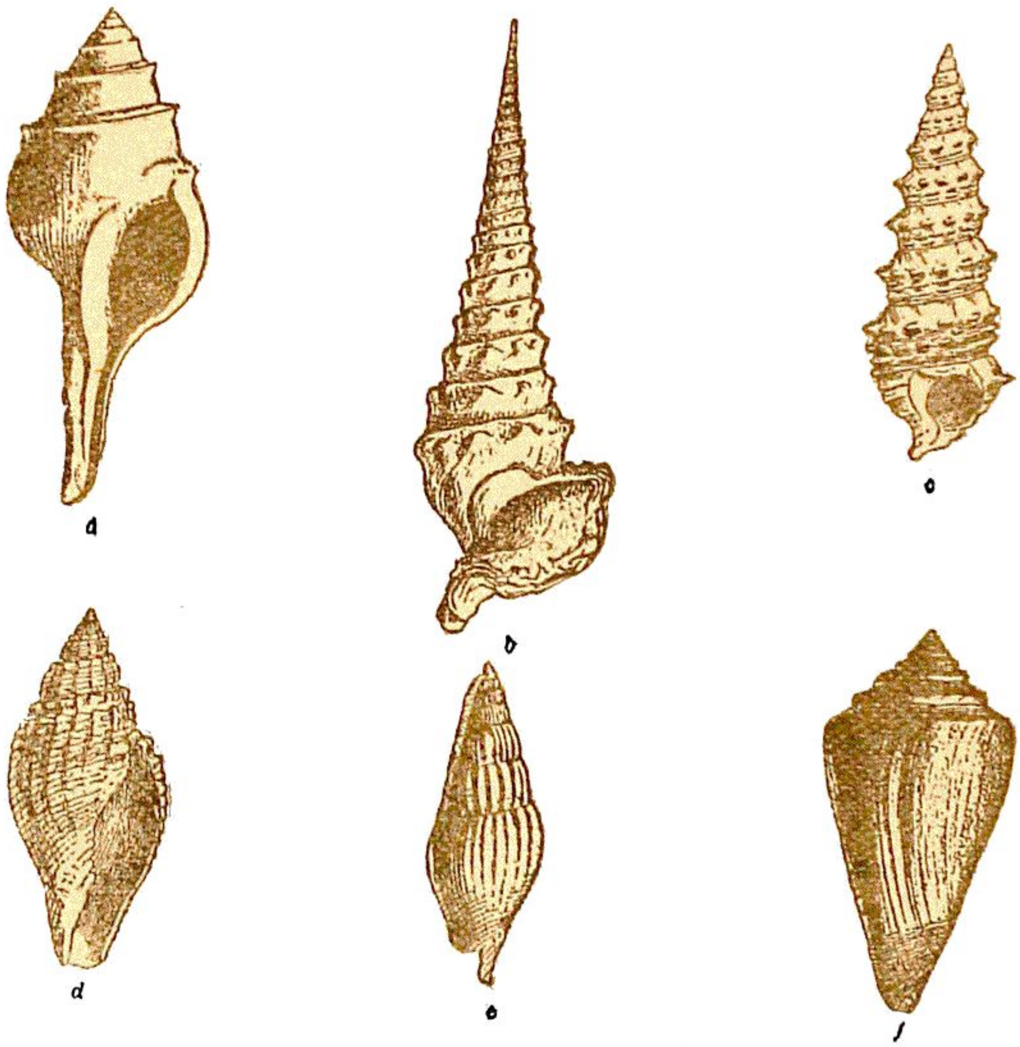

Fig. 427.—Eocene Gasteropods.

a, Fusus (Clavalithes) longævus, Brand. (2/3); *b*, Cerithium (Campanile) gigantium, Lam. (1/10); *c*, Melania inquinata, Defr. (2/3); *d*, Voluta (Volutilithes) elevata, Sow. (2/3); *e*, Rostellaria (Rimella) fissurella, Desh. (2/3); *f*, Conus deperditus, Brug. (1/2)

African hornbill.[10] But the most notable feature in the palæontology of the period is the advent of some of the numerous mammalian forms for which Tertiary time was so distinguished. In the lower Eocene period appeared

[10] Owen, Q. J. Geol. Soc. 1856, 1873, 1878, 1880; Boyd Dawkins, "Early Man in Britain," p. 33; Milne Edwards, "Oiseaux Fossiles," i. 543.

the primitive carnivores Arctocyon and Palæonictis, two animals with marsupial affinities, the former with bear-like teeth, the latter with teeth like those of the Tasmanian dasyure; also the tapir-like Coryphodon; the small hog-like Hyracotherium, with canine teeth like those of the peccary, and a form intermediate between that of the hog and the hyrax. Middle Eocene time was distinguished by the advent of a group of remarkable tapir-like animals (Palæotherium, Palaplotherium, Lophiodon,[11] Pachynolophus); true carnivores (Pterodon and Proviverra); insectivores (Heterohyus, Microchœrus) and the lemuroid Cœnopithecus, the earliest representative of the tribe of monkeys. With the upper Eocene period, besides the abundant older tapir-like forms, there came others (Anchitherium), which presented characters intermediate between those of the tapiroid Palæotheres and the true Equidæ. They were about the size of small ponies, had three toes on each foot, and are regarded as ancestors of the horse. Numerous hog-like animals (Diplopus, Hyopotamus) mingled with herds of ancestral hornless forms of deer and antelopes (Dichobune, Dichodon, Amphitragulus). Opossums abounded. Among

a b

Fig. 428.—Eocene Fishes.
a, Lamna elegans, tooth of, Ag. (2/3); *b*, Odontaspis (Otodus) obliquus, tooth of, Ag. (2/3).

[11] H. Filhol, Mem. Geol. Soc. France (3) v. No. 1, 1888.

the carnivores were animals resembling wolves (Cynodon), foxes (Amphicyon), and wolverines (Tylodon), but all possessing marsupial affinities. There appear to have been also representatives of our hedgehogs, squirrels, and bats.[12]

It is from the thick Eocene lacustrine formations of the Western Territories of the United States that the most important additions to our knowledge of the animals of early Tertiary time have been made, thanks to the admirable and untiring labors, first of Leidy, and subsequently of Marsh at New Haven, and Cope at Philadelphia. The Laramie

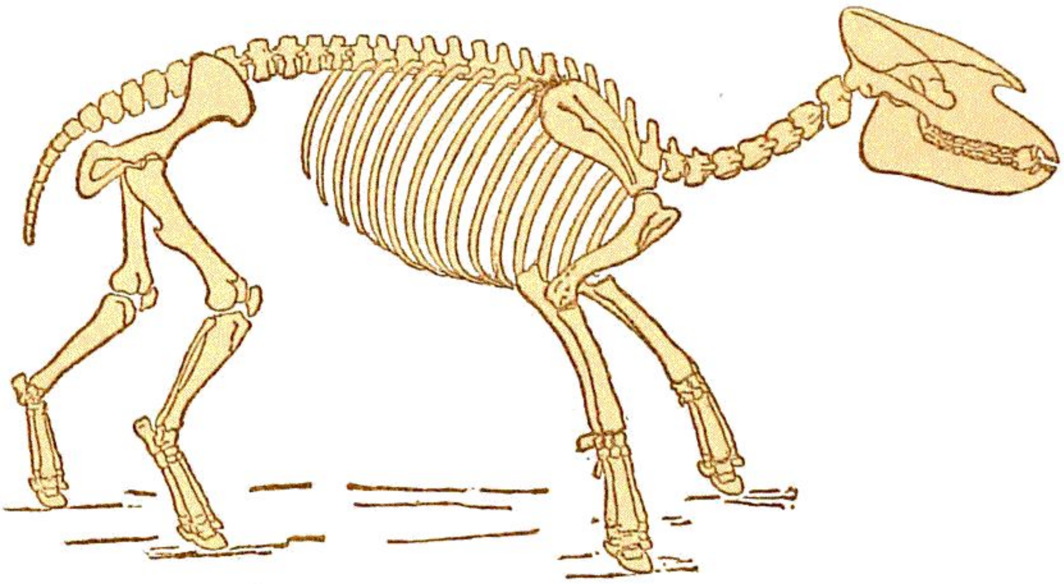

Fig. 429.—Palæotherium magnum, Cuv. ($\frac{1}{25}$).

group, in particular, has yielded an extraordinarily abundant and varied fauna, comprising ophidians (Coniophis), true lacertilians (Chamops, Iguanavus), and gigantic forms of deinosaurs. These last-named animals are of peculiar interest, inasmuch as they show that just before the final extinction of the sub-class to which they belong they had developed into many highly specialized types (Ornithomimus, Claosaurus).[13] The herbivorous ungulata appear to

[12] Gaudry, "Les Enchaînements du Monde Animal," p. 4; Boyd Dawkins, "Early Man in Britain," chap. ii.

[13] O. Marsh, Amer. Journ. Sci. xliii. 1892, p. 449.

have formed a chief element in this Western fauna. They included some of the oldest known ancestors of the horse, with four-toed feet, and even in one form (Eohippus) with rudiments of a fifth toe; also various hog-like animals (Eohyus, Parahyus). Some of the most peculiar forms were those of the type termed Tillodont by Marsh, presenting a remarkable union of the characters of ungulates, rodents, and carnivores, and especially striking from their pair of long incisor teeth (Tillotherium, Anchippodus, Calamodon). This author, from another assemblage of skulls

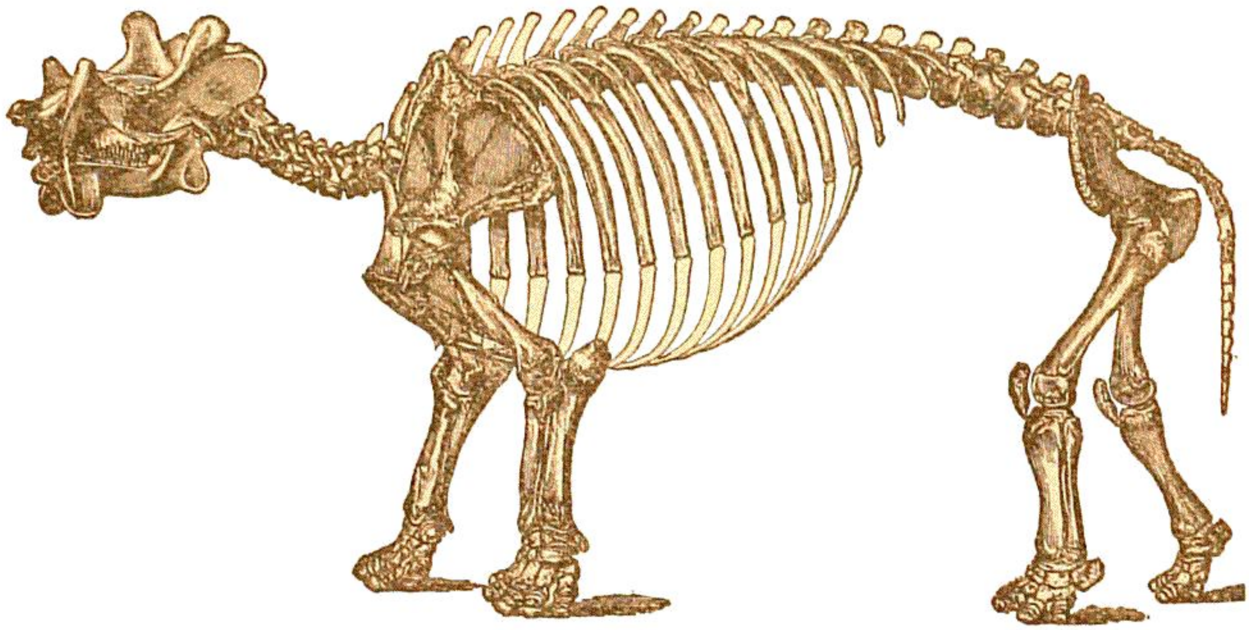

Fig. 430.—Deinoceras (Uintatherium) mirabile, Marsh ($\frac{1}{30}$).

and bones of animals about as large as a fox, has proposed to establish a separate order of mammals, that of the Mesodactyla, which in his opinion stands in somewhat the same relation to the typical Ungulates that the Tillodonts do to Rodents.[14] Still more extraordinary were the Deinocerata, ranked as a distinct sub-order, possessing, according to Marsh, the size of elephants, with the habits of rhinoceroses, but bearing a pair of long horn-like prominences on

[14] Marsh, op. cit. 1892, p 445. Compare H. F. Osborn, Journ. Acad. Philadelph. ix. 1888.

the snout, another pair on the forehead, and a single one on each cheek (Uintatherium, Fig. 430,[15] with the forms described under the names Deinoceras, Tinoceras, Fig. 431, Octotomus, Eobasileus, Loxolophodon). With these animals there coexisted large and small carnivores and some lemuroid monkeys.

§ 2. Local Development

Britain.[16]—Entirely confined to the southeastern part of England,[17] the British Eocene strata occupy two synclinal depressions in the Chalk, which, owing to denudation, have become detached into the two well-defined basins of London and Hampshire. They have been arranged as in the subjoined table:

	Hampshire.	*London.*
Upper.	Headon Hill or Barton Sands. Barton Clay.	Upper Bagshot Sands.
Middle.	Bracklesham beds, and leaf beds of Bournemouth and Alum Bay.	Middle Bagshot beds, part of Lower Bagshot Sands.
	Hampshire.	*London.*
Lower.	London Clay (Bognor beds). Woolwich and Reading beds.	Part of Lower Bagshot Sands. London Clay. Oldhaven beds. Woolwich and Reading beds. Thanet Sand.

Lower Eocene.—The Thanet Sand[18] at the base of the London basin consists of pale yellow and greenish sands, sometimes clayey, and containing at their bottom a thin,

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[15] This restoration was kindly supplied by Prof. Marsh, whose Monograph on the Deinocerata the student should consult. Mon. U. S. Geol. Surv. vol. x. 1886.

[16] See Conybeare and Phillips, "Geology of England and Wales"; Prestwich, Q. J. Geol. Soc. vols. iii. vi. viii. x. xi. xiii.; Edward Forbes, "Tertiary Fluvio-marine Formation of the Isle of Wight," Mem. Geol. Surv. 1856; H. W. Bristow, C. Reid, and A. Strahan, "Geology of the Isle of Wight," Mem. Geol. Surv. 2d edition, 1889; Whitaker, "Geology of London," Mem. Geol. Surv. 1889; Phillips, "Geology of Oxford and the Thames Valley," 1871.

[17] Mr. J. S. Gardner, however, has classed as Eocene the plant-bearing beds of Bovey, Antrim, etc., described at p. 1622 under the Oligocene subdivision.

[18] Prestwich, Q. J. Geol. Soc. viii. 1852, p. 237.

but remarkably constant, layer of green-coated flints resting directly on the Chalk. According to Mr. Whitaker, it is doubtful if proof of actual erosion of the Chalk can anywhere be seen under the Tertiary deposits in England, and he states that the Thanet Sand everywhere lies upon an even surface of Chalk with no visible unconformability.[19] Prof. Phillips, on the other hand, describes the Chalk at Reading as having been "literally ground down to a plane or undu-

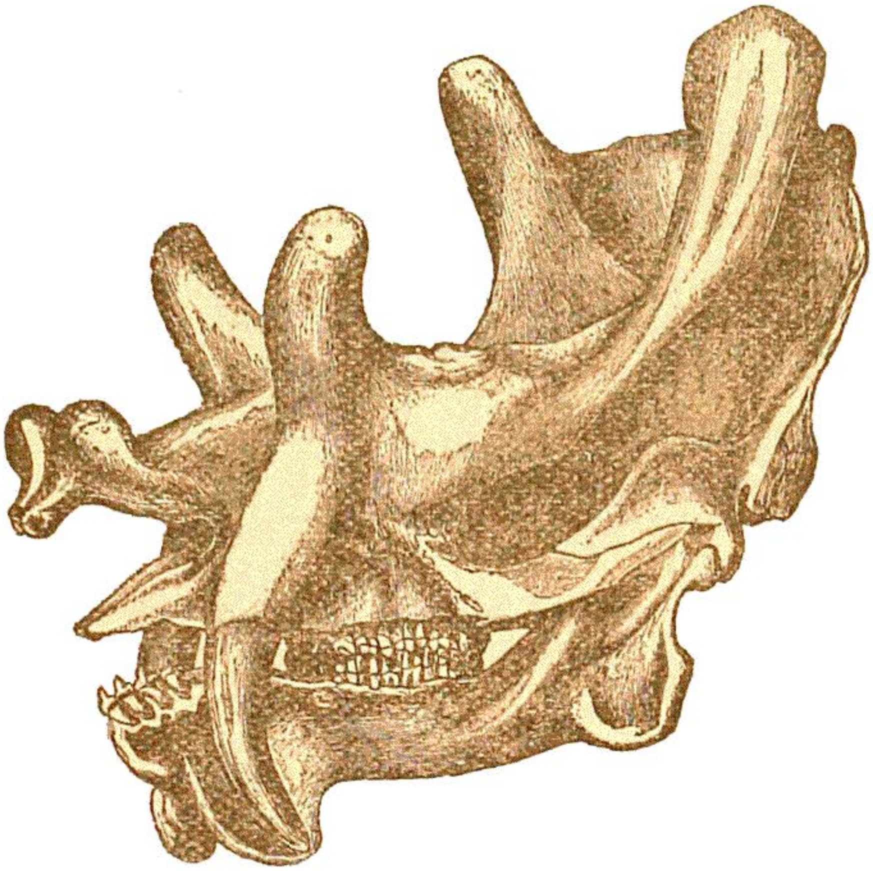

Fig. 431.—Skull of Tinoceras (Uintatherium) ingens, Marsh (about $\frac{1}{10}$).

lated surface, as it is this day on some parts of the Yorkshire coast," and having likewise been abundantly bored by lithodomous shells.[20] The Thanet Sand appears to have been formed only in the London basin; at least it has not been recognized at the base of the Eocene series in Hampshire. It has yielded numerous organic remains in East Kent, but is almost unfossiliferous further west. Its fossils comprise about 70 known species (all marine except a few fragments of terrestrial vegetation). Among them are several foraminifera, numerous lamellibranchs (Astarte tenera, Cyprina scutellaria [planata], Ostrea bellovacina, Cucullæa

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[19] "Geology of London," p. 107.
[20] "Geology of Oxford," p. 442.

decussata [crassatina], Pholadomya [martesia?] cuneata, P. Koninckii, Corbula regulbiensis, etc.), a few species of gasteropods (Natica infundibulum [subdepressa], Aporrhais Sowerbii, etc.), a nautilus, and the teeth, scales, and bones of fishes (Odontaspis, Pisodus).

The Woolwich and Reading Beds,[21] or "Plastic Clay" of the older geologists, consist of lenticular sheets of plastic clay, loam, sand, and pebble-beds, so variable in character and thickness over the Tertiary districts that their homotaxial relations would not at first be suspected. One type (Reading) presenting unfossiliferous lenticular, mottled, bright-colored clays, with sands, sometimes gravels, and even sandstones and conglomerates, occurs throughout the Hampshire basin and in the northern and western part of the London basin. A second type (Woolwich), found in West Kent, Surrey, and Sussex, from Newhaven to Portslade, consists of light-colored sands and gray clays, crowded with estuarine shells. A third type, seen in East Kent, is composed only of sands containing marine fossils. These differences in lithological and palæontological characters serve to indicate the geographical features of the southeast of England at the time of deposit, showing in particular that the sea of the Thanet beds had gradually shallowed, and that an estuary now partly extended over its site. The organic remains as yet obtained from this group amount to more than 100 species. They include a few plants of terrestrial growth, such as Ficus Forbesi, Grevillea Heeri, Laurus Hookeri, Aralia, Lygodium, Liriodendron, Palmetto, and Platanus—a flora which, containing some apparently persistent types, has a temperate facies.[22] The lamellibranchs are partly estuarine or fresh-water, partly marine; characteristic species being Cyrena cuneiformis, C. cordata, and C. tellinella. Ostrea bellovacina forms a thick oyster-bed at the base of the series, besides occurring throughout the group. Ostrea tenera is likewise abundant. The gasteropods include a similar mixture of marine with fluviatile species (Potamides [Cerithium] funatus, Melania inquinata, Melanopsis buccinoides, Neritina globulus, Natica infundibulum, Pisania [Fusus] lata, Viviparus [Paludina] lentus, Planorbis lævigatus, Pitharella Rickmanni, etc.). The fish are chiefly sharks (Odontaspis). Bones of turtles, scutes of

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[21] Prestwich, Q. J. Geol. Soc. x. p. 75; Whitaker, "Geology of London," p. 122.

[22] J. S. Gardner, "British Eocene Flora," Palæontog. Soc. p. 29.

crocodiles, and remains of gigantic birds (Gastornis) have been found. The highest organisms are bones of mammalia, including the Coryphodon.

The Blackheath or Oldhaven Beds,[23] at the base of the London Clay, consist in W. Kent almost wholly of rolled flint-pebbles in a sandy base, which, as Mr. Whitaker suggests, may have accumulated as a bank at some little distance from shore. Though of trifling thickness (20–40 feet), they have yielded upward of 150 species of fossils. Traces of Ficus, Cinnamomum, and Coniferæ have been obtained from them, indicating perhaps a more subtropical character than the flora of the beds below, but without the Australian and American types which appear in so marked a manner in the later Eocene floras.[24] The organisms, however, are chiefly marine and partly estuarine shells, the gasteropods being particularly abundant (Calyptræa trochiformis, Potamides [Cerithium] funatus, Melania inquinata, Natica infundibulum, Cardium plumstediense, Pectunculus terebratularis, etc.).

The London Clay[25] is a deposit of stiff brown and bluish-gray clay, with layers of septarian nodules of argillaceous limestone. Its bottom beds, commonly consisting of green and yellow sands, and rounded flint-pebbles, sometimes bound by a calcareous cement into hard tabular masses, form in the London basin a well-marked horizon. The London Clay is typically developed in that basin, attaining its maximum thickness (500 feet) in the south of Essex. Its representative in the Hampshire basin, known as the "Bognor Beds," and exposed at Bognor on the Sussex coast and at Portsmouth, consists of clays, sands, and calcareous sandstones, thus differing somewhat, both lithologically and palæontologically, from the typical development in the London basin. The London Clay has yielded a long and varied suite of organic remains, that point to its having been laid down in the sea beyond the mouth of a large estuary, into which abundant relics of the vegetation, and even sometimes of the fauna, of the adjacent land were swept. According to Prof. T. Rupert Jones, the depth of the sea, as indicated by the foraminifera of the deposit, may have been

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[23] Whitaker, Q. J. Geol. Soc. xxii. 1866, p. 412; "Geology of London," p. 214.

[24] J. S. Gardner, op. cit. pp. 2, 10.

[25] Prestwich, Q. J. Geol. Soc. vi. p. 255; x. p. 435; Whitaker, "Geology of London," p. 238.

about 600 feet. Prof. Prestwich has pointed out that there are traces of the existence of palæontological zones in the clay, the lowest zone indicating, in the east of the area of deposit, a maximum depth of water, while a progressive shallowing is shown by three higher zones, the uppermost of which contains the greater part of the terrestrial vegetation, and also most of the fish and reptilian remains. The fossils are mainly marine mollusca, which, taken in connection with the flora, indicate that the climate was somewhat tropical in character. The plants include the fruits, seeds, or leaves of the following, among other genera, the fossils having been mostly obtained from the Isle of Sheppey: Sequoia, Pinus, Callitris, Salisburia; Musa, Nipa, Sabal, Chamærops; Quercus, Liquidambar, Laurus, Nyssa, Diospyros, Symplocos, Magnolia, Victoria, Hightea, Sapindus, Cupania, Eugenia, Eucalyptus, Amygdalus.[26] Diatoms are plentifully diffused through the London Clay, and numerous foraminifera have been found by washing it. Crustacea abound (Xanthopsis, Hoploparia). Of the lamellibranchs some of the most usual genera are Avicula, Cardium, Corbula, Leda, Modiola, Nucula, and Pinna. Gasteropods are the prevalent mollusks, the common genera being Pleurotoma (45 species), Fusus (15 species), Cypræa, Murex, Natica, Cassis (Cassidaria), Pyrula, and Voluta. The cephalopods are represented by 6 or more species of Nautilus, by Belosepia sepioidea, and Beloptera Levesquei. Nearly 100 species of fishes occur in this formation, the rays (Myliobates, 14 species) and sharks (Odontaspis, Lamna, etc.) being specially numerous. A sword-fish (Tetrapterus priscus), and a saw-fish (Pristis) have likewise been met with. The reptiles were numerous, and markedly unlike, as a whole, to those of Secondary times. Among them are numerous turtles and tortoises (Chelone, 10 species, Trionyx, 1 species, Platemys, 6 species), two species of crocodile, and a sea-snake (Palæophis toliapicus), estimated to have equalled in size a living Boa constrictor. Remains of birds have also been met with (Lithornis vulturinus, Halcyornis toliapicus, Dasornis londinensis, Odontopteryx toliapicus, Argillornis longipennis). The mammals included forms resembling the tapirs (Hyracotherium, Coryphodon, etc.), an opossum (Didelphys), and a bat. The carcasses of these animals must

[26] Ettingshausen and Gardner, "British Eocene Flora," Palæontograph. Soc. p. 12; Ettingshausen, Proc. Roy. Soc. xxix. 1879.

have been borne seaward by the great river which transported so much of the vegetation of the neighboring land.

MIDDLE EOCENE.—In the London basin this division consists chiefly of sands, which are comprised in the two sub-stages of the lower and middle "Bagshot Beds." The lower of these, consisting of yellow, siliceous, unfossiliferous sands, with irregular light clayey beds, attains a thickness of about 100 to 150 feet. The second sub-stage, or "Middle Bagshot Beds," is made up of sands and clays, sometimes 50 or 60 feet thick, containing few organic remains, among which are bones of turtles and sharks, with a few mollusks (Cardita acuticosta, C. elegans, C. planicosta, C. imbricata, Corbula gallica, C. Lamarckii, Ostrea flabellula).

In the Hampshire basin, the Middle Eocene beds attain a much greater development, being not less than 660 feet thick at the west end of the Isle of Wight, where they consist of variously-colored unfossiliferous sands and clays, with minor beds of ironstone and plant-bearing clays, pointing to an alternation of marine and estuarine conditions of deposit.[27] On the mainland at Studland, Poole, and Bournemouth, the same beds appear. The important series of clays, marls, sands, and lignites, upward of 100 feet thick, known as the Bracklesham beds from their occurrence at Bracklesham, on the coast of Sussex, has yielded a large series of marine organisms. Among these are the fishes Pristis, Odontaspis, Lamna, Myliobates, also Palæophis, and the mollusks Belosepia sepioidea, B. Owenii, Cypræa inflata, C. tuberculosa, Marginella eburnea, M. ovulata, Voluta crenulata, V. spinosa, V. angusta, V. Branderi, V. cythara, V. muricina, Mitra labratula, Conus deperditus, C. Lamarckii, Pleurotoma dentata, P. textiliosa, Pteronotus (Murex) asper, Clavalithes (Fusus) longævus, Turritella imbricataria, Ostrea dorsata, O. flabellula, Pseud-amusium (Pecten) corneus, P. squamula, Lima expansa, Spondylus rarispina, Avicula media, Pinna margaritacea, Modiola (Lithodomus?) Deshayesi, Arca biangula (Branderi), A. interrupta, A. planicosta, Limopsis granulata, Nucula minor, Nuculana (Leda) galeottiana, Cardita acuticosta, C. elegans, C. imbricata, C. planicosta, Crassatella grignonensis, Chama calcarata, C. gigas, Nummulites lævigata, (N. scabra) Alveolina fusiformis.[28] The Bracklesham beds reap-

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[27] "Geology of the Isle of Wight" in Mem. Geol. Surv. p. 109.

[28] See Dixon's "Geology of Sussex"; Edwards and S. Wood, "Monograph of Eocene Mollusca," Palæontograph. Soc.

pear to a small exent, as greenish clayey sands, in the London basin, where they form part of the Middle Bagshot beds.

One of the most characteristic features of the English Middle Eocene division is the abundant terrestrial flora which has been disinterred especially from the plant-beds of Alum Bay and Bournemouth. It is remarkable that this vegetation is apt to occur in patches or "pockets" which may mark the sites of pools into which it was blown by wind or transported by streams, so that varied though it be, it probably affords no adequate picture of the variety of the flora from which it was derived. From Alum Bay, in the Isle of Wight, according to Ettingshausen's census, no fewer than 116 genera and 274 species belonging to 63 families have been obtained.[29] A feature of special interest in this flora is to be found in the fact that it is the most tropical in general aspect which has yet been studied in the northern hemisphere. This character is particularly indicated by the numbers of species of fig, and by the Artocarpeæ, Cinchonaceæ, Sapotaceæ, Ebenaceæ, Büttneriaceæ, Bombaceæ, Sapindaceæ, Malpighiaceæ, etc. The most conspicuous and typical forms are Ficus Bowerbankii, Aralia primigenia, Dyandra acutiloba, D. Bunburyi, Cassia Ungeri, and the fruits of Cæsalpina. Many of the dicotyledons belong to species elsewhere found in what have been considered to be Miocene deposits. More than fifty species of the Alum Bay flora are found also in those of Sotzka and Häring (p. 1610), while a lesser number occur in those of Sézanne (p. 1604) and the Lignitic series of Western America.[30] The Bournemouth beds are believed to be rather higher in the series than those of Alum Bay, and lie immediately below the Bracklesham beds. None of the prevailing types of plants are found in them that occur at Alum Bay, but this may no doubt be due to local accidents of deposition. The Bournemouth flora is likewise an abundant one, and suggests a comparison of its climate and forests with those of the Malay archipelago and tropical America.[31] The celebrated lignitiferous deposit of Bovey Tracey in Devonshire has been referred by Mr. Gard-

[29] Mr. Gardner suspects that in this estimate species from other localities have been included with those from Alum Bay, "Geology of the Isle of Wight" in Mem. Geol. Surv. p. 105.

[30] Ettingshausen, Proc. Roy. Soc. 1880, p. 228. See J. S. Gardner, Geol. Mag. 1877, p. 129; Nature, vol. xxi. 1879, 181, the Monograph on Eocene Flora already cited, and "Geology of the Isle of Wight" in Mem. Geol. Surv. p. 104.

[31] J. S. Gardner, Q. J. Geol. Soc. xxxv. 1879, p. 209; xxxviii. 1882, p. 1; Proc. Geol. Assoc. v. p. 51; viii. p. 305; Geol. Mag. 1882, p. 470.

ner to this horizon.[32] Crocodiles still haunted the waters, for their bones are mingled with those of sea-snakes and turtles, and with tapiroid and other older Tertiary types of terrestrial creatures. The occurrence of the foraminiferal genus Nummulites is noteworthy. Though not common in England, it abounds, as already stated, in the Eocene deposits of central and eastern Europe.

UPPER EOCENE.—The highest division of the Eocene strata of England, according to the classification here followed, includes the uppermost part of the Hampshire series, which has long been known as the "Barton Clay," with, perhaps, the Upper Bagshot Sand of the London basin. The Barton Clay does not occur in that basin, but forms an important feature in Hampshire, where, on the cliffs of Hordwell, Barton, and in the Isle of Wight, it attains a thickness of 300 feet. It consists of gray, greenish, and brown clays, with bands of sand, and has long been well known for the abundance and excellent preservation of its fossils, chiefly mollusks, of which more than 500 species have been collected, but including also fishes (Lamna, Myliobates, Arius) and a crocodile (Diplocynodon). The following list includes some of the more important species for purposes of comparison with equivalent foreign deposits: Voluta luctatrix, V. ambigua, V. athleta, Conorbis (Conus) scabriculus, C. dormitor, Pleurotoma rostrata (and numerous other species), Clavalithes (Fusus) longævus, Leistoma pyrus, Ostrea gigantea, O. flabellula, Vulsella deperdita, Pecten reconditus, Lima compta, L. soror, Arvicula media, Modiola seminduda, M. sulcata, M. tenuistriata, Arca appendiculata, Axinæa (Pectunculus) deleta, Cardita Davidsoni, C. sulcata, Crassatella sulcata, Chama squamosa, Nummulites elegans, N. variolaria.

In the London basin the position of the so-called "Upper Bagshot Sands" has been the subject of some discussion, there being no marked separation between them and the group known as "Middle Bagshot." They consist of sands with ferruginous concretions which have yielded Turritella imbricataria, Ostrea flabellula, and other shells found in the Barton Clay.

Above the Barton Clay and forming the highest member of the Eocene series comes a mass of unfossiliferous or sparingly fossiliferous sand, from 140 to 200 feet in thick-

[32] Quart. Journ. Geol. Soc. xxxv. p. 227; xxxviii. p. 3. For an account of this deposit and its flora, see W. Pengelly and O. Heer, Phil. Trans. 1862.

ness, so purely siliceous as to be valuable for glass-making. These deposits in the Isle of Wight are immediately covered by the base of the Oligocene series. They have been called "Upper Bagshot," but as they probably occupy a higher horizon than the true Upper Bagshot Sand of the London basin, the local term Headon Hill Sand or Barton Sand is more convenient for them.[33]

It is probably from the Bagshot sands that the great majority of the so-called "Gray Wethers" or "Druid stones" of the south of England have been derived, which have already (p. 604) been referred to.

Northern France and Belgium.[34]—The anticline of the Weald which separates the basins of London and Hampshire is prolonged into the Continent, where it divides the Tertiary areas of Belgium from those of Northern France. There is so much general similarity among the older Tertiary deposits of the whole area traversed by this fold as to indicate a probable original relation as parts of one great tract of sedimentation. Local differences, such as the replacement of fresh-water beds in one region by marine beds in another, together with occasional gaps in the record, show us some of the geographical conditions and oscillations during the time of deposition. The following table gives the general grouping and correlation of the Eocene formations in this region:

Upper.	Marine gypsum of Paris basin. Middle sands (Sables Moyens).	Wemmelian sands of Belgium.
Middle.	Caillasses or Upper Calcaire Grossier (fresh-water).	Lackenian sands.
	Middle Calcaire Grossier (marine).	Bruxellian sands and sandstones.
	Lower Calcaire Grossier (fresh-water).	
Lower.	Sands of Cuise and Soissons.	Paniselian sands.
	Plastic clays and lignite. Limestones of Rilly and Sézanne.	Ypresian sands and clays.
	Sands of Bracheux and Meudon Marl.	Mandenian sands.

LOWER EOCENE.—In the Paris basin, the Sables de Bracheux form an excellent horizon, which corresponds to the Thanet Sand of England and Dumont's "Système Landenien" in Belgium. Below this horizon, there occurs in the Franco-Belgian region a lower series of deposits than

[33] C. Reid, "Geology of the Isle of Wight," Mem. Geol. Surv. p. 122.

[34] For a comparison of the Lower Eocene groups of Paris. Belgium and England, see Hebert, Bull. Soc. Geol. France (3), ii. p. 27. Prestwich (Brit. Assoc. 1882, p. 538) regards the Sables de Bacheux as representing only the lower part of the Woolwich beds.

is found in England.[35] In the Paris basin, these strata present variable and local characters. They include the Marnes de Meudon, remarkable for containing 20 per cent of carbonate of strontia; and the limestones of Rilly and Sézanne—a form of travertine from which fresh-water shells and a rich assemblage of plants have been obtained (Chara, Asplenium, Alsophylla, Juglandites, Sassafras, Hedera, etc.).[36] To the north of Paris, the Marnes de Meudon disappear, and their place is taken by the Sables de Bracheux—greenish glauconitic sands with a basement-band of green-coated flints resting generally directly on the Chalk. This sandy member of the series, traceable as a definite platform through the Anglo-French and Belgian area, contains among its characterstic fossils Pholadomya cuneata, P. Koninckii, Cyprina Morrisii, Cucullæa crassatina, Pecten breviauritus, Psammobia Edwardsii, Ostrea bellovacina, Corbula regulbiensis, Turritella bellovacina, Natica deshayesiana, Voluta depressa. Higher in the series comes the "Argile plastique" of the Paris basin, with the associated lignites of the Soissonnais. The molluscan fauna of these strata resembles that of the Woolwich and Reading beds. But a break seems to occur in the series at this point; for in the Paris basin no representative of the London Clay is found. The lignites of the Soissonnais are covered by sands (Sables de Cuise or du Soissonnais) containing, among other abundant marine organisms, Nummulites planulata, Turritella edita, T. hebrida, Crassatella propinqua, Lucina squamula; they are regarded as the equivalent of the lower part of the English Bagshot Sand, and form the highest member of the Lower Eocene stages of the Paris basin.

In the Belgian area, some differences are presented in the succession of sediments. The strata of that district have been grouped by Dumont into a series of "systèmes." The most ancient Tertiary deposit of the west of Europe appears to be the limestone of Mons (Système Montien). This rock lies in a denuded hollow of the Chalk, and has been found by boring to be more than 300 feet thick. It consists of friable and compact limestone, charged with a remarkable series of organic remains. Upward of 400 species of fossils have been obtained from it, including marine, fresh-water,

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35 Hébert, Ann. Sciences Geol. iv. 1873, Art. iv. p. 14.

36 Saporta, Mem. Soc. Geol. France (2) viii.; "Le Mondes des Plantes," p. 212 *et seq.*

and terrestrial shells. Among them are about 200 species of gasteropods, about 125 lamellibranchs, and fifty polyzoa, besides numerous foraminifers (Quinqueloculina), and calcareous algæ (Dactylopora, Acicularia, etc.). Two conspicuous features in this deposit are the extraordinary proportion of its new and peculiar species, and the resemblance of its fauna, especially its numerous Cerithiums and Turritellas, to that of the Middle Eocene beds of Belgium and the Paris basin rather than to that of the Lower Eocene. The Mons limestone has thus been cited as an illustration of Barrande's doctrine of colonies.[37]

Above this deposit comes the "Système Heersien," so named from its development at Heers, in Limbourg. With a total depth of about 100 feet, it consists of (1) a lower division of sandy beds, with Cyprina planata, C. Morrisii, Modiola elegans, and other marine shells, some of which occur in the Thanet Sand of England and the Sables de Bracheux; and (2) an upper division of marls, containing, besides some of the marine shells found in the lower division, numerous remains of a terrestrial vegetation (Osmunda eocenica, Chamæcyparis belgica, Poacites latissimus, and species of Quercus, Salix, Cinnamomum, Laurus, Viburnum, Hedera, Aralia, etc.).[38]

The "Système Landien," corresponding to the Thanet and Woolwich and Reading beds of England and the Sables de Bracheux, Argile plastique, and Lignites du Soissonnais of France, is divisible into two stages: 1st, Lower marine gravels, conglomerates, sandstones, marls, etc., with badly preserved fossils, among which are Turritella bellovacina, Cucullæa decussata (crassatina), Cardium Edwardsii, Cyprina planata, Corbula regulbiensis, Pholadomya Koninckii; 2d, Upper fluvio-marine sands, sandstones, marls, and lignites containing Melania inquinata, Melanopsis buccinoides, Cerithium funatum, Ostrea bellovacina, Cyrena cuneiformis, with leaves and stems of terrestrial plants.

The "Système Yprésien" consists of a great series of clays and sands answering generally to the London Clay, but not represented in France. It is divided into two stages: 1st, Lower stiff gray or brown clay (Argile de Flanders ou d'Ypres), sometimes becoming sandy, and

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[37] Briart and Cornet, Mem. Couronn. Acad. Roy. Belg. xxxvi. 1870; xxxvii. 1873; xliii. 1880. Mourlon, "Geol. Belg." 1880, p. 192. Hébert (Ann. Sciences Geol. iv. 1873, p. 15) has noticed an affinity to the uppermost Cretaceous fauna of Paris.

[38] De Saporta and Marion, Mem. Cour. Acad. Roy. Belg. xli. 1878.

probably an eastward extension of the London Clay. The break between this deposit and the top of the Landenian beds below is regarded as filled up by the Oldhaven beds of the London basin. The only recorded fossils are foraminifera agreeing with those of the London Clay. 2d, Upper sands with occasional lenticular intercalations of thin grayish-green clays, with abundant fossils, the most frequent of which are Nummulites planulata (forming aggregated masses), Turritella edita, T. hybrida, Vermetus bognorensis, Pecten corneus, Pectunculus decussatus, Lucina squamula, Ditrupa plana. Out of 72 species of mollusks, 45 are found also in the Sables de Cuise and 20 in the London Clay.[39]

The "Système Paniselien," so named from Mont Panisel near Mons, consists chiefly of sandy deposits not markedly fossiliferous, but containing among other forms Rostellaria fissurella, Voluta elevata, Turritella Dixoni, Cytherea ambigua, Lucina squamula. Out of 129 species of mollusca found in this deposit, 91 appear in the Sables de Cuise, and only 36 pass up into the Calcaire Grossier. Hence the Paniselian beds are placed at the top of the Lower Eocene stages of Belgium.

MIDDLE EOCENE.—This division in the Paris basin is formed by the characteristic, prodigiously fossiliferous Calcaire Grossier, which is subdivided as under:[40]

Caillasses or Upper (Fresh-water) Calcaire Grossier.	Upper sub-group with Cardium obliquum and Cerithium denticulatum	4. Limestone with Cardium obliquum and Cerithium Blainvilli.
		3. Limestone with Cerithium denticulatum and C. cristatum.
		2. Siliceous limestone with undetermined forms of Potamides.
		1. Coral limestone (Stylocœnia).
	Middle sub-group with Lucina saxorum and Miliola.	4. Siliceous limestone with parting of laminated marl.
		3. Limestone in small thin boards with Carbula (Rochette).
		2. Limestone with Miliola and Lucina saxorum (Roche).
		1. Siliceous limestone with indeterminate fossils (Bancs francs).
	Lower sub-group with Cerithium lapidum and Miliola.	4. Limestone (dolomitic) with Miliola (Cliquart).
		3. Green marl . . . . / Siliceous limestone in two beds / Green marl . . . . } Blanc vert.
		2. Miliola limestone (dolomitic) (Saint Nom).
		1. Siliceous limestone with Potamides.

39 Mourlon, "Geol. Belg." p. 211.

40 Dollfus, Bull. Soc. Geol. France, 3e ser. vi. 1878, p. 269. Compare Michelet, op. cit. 2e ser. xii. p. 1336.

Middle Calcaire Grossier.	5. Limestone with Lucina concentrica, Arca barbatula, Cardium aviculare, Miliola, etc.
	4. Limestone with Orbitolites, Fusus bulbiformis, Volvaria bulloides, Cardium granulosum, Arca quadrilatera, several species of large Flustra or Membranipora.
	3. Limestone with Fabularia and terrestrial vegetation (Orbitolites complanata, Chama calcarata, Cardita imbricata, etc.).
	2. Mass of Miliola limestone (Turritella imbricataria, Chama calcarata, Lucinamutabilis, etc.).
	1. Limestone with Miliola and Terebratula (T. bisinuata).
Lower Calcaire Grossier.	5. Glauconitic calcaire grossier with Cerithium giganteum.
	4. Glauconitic calcareous sand with Lenita patellaris.
	3. Sandy glauconitic calcaire grossier with Cardium porulosum.
	2. Sandy glauconitic calcaire grossier, with Nummulites lævigata, N. scabra, Ostrea multicostata, O. flabellula, Ditrupa plana.
	1. Glauconitic sand, sometimes calcareous and indurated, with pebbles of green quartz, shark's teeth, and rolled fragments of coral.

In Belgium the Middle Eocene presents a different aspect from that of Paris, approximating rather to the English Type. It consists of (1) a lower set of sandy beds grouped under the name of "Bruxellien," rich in fossils, which, however, are usually badly preserved. Among the forms are remains of terrestrial vegetation (Nipa Burtini), also Paracyathus crassus, Maretia grignonensis, Pyripora contesta, Ostrea cymbula, Cardita decussata, Chama calcarata, Cardium porulosum, Cerithium unisulcatum, Natica labellata, Voluta lineola, Ancillaria buccinoides, Clavalithes (Fusus) longævus, numerous remains of fishes, especially of the genera Myliobates, Odontaspis, Lamna, Galeocerdo, and various reptiles, including species of Trionyx and Chelone, with Emys Camperi, Garialis Dixoni, and Palæophis typhæus; (2) a group of sands and fossiliferous calcareous sandstones ("Lackenien"), made up of Ditrupa strangulata and Nummulites (N. lævigata, N. scabra, N. Heberti, N. variolaria), and abounding in Anomia sublævigata.

UPPER EOCENE.—In the Paris basin this subdivision consists of the following stages:[41]

Gyps Marin.	Gypsum with nodules of silica (menilite), and containing marine fossils (Cerithium tricarinatum, C. pleurotomoides, Turritella incerta).
	Yellow marls with Lucina inornata.
	Gypsum, saccharoid and crystallized, with brown marls.
	Yellow, brown and greenish marls, with Pholadomya ludensis, Crassotella Desmaresti, etc.

[41] See Dollfus, op. cit.

Sables Moyens.
- Green sands of Monceaux (Cerithium Cordieri, C. tricarinatum, Natica parisiensis).
- Limestones of Saint Ouen—a marly fresh-water rock 20 to 26 feet thick, composed of two zones, the lower full of Bythinia, and the upper abounding in Limnæa.
- Sands of Mortefontaine (Avicula Defrancei).
- Sands and sandstones of Beauchamp (Cerithium mutabile, C. tuberculosum, C. Bouei, Melania hordacea, M. lactea, Cyrena deperdita, Planorbis nitidulus, Corbula gallica, etc.)
- Sands, etc., with Nummulites variolaria, Ostrea dorsata, Cyrena deperdita, corals, Lamna elegans, Odontaspis (Otodus) obliquus, etc.

Northward in the Belgian area, near Brussels, the highest Eocene strata consist of sands and calcareous sandstones ("Wemmelien"), separated from the similar Lackenian beds below by a gravel full of Nummulites variolaria. Other common fossils are Turbinolia sulcata, Corbula pisum, Cardita sulcata, Turritella brevis, Clavalithes (Fusus) longævus.

Receding from the Paris basin, the Eocene deposits assume entirely different characters as they are traced into the west, centre, and south of France. According to Vasseur's detailed researches, a long irregular arm of the sea penetrated Brittany in Eocene times from where the Loire now enters the Atlantic, while the northwestern part of Vendée was likewise submerged. In these waters a series of limestones and sands was deposited, which from their fossil contents appear to be the equivalents of the Calcaire Grossier. They pass up into lacustrine and brackish-water beds like the corresponding groups at Paris.[42] In the south of France, the Eocene rocks chiefly present the nummulitic facies to be immediately referred to, and in some places attain a great development, as near Biarritz, where they are more than 3000 feet thick.

Southern Europe.—The contrast between the facies of the Cretaceous system in northwestern and in southern Europe is repeated with even greater distinctness in the Eocene series of deposits. From the Pyrenees eastward, through the Alps and Apennines into Greece and the southern side of the Mediterranean basin, through the Carpathian Mountains and the Balkan into Asia Minor, and thence through Persia and the heart of Asia to the shores of China and Japan, a series of massive limestones has been traced, which,

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[42] G. Vasseur, Ann. Sci. Geol. xiii. 1881. Hébert, Bull. Soc. Geol. France (3) x. 1882, p. 364.

from the abundance of their characteristic foraminifera, have been called the Nummulitic Limestone. Unlike the thin, soft, modern-looking, undisturbed beds of the Anglo-Parisian area, these limestones attain a depth of sometimes several thousand feet of hard, compact, sometimes crystalline rock, passing even into marble; and they have been folded and fractured on such a colossal scale that their strata have been heaved up into lofty mountain crests sometimes 10,000 and in the Himalaya range more than 16,000 feet above the sea. With the limestones is associated the sandy series known as Nummulite Sandstone. The massive unfossiliferous Vienna sandstone and Flysch, already referred to as probably in part Cretaceous, are no doubt also partly referable to Eocene time.[43] One of the most remarkable features of these Alpine Eocene deposits is the occurrence in them of coarse conglomerates and gigantic erratics of various crystalline rocks. As far east as the neighborhood of Vienna, and westward at Bolgen near Sonthofen in Bavaria, near Habkeren and in other places, blocks of granite, granitite, and gneiss occur singly or in groups in the Eocene strata. These travelled masses appear to have most petrographical resemblance, not to any Alpine rocks now visible, but to rocks in southern Bohemia. Their presence may possibly indicate the existence of glaciers in the middle of Europe during some part of the Eocene age.[44] Another interesting Eocene deposit of the Alpine region is the coal-bearing group of Häring, in the Northern Tyrol, where a seam of coal occurs which, with its partings, attains a thickness of 32 feet.

The Nummulitic series has been divided into stages in

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[43] The history of the Flysch has given rise to some discussion. Th. Fuchs, for instance, regarded it as having probably been derived from eruptive discharges such as those of mud volcanoes (Sitz. Akad. Wien, lxxv. 1877, p. 340; Verh. Geol. Reich. 1878, p. 135). This view was opposed by K. M. Paul, who looked on the Flysch as a normal sedimentary formation (Jahrb. Geol. Reich. 1877, p. 431; Verh. Geol. Reich. 1878, p. 179). By some geologists the rocks have been regarded as a deep-sea deposit, by others as an accumulation in shallow water, Renevier, Arch. Sci. Phys. Nat. Geneva (3) xii. 1884, p. 310. See also Mantovani, Neues Jahrb. 1877; Schardt and Favre, "Description Geol. des Prealpes du Canton de Vaud," etc. 1887. Kauffmann, "Description de la partie nord-ouest de la feuille xii. de la Carte Geol. Suisse," 1886. F. Sacco, Bull. Soc. Belge. de Geol. iii. 1889, p. 153. C. Mayer-Eymar, "Versuch einer Classification der tertiar Gebilde Europas," Verh. Schweitz. Naturf. Ges. 1857.

[44] That a glacial period occurred at the close of the Cretaceous period, again at the end of the Eocene and in the Miocene (erratics of Superga, near Turin) has been regarded by some geologists as probable: A. Vezian, Rev. Sci. xi. 1877, p. 171; Schardt, "Etudes Geologiques sur le pays d'Enhaut Vaudois," Bull. Soc. Vaud. 1884.

different regions of its distribution, and attempts have been made by means of the included fossils to parallel these stages in a general way with the subdivisions in the Anglo-Parisian basin. But the conditions of deposition were so different that such correlations must be regarded as only wide approximations to the truth. In the Northern Alps (Bavaria, etc.) Gumbel arranges the Eocene series as under:[45]

Flysch or Vienna sandstone (Upper Eocene), including younger Nummulitic beds and Häring beds.
Lower Nummulitic group. Kressenberg beds—greenish sandy strata abounding in fossils, which on the whole point to a correspondence with the Calcaire Grossier.
Burberg beds—greensand with small Nummulites and Exogyra Brongniarti, answering possibly to the upper part of the lower Eocene beds of the Anglo-Parisian area.

In the southern and southeastern Alps the Eocene rocks attain a much larger development. The following subdivisions in descending order have been recognized:[46]

Upper Eocene	Macigno or Tassello, having the usual character of the Vienna sandstone. No fossils but fucoids.
	Fossiliferous calcareous marls and shales, and thick conglomerates.
Nummulite Limestone	Chief Nummulite limestone, containing the most abundant and varied development of nummulites, and attaining the thickest mass and widest geographical range.
	Borelis (Alveolina) limestone, containing numerous large foraminifera of the genus Borelis.
	Lower Nummulite limestone, with small nummulites, and in many places banks of corals.
Liburnian Stage	Upper Foraminiferal limestone, containing also intercalations of fresh-water beds (Chara).
	Cosina beds, with a peculiar fresh-water fauna (Stromatopsis, Melania, Chara, etc.
	Lower Foraminiferal limestone, with numerous marine mollusca (Anomia, Cerithium, etc.), and occasional beds of fresh-water limestone (Chara, Melania, etc.).

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[45] "Geognostische Beschreib. Bayerisch. Alpen," 1861, p. 593 *et seq.*

[46] Von Hauer, "Geologie," p. 569. For an exhaustive account of the stratigraphy and palæontology of the Liburnian stage, see G. Stache's great monograph, "Die Liburnische Stufe," Abhandl. k. k. Geol. Reichsanst. xiii. 1889. On the classification of the older Tertiary formations of Austria, consult Tietze, Zeitsch. Deutsch. Geol. Ges. xxxvi. 1884, p. 68; xxxviii. 1886, p. 26; T. Fuchs, op. cit. xxxvii. 1885, p. 131.

In the central part of the northern Apennines Prof. Sacco regards as Eocene a mass of strata 5500 feet thick, which he subdivides as follows:[47]

Bartonian. 100 metres.	Gray marls with sandy calcareous layers; numerous fossils (Zoophycus, Lithothamnium, Nummulites Tchihatcheffi, N. striata, Orbitoides radians, Operculina, corals, bryozoa, crinoids, etc.)
Parisian. 1500 metres.	A thick series of marly and shaly limestones (Flysch), alternating with sandstones (Helminthoidea labyrinthica, Chondrites and other fucoids). Roofing slates. Shales and sandstones (Macigno). Sandy grayish and brownish marls with calcareous sandy beds (Lithothamnium, Nummulites biarritzensis, N. Lamarcki, N. lucasana, Assilina exponens, A. granulosa, Orbitoides, Operculina, Alveolina, corals, echini, crinoids, fish-teeth, etc.)
Suessonian. 100 metres.	Shales and gray and brown marls, sandstones and limestones.

To the Upper Eocene series of this region has been assigned a great series of serpentines, gabbros, diabases, soda-potash granites, and other eruptive rocks, with tuffs and conglomerates, marking copious submarine volcanic activity.[48]

India, etc.—As above stated, the massive Nummulitic limestone extends through the heart of the Old World, and enters largely into the structure of the more important mountain chains. In India a tolerably copious development of Eocene rocks has been observed, but it is not quite certain where their upper limit should be drawn to place them on a parallel with the corresponding groups in Europe. The following subdivisions in descending order are observed in Sind:[49]

Nari group. Sandstones without marine fossils, and probably of fresh-water origin, 4000 to 6000 feet, representing, perhaps, Upper Eocene and Oligocene or Lower Miocene beds of Europe.

Kasauli and Dagshai groups of sub-Himalayas.

Kirthar group. A marine limestone formation in general, but passing locally into sandstones and shales. The upper limestones contain Nummulites garansensis, N. sublævigata.

Nummulitic limestone of Sind, Punjab, Assam,

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[47] Prof. Sacco has contributed many papers on this subject. See, for example, Bull. Soc. Geol. France (3) xvii. 1889, p. 212.

[48] C. de Stefani, Boll. Soc. Geol. Ital. viii. fasc. 2, 1889; a copious list of previous writers on the subject will be found in this paper.

[49] Medlicott and Blanford, "Geology of India," chap. xix.

Burmah, etc. Subathú of sub-Himalayas, Indus or Shingo beds of Western Tibet.

Ranikot beds—sandstones, shales, clays with gypsum and lignite, 1500 to 2000 feet; abundant marine fauna, including Nummulites spira, N. irregularis, N. Leymeriei.

Lower Nummulitic group of Salt Range.

North America.—Tertiary formations of marine origin extend in a strip of low land along the Atlantic border of the United States and Mexico, from the coast of New Jersey southward into Florida and round the margin of the Gulf of Mexico, whence they run up the valley of the Mississippi to beyond the mouth of the Ohio. On the western seaboard they also occur in the coast ranges of California and Oregon, where they sometimes have a thickness of 3000 or 4000 feet, and reach a height of 3000 feet above the sea. Over the Rocky Mountain region Tertiary strata cover an extensive area, but are chiefly of fresh-water origin.

In the States bordering the Atlantic and Gulf of Mexico the oldest Tertiary deposits are referred to the Eocene series, and in some places (New Jersey) appear to follow conformably on the Cretaceous rocks. They have been subdivided into four groups, which in the State of Mississippi are well developed, with the following characters:[50]

4. Jackson beds ("White Limestone" of Alabama), white and blue marls underlain by lignitic clay and lignite (80 feet) with Zeuglodon macrospondylus, Cardita planicosta, Cardium Nicolleti, Leda multilineata, Corbula bicarinata, Rostellaria velata, Voluta dumosa, Mitra dumosa, Conus tortilis, Cypræa fenestralis, etc.
3. Claiborne beds, white and blue marls, and sandy beds with numerous shells which indicate a horizon equivalent to that of part of the Calcaire Grossier of the Paris basin.
2. Buhrstone (Siliceous Claiborne), sandstones and siliceous impure limestones with Claiborne fossils (400 feet and upward).
1. Lignitic sands and clays, with marine fossils, and with interstratified lignites and plant-remains (Quercus, Populus, Ficus, Laurus, Persea, Cornus, Olea, Rhamnus, Magnolia, etc.).

[50] A. Heilprin, "Contributions to the Tertiary Geology and Palæontology of the United States," 1884; Proc. Acad. Philadelph. 1887.

Over the Rocky Mountain region and the vast plateau lying to the east of that range the older Tertiary formations consist mainly of lacustrine strata of great thickness, the extraordinary richness of which in vertebrate and particularly mammalian remains, already referred to (p. 1593), has given them a high importance in geological and palæontological history. The following subdivisions in descending order were established some years ago:

4. Uinta group (400 feet) or "Diplacodon beds."
3. Bridger group (5000 feet) or "Deinoceras beds."
2. Green River group (2000 feet).
1. Wahsatch (Vermilion Creek) group (5000 feet).

More recent researches in Colorado and elsewhere have somewhat modified this grouping. In the Denver region the so-called "Laramie" series (p. 1575) has been found to consist of three divisions: (1) a lower member, 700 to 800 feet thick, conformable with the Cretaceous Fox Hills group, containing productive coal-seams and a flora and fauna characteristic of the Laramie group as usually understood; (2) a middle member, called the Arapahoe group, resting on the first unconformably, with a conglomerate at its base, containing pebbles of the underlying formation and other older rocks; (3) an upper member, the Denver group, 1400 feet thick, unconformable to the middle division, and largely composed of the débris of andesitic lavas. The strong unconformability between the Laramie beds (No. 1) and the Arapahoe group (No. 2) is believed to mark a considerable interval of time between the highest Cretaceous and oldest Tertiary deposits of this region.[51] In southern Colorado the Eocene strata have been described as 7000 feet thick, resting unconformably on the Laramie series. The lowest member (Poison Cañon), 3500 feet thick, and the next division (Cuchara), 300 feet thick, are classed as Lower Eocene; the upper (Huerfano), 3300 feet thick, is believed to be equivalent to the Bridger group.[52]

Australasia.—Though vast areas in this region are covered with strata which sometimes attain a depth of several hundred feet, containing both terrestrial and marine deposits, and which are referable to various parts of Cainozoic time, no satisfactory correlation of the beds with European equiv-

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[51] Whitman Cross, Amer. Journ. Sci. xxxvii. 1889, p. 261; xliv. 1892, p. 19; Proc. Colorado Sci. Soc. Oct. 1892.

[52] R. C. Hills, Proc. Colorado Sci. Soc. iii. 1888, p. 148, 1889, p. 217, 1891.

alents has yet been made, if, indeed, such a correlation is at all probable or possible. All that can be safely affirmed is that a succession among these beds can be traced with an increasing proportion of recent species in the younger parts of the series. Throughout the whole eastern Australia, including most of New South Wales and Queensland, no marine Tertiary fossils have been discovered. In the southwest of New South Wales and in Victoria, previous to the eruption of basalt-sheets and tuffs, an extensive series of conglomerates, siliceous sandstones, clays, ironstones, and lignites was deposited in valleys and probably lake-basins. On the Dividing Range these strata rise to 4000 feet above the sea. At Bacchus Marsh in Victoria and elsewhere they have yielded leaves of Laurus, Cinnamomum, etc., some of which closely resemble species found at Oeningen. The general aspect of this flora is rather that of tropical than of extra-tropical Australia, and this indication of a warmer temperature than at present is corroborated by the occurrence of coral-reefs in Tasmania referred to the Miocene period. Above these plant-bearing beds which have been regarded as Lower Miocene or Upper Eocene, marine deposits supposed to be Middle and Upper Miocene occur on the flanks of the Dividing Range of New South Wales up to heights of 800 feet. In South Australia and Victoria extensive marine accumulations of clay, sand, and limestone, often underlying widespread basalt-plateaus, have yielded numerous foraminifera, especially at Mount Gambier and Murray Flats in South Australia; 40 species of corals, which are only slightly related to the living species of the surrounding seas, but include three European Tertiary species;[53] many echinoderms and polyzoa, and a large molluscan fauna, in which the genera Waldheimia, Cucullæa, Pectunculus, Trigonia, Cypræa, Fusus, Haliotis, Murex, Mitra, Trivia, Turritella, Voluta, etc., occur. The vertebrate organisms consist of fishes (including the worldwide genera Carcharodon, Lamna, Odontaspis, Oxyrhina), a few marsupials (Bettongia, Nototherium, Phascolomys, Sarcophilus), with some marine mammalia (Squalodon, Arctocephalus). In South Australia the older Tertiary deposits have been divided by Prof. Tate into four groups, which in ascending order are: (*a*) Inferior marine beds,

[53] Duncan, Q. J. Geol. Soc. 1870, p. 313. See also the papers of R. Tate, F. M'Coy, J. E. Tennison Woods, R. Etheridge jun., F. von Müller, Ettingshausen and R. M. Johnston.

chalk-rocks, clays, and limestones; (*b*) Lower Murravian sandstones with Zeuglodon, Lovenia, Magasella, Megalaster; (*c*) Middle Murravian limestones and sandstones, with an abundant and varied marine fauna (Carcharodon, Lamna, Odontaspis, Nassa, Ancillaria, Cassis, Voluta, Marginella, Mangelia, Cerithium, Conus, Cancellaria, Natica, Pecten, Lima, Spondylus, Nucula, Limopsis, Chama, Chione, Rhynchonella, Terebratulina, Waldheimia, Terebratula, Eupatagus, Deltocyathus, etc.; (*d*) Upper Murravian oyster-beds and sandstones (Trigonia, Pectunculus, Tellina, Mactra, Clypeaster, etc.).

In Tasmania an important series of older Tertiary deposits has also been found. At the top, leaf-beds, lignites, and beds with marine fossils occur, associated with extensive sheets of felspar-basalts and tuffs. The tuffs have yielded Hypsiprimnus and Phascolomys. Next comes a great series of sandstones, clays, and lignites, varying from 400 to 1000 feet in thickness, and sometimes, as in the Launceston basin, covering an area of at least 600 square miles. This series incloses a rich flora, including species of oak, elm, beech, laurel, cinnamon, and araucaria, with fruits of proteaceous, sapindaceous, and coniferous trees. The fresh-water and terrestrial character of the deposits is further confirmed by the occurrence in them of Unio, Helix, Vitrina, Bulimus, etc. The third group in descending order is of marine origin, and is well seen at Table Cape. It consists of shelly limestones, calcareous sandstones, coral-rag and pebbly bands, and is replete with fossils, only from 1 to 3 per cent of the shells belonging to existing species. Characteristic forms are Voluta anticingulata, Cassis sufflatus, Cypræa Archeri, Ancillaria mucronata, Panopæa Agnewi, Waldheimia garibaldiana, Lovenia Forbesi, Cellepora gambierensis.[54]

In New Zealand rocks believed to be referable to the upper part of the Eocene series are mainly composed of a shelly calcareous sandstone with corals and polyzoa, which in its lower part passes occasionally into an imperfect nummulitic limestone (Nummulitic beds, Hutchison's Quarry beds, Mount Brown beds). Volcanic action was

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[54] Mr. R. M. Johnston, Registrar-General at Hobart, Tasmania, has published a useful memoir entitled, "Observations with respect to the Nature and Classification of the Tertiary Rocks of Australasia," 1888, with references to the principal sources of information on the subject of Tasmanian Tertiary geology.

greatly developed during the deposit of these strata in both islands. Hence interbedded lavas and tuffs are frequent, and in the North Island the calcareous deposits are often wholly replaced by widespread trachyte-flows and volcanic breccias.[55]

Section ii. Oligocene

§ 1. General Characters

The term "Oligocene" was proposed in 1854 and again in 1858 by Prof. Beyrich[56] to include a group of strata distinct from the Eocene formations of France and Belgium, and which Lyell had classed as "Older Miocene." They consist partly of terrestrial, partly of fresh-water and brackish, and partly of marine strata, indicating considerable oscillations of level in the European area. They consequently present none of the massive deep-water characters so conspicuous in some of the Eocene subdivisions. Among other geographical changes of which they preserve the chronicles is the evidence of the gradual conversion of portions of the sea-floor over the heart of Europe into wide lake-basins in which thick lacustrine deposits were accumulated. Some of these lakes did not attain their fullest development until the Miocene period.

The Oligocene flora, according to Heer, is composed mainly of an evergreen vegetation, and has characters linking it with the living tropical floras of India and Australia and with the subtropical flora of America. It includes some ferns, fan-palms, and feather-palms (Sabal, Phænicites), a number of conifers (Sequoia, Fig. 432, etc.), cinnamon-trees, evergreen oaks, custard-apples, gum-trees,

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[56] Monatsbericht. Akad. Berlin, 1854, pp. 640–666; 1858, p. 51.

[55] Hector's "Handbook of New Zealand," p. 28.

spindle-trees, oaks, figs, laurels, willows, vines, and proteaceous shrubs (Dryandra, Dryandroides).

Among the mollusca (Figs. 433, 434) some of the more

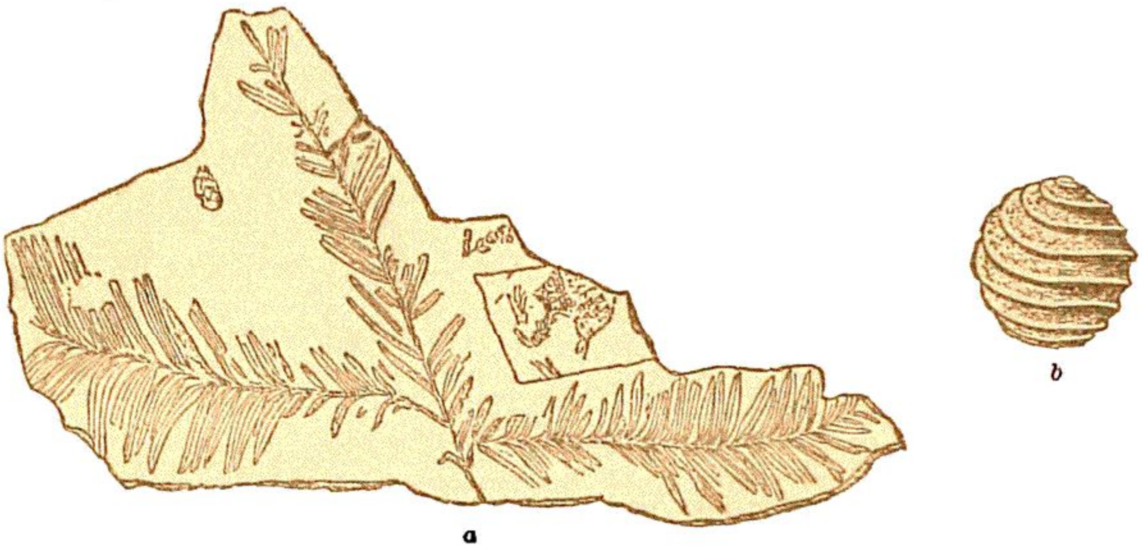

Fig. 432.—Oligocene Plants.
a, Sequoia Langsdorfii, Brongn. ($\frac{1}{2}$) (from Heer's "Flor. Tert. Helvetiæ," i. pl. 21); *b*, Chara Lyellii, Forbes ($\frac{10}{1}$).

important genera are Ostrea, Pecten, Nucula, Cardium, Meretrix (Cytherea), Cyrena, Cancellaria, Murex, Fusus, Typhis, Cassis, Pleurotoma, Conus, Voluta, Cerithium,

Fig. 433.—Oligocene Lamellibranchs.
***a*, Meretrix (Cytherea) incrassata, Sow. ($\frac{2}{3}$); *b*, Ostrea cyathula, Lam. ($\frac{3}{4}$).**

Melania, Planorbis.[57] Numerous remains of birds have been found in the lacustrine beds of the Department of the Allier, no fewer than 66 species having been described, which comprise parroquets, trogons, flamingoes, ibises, peli-

[57] For a list of British Oligocene mollusca, see Mr. R. B. Newton's volume cited on p. 1590.

cans, marabouts, cranes, secretary-birds, eagles, grouse, and numerous gallinaceous birds—a fauna reminding us of that of the lakes in Southern Africa.[58] The mammalia increase

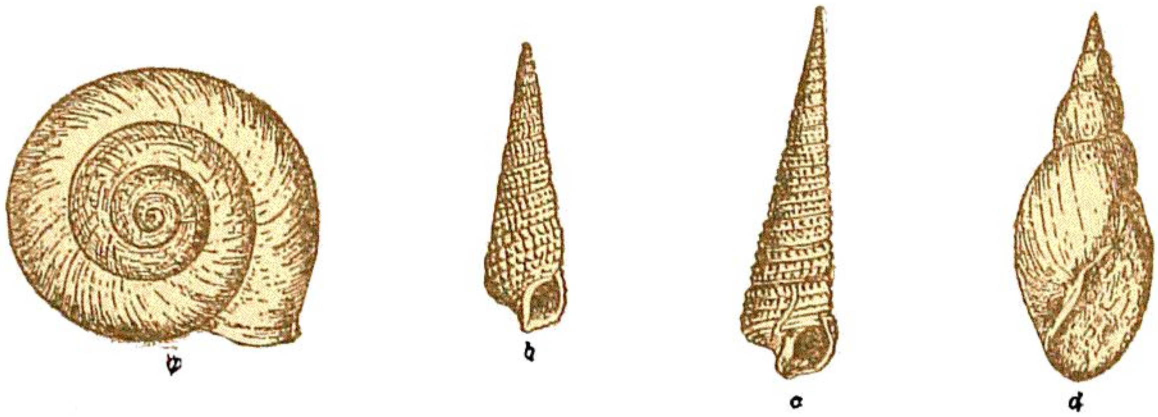

Fig. 434.—Oligocene Gasteropods.
a, Planorbis euomphalus, Sow. ($\frac{2}{3}$); *b*, Terebralia (Cerithium) plicata, Lam. ($\frac{2}{3}$); *c*, Potamides cinctus, Sow. ($\frac{2}{3}$); *d*, Limnæa longiscata, Brongn. ($\frac{2}{3}$).

in variety of forms. According to Gaudry the following chronological sequence of appearances and disappearances during the Oligocene period have been noted:[59]

Upper.—St. Gerand-le-Puy (Allier), Calcaire de Beauce in part, Sables de Fontainebleaux, Hamstead beds.	Appearance of the genera Rhinoceros (?), Tapir, Palæochœrus shrew, Plesiosorex, Mysarachne, mole, musk-rat, Lutrictis, Palæonycteris, Tetracus. Dissappearance of Palæotherium. Reign of Hyopotamus and Anthracotherium.
Middle.—Calcaire de Brie, etc.	Appearance of the genera Cadurcotherium, Hyrachius, Entelodon, Anthracotherium, Dacrytherium, Chalicotherium, Tragulohyus, Lophiomeryx, Hyæmoschus (?), Gelocus, Dremotherium, Thereutherium, dog (?), civet, marten, Plesictis, Plesiogale, Ælurogale, Rhinolophus, Necrolemur.
Lower.—Lacustrine gypsum of Paris, beds of Vaucluse, St. Hippolyte, Caton, Souvignargues, Bembridge beds.	Appearance of the genera opossum, Chœropotamus, Tapirulus, Anoplotherium (Fig. 435), Eurytherium, Cainotherium, Anchilophus, Acotherulum, Cebochœrus, Xiphodon, Amphimeryx, Plesiarctomys, dormouse (?), Trechomys, Galethylax (?), Hyænodon, Adapis. Reign of pachyderms. The carnivora have still partly marsupial characters.

58 A. Milne Edwards, "Oiseaux Fossiles de la France," 1867–71; Boyd Dawkins, "Early Man in Britain," p. 54.

59 "Les Enchainements du Monde Animal," 1878, p. 4.

§ 2. Local Development

Britain.—Oligocene strata are confined to one small area in this country. They occur in the Hampshire basin and Isle of Wight, where, resting conformably upon the top of the Eocene deposits, they consist of sands, clays, marls, and limestones, in thin-bedded alternations. They were accumulated partly in the sea, partly in brackish, and partly in fresh-water. They were hence named by Edward

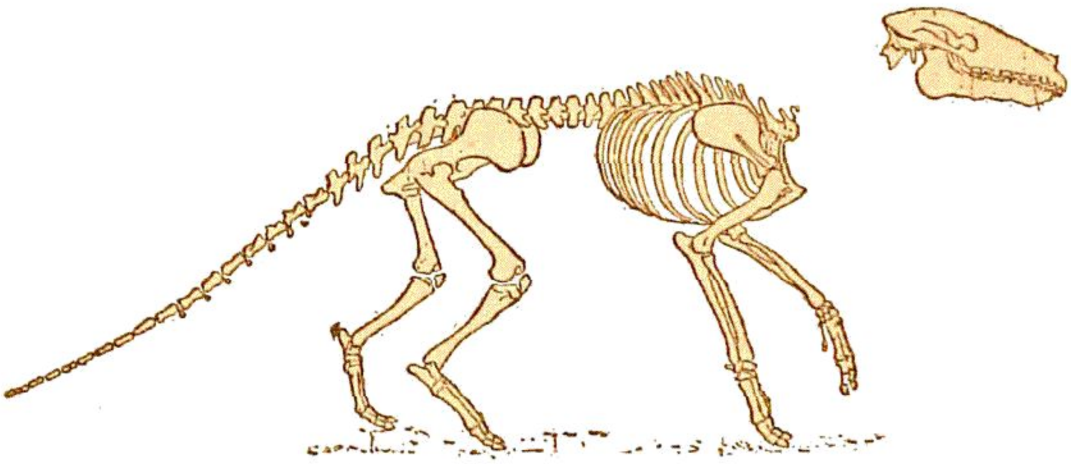

Fig. 435.—Anoplotherium commune, Cuv.

Forbes "the fluvio-marine series," and were divided by him and Mr. Bristow into the following groups in descending order:[60]

Hamstead Beds.—(*b*) Marine stage with Corbula, Cytherea, Ostrea callifera, Voluta, Natica, Cerithium and Melania	31 ft.
(*a*) Fresh-water, estuarine and lagoon stage, with Unio, Cyrena, Cyclas, Paludina, Hydrobia, Melania, Planorbis, Cerithium (rare), turtles, crocodiles, mammals, leaves and seeds	225 "
Bembridge Beds.—(*b*) Bembridge marls—a fresh-water, estuarine and marine series of clays and marls, with Viviparus (Paludina), Melania, Melanopsis, Limnæa, Cyrena, Unio, Ostrea, Cytherea, Mytilus, Nucula	70–120 "
(*a*) Bembridge Limestone—full of fresh-water shells (Limnæa, Planorbis, etc.), and sometimes with many land-shells (Bulimus, Achatina, Helix, etc.)	15–25 "
Osborne Beds.—Marls, clays, shales and limestones, with Limnæa, Planorbis, Paludina, Melanopsis, Melania, Chara, etc. . . .	80–110 "
Headon Beds.—(*c*) Upper stage, consisting of fresh-water clays, marls and bands of limestone, with Potamomya, Limnæa, Cyrena, Unio, Potamides, Planorbis, Paludina, Bulimus, etc. . . .	40–60 "

[60] "Geology of the Isle of Wight," Mem. Geol. Survey, 2d edit. p. 124. The grouping as here given has been slightly modified by Mr. C. Reid in the course of a re-survey of the Isle of Wight. The strata were formerly regarded as Upper Eocene.

(*b*) Middle stage, clays, sands, loams and limestone, with brackish-water and marine fossils (Cerithium, Planorbis, Limnæa, Melania, Natica, Neritina, Ostrea, Cyrena, etc.) . . . . . . 30–126 ft.

(*a*) Lower stage, marls, clays, sandstones and tufaceous limestones with fresh- and brackish-water shells (Limnæa, Paludina, Planorbis, Cyrena, Potamomya, etc.) . . . . . . 60–175 "

A large number of the marine mollusca of the Headon Beds range downward into the Barton Clay, but about half are peculiar to the Oligocene series. Among the more abundant forms in the Isle of Wight are Cytherea incrassata, Ostrea velata, O. flabellula, Nucula headonensis, Cerithium concavum, Melanopsis subfusiformis, Buccinum labiatum, Murex sexdentatus, Nerita aperta, Neritina concava, Ancillaria buccinoides, Melania muricata, and several species of Cancellaria, Natica, Pleurotoma, and Voluta, with Balanus unguiformis. The estuarine and fresh-water strata are marked by species of Potamomya and Cyrena, while the purely fresh-water deposits are full chiefly of Limnæids belonging to the genera Limnæa and Planorbis, L. longiscata and P. euomphalus being perhaps the most abundant and conspicuous species; Paludina lenta is also plentiful. Mr. Reid has remarked that every variation in the salinity of the water seems to have affected the molluscan fauna of the estuary in which these deposits were accumulated. When the water was quite fresh the pond snails flourished in abundance, and their remains were mingled with those of Unio and Helix. The gradual inroad of salt water is marked by the advent of Potamomya, Cyrena, Cerithium (Potamides), Melania, and Melanopsis, while the thoroughly marine fauna with volutes and cones shows when the sea had entirely replaced the fresh water.[61]

The Bembridge Limestone, one of the most conspicuous members of the Oligocene series in the Isle of Wight, is a remarkable example of a fresh-water limestone, full of fresh-water and terrestrial shells and nucules of Chara. The land-shells comprise tropical-looking gigantic species of Bulimus and Achatina. An interesting feature in the overlying Bembridge marls is the occurrence of a thin band from two inches to two feet in thickness of a fine-grained limestone like lithographic stone, containing many insect-remains with leaves and fresh-water shells. Some twenty genera of insects have been detected in it, including forms of coleoptera,

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[61] C. Reid, "Geology of the Isle of Wight," Mem. Geol. Survey, p. 147.

hymenoptera, lepidoptera, diptera, neuroptera, orthoptera, and hemiptera.[62]

The Hamstead (formerly Hempstead) beds form an interesting close to the Oligocene series. They consist chiefly of fresh-water, estuarine, and lagoon deposits. But they pass upward into a group of marine strata of which only about 30 feet are now visible. Among the more abundant or peculiar of the shells in this marine band the following may be mentioned: Ostrea cyathula, O. adlata (both peculiar), Cytherea Lyellii, Corbula pisum, C. vectensis, Cuma Charlesworthi, Voluta Rathieri, Cerithium plicatum, C. Sedgwickii, C. inornatum, Strebloceras.[63]

Considerable interest attaches to the marine band forming the middle division of the Headon beds, as it serves for a basis of correlation between the English strata and their equivalents on the Continent. The band, so well seen in the Isle of Wight, occurs also at Brockenhurst and other places in the New Forest. It has yielded more than 230 species of fossils, almost all marine mollusks, but including also 14 species of corals. Of these organisms, a considerable proportion is common to the Lower Oligocene of France, Belgium, and Germany, and 22 species are found in the Upper Bagshot beds.[64]

The Oligocene or fluvio-marine series of the Hampshire basin has likewise yielded vertebrate remains such as characterize the corresponding deposits of the Continent. They include those of rays (Myliobates), snakes (Palæoryx), crocodiles, alligators, turtles (Emys, Trionyx, numerous species), and a cretacean (Balænoptera); while from the Bembridge beds have come the bones of a number of the characteristic mammals (Anchilophus, Anthracotherium, Anoplotherium, two species, Palæotherium, six or more species, Chœropotamus, Dichodon). The top of the fluvio-marine series in the Isle of Wight has been removed in denudation, so that the records of the rest of the Oligocene period have there entirely disappeared.

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62 H. Woodward, Quart. Journ. Geol. Soc. xxxv. p. 342. C. Reid, "Geology of the Isle of Wight," p. 177.

63 C. Reid, op. cit. p. 206.

64 A. von Koenen, Q. J. Geol. Soc. xx. 1864, 97. Duncan, op. cit. xxvi. 1870, p. 66. J. W. Judd, op. cit. xxxvi. 1880, p. 137; xxxviii. 1882, p. 461. H. Keeping and E. B. Tawney, op. cit. xxxvii. 1881, p. 85; xxxix. 1883, p. 566. E. B. Tawney, Geol. Mag. 1883, p. 157. W. Keeping, Geol. Mag. 1883, p. 428. J. W. Elwes, Brit. Assoc. 1882. Sects. p. 539.

For many years it was customary to consider as Miocene certain plant-bearing strata, of which a small detached basin occurs at Bovey Tracey, Devonshire, but which are mainly distributed in the great volcanic plateaus of Antrim and the west of Scotland. These strata have since been regarded as equivalents of what are now termed Oligocene formations on the Continent. At the Bovey Tracey locality, which is not more than 80 miles from the Eocene leaf-beds of Bournemouth and the Isle of Wight, a small but interesting group of sand, clay, and lignite beds, from 200 to 300 feet thick, lies between the granite of Dartmoor and the Greensand hills, in what was evidently the hollow of a lake. From these beds, Heer of Zurich, who has thrown so much light on the Tertiary floras of both the Old World and the New, described about 50 species of plants, which, in his opinion, place this Devonshire group of strata on the same geological horizon with some part of the Molasse or Oligocene (Lower Miocene) groups of Switzerland. Among the species are a number of ferns (Lastræa stiriaca, Pecopteris [Osmunda] lignitum, etc.); some conifers, particularly Sequoia Couttsiæ, the matted débris of which forms one of the lignite beds; cinnamon-trees, evergreen oaks, custard-apples, eucalyptus, spindle-trees, a few grasses, water-lilies, and a palm (Palmacites). Leaves of oaks, figs, laurels, willows, and seeds of grapes have also been detected—the whole vegetation implying a subtropical climate.[65] More recently, however, Mr. Starkie Gardner has expressed the opinion that this flora is on the same horizon as that of Bournemouth, that is, in the Middle Eocene group.[66] If this view were established, the volcanic rocks of the northwest, with their leaf-beds, might be also relegated to the Eocene period. In the meantime, however, they are placed in the Oligocene series as probable equivalents of the brown-coal and molasse of the Continent.

The plateaus of Antrim, Mull, Skye, and adjacent islands are composed of successive outpourings of basalt, which are prolonged through the Faroe Islands into Iceland, and even far up into Arctic Greenland. In Antrim, where the great basalt sheets attain a thickness of 1200 feet, there occurs in them an intercalated band about 30 feet thick, consisting of

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65 Phil. Trans. 1862.

66 "British Eocene Flora," Palæont. Soc. 1879, p. 18. See also Q. J. Geol. Soc. xli. p. 82. The great uncertainty in the correlation of deposits by means of land-plants has been already referred to (pp. 1095, 1111, 1577).

tuffs, clays, thin conglomerate, pisolitic iron-ore and thin lignites. Some of these layers are full of leaves and fruits of terrestrial plants, with occasional insect-remains. According to the data collected by a Committee of the British Association, upward of thirty species of plants have been obtained, including conifers (Cupressinoxylon, Taxodium, Sequoia, Pinus), monocotyledons (Phragmites, Poacites, Iris), dicotyledons (Salix, Populus, Alnus, Corylus, Quercus, Fagus [?], Platanus, Sassafras, Acer, Andromeda, Viburnum, Aralia, Nyssa, Magnolia, Rhamus, Juglans, etc.)[67] In the west of Scotland the volcanic sheets attain still greater dimensions, reaching in Mull a thickness of 3000 feet, and there also including thin tuffs, leaf-beds, and coals. In Mull, Skye, and Antrim, the terraces of basalt, with occasional comparatively thin bands of tuff, form a noble example of the extravasation of great piles of lava without the formation of central cones or the discharge of much fragmentary matter (p. 437). They have been invaded by huge bosses of gabbro and of various granitoid rocks, which send veins into and alter the basalt. They are likewise traversed by veins of pitchstone, but more especially by prodigious numbers of basalt-dikes, which in Scotland have a prevalent W.N.W. and E.S.E. direction. The basalt-plain was channelled by rivers, and into the ravines thus eroded streams of pitchstone made their way (Scuir of Eigg), whence it is evident that the volcanic eruptions lasted during a protracted period.[68]

France.—In the Paris basin, where a perfect upward passage is traceable from Eocene into Oligocene beds, the latter are composed of the following subdivisions:[69]

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[67] W. H. Baily, Brit. Assoc. 1879, Rep. p. 162; 1880, p. 107; 1881, p. 152. On the north coast of Antrim, near Ballintoy, a band of tuff occurs about 150 feet thick. But in Ireland, as in Scotland, the tuffs take quite a subordinate place among the great piles of basalt.

[68] Proc. Roy. Soc. Edin. vi. 1867, p. 71; Q. J. Geol. Soc. xxvii. 1871, p. 280; Trans. Roy. Soc. Edin. xxxv. 1888, p. 21; Q. J. Geol. Soc. xlviii. 1892, Pres. Address, p. 162. Prof. Judd (op. cit. xxx. 1874, p. 220; xlv. 1889, p. 187), on the other hand, believes that there were five great volcanic cones in the Western Islands whence the streams of basalt flowed, and of which the mountains of Mull, Skye, etc., are the degraded ruins, and he regards the granitoid rocks as older than the others.

[69] Dollfus, Bull. Soc. Geol. France, 3e ser. vi. 1878, p. 293. The separation of an Oligocene series in the Paris basin is not admitted by many eminent French geologists.

Upper.	**Helix-limestone** of the Orleanais (Helix, Planorbis, etc.). **Meulieres de** Montmorency—very hard siliceous, cellular, fossiliferous, fresh-water limestones employed for millstones (Limnæa, Bythinia, Planorbis, Valvata, Chara). This deposit is replaced toward the south by the fresh-water Calcaire de la Beauce, which is separable into a higher assise (Molasse du Gâtinais, sometimes 57 feet) consisting of green marl, siliceous sand and calcareous sandstone passing into limestones (Helix Morognesi, H. aurelianus, H. Tristani, Planorbis solidus, Limnæa Larteti, Melania aquitanica, etc.); and a lower, composed of limestone (Limnæa Brongniarti, L. cornea, L. cylindrica, Helix Ramondi, Cyclostoma antiquum, Planorbis cornu, Potamides Lamarcki, etc.). Gres de Fontainebleau. Sands, and hard siliceous sandstones. At the top of this subdivision there occurs at Ormoy, near Étampes, and elsewhere a band of calcareous marl full of marine fossils: Cardita Bazini, Cytherea incrassata, Lucina Heberti.
Middle.	Sables de Fontenay, Jeurre et Morigny, a thick accumulation of yellow ferruginous, generally unfossiliferous sands, covering a large area around Paris, and serving as a foundation for most of the new military forts of that locality. The "falun de Jeurre" contains many fossils: Natica crassatina, Cerithium, several species, Cytherea incrassata, Avicula stampinensis, etc. Oyster-marls with Ostrea longirostris, O. cyathula, and Corbula subpisum. These pass into the Molasse d'Étrechy with Cerithium plicatum, Melania semidecussata, Cytherea incrassata, etc. Calcaire de la Brie, a lacustrine limestone with few fossils, Limnæa cornea, Planorbis cornu, Chara, etc. Green marls (Marnes à Cyrènes, glaises vertes), consistting of an upper mass of non-fossiliferous clay, and a lower group of fossiliferous laminated marls (Cerithium plicatum, Psammobia plana, Cyrena convexa).
Lower.	White marls (Marnes de Pantin) with Limnæa strigosa, Planorbis planulatus, Nystia Duchasteli. Supra-gypseous blue marls, with very few fossils (Nystia plicata). Lacustrine gypsum (Gyps lacustre). The highest and most important gypsum bed of the Paris basin, 65 feet thick at Montmartre, with a remarkable prismatic structure, containing skeletons and bones of mammals (Palæotherium, Anoplotherium, Xiphodon), fragments of terrestrial wood, and a few terrestrial shells (Helix, Cyclostoma, etc.). This deposit is continuous with the marine gypsum underneath it (p. 1607).

Geographical names have been assigned to the subdivisions of the Oligocene series in France, Belgium, Switzerland, and North Italy. The lowest member is called Tongrian, from Tongres, in Limbourg. Above it comes the Stampian, so named from Etampes, where it is typically developed. The uppermost group is known as Aquitanian, from its well-marked occurrence in Aquitania.

The chief area of Oligocene strata in France lies between Paris and Orleans, where, spreading over a wide extent of country, they have been cut down by the streams so as in some cases to reveal the Eocene formations below them. The next area in importance lies far to the southwest (Aquitania), where the Lower Oligocene division (Tongrian of

Belgium) is represented by a thick yellowish marine limestone (Calcaire à Astéries) with Cerithium plicatum, Trochus Bucklandi, Natica crassatina, etc. The Aquitanian stage is represented in Languedoc by marine marls with Cerithium, and marine conditions are indicated by the corresponding deposits in Provence.

But over the centre and south of France marine Oligocene deposits are generally absent, their place being taken by the marls, clays, and limestones of former lakes, which have preserved many of the terrestrial plants and animals of the period. One or more large sheets of fresh water lay in the heart of the country, surrounded by slopes clothed with a tropical flora. In these basins, a series of marls and limestones (1500 feet thick in the Limagne d'Auvergne) accumulated, from which have been obtained the remains of nearly 100 species of mammals, including some palæotheres, like those of the Paris basin, a few genera found also in the Mainz basin, crocodiles, snakes, numerous birds, and relics of the surrounding land-vegetation of the time. This water-basin appears to have been destroyed by volcanic explosions, which afterward poured out the great sheets of lava, and formed the numerous cones or *puys* so conspicuous on the plateau of Auvergne. In the south of France, the Eocene groups are sometimes surmounted by lacustrine or brackish-water beds that point to the retirement of the nummulitic sea, and the advent of those more terrestrial and shallow-water conditions in which the Oligocene deposits were accumulated. In Provence, lacustrine beds (Physa, Planorbis, Limnæa, Bulimus, etc.) lie immediately upon the Upper Cretaceous rocks. At Aix these beds have long been noted for their abundant plants (Callitris Brongniarti, Widdringtonia brachyphylla, Flabellaria lamanonis, Quercus, Laurus, Cinnamomum), insects and mammals (Palæotherium, Xiphodon, Anoplotherium, Chœropotamus).

A singular and interesting development of Oligocene deposits in France, Switzerland, and southern Germany is found where they have filled up fissures and cavities of older, especially Upper Jurassic, limestones. One of the most remarkable of these occurrences is that of Quercy, now famous for the large number of remains of mammals which have been found there. These deposits are related to Tertiary strata in their vicinity, and never occur at a higher altitude than these strata. They consist of red clay and loam, with pisolitic limonite. becoming more phosphatic toward the bottom, where the phosphate of lime occurs in such quantity as to be profitably worked. Among the fossils recovered from these recesses are a number of shells (Cyclostoma, Limnæa, Planorbis) and species of Palæotherium, Anoplotherium, Xiphodon, Hyænodon, Cainotherium, Amphitragulus, etc. There have also been found the remains of a lemur (Necrolemur antiquus).[70]

Belgium.[71]—The succession of Oligocene beds in this country differs from that of France, and has received a different nomenclature, as follows:

Upper.—Wanting.

Middle	Rupelian	Marine	White sands of Bolderberg (Bolderian). Clay of Boom and Nucula clay of Bergh—upward of 40 species of fossils, including Nucula compta (Leda lyelliana), Corbula subpisum (=" Septarienthon " of northern Germany).
		Fluvio-marine.	Cerithium sands of Vieux Jonc (Klein Spauwen) and Pectunculus sands of Bergh. Henis clay. The fossils in this clay and the overlying sands are fluvio-marine (Cyclostoma, Succinea, Pupa; Planorbis, Limnæa, Neritina; Cerithium, Melania, Bythinia, Cyrena).
Lower	Tongrian	Marine	Sands of Neerepen. Sands of Grimmertingen. The Tongrian deposits contain an abundant marine funa = the Egeln beds of Germany.

Germany.[72]—In northern Germany, while true Eocene deposits are wanting, the Oligocene groups are well developed both in their marine and fresh-water facies, and it was from their characters in that region that Beyrich proposed for them the term Oligocene. They occupy large more or less detached areas or basins, with local lithological and palæontological variations, but the following general subdivisions have been established:

Upper.	Marine marls, clays, sands, sparingly distributed (Doberg, Hanover; Wilhelmshöhe; Mecklenburg-Schwerin), with Spatangus Hoffmanni, Terebratula grandis, Pecten Janus, P. decussatus, Arca Speyeri, Nassa pygmæa, Pleurotoma subdenticulata. Brown-coal deposits of the Lower Rhine,[73] etc., with a flora of less tropical Indian and Australian type and more allied to that of subtropical North America (Acer, Cinnamomum, Cupressinoxylon, Juglans, Nyssa, Pinites, Quercus, etc.). Some marine beds in this division contain Terebratula grandis, Pecten Janus, P. Münsteri, etc.

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[70] Filhol, Ann. Sci. Geol. 1876.

[71] Mourlon, "Geol. Belg."

[72] Beyrich, Monatsbericht. Akad. Berlin, 1854, p. 640; 1858, p. 51. A. von Koenen, Zeitsch. Deutsch. Geol. Ges. xix. 1867, p. 23.

[73] For a popular account of the brown-coal of Germany see M. Vollert, "Der

Middle.

Stettin (Magdeburg) sand and Septaria-clay (Septarienthon), with an abundant marine fauna (Foraminifera, Pecten permistus, Leda deshayesiana, Nucula Chasteli, Pleurotoma scabra, Axinus obtusus, Fusus Koninckii, F. multisulcatus, etc.). These beds are widely distributed in north Germany, and are usually the only representatives there of the Middle Oligocene deposits. In some places, however, a local brown-coal group occurs (Alnus Kefersteini, Cinnamomum polymorphum, Populus Zaddachi, Taxodium dubium).

Lower.

Egeln marine beds (Ostrea ventilabrum, Pecten bellicostatus, Leda perovalis, Arca appendiculata, Cardita Dunkeri, Cardium Hausmanni, Cytherea Solandri, Cerithium lævum, Pleurotoma Beyrichi, P. subconoidea, Voluta decora, Buccinum bullatum, etc., and corals of the genera Turbinolia, Balanophyllia, Caryophyllia, Cyathina).[74]

Amber beds of Königsberg, consisting of lignitiferous sands resting on marine glauconitic sands, near the base of which lies a band containing abundant pieces of amber. The latter, derived from several species of conifers, especially Pinus succinifera, have yielded a plentiful series, estimated at about 2000 species, of insects, arachnids and myriapods, together with the fruits, flowers, seeds, and leaves of a large number of conifers (Pinites, Pinus, Abies, Sequoia Langsdorfii, Widdringtonites, Libocedrus, Thuja, Capressus, Taxodium) and dicotyledons (Quercus, Castanea, Fagus, Myrica, Polygonum, Cinnamomum, Geranium, Linum, Acer, Ilex, Rhamnus, Deutzia, Proteaceæa, several genera, Andromeda, etc.)[75] The sands contain Lower Oligocene marine mollusca, sea-urchins, etc.

Lower Brown-coal series—sands, sandstones, conglomerates and clays with interstratified varieties of brown-coal (pitch-coal, earthy lignite, paper-coal, wax-coal, etc.), a single mass of which sometimes attains a thickness of 100 feet or more. These strata may be traced intermittently over a wide area of northern Germany. The flora of the brown-coal is largely composed of conifers (Taxites, Taxoxylon, Cupressinoxylon, Sequoia, etc.), but also with Quercus, Laurus, Cinnamomum, Magnolia, Dryandroides, Ficus, Sassafras, Alnus, Acer, Juglans, Betula and palms (Sabal, Flabellaria). The general aspect of this flora most resembles that of the southern states of North America, but with relations to earlier tropical floras having Indian and Australian affinities.

In the Mainz basin some marine sands, clays, and marls in the lower part of its Tertiary deposits are referred to the Oligocene series, and are arranged as follows:

Cerithium Beds.—Sandy and calcareous strata with brackish-water and land-shells (Cerithium plicatum, Mytilus Faujasi, Helix, etc.).

Cyrena marl and sand (Cyrena semistriata, Cerithium plicatum, C. margaritaceum, Perna Sandbergeri, etc.).

Braunkohlenbergbau," Halle, 1889, the "Festschrift" of the fourth Deutsche Bergmannstage in 1889.

[74] For detailed descriptions of the Lower Oligocene molluscan fauna of north Germany see Prof. A. von Koenen's elaborate monograph, Abhand. Geol. Specialkart. Preuss. x. 1889-92.

[75] "Flora des Bernsteins," vol. i. on the coniferæ, H. R. Goeppert, 1883, vol. ii. on the dicotyledons, Goeppert, A. Menge and H. Conwentz, 1886.

Septaria-clay with Leda deshayesiana.
Marine sand of Weinheim with Ostrea callifera, Pectunculus obovatus, Cytherea incrassata, Natica crassatina.

Switzerland.[76]—Nowhere in Europe do Oligocene strata play so important a part in the scenery of the land, or present on the whole so interesting and full a picture of the state of the Continent when they were deposited, as in Switzerland. Rising into massive mountains, as in the well-known Rigi and Rossberg, they attain a thickness of several thousand feet. While they include proofs of the presence of the sea, they have preserved with marvellous perfection a large number of the plants which clothed the Alps, and of the insects which flitted through the woodlands. They form part of a great series of deposits which have been termed "Molasse" by the Swiss geologists. The Molasse was formerly considered to be entirely Miocene. The lower portions, however, are now placed on the same parallel with the Oligocene beds of the regions lying to the north, and consist of the following subdivisions:

Lower Brown-coal or red Molasse (Aquitanian stage)—the most massive member of the Molasse, consisting of red sandstones, marls, and conglomerates (Nagelflue) with well-rounded mutually indented pebbles, resting upon variegated red marls. It contains seams of lignite, and a vast abundance of terrestrial vegetation.

Lower marine Molasse (Tongrian stage)—sandstone containing marine and brackish-water shells, among which are Ostrea cyathula, O. longirostris, O. callifera, Cyrena semistriata, Cytherea incrassata, Pectunculus obovatus, Cerithium plicatum, Natica crassatina. This division is well developed between Basel and Berne.

By far the larger portion of these strata is of lacustrine origin. They must have been formed in a large lake, the area of which probably underwent gradual subsidence during the period of deposition, until in Miocene times the sea once more overflowed the area. We may form some idea of

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[76] Studer's "Geologie der Schweiz," vol. ii.; Heer's "Urwelt der Schweiz," 1865 (an English translation of which by Mr. W. S. Dallas appeared in 1876); "Flora Fossilis Helvetiæ," 1854–59; A. Favre, "Description Geologique du Canton de Geneve," 1880, vol. i. p. 69.

the importance of the lake from the fact that the deposits formed in its waters are upward of 9000 feet thick. Thanks to the untiring labors of Prof. Heer, we know more of the vegetation of the mountains round that lake, during Oligocene and Miocene time, than we do of that of any other ancient geological period. The woods were marked by the predominance of an arborescent subtropical vegetation, among which evergreen forms were conspicuous, the whole having a decidedly American aspect. Among the plants were palms of American type, the Californian coniferous genus Sequoia, alders, birches, figs, laurels, cinnamon-trees, evergreen oaks, with many other kinds.

A portion of the great Flysch formation of the Alps (which has been already referred to as partly Cretaceous, partly Eocene) is referred to the Oligocene series. It includes the shales of Glarus, long known for their fish-remains.

Vienna Basin.[77]—This area contains a typical series of Tertiary deposits, sometimes classed together as "Neogene." At the bottom lies an inconstant group of marls and sandstones (Aquitanian stage), containing occasional seams of brown-coal and fresh-water beds, but with intercalations of marine strata. The marine layers contain Cerithium plicatum, C. margaritaceum, etc. The brackish and fresh-water beds yield Melania Escheri and Cyrena lignitaria. Among the vertebrates are Mastodon angustidens, M. tapiroides, Rhinoceros sansaniensis, Amphicyon intermedius, Anchitherium aurelianense, and numerous turtles. These strata have suffered from the upheaval of the Alps, and may be seen sometimes standing on end. It is interesting also to observe that the subterranean movements east of the Alps culminated in the outpouring of enormous sheets of trachyte, andesite, propylite, and basalt in Hungary and along the flanks of the Carpathian chain into Transylvania. The volcanic action appears to have begun during the Aquitanian stage, but continued into later time. Further curious changes in physical geography are revealed by the other "Neogene" deposits of southeastern Europe. Thus in Croatia, the Miocene marls, with their abundant land-plants, insects, etc., contain two beds of sulphur (the upper 4 to 16

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[77] Suess, "Der Boden von Wien, "1860. Th. Fuchs, "Erläuterungen zur Geol. Karte der Umgebungen Wiens," 1873; and papers in Zeitsch. Deutsch. Geol. Gesel. 1877, p. 653; Jahrb. Geol. Reichsanst. vols. xviii. *et seq.* Von Hauer's "Geologie."

inches thick, the under 10 to 15 inches), which have been worked at Radoboj. At Hrastreigg, Buchberg, and elsewhere, coal is worked in the Aquitanian stage in a bed sometimes 65 feet thick. In Transylvania, and along the base of the Carpathian Mountains, extensive masses of rock-salt and gypsum are interstratified in the "Neogene" formations.

Italy.—In the north of Italy strata assigned to the Oligocene series attain an enormous development, their total estimated thickness amounting to nearly 12,000 feet. They dovetail regularly with the Eocene below and the Miocene above, and are thus grouped by Prof. Sacco in the central part of the northern Apennines:

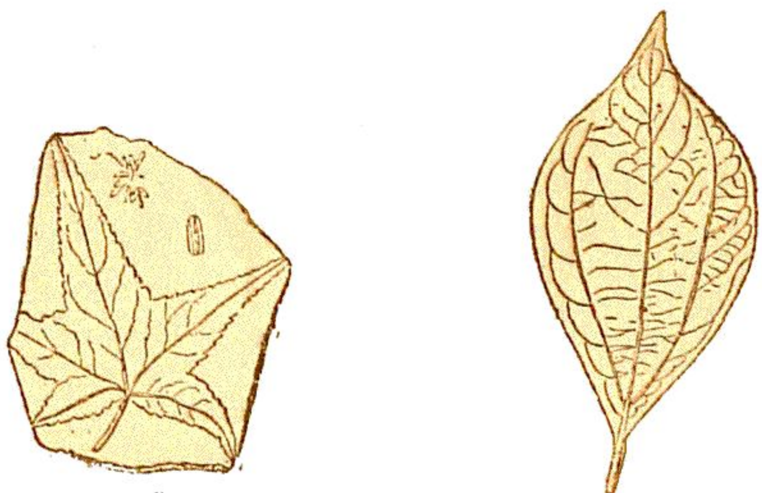
Aquitanian Stage 1000 metres	A great thickness of gray and yellowish sands and occasional grayish marls, the marly character increasing northward and eastward. Fossils scarce.
Stampian Stage 600 metres	Gray marls more or less sandy and friable.
Tongrian Stage 2000 metres	A vast series of sandy marls, sands, conglomerates, and lenticles of lignite, with frequent nummulites (N. intermedia, N. Fichteli, N. striata), Orbitoides, fresh-water, brackish, and marine shells (Ampullina crassatina, Potamides, Cyrena convexa, etc.), Anthracotherium magnum, etc. Sometimes with grayish violet marls.
Sestian Stage 20 metres	A thin band of sandy marls with Nummulites Fichteli, N. vasca, N. Boucheri, Orbitoides, Heterostegina, etc.

North America.—Overlying the Jackson beds referred to on p. 1612 a conformable group of strata known as the "Vicksburg beds" (Orbitoitic) occupies a narrow band in Alabama, Mississippi, and Louisiana, covers the greater part of Florida, and extends into Georgia and Texas. These strata in Mississippi are composed of a lower ferruginous rock (Red Bluff) 12 feet thick, and a set of crystalline limestones and blue marls (80 feet) resting on lignitic clays and lignites (20 feet). Among the fossils are Ostrea gigantea, Pecten Poulsoni, Cardium diversum, Cardita planicosta, Panopæa oblongata, Cypræa lintea, Mitra mississippiensis, Cassidaria lintea, Conus sauridens, Madrepora mississippiensis, Flabellum Wailesii, Orbitoides Mantelli. The last-named fossil is specially characteristic, and is found also in the West Indies, Malta, and the Turco-Persian frontier.

Section iii. Miocene

§ 1. General Characters

The European Miocene deposits reveal great changes in the geography of the Continent as compared with its condition in earlier Tertiary time. So far as yet known, Britain and northern Europe generally, save an area over the site of Schleswig-Holstein and Friesland, were land during the Miocene period; but a shallow sea extended toward the southeast and south, covering the lowlands of Belgium and the basin of the Loire. The Gulf of Gascony then swept



a. b

Fig. 436.—Miocene Plants.
a, Liquidambar europæum, Braun. ($\frac{1}{3}$); *b*, Cinnamomum Buchi, Heer ($\frac{2}{3}$).

inland over the wide plains of the Garonne, perhaps even connecting the Atlantic with the Mediterranean by a strait running along the northern flank of the Pyrenees. The sea washed the northern base of the now uplifted Alps, sending, as in Oligocene time, a long arm into the valley of the Rhine as far as the site of Mainz, which then probably stood at the upper end, the valley draining southward instead of northward. The gradual conversion of salt into brackish and fresh water at the head of this inlet took place in Miocene time. From the Miocene firth of the Rhine, a sea-strait ran eastward, between the base of the Alps and the line of the Danube, filling up the broad basin of Vienna, sending thence an arm northward through Moravia, and spreading far and wide among the islands of southeastern Europe, over the regions where now the Black Sea and Caspian basins remain as the last relics of this Tertiary extension of the ocean across

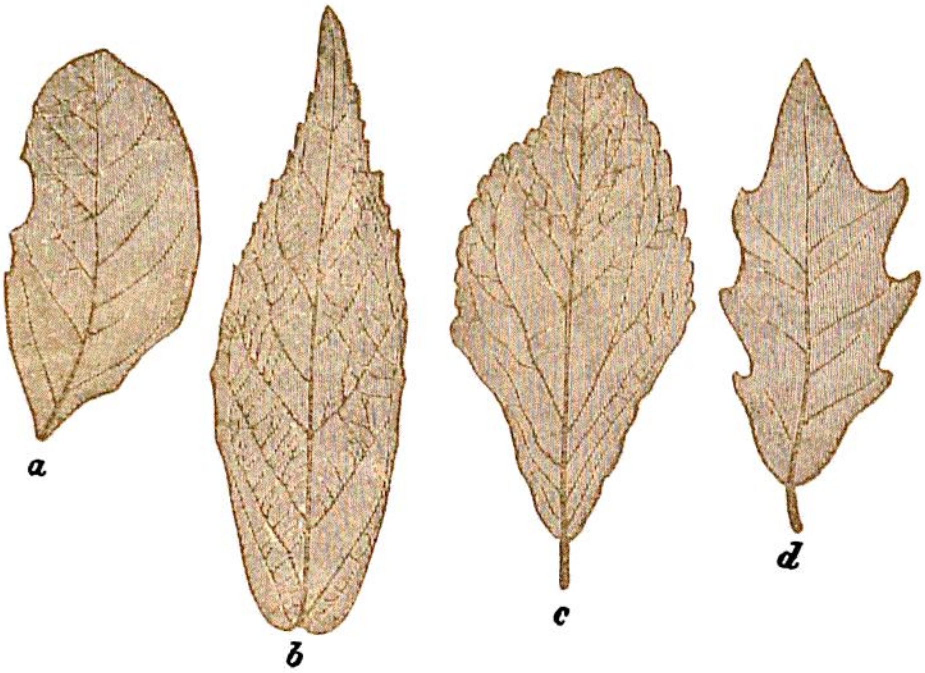


Fig. 437.—Miocene Plants.

a, Magnolia Inglefieldi (1/3); *b*, Rhus Meriani (nat. size). *c*, Ficus decandolleana (1/2); *d*, Quercus ilicoides (2/3).

southern Europe. The Mediterranean also still presented a far larger area than it now possesses, for it covered much of the present lowlands and foothills along its northern border, and some of its important islands had not yet appeared or had not acquired their present dimensions.

Among the revolutions of the time not the least important in European geography was the continued uprise of the Alps by which the Eocene strata had been so convoluted and overthrown. These disturbances still went on in a diminished degree in Miocene time. One of their results was the restoration and extension of the wide lake or chain of lakes, over the northern or molasse region of Switzerland, in which the red molasse of Oligocene time had been deposited. The lacustrine deposits accumulated there have preserved with remarkable fulness a record of the terrestrial flora and fauna of the time.

The flora of the Miocene period (Figs. 436, 437) indicates a decidedly subtropical climate in the earlier part of

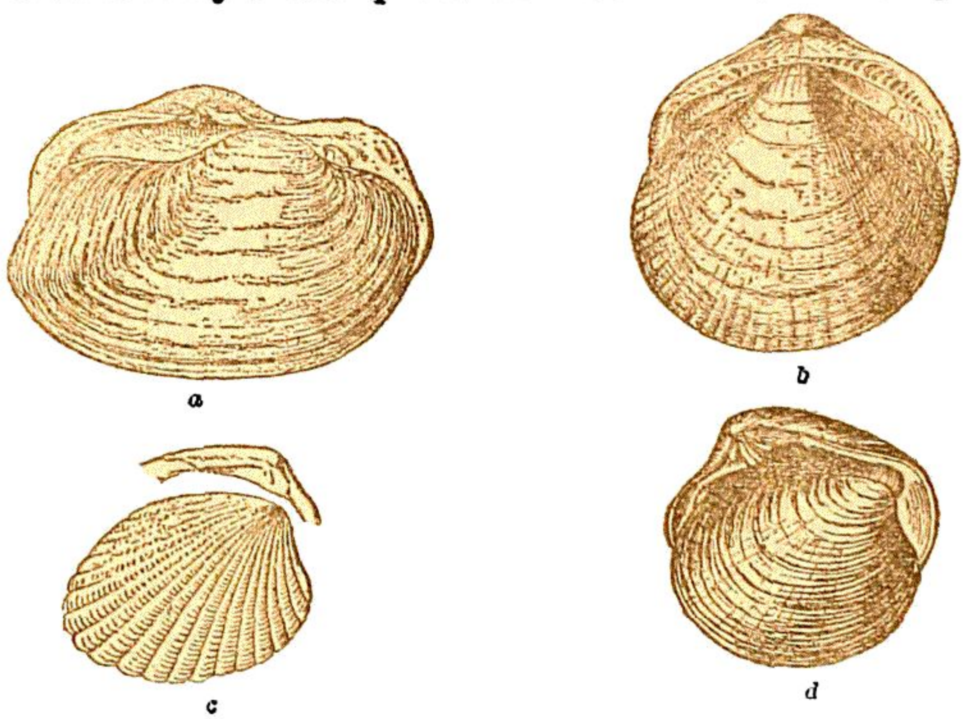


Fig. 438.—Miocene Mollusks.
a, Panopæa Faujasii, Men. de la Groye ([illegible]); *b*, Pectunculus glycimeris (P. pilosus), Linn. ([illegible]); *c*, Cardita affinis, Duj.; *d*, Tapes gregaria, Partsch. ([illegible]).

that period in Europe, many of the plants having their nearest modern representatives in India and Australia.[78] Among the more characteristic genera are Sabal, Phœnicites, Libocedrus, Sequoia, Myrica, Quercus, Ficus, Laurus, Cinnamomum, Daphne, Persaonia, Banksia, Dryandra, Cissus, Magnolia, Acer, Ilex, Rhamnus, Juglans, Rhus, Myrtus, Mimosa, and Acacia. In the later part of the period, the climate, if we may judge from the character of

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[78] Heer, "Urwelt der Schweiz"; "Flora Fossilis Helvetiæ."

the flora, had become less warm; for as the palms disappeared there came the flora of a more temperate type, including among the more frequent plants species of Glyptostrobus, Betula, Populus, Carpinus, Ulmus, Laurus, Persea, Ilex, Podogonium, and Potamogeton.[79]

The fauna points to somewhat similar climatal conditions in Europe. There occur such molluscan genera as Ancillaria, Buccinum, Cancellaria, Cassis, Cypræa, Mitra, Murex, Pyrula, Strombus, Terebra, Arca, Cardita, Cardium, Cytherea, Mactra, Ostrea, Panopæa, Pecten, Pectunculus,

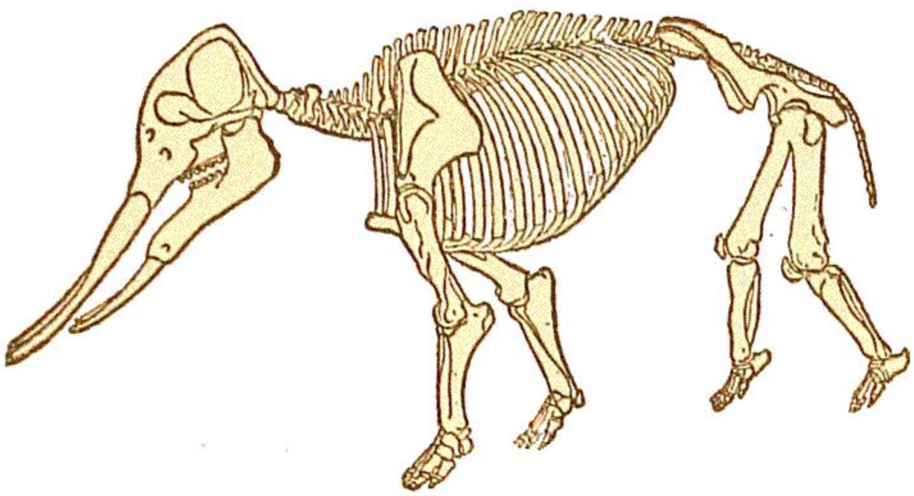

Fig. 439.—Mastodon angustidens, Owen. Reduced from restoration by M. Gaudry.[80]

Spondylus, Tapes, Tellina, etc. (Fig. 438). The mammalian forms present many points of contrast with those of older Tertiary time. Huge proboscideans now take a foremost place. Among the more important generic types of the time are the colossal Mastodon (Fig. 439) and Deinotherium (Fig. 440), the latter having tusks curving downward from the lower jaw. With these are associated Rhinoceros, of which a hornless and a feebly horned species have been

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[79] Saporta, "Monde des Plantes," p. 272.

[80] For a restoration of M. americanus, see Marsh, Amer. Journ. Sci. xliv. 1892, p. 350.

noted; Anchitherium, a small horse-like animal, about as big as a sheep, surviving from earlier Tertiary time; Macrotherium, a huge ant-eater; Dicroceras, a deer allied to the living muntjak of eastern Asia; Hyotherium, an animal nearly related to the hog. A number of living genera likewise made their entry upon the scene, such as the hog, otter, antelope, beaver, and cat. Some of the most formidable animals were the sabre-toothed tigers (Machairodus), and the earliest form of bear (Hyænarctos). The

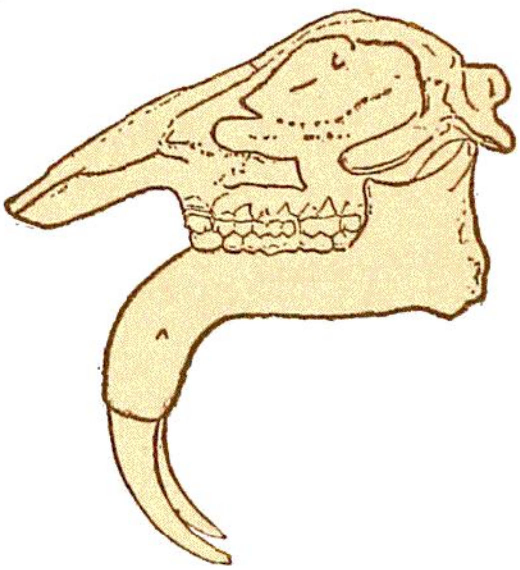

Fig. 440.—Deinotherium giganteum, Kaup., reduced.

Miocene forests were also tenanted by apes, of which several genera have been detected. Of these, Pliopithecus was probably allied to the anthropoid apes; Dryopithecus (Fig. 441) was regarded by Owen as allied to the living gibbons, but Gaudry regards it as an anthropoid form, and as the only one yet found fossil which can be compared with man;[81] Oreopithecus is supposed to have had affinities with the anthropoid apes, macaques, and baboons; and a species of Colobus is found in Wurtemburg.[82]

[81] Mem. Soc. Geol. France (3), i. fasc. 1, 1890.

[82] Gaudry, "Les Enchaînements," p. 306; Boyd Dawkins, "Early Man in Britain," p. 57.

Among the discoveries in western America, which have thrown so much light upon the history of vertebrate life, mention should be made here of the remarkable assemblage of mammals disinterred from the base of the vast lacustrine Miocene formations on the eastern flanks of the Rocky Mountains. The Brontotheridæ or Titanotheridæ, the largest of these animals, formed a distinct family more nearly allied to the living rhinoceros than to any other recent form.

Considerable uncertainty must be admitted to rest upon the correlation of the later Tertiary deposits in different parts of Europe. In many cases, their stratigraphical

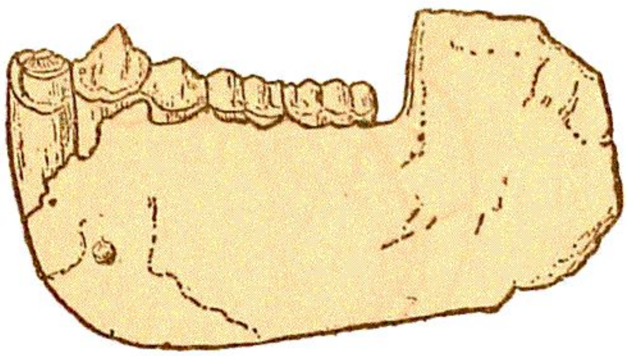

Fig. 441.—Jaw of Dryopithecus Fontani, Gaudry (2/3).

relations are too obscure to furnish any clew, and their identification has therefore to be made by means of fossil evidence. But this evidence is occasionally contradictory. For example, the remarkable mammalian fauna described by M. Gaudry from Pikermi in Attica (postea, p. 1670) has so many points of connection with the recognized Miocene fauna of other European localities, that this observer classed it also as Miocene. He has pointed out, however, that in a shell-bearing bed underlying the ossiferous deposit of Pikermi some characteristic Pliocene species of marine mollusca occur. Remembering how deceptive sometimes is the chronological evidence of terrestrial faunas and floras (ante, pp. 1096, 1111) we may here take marine shells as our guide, and place the Pikermi beds in the Pliocene series.

§ 2. Local Development

France.—True Miocene deposits are not known to occur in Britain. In France, however, in the district of Touraine, traversed by the rivers Loire, Indre, and Cher, there occurs a group of shelly sands and marls, which, as far back as 1833, was selected by Lyell as the type of his Miocene subdivision. These strata occur in widely extended but isolated patches, rarely more than 50 feet thick, and are better known as "Faluns," having long been used as a fertilizing material for spreading over the soil. They present the characters of littoral and shallow-water marine deposits, consisting sometimes of a kind of coarse breccia of shells, shell-fragments, coral, polyzoa, etc., occasionally mixed with quartz-sand, and now and then passing into a more compact calcareous mass or even into limestone. Along a line that may have been near the coast-line of the period, a few land and fresh-water shells, together with bones of terrestrial mammals, are found, but, with these exceptions, the fauna is throughout marine. Among the fossils are numerous corals, and upward of 300 species of mollusks, of which the following are characteristic: Pholas Dujardini, Venus clathrata, Ostrea crassissima, Pecten striatus, Cardium turonicum, Cardita affinis, Trochus incrassatus, Cerithium intradentatum, Turritella Linnæi, T. bicarinata, Pleurotoma tuberculosa, with species of Cypræa, Conus, Murex, Oliva, Ancillaria, and Fasciolaria. This assemblage of shells indicates a warmer climate than that of southern Europe at the present time. The mammalian bones include the genera Mastodon, Rhinoceros, Hippopotamus, Chœropotamus, deer, etc., and extinct marine forms allied to the morse, sea-cow, and dolphin. Similar faluns, perhaps slightly later in age, are found in Anjou and Maine.

In the region of Bordeaux and the plains of the Garonne southward to the base of the Pyrenees, a large area is overspread with Oligocene deposits, equivalents of the younger Tertiary series of the Paris basin. Above these fresh-water and marine beds lie patches of faluns like those of Touraine, containing a similar assemblage of marine fossils. Other marine deposits of Miocene age are found running up the valley of the Rhone. But in the south and southeast of France the Miocene strata are mainly of lacustrine origin, sometimes attaining a thickness of 1000 feet, as in the important series of limestones and marls of Sansan and Simorre, whence remains of numerous interesting mammalia have been obtained. Among these remains are Deinotherium giganteum, Mastodon angustidens, M. tapiroides, M. pyrenaicus, Rhinoceros Schleiermacheri, R. sansaniensis, R. brachypus, Anchitherium aurelianense, Anthracotherium onoideum, Amphicyon giganteus, Machairodus cultridens, Helladotherium Duvernoyi, Dicroceras elegans, and several apes and monkeys (Pliopithecus, Dryopithecus).

The Miocene deposits of France, though scattered in isolated patches, have been grouped into three stages in the following ascending order: 1st, Lhangian—sands and marls (l'Orléanais, Sologne, etc.), limestones (Sansan, Simorre); 2d, Helvetian—shelly sands, faluns (Touraine, Anjou, Aquitaine); 3d, Tortonian—marls with Helix turonensis.

Belgium.—In this country, the upper Oligocene strata of Germany are absent. In the neighborhood of Antwerp certain black, gray, or greenish glauconitic sands ("Black Crag," Bolderian and Anversian), of which the palæontological characters were at one time supposed to present a mingling of Miocene and Pliocene affinities. These deposits were accordingly termed by some geologists Mio-pliocene. They consist of gravelly sands at the base, containing cetacean bones (Heterocetus), fish-teeth, Ostrea navicularis, Pecten, Caillaudi, etc. They are followed by sands with Pectunculus glycimeris (pilosus), and these by sands with Panopæa Faujasii (Menardi). More recent research has shown that the lower part of this series of deposits is Miocene, and is separated by a break and erosion-line from the superincumbent Diestian group which is referable to the Pliocene series.

Germany.—Certain deposits of dark clay and sand spread over parts of the northwest of Germany containing Conus Dujardini, C. antediluvianus, Fusus festivus, Isocardia cor, Pectunculus glycimeris (pilosus), Limopsis aurita, etc., and are referred to the Miocene formations. These are doubtless a prolongation of the Belgian series. Elsewhere the deposits referable to this geological period are lacustrine or fluviatile in origin, and are especially marked by the occurrence in them of brown-coals which are worked.

In the Mainz Tertiary basin an important series of marine, brackish, and fresh-water deposits occurs, which has been arranged by Fridolin Sandberger as follows:[83]

Pliocene—
- Uppermost brown-coal.
- Bone-sand of Eppelsheim (Deinotherium sand), see p. 1668.

Miocene—
- Clay, sand, etc, with leaves.
- Limestone with Litorinella (Hydrobia) acuta, Helix moguntina, Planorbis, Dreissena, etc.
- Corbicula beds with Corbicula Faujasii, Hydrobia inflata, H. acuta.
- Cerithium limestone and land-snail limestone.
- Sandstone with leaves (Cinnamomum, Sabal, Quercus, Ulmus).

Oligocene (see p. 1628).

The lower Miocene beds of this area present much local variation, some being full of terrestrial plants, some containing fresh-water, and other brackish-water and marine shells, indicating the final shoaling of the Oligocene fjord which ran down the upper valley of the Rhine as far as Mainz. Among the plants are species of Quercus, Ulmus, Planera, Cinnamomum, Myrica, Sabal, etc. The land-snail limestone contains numerous species of Helix and Pupa, with Cyclostoma and Planorbis. The Cerithium limestone contains marine or estuarine shells, as Perna, Mytilus, Cerithium (C. Rahtii, C. plicatum), Nerita. Among the various strata, bones of some of the terrestrial mammals of the time occur (Microtherium, Palæomeryx). The Litorinella limestone, the most extensive bed in the series, is composed of limestone, marl, and shale, sometimes made up of Hydrobia (Litorinella) acuta, in other places of Dreissena (Tichogonia, Congeria) Brardi, or Mytilus Faujasii. Abundant land and fresh-water shells also occur. Of greater interest are the mammalian remains, which include those of Deinotherium giganteum, Palæomeryx, Microtherium, and Hipparion (Hippotherium). The flora of the higher parts of the Miocene series includes several species of oak and beech, also varieties of evergreen, oak, magnolia, acacia, styrax, fig, vine, cypress, and palm.

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83 "Untersuchungen über das Mainzer Tertiärbecken," 1853; "Die Conchylien des Mainzer Tertiärbeckens," 1863.

Vienna Basin.[84]—Overlying the Aquitanian stage (p. 1630), where that is present, in other cases resting unconformably upon older Tertiary rocks, come the younger Tertiary or Neogene deposits of the Vienna basin—a large area comprising the vast depression between the foot of the eastern Alps near Vienna, the base of the plateau of Bohemia and Moravia, and the western slopes of the Carpathians. This tract communicated with the open Miocene sea by various openings in different directions. Its Miocene deposits are composed of two chief divisions or stages as follows, in descending order:

Sarmatian or Cerithium Stage.—Sandstones passing into sandy limestones and clays, or "Tegel" (the local name for a calcareous clay). According to Fuchs, the following subdivisions occur around Vienna:

Upper Sarmatian Tegel, or Muscheltegel—distinguishable from the Hernals Tegel below by an abundance of shells (Tapes gregaria, Ervilia, Cardium, etc.), 295 feet.

Cerithium-sand—a yellow, abundantly shell-bearing, quartz-sand—the main source of water-supply at Vienna, where it is sometimes nearly 500 feet thick.

Hernals Tegel—sand and gravel, with Cerithium, Rissoa, Paludina, remains of turtles, fish, and land plants.

The Sarmatian stage is characterized by the prodigious number of individuals of a comparatively small number of species of shells, of which some of the most characteristic forms are Tapes gregaria (Fig. 438), Mactra podolica, Ervilia podolica, Cerithium pictum, C. rubiginosum, Buccinum baccatum, Trochus podolicus, Murex sublævatus. The general character of the fauna is that of a temperate climate, and is strongly contrasted with that of the Mediterranean stage in the absence of the affinities with tropical or sub-tropical forms, and even with those of the present Mediterranean, and on the other hand in some curious analogies with the living fauna of the Black Sea. Corals, echinoderms, bryozoa, foraminifera are absent or very rare, and the suggestion

[84] T. Fuchs, Z. Deutsch. Geol. Ges. 1877, p. 653; Hörnes and Partsch, "Die Fossil Mollusken Tertiär. Beckens," Wien, 1851–70; Ettingshausen, "Die Tertiärfloren d. Oesterr Monarchie," 1851; Von Hauer's "Geologie," p. 617.

has been made that the change of the earlier Mediterranean fauna into that of the Sarmatian stage points to a gradual diminution of the salinity of the waters of the Vienna basin, as has happened with the existing Black Sea. The terrestrial flora is characterized by some plants that survived from the earlier or Mediterranean stage; but palms are entirely absent, and the American element in the flora is no longer surpassed by the preponderance of Asiatic types.

Mediterranean or Marine Stage.—A group of strata varying greatly from place to place in petrographical characters, with corresponding differences in fossil contents. Among the more important types of rock the following may be named:

Leithakalk, a limestone often entirely composed of organisms, and especially of reef-building corals, also bryozoa, foraminifera, echini (large clypeasters, etc.), large oysters (Pecten latissimus is specially characteristic), bones of mammals, and sharks' teeth. The Leithakalk passes frequently into sandy and marly beds, and into massive conglomeratic deposits (Leithakalk-schotter or conglomerate).

Tegel of Baden—fine blue clay, richly charged with shells, especially gasteropods (Pleurotoma, Cancellaria, Fusus, etc.) and foraminifera.

Marl of Gainfahren, Grinzing, Nussdorf, etc.—more calcareous than the Baden Tegel.

Sand of Potzleinsdorf—a fine loose sand with Tellina, Psammobia, and many other lamellibranchs.

Sandstone of Sievering with many lamellibranchs, especially pectens and oysters.

These various strata are believed to represent different conditions of deposit in the area of the Vienna basin during the time of the Mediterranean stage. With them are grouped certain fresh-water beds (brown-coals, etc.), found along the margin of the basin, which are supposed to mark some of the terrestrial accumulations of the period.

The characteristically marine fauna of this stage is abundant and varied. It presents as a whole a more tropical character than that of the Sarmatian stage above. Of its molluscan genera (of which more than 1000 species have been described) some of the more characteristic are: Conus, Oliva, Cypræa, Voluta, Mitra, Cassis, Strombus, Triton, Murex, Pleurotoma, Cerithium, Spondylus, Pinna, Pectunculus, Cardita, Venus. A number of the species still live in the Mediterranean, or in the seas off the West Coast of Africa. The abundant flora, with its various kinds of palms, had also a tropical aspect, somewhat like those of India and Australia.

Switzerland.—Immediately succeeding the strata described on p. 1628, as referable to the Oligocene series, come the following groups in descending order:

Upper fresh-water Molasse and brown-coal (Oeningen or Tortonian stage), consisting of sandstones, marls, and limestones, with a few lignite-seams and fresh-water shells, and including the remarkable group of plant- and insect-bearing beds of Oeningen.

Upper marine or St. Gallen Molasse (Helvetian stage)—sandstones and calcareous conglomerates, with 37 per cent of living species of shells, which are to be found partly in the Mediterranean, and partly in tropical seas: Pectunculus glycimeris (pilosus), Panopæa Faujasii (Menardi), Conus ventricosus, etc.

Lower fresh-water or Gray Molasse (Lhangian stage, Mayencian)—sandstones with abundant remains of terrestrial vegetation, and containing also an intercalated marine band with Cerithium lignitarum, Murex plicatus, Venus clathrata, Ostrea crassissima, etc.

In the Oeningen beds, so gently have the leaves, flowers, and fruits fallen, and so well have they been preserved, we may actually trace the alternation of the seasons by the succession of different conditions of the plants. Selecting 482 of those plants which admit of comparison, Heer remarks that 131 might be referred to a temperate, 266 to a sub-tropical, and 85 to a tropical zone. American types are most frequent among them; European types stand next in number, followed in order of abundance by Asiatic, African, and Australian. Great numbers of insects (between 800 and 900 species) have been obtained from Oeningen. Judging from the proportions of species found there, the total insect fauna may be presumed to have been then richer in some respects than it now is in any part of Europe. The wood-beetles were specially numerous and large. Nor did the large animals of the land escape preservation in the silt of the lake. We know, from bones found in the Molasse, that among the inhabitants of that land were species of tapir, mastodon, rhinoceros, and deer. The woods were haunted by musk-deer, apes, opossums, three-toed horses, and some of the strange, long-extinct Tertiary ruminants, akin to those of Eocene times. There were also frogs, toads, lizards, snakes, squirrels, hares, beavers, and a number of small carnivores. On the lake, the huge Deinotherium floated, mooring himself perhaps to its banks by the two strong tusks in his under jaw. The waters were likewise tenanted by numerous fishes, of which 32 species have been described (all save one referable to existing genera), crocodiles, and chelonians.

Italy.—The enormous Aquitanian stage of Liguria (p. 1630) is followed by (1) blue homogeneous marine marls, reaching a depth of nearly 2000 feet and marked by the abundance of pteropods, also Ostrea neglecta, Cassidaria vulgaris, and Aturia aturi. This stage, called by Mayer "Langhien," is paralleled with that of Mainz. It is surmounted by (2) the Helvetian stage (3280 feet), composed of three divisions: a lower (1000 to 1300 feet) composed of shaly marls rich in Vaginella, Cleodora, etc.; a middle (700 to 750 feet) consisting of yellowish sandy molasse with bryozoa, Pecten ventilabrum, Terebratula miocenica, etc.; and an upper (more than 300 feet) composed of beds of conglomerate and nullipores, with oysters, pectens, etc. The Tortonian stage (3) is made up of blue marls (650 feet), forming a remarkably constant band, with a profusion of Pleurotomaria and species of Conus, Natica, Ancillaria, etc.[85]

Greenland.[86]—One of the most remarkable geological discoveries of modern times has been that of Tertiary plant-beds in North Greenland. Heer has described a flora extending at least up to 70° N. lat., containing 137 species, of which 46 are found also in the central European Miocene basins. More than half of the plants are trees, including 30 species of conifers (Sequoia, Thujopsis, Salisburia, etc.), besides beeches, oaks, planes, poplars, maples, walnuts, limes, magnolias, and many more. These plants grew on the spot, for their fruits in various stages of growth have been obtained from the deposits. From Spitzbergen (78° 56′

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[85] C. Mayer, Bull. Soc. Geol. France (3) v. p. 288. F. Sacco, "Il Bacino Terziario del Piemonte," Turin, 1889.

[86] Heer, "Flora Fossilis Arctica," in seven vols. 1868–83; Q. J. Geol. Soc. 1878, p. 66; Nordenskiöld, Geol. Mag. iii. 1876, p. 207. In this paper sections, with lists of the plants found in Spitzbergen, are given.

N. lat.) 136 species of fossil plants have been named by Heer. But the latest English Arctic expedition brought to light a bed of coal, black and lustrous like one of the Palæozoic fuels, from 81° 45′ N. lat. It is from 25 to 30 feet thick, and is covered with black shales and sandstones full of land-plants. Heer notices 30 species, 12 of which had already been found in the Arctic Miocene zone. As in Spitzbergen, the conifers are most numerous (pines, firs, spruces, and cypresses), but there occur also the Arctic poplar, two species of birch, two of hazel, an elm, and a viburnum. In addition to these terrestrial trees and shrubs, the lacustrine waters of the time bore water-lilies, while their banks were clothed with reeds and sedges. When we remember that this vegetation grew luxuriantly within 8° 15′ of the North Pole, in a region which is now in darkness for half of the year, and almost continuously buried under snow and ice, we can realize the difficulty of the problem in the distribution of climate which these facts present to the geologist.

India.—The Oligocene and Miocene deposits of Europe have not been satisfactorily traced in Asia. As already stated, the upper part of the massive Nari group of Sind may represent some part of these strata. The Nari group is succeeded in the same region by the Gaj group, 1000 to 1500 feet thick, chiefly composed of marine sands, shales, clays with gypsum, sandstones, and highly fossiliferous bands of limestone. The commonest fossils are Ostrea multicostata, and the urchin Breynia carinata. Some of the species are still living, and the whole aspect of the fauna shows it to be later than Eocene time. The uppermost beds are clays with gypsum, containing estuarine shells and forming a passage into the important Manchhar strata. The Manchhar group of Sind consists of clays, sandstones, and conglomerates, sometimes probably 10,000 feet thick, divisible into two sections, of which the lower may possibly be Miocene, while the upper may represent the Pliocene Siwalik beds (p. 1672). As a whole, this massive group of strata is singularly unfossiliferous, the only organisms of any importance yet found in it being mammalian bones, of which 22 or more species have been recognized. All of these occur in the lower section of the group. They include the carnivore Amphicyon palæindicus, three species of Mastodon, one of Deinotherium, two of Rhinoceros, also one of Sus, Chalicotherium, Anthracotherium, Hyopotamus, Hyotherium, Dorcatherium (two), Manis, a crocodile, a chelonian, and an ophidian.[87]

North America.—Overlying the Eocene formations (p. 1612), and following in a general way their trend, but sometimes with a slight unconformability, a belt of marine deposits, referred to the Miocene period, runs along the Atlantic border through the States of New Jersey, Delaware, Maryland, Virginia, North and South Carolina, and Georgia. These strata ("Yorktown" and "Sumpter" groups of Dana) have recently been classified by A. Heilprin as follows: 3, Upper or Carolinian (North and South Carolina, Sumpter beds). 2, Middle or Virginian (Virginia and newer group in Maryland; Yorktown beds, in part); one of the most interesting members of this subdivision is the "Richmond earth," a diatomaceous deposit, sometimes 30 feet thick, lying near the base of the group. 1, Lower or Marylandian (older Miocene deposits of Maryland and possibly lower beds in Virginia; Yorktown beds, in part).[88]

Westward, in the Upper Missouri region, and across the Rocky Mountains into Utah and adjacent territories, strata assigned to the same geological period have been termed the White River group. They were laid down in great lakes, and attain thicknesses of 1000 to 2000 feet. The organic remains of these ancient lakes, so well studied by Leidy, Marsh, and Cope, embrace examples of three-toed horses (Anchitherium, Miohippus, Mesohippus), tapir-like animals, differing from those of the older Tertiary strata (Lophiodon); hogs as large as rhinoceroses (Elotherium); true rhinoceroses (Rhinoceros, Hyracodon, Diceratherium), huge elephantoid creatures allied to the Deinoceras and tapir (Brontotherium, Titanotherium); also even-toed ruminant ungulates, some allied to the hog (Oreodonts), others like stags (Leptomeryx) and camels (Poebrotherium); carnivores (Canis, Amphicyon [Daphænus], Machairodus, Hyænodon), several of which are generically identical with European Tertiary wolves, lions, and bears. Among the smaller forms are the remains of the earliest known beavers (Palæocastor).

Australia.—Tertiary deposits are extensively developed in various parts of the Australian continent. In Victoria they cover nearly half of the colony, and are there capable of subdivision into an older and newer series. The older

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[87] Medlicott and Blanford's "Geology of India," p. 472.
[88] A. Heilprin, as cited on p. 1612.

series is believed to be later than Eocene and to be possibly of Oligocene or older Miocene age. It consists principally of blue or gray clays with septarian nodules, rich in fossils, among which gigantic forms of Volutes and Cowries are conspicuous. Later than these clays are certain (Miocene) deposits indicating marine, lacustrine, and terrestrial conditions, with the existence of contemporaneous volcanic activity toward the end of the series. The marine rocks consist mainly of calcareous sandy strata and limestones, with Cellepora, Spatangus, Terebratula, etc. The lacustrine deposits are clays and lignites, and the fluviatile materials consist of gravels and sands which are often auriferous. Great sheets of basalt, forming the older volcanic series, have been poured over these various accumulations, which are sometimes 300 feet thick. A large series of plants, mollusks, fishes, and marine mammals has been obtained from the Miocene series of Victoria.[89]

New Zealand.—Rocks assigned to Miocene time in New Zealand are divisible into: 1st, A lower series, consisting of calcareous and argillaceous strata widely spread over the east and central part of the North Island and both sides of the South Island. They can be traced to a height of 2500 feet above the sea. Marine shells abound in them, including 55 species which are found among the 450 shells that now live in the adjacent seas. Some of the most notable fossils are Dentalium irregulare, Pleurotoma awamoaensis, Conus Trailli, Turritella gigantea, Buccinum Robinsoni, Cucullæa alta. In some places thick deposits of an inferior kind of brown-coal occur in this subdivision. 2d, An upper series composed of littoral or sub-littoral accumulations of sand, gravel, and clay. They have yielded 120 recent species of shells, and 25 species which appear now to be extinct. Specially characteristic are Ostrea ingens, Murex octagonus, Fusus triton, Struthiolaria cingulata, Chione assimilis, Pecten gemmulatus.[90]

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[89] R. A. F. Murray, "Geology and Physical Geography of Victoria," 1887. M'Coy, "Prodromus of Victorian Palæontology."

[90] Hector, "Handbook on New Zealand," p. 27.

Section iv. Pliocene

§ 1. General Characters

The tendency toward local and variable development, which is increasingly observable as we ascend through the series of Tertiary deposits, reaches its culmination in those to which the name of Pliocene has been given. The only European area, in which Pliocene strata attain any considerable dimensions as rock-masses, is in the basin of the Mediterranean, especially along both sides of the Apennine chain and in Sicily. In that region, reaching a thickness of 1500 feet or more, they were accumulated during a slow depression of the sea-bottom, and their growth was brought to an end by the subterranean movements which culminated in the outbreak of Etna, Vesuvius, and the other late Tertiary Italian volcanoes, and in the uprise of the land between the base of the Apennines and the sea on either side of the peninsula. Elsewhere the marine Pliocene deposits of Europe, local in extent and variable in character, reveal the beds of shallow seas, the elevation of which into land completed the outlines of the Continent at the close of Tertiary time. Thus these waters covered the south and southeast of England, spreading over Belgium and a small part of northern France, but leaving the rest of northern and western Europe as dry land. Here and there, in south-eastern Europe, evidence exists of the gradual isolation of portions of the sea into basins, somewhat like those of the Aralo-Caspian depression, with a brackish or less purely marine fauna. In some portions of these basins, however, as in the Karabhogas Bay of the existing Caspian Sea, such concentration of the water took place as to give rise to extensive accumulations of salt and gypsum. In a few localities, fluviatile and lacustrine deposits of the Pliocene period have been preserved, from which numerous remains of terrestrial vegetation and mammals have been obtained.

The Pliocene flora is transitional between the luxuriant evergreen and sub-tropical vegetation of the Miocene period and that of modern Europe. From the evidence of

a b

Fig. 442.—Pliocene Plants.
a, Glyptostrobus europæus, Brongn. (½); *b*, Hakea exalata, Heer.

the deposits in the upper part of the valley of the Arno, above Florence, it is known to have included species of pine, oak, evergreen-oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, buckthorn, hickory, sumach, sarsaparilla, sassafras, cinnamon, glyptostrobus, taxodium, sequoia, etc.[91] The researches of Count de Saporta have shown that the flora of Meximieux, near Lyons, comprised species of bamboo, liquidambar, rose-laurel, tulip-tree maple,

[91] Gaudin, "Feuilles fossiles de la Toscane"; Gaudin and Strozzi, "Contributions à la Flore fossile italienne"; Lyell, "Student's Elements." 4th edit. p. 172.

ilex, glyptostrobus, magnolia, poplar, willow, and other familiar trees.[92] The forests of that part of Europe during Pliocene time conjoined some of the more striking characters of those of the present Canary Islands, of North

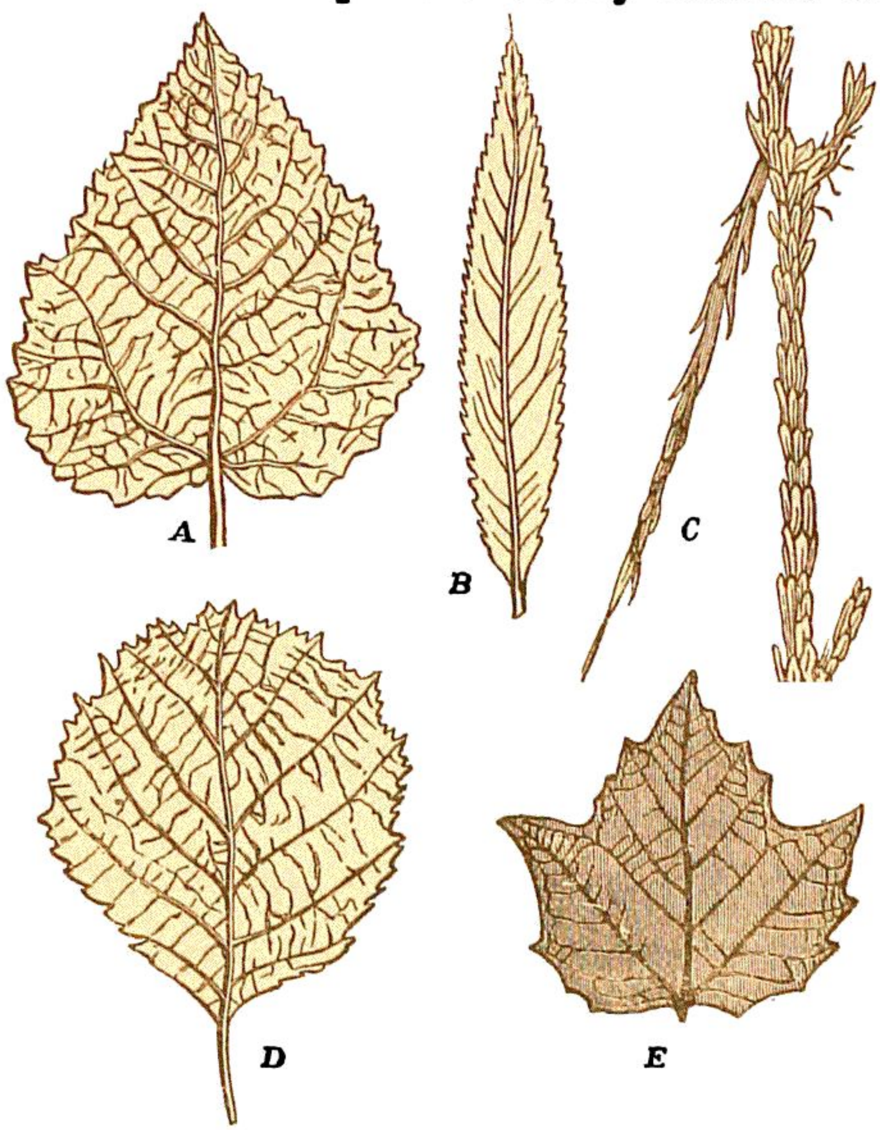


Fig. 443.—Pliocene Plants.
(A) Populus canescens; (B) Salix alba; (C) Glyptostrobus europæus; (D) Alnus glutinosa; (E) Platanus aceroides (⅓).

America, and of Caucasian and eastern Asia, including Japan. There is evidence, however, that a marked refrigeration of climate was in gradual progress, during which the plants, such as the palms, especially characteristic of warmer latitudes, one by one retreated from the

[92] "Recherches sur les Vegetaux fossiles de Meximieux," Archiv. Mus. Lyon, i. 1875–76, and his "Monde des Plantes," p. 314.

European region, or lingered only on its southern borders. In England, toward the end of the Pliocene period, the climate, if we may judge of it from the plants preserved in the Cromer Forest-bed, had come to be very much what it is to-day. Among the vegetable remains found in that deposit are those of many of the familiar forest trees still living in the southeast of England. Some of our common wild-flowers and water-plants had now made their appearance, such as the buttercup, marsh-marigold, chickweed, milfoil, marestail, dock, sorrel, pondweed, sedge, cotton-grass, reed and royal fern.[93]

The fauna of the Pliocene period still retained a number of the now extinct types of earlier time, such as the

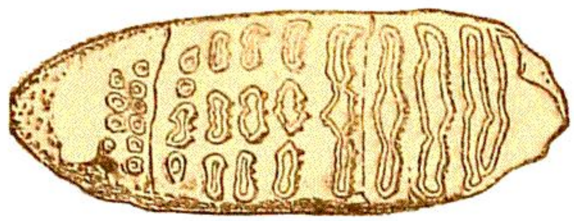


Fig. 444.—Elephas meridionalis, Nesti. Crown of molar (⅓).

Deinotherium and Mastodon. It was specially characterized also by troops of rhinoceroses, hippopotamuses, and elephants, the Elephas meridionalis being a distinctive form; by large herds of herbivora, including numerous forms of gazelle, antelope, deer, now mostly extinct, and types intermediate between still living genera. Among these were some colossal ruminants, including a species of giraffe and the extinct giraffe-like genera Helladotherium and Samotherium, as well as other types met with among the Siwalik beds of India (Sivatherium, Fig. 453, Bramatherium). The Equidæ were represented by the existing

[93] C. Reid, "Pliocene Deposits of Britain," Mem. Geol. Surv. 1890, pp. 185, 231.

Equus, and by extinct forms, one of the most abundant of which was Hipparion (Fig. 445), like a small ass or

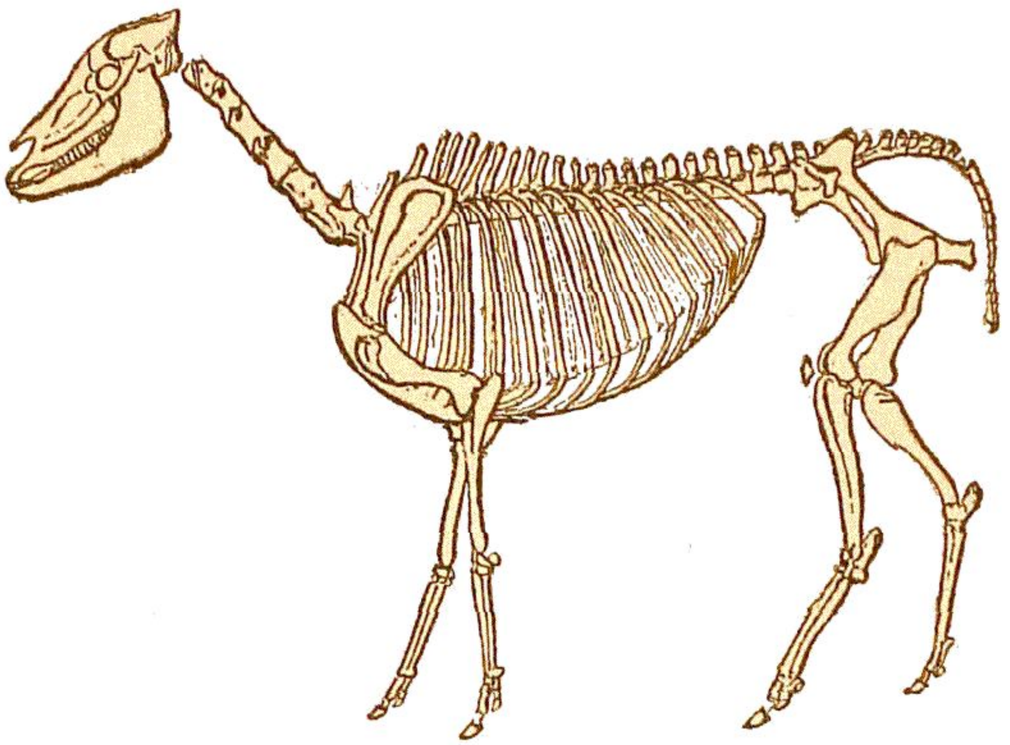


Fig. 445.—Hipparion gracile, Gaudry ($\frac{1}{20}$).

quagga, with three toes on each foot, only the central one actually reaching the ground. Besides these animals there lived also various apes (Mesopithecus, Fig. 446, Dolicho-

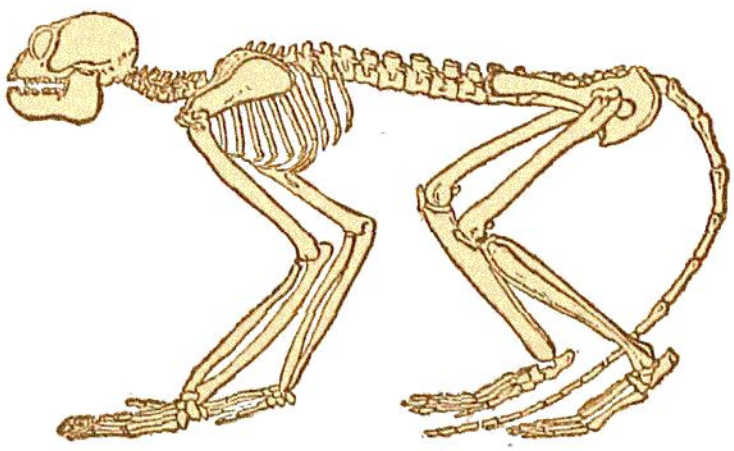


Fig. 446.—Mesopithecus Pentelici, Gaudry ($\frac{1}{8}$).

pithecus), likewise species of ox, cat, bear, machairodus, hyæna, fox, viverra, porcupine, beaver, hare, and mouse.

The advent of a colder period is well shown in the younger Pliocene deposits of southeastern England, where a number of northern mollusks make their appearance. The proportion of northern species increases rapidly in the next succeeding or Pleistocene beds. The Pliocene period, therefore, embraces the long interval between the warm temperate climate of the later ages of Miocene and the cold Pleistocene time. The evidence of change of

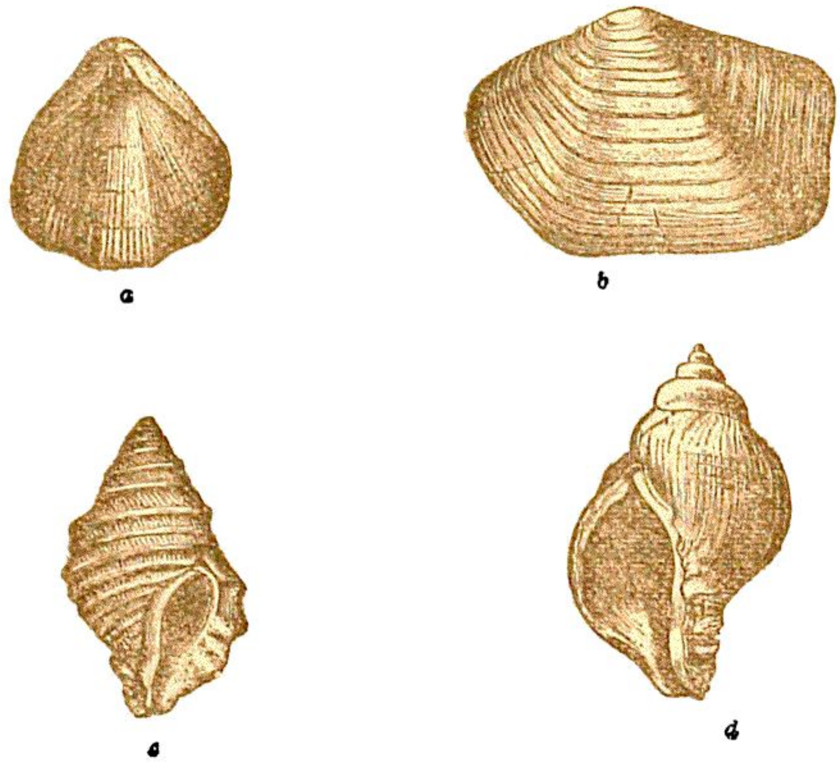


Fig. 447.—Pliocene Marine Shells.

a, Rhynchonella psittacea; *b*, Panopæa norvegica (1/3); *c*, Purpura lapillus (1/5); *d*, Trophon antiquus (1/4). All these species still live in the seas around Britain.

climate derivable from the English Pliocene marine mollusca may be grouped as in the subjoined table, which shows the gradual extirpation of southern and advent of northern forms in the long interval between the deposition of the oldest and newest Pliocene deposits.[94]

[94] C. Reid, op. cit. p. 145.

	Total Species	Arctic	Mediterranean	Extinct
Weybourn Crag . . .	53	9	0	5
Chillesford Crag . . .	90	7	2	14
Fluvio-marine Crag . . .	112	9	7	18
Red Crag of Boyton, etc. . .	119	13	23	55
Red Crag of Walton . . .	148	2	22	50
Coralline Crag	420	1 (?)	75	169

§ 2. Local Development

Britain.[95]—In the Pliocene period, after a long period of exposure as a land-surface, during which a continuous and ultimately stupendous subaerial denudation was in progress, Britain underwent a gentle, but apparently only local, subsidence. We have no evidence of the extent of this depression. All that can be affirmed is that the southeastern counties of England began to subside, and on the submerged surface some sand-banks and shelly deposits were laid down, very much as similar accumulations now take place on the bottom of the North Sea. These formations, termed generally "Crag," are followed by estuarine and fresh-water strata, the whole being subdivided, according to the proportion of living species of shells, into the following groups in descending order:

Base of the Pleistocene.	Arctic Fresh-water Bed—with salix polaris, Betula nana, etc.	
Newer Pliocene (cold temperate).	Leda myalis Bed, classed provisionally as Pliocene.	
	Forest-bed group (10 to 60 feet): Upper Fresh-water, Estuarine, Lower Fresh-water.	Gravels with Elephas meridionalis at Dewlish.
	Weybourn Crag (and Chillesford Clay ?), 1 to 22 feet.	
	Chillesford Crag—5 to 15 feet.	
	Norwich Crag and Scrobicularia Crag—5 to 10 feet.	147 feet at Southwold.
	Red Crag of Butley, etc.	
	Walton Crag—Lower Red Crag, 25 feet.	
Older Pliocene (warm temperate).	St. Erth Beds.	
	Coralline Crag—40 to 60 feet.	
	Lenham Beds (Diestian).	
	Box-stones and phosphate beds—with derivative early Pliocene fossils.	

[95] Prestwich, Q. J. Geol. Soc. xxvii.; Lyell, "Antiquity of Man," chap. xii.; Searles Wood, "Crag Mollusca," Palæont. Soc.; H. B. Woodward, "Geology of Norwich," and W. Whitaker, "Geology of Ipswich," etc., both in Mem. Geol. Survey. The fullest account of the subject will be found in the monograph by C. Reid, already cited, on the "Pliocene Deposits of Britain," Mem. Geol. Survey, 1890.

OLDER PLIOCENE.—The deposits of this age probably at one time extended over a large part of the south and south-east of England, but they have been reduced by denudation to a few widely separated patches, the largest of which, around Oxford in Suffolk, does not cover more than about ten square miles. They consist chiefly of shelly sands known as the Coralline Crag of Suffolk, but a small outlier of fossiliferous sand occurs on the edge of the North Downs at Lenham, and other ironstone patches, probably of the same age, cap the Down as far as Folkestone. Far to the west, at St. Erth in Cornwall, an isolated deposit of older Pliocene age has been detected. These thin and scattered fragments convey no adequate conception of the length or importance of the geological period which they represent. It is not until we pass into the north of Italy and the basin of the Mediterranean that we discover the Pliocene system to be represented by thick accumulations of upraised marine strata comparable in extent and thickness to some of the antecedent Tertiary series.

A strongly marked break, both stratigraphical and palæontological, separates the Pliocene deposits of Britain from all older formations. They lie unconformably on everything older than themselves, and in their fossils show a great contrast even to those of the Oligocene series. The sub-tropical plants and animals of older Tertiary time are there replaced by others of more temperate types, though still pointing to a climate rather warmer than that of southern England at the present time.

A conglomeratic deposit (Nodule beds) forms the base of the Red Crag, and appears generally to underlie also the Coralline Crag. It includes fragments of various rocks such as flints, septaria, sandstones, quartz, quartzite, granite, and other igneous materials, together with a miscellaneous assortment of derivative fossils, including Jurassic ammonites and brachiopods, sharks' teeth and other fossils from the London Clay, the teeth of many land mammals (pig, rhinoceros, mastodon, tapir, deer, hipparion, etc.), and pieces of the rib-bones of whales. Many of these organic remains must have been derived from some older Pliocene deposit which has otherwise entirely disappeared. They have been to a large extent phosphatized, and hence have been extracted as a source of phosphate of lime. Among the contents of the deposit some of the most interesting and important are rounded pieces of brown sandstone, known as "box-stones," evidently derived from the denudation of a single horizon, and inclosing casts of marine shells. The general facies of the assemblage of shells obtained from these fragments of a lost formation points unmistakably to early Pliocene time. At present 16 species have been determined, all of which are well-known British Pliocene forms, except two which occur in Continental Pliocene deposits.[96]

Coralline Crag (Bryozoan, White, or Suffolk Crag) consists essentially of calcareous sands, mainly made up of shells and bryozoa, and is exposed at various localities in the county of Suffolk. According to the census of Searles Wood, published in 1882, the number of mollusks found in this deposit amounts to 420 species, of which 251 or 60 per cent are still living. Some of the genera of shells give a southern character to the fauna, such as large and showy species of Voluta, Cassidaria, Cassis, Ficula, Hinnites, Chama, Cardita, and Pholadomya, likewise Ovula, Mitra, Triton, Vermetus, Ringicula, Verticordia, Coralliophaga, and Solecurtus. Characteristic species are Cardita corbis, Cardita senilis, Limopsis pygmæa, Ringicula buccinea, Voluta Lamberti (Fig. 450), Pyrula reticulata, Astarte Omalii (Fig. 449), Pholadomya histerna, Pecten opercularis, Lingula Dumortieri, and Terebratula grandis. Hardly less abundant and varied are the bryozoa or "Corallines," from which the name of the deposit is taken. No fewer than 118 species have been named, of which 76, or about 64 per cent, appear to be extinct. Specially characteristic and peculiar are the large massive forms known as Alveolaria and Fascicularia (Fig. 448). There are three species of corals all extinct. Of the 16 species of echinoderms at present known, only three are now living. Remains of fishes are of common occurrence, especially in the form of ganoid otoliths. Teeth and dermal spines of the skate and wolf-fish are met with, and to these shell-eating fish the broken condition of so many of the shells may probably be ascribed. Traces of one of the larger dolphins have been found, but no remains of any of the contemporaneous land-mammals, though a few drifted land-shells show that the land lay probably at no great distance. The Coralline Crag may be regarded as an elevated shell-bank, which accumulated on the floor of a warm sea at a depth of from 40 to 60 fathoms.[97]

Lenham Beds, Diestian.—On the edge of the Chalk Down of Kent near Lenham, patches of sand are found capping the Chalk, and descending into pipes on its

[96] C. Reid, op. cit. p. 6 *et seq.*

[97] C. Reid, op. cit. p. 19 *et seq.*

surface, at a height of more than 600 feet above the sea, and other similar nests of ferruginous sands are met with along the Downs as far as Folkestone. At first these deposits were thought to be portions of the base of the Tertiary series, but the occurrence of apparently Pliocene shells in them led to a more thorough investigation of them, with the result that they have been proved to be of the same age as similar deposits which cap the hills on the other side of the Straits of Dover from Boulogne into Belgian Flanders, whence they stretch northward as a wide continuous sheet into Holland. These sands, known as Diestian, have yielded at Diest and Antwerp a large assemblage of fossils, which prove them to be of older Pliocene age. Of the Diestian fossils of Holland and Belgium so large a proportion has been detected, generally in the form of hollow casts, in the Lenham deposits as to leave no doubt of the geological horizon of these scattered fragments of a formation. About 67 species have been obtained from Lenham, the southern character of which is indicated by the genera Ficula (Pyrula), Xenophora (Phorus), Triton, and Avicula, with abundant examples of Arca diluvii, Cardium papillosum, and Cupularia canariensis. It is interesting to notice the great change of level which this fragmentary formation serves to prove since older Pliocene time in the south of England. From the general character of the fauna found at Lenham it is probable that the shells lived in a depth of not less than 40 fathoms of water. This vertical amount, added to the present height of the deposit above the sea, gives a minimum of 860 feet of uplift.[98]

Fig. 448.—Pliocene Polyzoon. Fascicularia aurantium, M. Edw. (1/1).

St. Erth Beds.—The only other fragment yet known of older Pliocene formations in Britain lies far to the west between St. Ives and Mount's Bay in Cornwall, where a patch of clay, probably less than a quarter of a square mile in area, contained in a hollow of the slates, has preserved an interesting series of organic remains. Among the forms which connect this deposit with corresponding strata elsewhere the following may be mentioned: Chemnitzia plicatula, Columbella sulcata, Cypræa avellana, Eulimene terebellata, Fissurella costaria, Lacuna suboperta, Melampus

[98] C. Reid, op. cit. pp. 42, 69.

pyramidalis, Nassa reticosa, Natica millepunctata, Ringicula acuta, Trochus noduliferens, Turritella incrassata, Cardita aculeata, Cardium papillosum.[99]

NEWER PLIOCENE.—The British deposits of this age are, so far as we know, confined to the counties of Norfolk and Suffolk. They are separated by a considerable break from the older series, for they lie on an eroded surface of the latter, and pass across it so as to rest upon the Eocene formations, and even on the Chalk. There is likewise a marked contrast between the fauna of the two series. The newer deposits show that the break must represent a long period of geological time, during which a great change of climate took place in Europe, for the southern forms are now found to have generally disappeared, and to have been replaced by northern forms that, following the change of temperature, had migrated from the colder north.

Red Crag.—Under this name is classed a series of local accumulations of dark-red or brown ferruginous shelly sand, which, though well marked off from the Coralline Crag below, is less definitely separable from the Norwich Crag above. Judging from the variations in its fossil contents, geologists have inferred that some portions of the deposit are older than others, and that they successively overlap each other as they are followed northward. The oldest part is believed to occur at the southern end of the area at Walton, where it yields a fauna closely similar to that of the Coralline Crag. This portion is lost a few miles further north, where the Red Crag of Butley appears, containing many Arctic mollusca. In the older crag of Walton the advent of a colder climate is indicated by the appearance of the northern shells Buccinum glaciale and Trophon scalariformis, but many of the southern forms still linger, such as Cerithium trilineatum, Chemnitzia internodula, Nassa limata, Natica millepunctata, Ovula spelta, Pleurotoma hystrix, Turritella incrassata, Cardita corbis, Cytherea rudis, and Limopsis pygmæa. In the younger part of the Red Crag the proportion of northern shells greatly increases. Among them are Cancellaria viridula, Natica occlusa, Pleurotoma pyramidalis, P. scalaris, Trophon scalariformis, T. Sarsii, Cardium grœnlandicum, Leda lanceolata, and Solen gladiolus. Characteristic shells of the Red Crag are Actæon Noæ, Capulus obliquus, Cerithium tricinctum, Eulimene terebellata, Natica

[99] C. Reid, op. cit. pp. 59, 236.

hemiclausa, Pleurotoma turrifera, Scalaria funiculus, Trochus cineroides, Astarte obliquata, Tellina Benedeni, which are all extinct. A few land and fresh-water mollusks have been met with in the deposit, including Ancylus lacustris, Helix hispida, Limnæa palustris, Paludina media, Planorbis complanatus, Pupa muscorum, Succinea putris, and Corbicula fluminalis.

N o r w i c h C r a g (Fluvio-marine or Mammaliferous Crag).—As above stated, it is impossible to draw any sharp line between the Red and the Norwich Crags. They

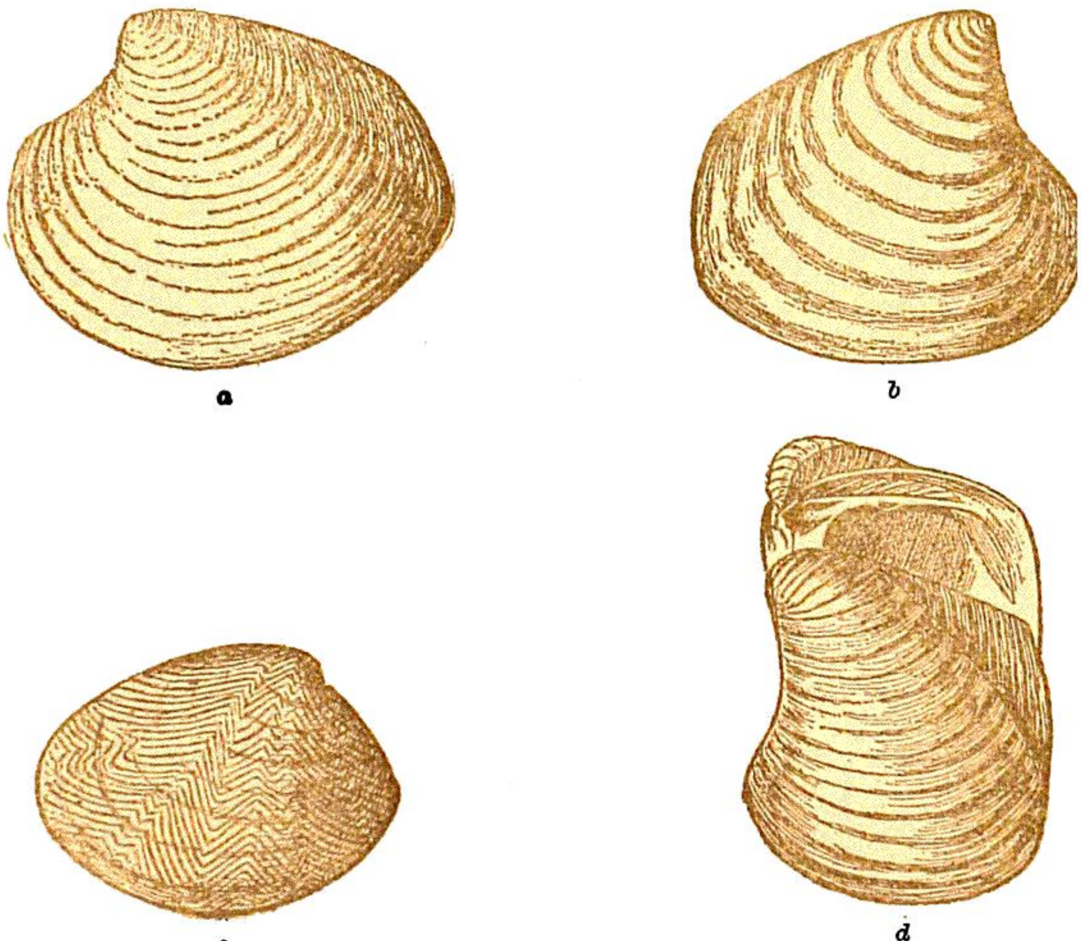
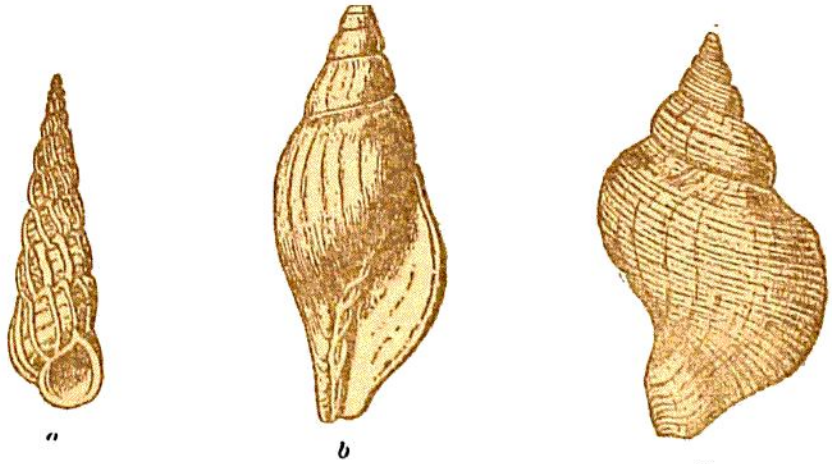


Fig. 449.—Pliocene Lamellibranchs.

a, Astarte borealis, Chemn. (living northern species); *b*, Astarte Omalii, Laj. (extinct); *c*, Nucula Cobboldiæ, Sow. (extinct); *d*, Congeria subglobosa, Partsch. (extinct) (⅔).

probably represent varying local conditions of sedimentation rather than different ages of deposit. The Norwich Crag consists of a few feet of shelly sand and gravel, containing, so far as known, 134 species of shells, of which 16 per cent are extinct. About 20 of the species are land or fresh-water shells. The name of "Mammaliferous" was given from the large number of bones, chiefly of extinct species of elephant, recovered from this deposit. The mammalian remains comprise both land and marine forms. Of the former are Lutra

Reevli, Gazella anglica, Cervus carnutorum, Equus Stenonis, Mastodon arvernensis, Elephas antiquus, Arvicola intermedius, Trogontherium Cuvieri. The marine animals include Trichechus Huxleyi and Delphinus delphis. A few remains of sea-fishes have also been found, such as the cod and pollack. Among the mollusca the following are characteristic forms: Paludina media, Hydrobia ventrosa, Turritella communis, Trophon scalariformis, Littorina littorea, Mytilus edulis, Nucula Cobboldiæ (Fig. 449), Cardium edule. One interesting feature is the decided mixture of northern species of shells, such as Rhynchonella psittacea, Scalaria grœnlandica (Fig. 450), Panopæa norvegica, and Astarte borealis (Fig. 449). These, with those above mentioned, were forerunners of the great invasion of Arctic plants and animals



a b c

Fig. 450.—Pliocene Gasteropods.

a, Scalaria grœnlandica, Chemn.; *b*, Voluta Lamberti, Sow. (⅓); *c*, Trophon antiquus, Mull. (Fusus contrarius) (⅓).

which, in the beginning of the Quaternary ages, came southward into Europe, with the severe climate of the north.

The upper part of the Red Crag sometimes passes into a band, called from its prevailing mollusk the "Scrobicularia Crag." This band, which is probably a continuation of the Norwich Crag of Norfolk, is seen at Chillesford, in Suffolk, to pass upward without a break into the Chillesford Crag.[100]

Chillesford Crag.—Under this name is grouped a local series of sands with occasional seams of clay and bands of shells. Some of these shells (Mya arenaria) are upright and in the position in which they lived. Northern

[100] C. Reid, op. cit. p. 100. For an account of the vertebrate fauna of these deposits see E. T. Newton's monographs on "The Vertebrata of the Forest Bed Series of Norfolk and Suffolk," 1882, and "The Vertebrata of the Pliocene Deposits of Britain," in Mem. Geol. Surv.

forms are still more prominent here, while a number of the common Red Crag forms seem to have disappeared. The fauna comprises Buccinum undatum, Hydrobia subumbilicata, Melampus pyramidalis, Natica incrassata, N. reticosa, Purpura lapillus, Ringicula ventricosa, Trochus tumidus, Trophon antiquus, Anomia ephippium, Astarte borealis, Cardita corbis, Cardium grœnlandicum, Cyprina islandica, Leda lanceolata, Lucina borealis, Mactra arcuata, Nucula Cobboldiæ, Panopæa norvegica, Pecten opercularis, Tellina calcarea, Rhynchonella psittacea.

Weybourn Crag and Chillesford Clay.—At Chillesford the Chillesford Crag passes insensibly upward into the Chillesford Clay, which is there a fine micaceous loam or clay containing a few shells and fish-vertebræ. Among the shells of this deposit are Buccinum undatum, Purpura lapillus, Astarte compressa, Cyprina islandica, Lucina borealis, Nucula Cobboldiæ, N. tenuis, Tellina obliqua, Cardium grœnlandicum. Traced northward the Chillesford Clay appears to pass into the deposit known as the Weybourn Crag, which is a band of laminated green and blue clays with loamy sand full of marine shells, well seen along the Norfolk coast to the west of Cromer. This member of the series has yielded 53 species and marked varieties of marine shells (Tellina balthica, specially abundant, Saxicava arctica, Nucula Cobboldiæ, Mya arenaria, M. truncata, Cyprina islandica, Astarte compressa, A. sulcata, A. borealis, Turritella terebra, Trophon antiquus, Purpura lapillus, Pleurotoma turricola, Littorina littorea, Buccinum undatum, etc.), of which five, or 10·6 per cent, are extinct, and nine species are Arctic forms.

Forest-bed Group.[101]—One of the most familiar members of the English Pliocene series is that to which the name of the "Cromer Forest-bed" has been given. It occurs beneath the cliffs of bowlder-clay on the Norfolk coast, and was believed to mark a former land-surface, with the stumps of trees *in situ*. More careful study, however, has shown that the stumps have all been transported to their present position, and lie not on an old soil, but in an estu-

[101] On this group see Lyell, Phil. Mag. 3d ser. xvi. 1840, p. 245, and his "Antiquity of Man"; Prestwich, Quart. Journ. Geol. Soc. xxvii. 1871, pp. 325, 452; Geologist, iv. 1861, p. 68; John Gunn, "Geology of Norfolk," 1864; C. Reid, Geol. Mag. (2) vol. iv. 1877, p. 300; vii. 1880, p. 548; "Geology of the Country around Cromer" in Mem. Geol. Surv. 1882; "Pliocene Deposits of Britain" in Mem. Geol. Surv. 1890; E. T. Newton's monographs cited on the previous page.

arine deposit. It is now agreed that the group of strata known as the Forest-bed series may be divided into three groups, an upper and lower fresh-water bed separated by an estuarine layer. The general character of the strata comprised in this member of the Pliocene series is shown in the subjoined table:

Leda myalis Bed (p. 1663).

Cromer Forest-bed Group.
- Upper Fresh-water Bed, consisting of sand mixed with blue clay, 2–7 feet, and inclosing twigs and shells (Succinea putris, Cyclas cornea, Valvata piscinalis, Bythinia tentaculata, Pisidium amnicum, etc.).
- Forest-bed (estuarine), composed of laminated clay and lignite, alternating gravels and sands with pebbles, cakes of peat, branches and stumps of trees, and mammalian bones, etc. (ranging up to more than 20 feet in thickness).
- Lower Fresh-water Bed, made up of carbonaceous, green, clayey silt full of seeds, with laminated lignite and loam.

Weybourn Crag.

The vegetation preserved in this group of strata embraces at least 56 species of flowering plants, two of which, the water chestnut and spruce fir, do not appear to have belonged to the British flora since the Glacial period; the others are nearly all still living in Norfolk. The variety of forest-trees points to a mild and moist climate; they include the maple, sloe, hawthorn, cornel, elm, birch, alder, hornbeam, hazel, oak, beech, willow, yew, pine, and spruce. The land and fresh-water shells number 58 species, whereof five appear to be extinct (Limax modioliformis, Nematura runtoniana, Paludina glacialis, P. media, Pisidium astartoides) and five no longer live in Britain (including Hydrobia Steinii, Valvata fluviatilis, Corbicula fluminalis). The known marine shells in the Forest-bed series are so few in number (19 species) that they do not afford a satisfactory basis for comparison with other parts of the Pliocene formations. Some of them may have been washed out of the Weybourn Crag below, and they are all common Weybourn Crag fossils, including several extinct species (Melampus pyramidalis, Tellina obliqua, Nucula Cobboldiæ). They indicate that the climate of the time when they lived was probably not greatly different from that of the present day. Fourteen species of fishes have been recognized (Platax Woodwardi, cod, and tunny among marine forms, also perch, pike, barbel, tench, and sturgeon among fluviatile kinds). The fauna also includes two reptiles (Tropidonotus natrix, Pelias berus), four amphibians (frogs and tritons), five birds (eagle-owl, cormorant, wild goose, wild duck, shoveller duck), and fifty-nine mammals. These last-named fossils give the Forest-bed its chief geological interest. They include a few marine forms—seals, whales, walrus, and a large and varied assemblage of terrestrial and river-haunting forms, such as carnivores—Machairodus, Canis lupus, C. vulpes, Hyæna crocuta, Ursus spelæus, Mustela martes, Gulo luscus, Lutra vulgaris; ungulates—Bison bonasus, Ovibus moschatus, Alces latifrons, Cervus elaphus (and nine other species), Hippopotamus amphibius, Sus scrofa, Equus caballus, E. Stenonis, Rhinoceros etruscus, Elephas antiquus, E. meridionalis; rodents—Arvicola arvalis, Mus sylvaticus, Castor fiber, Trogontherium Cuvieri; insectivores—Talpa europæa, Sorex vulgaris, S. pygmæus, Myogale moschata. The contrast between this strange collection of animals and the familiar aspect of the plants associated with them was long ago remarked by Lyell.[102] The most abundant and conspicuous forms are the three species of elephant, while the hippopotamus and rhinoceros are of common occurrence. Of the two horses one is extinct, the bison and wild boar have survived, while the whole of the remarkably numerous species of deer have disappeared, with the single exception of the red-deer. The carnivores embraced also living and extinct forms, for the long-vanished machairodus haunted the same region with our still surviving fox, otter, and marten, and with other animals which, like the hyæna, wolf, and glutton, though no longer found in Britain, survive elsewhere. The total species of land mammals (exclusive of bats) found in the Forest-bed is 45, while the corresponding series of the living British fauna numbers only 29 species. Of the 30 large land mammals found in the Forest-bed only three are now living in Britain, or have died out there within the historic period, and only six species have survived in any part of the world.[103]

The Cromer Forest-bed is succeeded on the Norfolk coast by some sands and gravels of which the true position in the series of formations has not yet been definitely fixed. They include two distinct members, though their precise relations to the Crag below and the glacial materials above are still not satisfactorily settled. The lower band is known as the Leda myalis bed, and the upper as the Arctic freshwater bed. The former may be provisionally placed with

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[102] "Antiquity of Man," 1st edit. 1863, p. 216. See also C. Reid, "Pliocene Deposits of Britain," p. 182.

[103] C. Reid, op. cit.

the rest of the Pliocene formations of Norfolk. The latter can hardly be separated from it, and would not be so separated but for the remarkable character of its few included fossils. These indicate such a great increase of cold as to show that the conditions of the Glacial period must now have set in. Hence the Arctic fresh-water bed is classed with the Pleistocene series.

Leda myalis Bed.—This band, nowhere more than 20 feet in thickness, consists of false-bedded loamy sand, loam or clay, and a little gravel, and lies sometimes on the Forest-bed, sometimes on the Weybourn Crag. This unconformability may mark a considerable interval of time. Among the scanty organisms of this deposit the following may be mentioned: Buccinum undatum, Littorina littorea, L. rudis, Purpura lapillus, Tropon antiquus, Astarte borealis, Cardium edule, Cyprina islandica, Leda myalis, Mya truncata, Mytilus edulis, Ostrea edulis, Tellina balthica. Some of these shells (the Astarte, Leda, and Mya) are found with the valves united in the position of life. The Leda is an Arctic species not known in any of the underlying formations.

Arctic Fresh-water Bed.—Reference may be made here to this deposit which is so intimately linked with that last described. It consists of stiff blue loam, clay, and sand, sometimes more than two feet thick, like the deposits of transient floods. Its plants include a number of mosses, with the dwarf Arctic birch and willow (Betula nana and Salix polaris, Fig. 454)—a vegetation wherein trees seem to have as completely disappeared as in the Arctic lands. It may indicate a lowering of temperature by about 20° Fahr.—"a difference as great as between the south of England and the North Cape at the present day, and sufficient to allow the seas to be blocked with ice during the winter, and to allow glaciers to form in the hilly districts."[104] Among the plants a few land-shells have been found such as Succinea putris, S. oblonga, Pupa muscorum, together with some wing-cases of beetles.

Various pebble-gravels occur in different parts of southern England, the true stratigraphical position of which is still undetermined. They are generally unfossiliferous. Some parts of them may be Pliocene. In the southwest, at Dewlish in Dorset, a deposit of sand and gravel has

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[104] C. Reid, op. cit. p. 198.

yielded a number of elephant bones and teeth referred to Elephas meridionalis, and pointing to an Upper Pliocene age.

Belgium and Holland.—The sea in which the English Pliocene deposits were laid down probably extended across Belgium, Holland, and the extreme north of France, but no trace of its presence has yet been found eastward in Germany. In Belgium the base of the Pliocene is found to rest with a strong unconformability on all older deposits, even on the Miocene sands (Bolderian and Anversian). The older Pliocene group consists chiefly of sand, and has been named Diestian from the locality where it is typically developed. At Antwerp, Utrecht, and other places it has yielded a large assemblage of fossils (190 species), all of which save 22 occur in the English Coralline Crag and Lenham beds. This horizon may be paralleled with the Plaisancian group of southern France and Italy. Above the Diestian sands comes the group known as Scaldesian, which is likewise made up mainly of sands inclosing a fauna closely resembling that of the lower part of the English Red Crag (Walton Crag). The higher groups seen in England have not yet been identified by means of fossils in Belgium and Holland. Yet the Pliocene deposits attain in these countries a far greater thickness than they do in England. At Amsterdam, for example, a deep boring has passed through younger Tertiary strata to a depth of 1096 feet below sea-level, and yet it is doubtful, according to Mr. Reid, whether any portion of this great thickness is so old as the Diestian group.[105] Belgian Pliocene deposits, of which the precise horizons have not been determined, have yielded a large number of bones of marine mammalia, including seals, dolphins, and numerous cetaceans, as well as remains of fishes (Carcharodon, Lamna, Oxyrhina, etc.).

France.—In the north of this country unfossiliferous sands which cap the hills between Boulogne and Calais at heights of 400 or 500 feet, and stretch eastward into French Flanders, are believed to be continuations of the Lenham and Diestian group.[106] In central France, younger Pliocene deposits associated with the volcanic materials of that region have preserved an interesting record of the terrestrial fauna of the time. The trachytic conglomerate of Perrier and the ossiferous deposits of other localities in Auvergne have

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[105] C. Reid, op. cit. p. 220.

[106] Op. cit. p. 56.

yielded an abundant fauna, in which the apes are absent, the antelopes have dwindled in size and number, the deer have grown very abundant, true elephants for the first time appear, associated with a species of hippopotamus, nearly if not quite identical with the living African one, two kinds of hyæna, and the hipparion and machairodus that had survived from earlier times. This fauna indicates a decided change of climate to a more temperate character. Among the volcanic products of Haute Loire remains of Mastodon arvernensis, Rhinoceros leptorhinus, Equus Stenonis, and Machairodus pliocænus have been collected.

Along the southern coast of France, marine Pliocene deposits lying unconformably on every series older than themselves bear witness to the elevation of that region since Pliocene time, some of the beds reaching a height of 1150 feet above the present sea-level. These marine strata extend for some distance up the valley of the Rhone, where they mark the final deposits of the sea in that part of the mainland of Europe. They cap the plateaus and rise toward the north and west, indicating a maximum of elevation in that direction. The marls of Hauterives (formerly regarded as Miocene) are remarkable for their beds of coarse conglomerate, which represent some of the torrential deposits swept down from the neighboring hills. These marls contain land and fresh-water shells.

The whole series of Pliocene deposits in southern France has been divided into the following groups.[107]

Arnusian.	Fresh-water and volcanic groups of Auvergne, etc. (St. Prest, Perrier[108]) with Elephas meridionalis in the younger and Mastodon arvernensis in the older deposits.
Astian.	Sands and clays of fluvatile or lacustrine origin, with a few shells (Unio, Anodonta, Planorbis, Helix) and a large and varied assemblage of terrestrial and fluviatile vertebrates (Dolichopithecus, Machairodus, Caracal, Hyena, Mastodon arvernensis, Rhinoceros leptorhinus, Tapirus arvernensis, Hipparion, Helarctos, Gazella, Cervus, etc., Montpelier, Rousillon). Yellow sands with Potamides Basterioti, Cerithium vulgatum, Congeria, Ostrea cucullata, Pecten benedictus, Cardium, Venus multilamella.
Plaisancian (200–250 metres).	Sandy blue micaceous clays (with a large marine fauna, 233 species, comprising Nassa semistriata, Mitra striatula, Conus pelagicus, Cerithium vulgatum, Cytherea chione, Pecten benedictus, P. scabrellus, Ostrea cucullata). Lower conglomerates sometimes 80 feet thick.

[107] Fontannes, "Études Stratigraph. Paleont. pour servir à l'histoire de la Periode, Tertiare dans le Bassin du Rhône," Paris, 1875–89; Deperet, Ann. Sci. Geol. xvii. 1885; Mem. Soc. Geol. France, I. fascie. 1, 1890.

[108] Pottier, Bul. Soc. Geol. France, vii. 1879, p. 937.

Italy.—As the Pliocene series is traced eastward into Italy its lacustrine intercalations disappear and it becomes mainly a marine formation, which is so amply developed there that it might be taken as typical for the rest of Europe. Along both sides of the chain of the Apennines it forms a range of low hills, and has been named from that circumstance the "sub-Apennine series." In the Ligurian region, according to C. Mayer, it consists of the following groups in ascending order: 1, Messinian (=Zanclean of Seguenza), composed of (*a*) marls, conglomerates, and molasse (65 feet), with Cerithium pictum, C. rubiginosum, Venus multilamella, Pecten cristatus, Turritella communis, T. subangulata; (*b*) gypsiferous marls, limestones, dolomites (320 feet), traceable along the range of the Apennines as far as Girgenti in Sicily by its well-known gypsum zone, and containing Turritella subangulata, Natica helicina, Pleurotoma dimidiata, etc.; (*c*) gravels and yellow marls, with beds of lignite (upward of 300 feet). 2, Astian, composed, at the foot of the Ligurian Apennines, of two groups (*a*) blue marls with Dentalium sexangulare, Turritella communis, T. tornata, Murex trunculus, Natica millepunctata, etc.; (*b*) yellow sands with few fossils (300 feet and more).[109] More recently Prof. Sacco has estimated the whole series in the central portion of the northern Apennines to have a thickness of nearly 1500 feet, which he groups as in the subjoined table:[110]

Villafranchian (100 metres).	Fluvio-lacustrine alluvial sands, marls, clays and conglomerates, with shells indicating a warm, moist climate, Rhinoceros etruscus, Mastodon arvernensis, etc.
Astian (100 metres).	Yellow sands and gravels, rich in littoral, marine or estuarine fossils.
Plaisancian (150 metres).	Marls and sandy clays with abundant marine fossils, from one-third to one-half of the shells belonging to living species.
Messinian (100 metres).	Sandy and clayey marls with seams of gypsum and limestone marking alternations of brackish-water and marine conditions. The shells include Dreissena, Adacna, Cyrena, Neritodonta, Melania, Melanopsis, Hydrobia, etc. Some of the marls are full of leaves (Thuja, Phragmites, Myrica, Quercus, Castanea, Fagus, Ulmus, Ficus, Liquidambar, Laurus, Sassafras, Cinnamomum, Rhamnus, etc.).

In Sicily a similar threefold grouping has been made by Seguenza, who has traced the same arrangement throughout

[109] C. Mayer, Bull. Soc. Geol. France (3), v. 292.

[110] F. Sacco, "Il Bacino Terziario del Piemonte," Milan, 1889. See also De Stefani Atti. Soc. Tosc. Sci. Nat. 1876–84.

a large part of the mainland. The lowest group is named by him Zanclean, and consists of marls and light-colored limestones. The Plaisancian follows in a group of blue clays or marls, while the succeeding Astian consists of yellow sands. Of these stages the first is characterized by a fauna of which nearly $\frac{9}{10}$ are peculiar species, and only 85 out of 504 species, or about 17 per cent, belong to living forms which are nearly all found in the Mediterranean. Some of the common species of the deposit are Janira flabelliformis, Terebratulina caput-serpentis, Rhynchonella bipartita, Dentalium triquetrum, Limopsis aurita, Leda dilatata, L. striata, Phill., Modiola phaseolina. Tropical genera are well represented among the shells of the Italian Pliocene beds, while some of the still living Mediterranean genera occur there more abundantly, or in larger forms than on the present sea-bottom. The newer Pliocene deposits attain in Sicily a thickness of 2000 feet or more, rising to a height of nearly 4000 feet above the present sea-level, and covering nearly half of the island. To this series, though possibly it should be regarded as Pleistocene, is assigned a yellowish limestone, sometimes remarkably massive and compact, and 700 or 800 feet thick, yet full of living species of Mediterranean shells, some of which even retain their color, and a part of their animal matter. It was during the accumulation of the Pliocene strata that the history of Etna began, the first stages being submarine eruptions, which were followed by the piling-up of the present vast subaerial cone upon the upraised Pliocene sea-bottom.

There is distinct evidence of a lowering of the climate of southern Europe during the deposition of the Italian Pliocene series. Not only did many of the distinctively southern types of shells gradually disappear from the Mediterranean, but others of markedly northern character, such as species of Astarte, took their place. The Italian Pliocene deposits, while chiefly of marine origin, contain also among their higher members lacustrine or fluviatile strata, in which remains of the terrestrial flora and fauna have been preserved. In the upper part of the valley of the Arno an accumulation of lacustrine beds attains a depth of 750 feet. The older portion consists of blue clays and lignites, with the abundant vegetation above referred to (p. 1648). The upper 200 feet consist of sands and a conglomerate ("sansino"), and have yielded remains of 39 species of mammals including Macacus florentinus, Mastodon arvernensis, Elephas meridionalis, Rhinoceros etruscus, Hippopotamus amphibius (major), Hyæna (3 sp.), Felis (3 sp.), Ursus etruscus, Machairodus (3 sp.), Equus Stenonis, Bos etruscus, Cervus (5 sp.), Palæoryx, Palæoreas, Castor, Hystrix, Lepus arvicola.[111] These strata are sometimes grouped as a higher zone of the Pliocene series under the name of Arnusian.[112]

Germany.—The absence of marine Pliocene formations in Germany has been already referred to. Among the lacustrine and fluviatile deposits of the period, however, numerous remains of the terrestrial flora and fauna have been preserved. One of the most celebrated localities for the discovery of these remains lies in the Mainz basin, where at Eppelsheim, near Worms, above the Miocene beds, described on p. 1639, a group of sands and gravels with lignite (Knochensand), from 20 to 30 feet thick, has yielded a considerable number of mammalian bones. Among these the Deinotherium giganteum occurs, showing the long survival of this animal in central Europe; also Mastodon angustidens, Rhinoceros incisivus, and other species, Hippotherium gracile, several species of Sus, five or more of Cervus, and some of Felis.

Interesting collections of the terrestrial fauna of the period have been preserved in the calcareous tuffs of mineral springs in different parts of Germany. Besides numerous remains of land-plants, large numbers of land and fresh-water shells have been obtained from these deposits, which in some cases point to a colder climate than now exists. In the Franconian Alb, for instance, the occurrence of alpine and northern European forms of land-shells (Patula solaria, Clausilia densestriata, C. filograna, Helix vicina, Pupa pagodula, Isthmia costulata) has been noted. The mammals include many extinct as well as some still living forms (Elephas antiquus, Rhinoceros Merkii, Sus scrofa, Cervus elaphus, C. capreolus, Bos primigenius, Equus caballus, Ursus spelæus, Meles vulgaris, Hyæna spelæa).[113]

Vienna Basin.—In consecutive conformable order above the

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111 C. J. Forsyth Major, Q. J. Geol. Soc. xli. 1885, p. 1.

112 Mr. C. Reid suggests that the lignite deposits of the Val d'Arno (with Tapirus) may be much older than the rest of the lacustrine strata (with Mastodon and Elephas). A large proportion of the plants in them is extinct, and the tapir is the only animal whose remains are found in them. They may possibly be even Miocene.

113 F. von Sandberger, "Land und Süsswasser Conchylien der Vorwelt," 1875, p. 936; Sitzb. Bayer. Akad. xxiii. 1893, Heft 1; Hellmann, Palæontographica, suppl.

Miocene strata described on p. 1640, come the highest Tertiary beds of this area, referred to the Pliocene period, and known by the name of the "Congerian stage," from the abundance in them of the molluscan genus Congeria (Dreissena) (Fig. 449). They are separable into two tolerably well-defined zones, which in descending order are:

2. Belvedere-Schotter—a coarse conglomerate or gravel of quartz and other pebbles, occasionally yielding bones of large mammals; Belvedere-sand—a yellow micaceous sand, forming the lower member of the zone and containing in its more compact portions abundant terrestrial leaves. These strata resemble part of the alluvia of a large river. Their name is taken from the Belvedere in Vienna, where they are well developed.
1. Inzersdorf Tegel—a tolerably pure clay reaching a depth of often more than 300 feet. This deposit, the youngest Tertiary layer that is widely distributed over the Vienna basin, points to continued and general submergence. The facies of its fossils, however, shows that the water no longer communicated freely with the open sea, but seems rather to have partaken of a Caspian character. Among the conspicuous mollusks are Congeria subglobosa, C. Partschi, C. triangularis, C. spathulata, C. Czjzeki, Cardium carnuntinum, C. apertum, C. conjungens, Unio atavus, U. moravicus, Melanopsis martiniana, M. impressa, M. vindobonensis, M. Bouéi. The mammals include Mastodon longirostris, M. angustidens, Deinotherium giganteum, Aceratherium incisivum, Hippotherium gracile, antelope, pig, Machairodus cultridens, Hyæna hipparionum. The flora includes, among other plants, conifers of the genera Glyptostrobus, Sequoia, and Pinus, also species of birch, alder, oak, beech, chestnut, hornbeam, liquidambar, plane, willow, poplar, laurel, cinnamon, buckthorn, with the Asiatic genus Parrotia, the Australian proteaceous Hakea (Fig. 442), and the extinct tamarind-like Podogonium.

In other parts of the Austro-Hungarian empire interesting evidence exists of the gradual uprise of the sea-floor during later Tertiary time and the isolation of detached areas of sea, so that the southeast of Europe must then have presented some resemblance to the great Aralo-Caspian depression of the present time. The Congerian stage brings before us the picture of an isolated gulf gradually freshening, like the modern Caspian, by the inpouring of rivers; but on both sides of the Carpathian range there were bays nearly cut off from the main body of water, and exposed to so copious an evaporation without counterbalancing inflow that their salt was deposited over the bottom. Of the Transylvanian localities, on the south side of the mountains, the most remarkable is Parajd, where a mass of rock-salt has been accumulated, having a maximum of 7550 feet in length, 5576 feet in breadth, and 590 feet in depth, and estimated to contain upward of 10,595 millions of cubic feet. On the northern flank of the Carpathian Mountains, near Cracow, lie the famous and extensive salt-works of Wieliczka, with their massive beds of pure and impure rock-salt, gypsum, and anhydrite, some of the strata being full of fossils characteristic of the upper zones of the Vienna basin.

The southeast of Europe, during later Tertiary time, was the scene of abundant volcanic action, and the outpourings of trachyte, rhyolite, basalt and tuff were specially abundant over the low districts to the south of the Carpathian chain.

Greece.—A remarkable series of mammalian remains brought to light from certain hard red clays, alternating

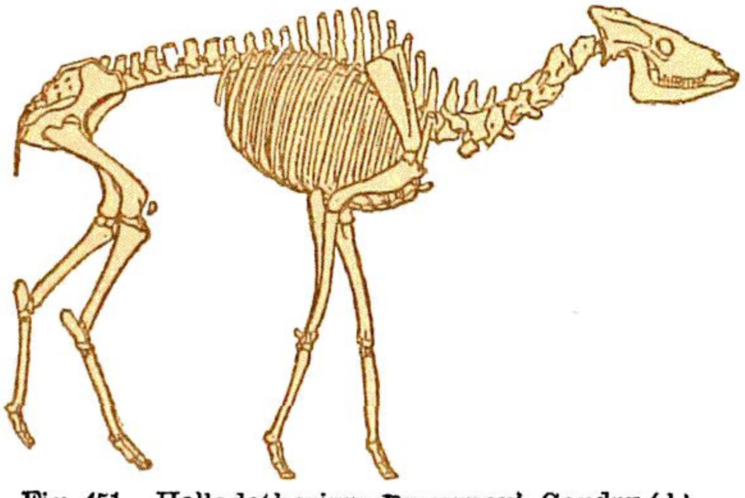

Fig. 451.—Helladotherium Duvernoyi, Gaudry ($\frac{1}{60}$).

with gravels at Pikermi, in Attica, has been carefully worked out by M. Gaudry.[114] The list includes a monkey

[114] "Animaux fossiles et Geologie de l'Attique," 4to, 1862, with volume of plates; Bull. Soc. Geol. France, xiv. 1885–86, p. 288. See also Roth and Wagner, *Abhandl. Bayer. Akad.* vii. 1854; T. Fuchs, *Denksch. Akad. Wien*, xxxvii. 1877, 2e Abtheil, p. 1; Boll. Com. Geol. Ital. ix. 1878, p. 110; W. T. Blanford,

(Mesopithecus) intermediate between the living Semnopithecus of Asia and the Macaques. The carnivores are represented by Simocyon, Mustela, Promephitis, Ictitherium—a genus allied to the modern civet—Hyænictis, Hyæna, Machairodus, and several species of Felis; the rodents by Hystrix, allied to the common porcupine; the edentates by the gigantic Ancylotherium; the proboscideans by Mastodon and Deinotherium; the pachyderms by Rhinoceros (several species), Aceratherium, Leptodon, Hipparion, and a gigantic wild boar (Sus erymanthius); the ruminants by Camelopardalis, of the same size as the living giraffe, Helladotherium—a form between the giraffe and the antelopes, three species of true antelope—Palæotragus, an antelope-like animal, Palæoryx, somewhat like the living African gemsbok, and Palæoreas, allied to the African eland and the gazelles, Gazella, a true gazelle, Dremotherium, probably a hornless ruminant like the living chevrotains. A few remains of birds have also been met with, including a Phasianus, related to our pheasant, a Gallus, smaller than our common

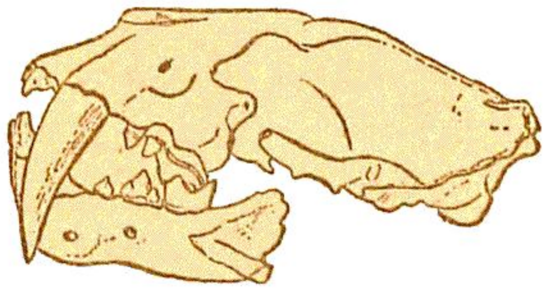

Fig. 452.—Head of Machairodus, the sabre-toothed Tiger, reduced.

domestic fowl, a Grus, closely related to the living crane; also bones of a turtle and a saurian (Varanus). This fauna is remarkable for the extraordinary abundance of its ruminants, the colossal size of many of the forms, such as the giraffe and Helladotherium, the singular rarity of the smaller mammals, the marked African facies which runs through the whole series, and the number of transitional types which it contains. Out of the 31 genera of mammals which have been obtained, 22 are extinct. The Pikermi beds have been classed as Upper Miocene, but the occurrence of 4 characteristic marine Pliocene species of shells below them (Pecten benedictus, Spondylus gœderopus, Ostrea lamellosa, O. undata) justifies their being placed in a later stage of the Ter-

Address, Geol. Sect. Brit. Assoc. 1884. W. Dames (Zeitsch. Deutsch. Geol. Ges. xxxvi. 1883, p. 9) has added a species of Cervus and one of Mus to the previously known Pikermi forms.

tiary series. They are shown by Fuchs to form part of the Pliocene series of Attica, and lie in the highest part of that series.

Samos.—In an irregular deposit of gravels, sandstones, and marls in the island of Samos, Dr. Forsyth Major has discovered a large assemblage of vertebrate remains of an age similar to that of the Pikermi strata. Among the fossils obtained by him are many of the same species as are found at the Greek locality, such as Promephitis Larteti, Mustela palæattica, Lycyæna Chæretis, Ictitherium robustum, I. hipparionum, Ancylotherium Pentelici, Mastodon Pentelici, Rhinoceros pachygnathus, Hipparion mediterraneum, Sus erymanthius; seven antelopes, Palæoreas Lindermayeri, Gazella brevicornis, Palæoryx Pallasii, and two others. Besides these, there are some half dozen antelopes of African types, and true edentates, Orycteropus Gaudryi, Palæomanis Neas, a new genus of gigantic ruminants, Samotherium, belonging to the family of the giraffes, and recalling the Helladotherium of Pikermi, and an ostrich (Struthio Karatheodoris).[116]

India.—Not less important than the massive Pliocene accumulations of the Mediterranean basin, are those which have been found in Sind, the Punjab, and other northwestern tracts of India. In Sind, the noteworthy fact has been made out by the Indian Geological Survey that, from the Upper Cretaceous to the Pliocene beds, the whole succession of strata, with some trifling local exceptions, is conformable and continuous; yet contains evidence of alternations of marine and terrestrial conditions, the latest marine intercalations being of Miocene date. The upper division of the Manchhar group (p. 1644) is not improbably referable to the Pliocene period. It consists of clays, sandstones, and conglomerate, 5000 feet thick, which have yielded some indeterminable fragmentary bones. Similar strata cover a vast area in the Punjab. They are admirably exposed in the long range of hills termed the Sub-Himalayas, which from the Brahmaputra to the Jhelum, a distance of 1500 miles, flank the main chain, and consist chiefly of soft massive sandstone, disposed in two parallel lines of ridge, having a steep southerly face and a more gentle northerly slope, and separated by a broad flat valley. These strata, with an aggregate thickness of between 12,000 and 15,000

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116 Compt. Rend. 31st Dec. 1888; 1891, pp. 608, 708.

feet, contain representatives of the older Tertiary or Nummulitic series, followed by younger Tertiary deposits which are classed together in what has been termed the Siwalik group. This group is of fresh-water origin, for its included organisms are entirely land or fresh-water forms. Its component clays, sandstones, and conglomerates have been deposited by great rivers, which appear to have flowed from the Himalayan chain by the same outlets as their modern representatives. These deposits vary according to their position relatively to the great rivers. They have been involved in the last colossal movements whereby the Himalayas have been upheaved, yet their structure shows that

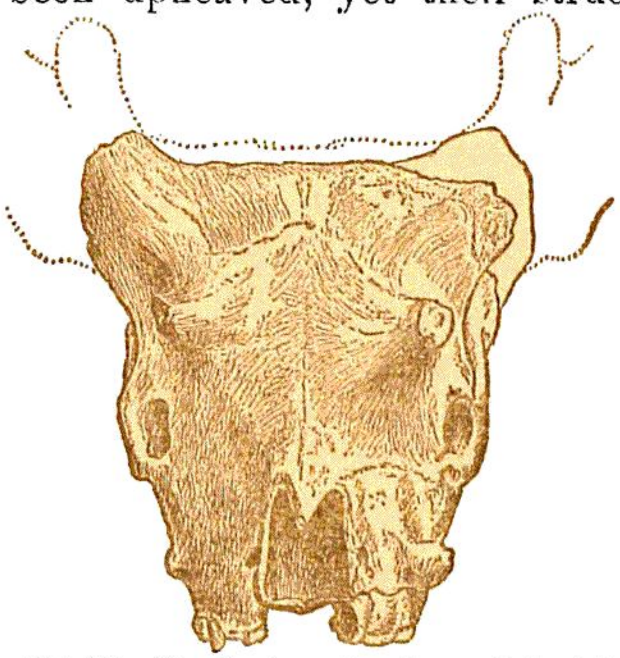

Fig. 453.—Sivatherium giganteum, Falc, reduced.
A gigantic form of antelope having two pairs of horns, found in the Siwalik beds of India.

the same distribution of the water-courses has been maintained as existed before the disturbance. In this instance, as in that of the Green River through the Uinta range in western America, the inference seems to be legitimate that the elevation of the mountains must have proceeded so slowly that the erosion by the rivers kept pace with it, and the positions of the valleys were therefore not sensibly changed (see Book VII.).

The Siwalik fauna consists partly of a few land or fresh-water mollusks, some, if not all, of which are identical with living species; but chiefly of mammalia; and the following list comprises the vertebrate fauna so far as at present known:[116]

[116] Falconer and Cautley, "Fauna Antiqua Sivalensis," 1845–49. Medlicott and Blanford, "Geology of India," p. 577. Blanford, Brit. Assoc. 1880, p. 577;

MAMMALIA.—Primates.—Palæopithecus, 1 sp.; Macacus, 2; Cynocephalus, 2.

Carnivora.—Mustela, 1; Mellivora, 2; Mellivorodon, 1; Lutra, 3; Hyænodon, 1; Ursus, 1; Hyænarctos, 3; Canis, 1; Amphicyon, 1; Viverra, 2; Hyæna, 5; Lepthyæna, 1; Æluropsis, 1; Ælurogale, 1; Felis, 5; Machairodus, 2.

Proboscidea.—Elephas, 6 (Euelephas, 1; Loxodon, 1; Stegodon, 4); Mastodon, 7.

Ungulata.—Chalicotherium, 1; Rhinoceros, 3; Equus, 2; Hipparion, 2; Hippopotamus, 2; Tetraconodon, 1; Sus, 7; Hippohyus, 2; Sanitherium, 1; Merycopotamus, 3; Cervus, 4; Dorcatherium, 2; Tragulus, 1; Palæomeryx, 1; Bramatherium, 1; Helladotherium (?), 1; Hydaspitherium, 2; Sivatherium, 1; Vishnutherium, 1; Giraffa, 1; Alcelaphus, 1; Gazella, 1; Oreas (?), 1; Palæoryx (?), 1; Leptobos, 2; Bubalus, 4; Bison, 1; Bos, 3; Bucapra, 1; Capra, 2; Camelus, 2; Boselaphus, Hippotragus, Cobus.

Rodentia.—Rhyzomys, 1; Hystrix, 1; Lepus, 1.

AVES.—Phalacrocorax, 1; Leptoptilus, 1; Pelecanus, 2; Mergus, 1; Struthio, 1.

REPTILIA.—Crocodilia.—Crocodilus, 2; Garialis, 5; Rhamphosuchus, 1.

Lacertilia.—Varanus, 1.

Chelonia.—Colossochelys, 1; Testudo, 2; Bellia, 2; Damonia, 1; Batagur, 1; Pangshura, 1; Emyda, 4; Trionyx, 1; Clemmys, 7; Chitra, 1.

PISCES.—Bagarius, 1; Arius, 2; Rita, 1; Chrysichthys, 1; Clarias (?), 1; Carcharodon, Carcharias.

In this list there is considerable resemblance to the grouping of mammalia in the Pikermi deposits just referred to, particularly in the preponderance of large animals, the absence or rarity of the smaller forms (rodents, bats, insectivores), and the marked Miocene aspect of certain parts of the fauna. Mr. Blanford and his colleagues of the Geological Survey of India have, however, shown that, though usually classed as Miocene, the Siwalik fauna has such relations to Pliocene and recent forms as are found in no true Miocene fauna. The large proportion of existing genera is the most striking feature of the assemblage. Twelve of the

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Address, Geol. Sect. Brit. Assoc. 1884. Lydekker, "Palæontologia Indica," ser. x. vols. i. ii. iii. Records Geol. Surv. India, 1883, p. 81; "Cat. Sowalik Vert. Ind. Mus." 1885–86, and Catalogues of British Museum.

genera are known elsewhere, 7 are Miocene and Pliocene; of the still living genera 9 range back in Europe to Upper Miocene time, 10 only to Pliocene, while 6 are only known elsewhere as living forms or as occurring in post-Pliocene beds. The large preponderance of species belonging to such familiar genera as Macacus, Ursus, Elephas, Equus, Hippopotamus, Bos, Hystrix, Mellivora, Meles, Capra, Camelus, and Rhizomys, give the whole assemblage a singularly modern aspect. It should be added that, of the six or seven determinable reptiles, three are now living in northern India; that of the birds, one is probably identical with the living ostrich, and that all the known land and fresh-water shells, with one possible exception, are of existing species.[117]

North America.—It appears to be doubtful whether any of the Tertiary deposits of the Atlantic border can be referred to the Pliocene series. They seem to be rather older and to be covered directly by post-Pliocene and recent accumulations.[118] In the Upper Missouri region, the White River group (p. 1645) is overlain by other fresh-water beds, 300 to 400 feet thick (Loup River group of Meek and Hayden, or Niobrara group of Marsh), from which an interesting series of vertebrate remains has been obtained. Among these, are those of an eagle, a crane, and a cormorant; a tiger, larger than that of India, an elephant, a mastodon, several rhinoceroses, the oldest known camels (Procamelus, Homocamelus), equine animals of the genera Protohippus, Pliohippus, Merychippus, and Equus, of which the last was as large as the living horse. The remarkably Oriental character of this fauna is worthy of special notice. At the eastern base of the Rocky Mountains in Colorado a group of sandstones (Denver beds) has yielded a large species of bison. Again, abundant remains of Aceratherium have recently been found in the Pliohippus beds of the Upper Pliocene series of Kansas.[119]

Australia.—In New South Wales, during what are supposed to correspond with the later Miocene, Pliocene, and Pleistocene periods, the land appears to have been gradually rising and to have been exposed to prolonged denudation and, in the Middle Pliocene period, to great volcanic ac-

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[117] Blanford, Brit. Assoc. 1880, p. 578, and 1884, Address.

[118] A. Heilprin, as cited on p. 1612.

[119] Marsh, Amer. Journ. Sci. xxxiv. 1887, p. 323.

tivity. Hence successive fluviatile terraces were formed and eroded in the valleys, and were in many cases buried under great streams of lava. It is in these buried river-beds that the "deep-leads" lie, from which such large quantities of gold are obtained. They have preserved with wonderful perfection remains of the flora and fauna of the period. Among the plants are large trunks, branches, and fruits of trees, and ferns. With these are associated fresh-water shells, traces of beetles, and bones of a number of extinct marsupials, some of which were distinguished by their great size. One of the most abundant and remarkable of these creatures was the Diprotodon, which attained the bulk of a rhinoceros or hippopotamus. Another is the Nototherium, probably somewhat like a large tapir, of which three species have been named. An extinct gigantic kangaroo (Macropus Titan) had a skull twice as long as that of the largest living species. There were also wombats (Phascolomys), and a marsupial lion (Thylacoleo), with the marsupial hyæna (Thylacinus), and Sarcophilus or "devil," which still live in Tasmania. To these may be added the Dromornis—a large bird represented now by the emu.[120]

In Victoria a younger Tertiary series overlies the older volcanic rocks referred to on p. 1639, and is likewise associated with newer volcanic ejections. It includes both marine and fluviatile deposits. The marine group, with species of Trigonia, Haliotis, Cerithium, Waldheimia, etc., is found up to heights of 1000 feet above sea-level. The fluviatile deposits, besides auriferous gravels, include also beds of lignite with abundant remains of terrestrial vegetation, and have yielded remains of Diprotodon, Phascolomys, Thylacoleo, Macropus, Procoptodon, Dasyurus, Hypsiprimnus, Canis dingo, etc. Vast sheets of basaltic and doleritic lavas have overspread the plains and filled up the Pliocene river-beds.[121]

In Queensland the presence of Tertiary rocks is inferred rather than proved. But from the similarity of the volcanic rocks of that colony to those of Victoria and New South Wales, it is believed that the older and newer volcanic groups which have been established are likewise of Tertiary age.[122]

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120 C. S. Wilkinson, "Notes on Geology of New South Wales," Sydney, 1882.

121 R. A. F. Murray, "Geology of Victoria," p. 113.

122 These volcanic accumulations are extensive and of great interest. They have been described by Mr. R. L. Jack in the "Geology and Palæontology of Queensland," chap. xxxv.

New Zealand.—Deposits referable to the Pliocene division of the geological record play an important part in the geology and industrial development of New Zealand. According to Sir J. Hector, they belong to a time when the land was much more extensive than it now is, and when in the North Island volcanic action reached its greatest activity. Some of the beds were formed on the sea-floor, and contain in abundance Rotella zealandica, with Dosinea anus, Struthiolaria Fraseri, Buccinum maculatum. From 70 to 90 per cent of the mollusca are of still living species. In the South Island, the Pliocene strata are to a large extent unfossiliferous gravels, such as those of the Canterbury Plains and the Monteri Hills, in Nelson, which were derived from the mountainous interior. That considerable terrestrial disturbance took place during and subsequent to the deposit of the Pliocene series is shown by the disturbed and elevated positions of the beds in some places. Here and there the marine strata have been raised to a height of 300 feet (near Napier to more than 2000 feet) above the sea without disturbance of their horizontal position; but elsewhere they have been completely overturned. The economic importance of these deposits arises mainly from their yielding the richest supplies of alluvial gold.[123]

PART V. POST-TERTIARY OR QUATERNARY

This portion of the Geological Record includes the various superficial deposits in which nearly all the mollusca are of still living species. It is usually subdivided into two series: (1) an older group of deposits in which many of the mammals are of extinct species—to this group the names Pleistocene, Post-Pliocene, and Diluvial have been given; and (2) a later series, wherein the mammals are all, or nearly all, of still living species, to which the names Recent, Alluvial, and Human have been assigned. These subdivisions, however, are confessedly very artificial, and it is often ex-

123 Hector, "Handbook of New Zealand," p. 26; Hutton, Quart. Journ. Geol. Soc. 1885, p. 211.

ceedingly difficult to draw any line between them. The names assigned to them also are not free from objection. The epithet "human," for example, is not strictly applicable only to the later series of deposits, for it is quite certain that man coexisted with the fauna of the Pleistocene series.

In Europe and North America a tolerably sharp demarcation can usually be made between the Pliocene formations and those now to be described. The Crag deposits of the southeast of England, as we have seen, show traces of a gradual lowering of the temperature during later Pliocene times, and the same fact is indicated by the Pliocene fauna and flora on the Continent even in the Mediterranean basin. This change of climate continued until at last thoroughly Arctic conditions prevailed, under which the oldest of the Post-Tertiary or Pleistocene deposits were accumulated in northern and central Europe, and in Canada and the northern part of the United States.

It is hardly possible to arrange the Post-Tertiary accumulations in a strict chronological order, because we have no means of deciding, in many cases, their relative antiquity. In the glaciated regions of the northern hemisphere the various glacial deposits are grouped as the older division of the series under the name of Pleistocene. Above them, lie younger accumulations such as river-alluvia, peat-mosses, lake-bottoms, cave-deposits, blown-sand, raised lacustrine and marine terraces, which, merging insensibly into those of the present day, are termed Recent or Prehistoric.

Section i. Pleistocene or Glacial

§ 1. General Characters

Under the name of the Glacial Period or Ice Age, a remarkable geological episode in the history of the northern hemisphere is denoted.[1] The Crag deposits (p. 1653) afford evidence of a gradual refrigeration of climate at the close of the Tertiary ages. This change of temperature affected the higher latitudes alike of the Old and the New World. It reached such a height that the whole of the north of Europe was buried under ice, which, filling up the basins of the Baltic and North Sea, spread over the plains even as far south as close to the site of London, and in Silesia and Gallicia to the 50th parallel of latitude. Beyond the limits reached by the northern ice-sheet, the climate was so arctic that snow-fields and glaciers spread even over the comparatively low hills of the Lyonnais and Beaujolais in the heart of France. The Alps were loaded with vast snow-fields, from which enormous glaciers descended into the plains, overriding ranges of minor hills on their way. The Pyrenees were in like manner covered, while snow-fields and glaciers extended southward for some

[1] No section of geological history now possesses a more voluminous literature than the Glacial Period, especially in Britain and North America. For general information the student may refer to Lyell's "Antiquity of Man," J. Geikie's "Great Ice Age," "Prehistoric Europe," Address to Geological Section of British Association, 1889, and paper in Trans. Roy. Soc. Edin. xxxvii. part i. 1893, p. 127; J. Croll's "Climate and Time," "Discussions on Climate and Cosmology"; A. Penck, "Vergletscherung der Deutschen Alpen," 1882; J. Partsch, "Die Gletscher der Vorzeit in den Karpathen," etc., 1882; A. Falsan and E. Chantre, "Anciens Glaciers, etc., de la partie moyenne du Bassin du Rhône," 1879, and for detailed descriptions, to the Quart. Journ. Geol. Soc., Geol. Mag., Zeitsch. Deutsch. Geol. Ges., Jahrb. Preuss. Geol. Landesanst., Amer. Journ. Science, Annual Reports U. S. Geol. Surv., Bull. Amer. Geol. Soc., for the last fifteen or twenty years.

distance over the Iberian peninsula. In North America also, Canada and the eastern States of the American Union down to about the 39th parallel of north latitude, lay under the northern ice-sheet.

The effect of the movement of the ice was necessarily to remove the soils and superficial deposits of the land-surface. Hence, in the areas of country so affected, the ground having been scraped and smoothed, the glacial accumulations laid down upon it usually rest abruptly, and without any connection, on older rocks. Considerable local differences may be observed in the nature and succession of the different deposits of the glacial period, as they are traced from district to district. It is hardly possible to determine, in some cases, whether certain portions of the series are coeval, or belong to different epochs. But the following leading facts have been established. First, there was a gradual increase of the cold, until the conditions of modern North Greenland extended as far south as Middlesex, Wales, the southwest of Ireland, and 50° N. lat. in central Europe, and about 39° N. lat. in eastern America. This was the culmination of the Ice Age—the first or chief period of glaciation. Then followed an interval or interglacial period, during which the climate seems to have become much milder. This interlude was succeeded by another cold period, marked by a renewed augmentation of the snow-fields and glaciers—a second period of glaciation.

It has been maintained by some observers that as many as four or five distinct epochs of cold are included within the geological interval represented by the Pleistocene deposits. Other writers contend for the essential unity of the glacial period. The truth will probably be found to lie somewhere between the extreme views. There seems to be demonstrable proof that there was at least one interglacial period. There may have been more than one advance of the northern ice into temperate latitudes. The interval of milder climate, of which there is clear proof, must have been of such prolonged duration that southern types of plant and animal life were enabled to spread northward and resume their former habitats.[2] Eventually, however, and no doubt very gradually, after intervals of increase and diminution, the ice finally retired toward the north, and with it went the Arctic flora and fauna that had peopled the plains of Europe, Canada, and New England. The existing snow-fields and glaciers of the Pyrenees, Switzerland, and Norway are remnants of the great ice-sheets of the glacial period, while the Arctic plants that people the mountains, and survive in scattered colonies on the lower grounds, are relics of the northern vegetation that covered Europe from Norway to Spain.

The general succession of events has been the same throughout all the European region north of the Alps, likewise in Canada, Labrador, and the northeastern States, though of course with local modifications. The following summary embodies the main facts in the history of the Ice Age. Some local details are given in subsequent pages.

Pre-glacial Land-surfaces.—Here and there, fragments of the land over which the ice-sheets of the glacial period settled have escaped the general extensive ice-abrasion of that ancient terrestrial surface, and have even retained relics of the forest growth that covered them. One of the best-known deposits in which these relics have been preserved is the so-called "Forest Bed" (p. 1660). Above

[2] Those who wish to enter into this debated subject will find it discussed from opposite sides in some recent papers by T. C. Chamberlin and G. F. Wright in the Amer. Journ. Sci. (1892, 1893), with references to other authorities.

that deposit, as already described (p. 1661), there is seen, here and there, on the Norfolk coast, a local or intermittent bed of clay containing remains of Arctic plants (Salix polaris, Betula nana, etc., Fig. 454), together with the little marmot-like rodent Spermophilus. These relics of a terrestrial vegetation are drifted specimens, but they cannot have travelled far, and they probably represent a portion of the Arctic flora which had already found its way into the middle of England before the advent of the ice-sheet. Judging from the present distribution of the same plants, we may infer that the climate had become about 20° colder than it was during the time represented by the Forest-bed —a difference as great as that between Norfolk and the North Cape at the present day.[3]

The Northern Ice-sheet.—At the base of the glacial deposits, the solid rocks over the whole of northern Europe and America present the characteristic smoothed flowing outlines produced by the grinding action of land-ice (p. 720). The rock-surfaces that look away from the quarter whence the ice moved are usually rough and weatherworn (Leeseite), while those that face in that direction (Stoss-seite) are all ice-worn. Even on a small boss of rock or along the side of a hill, it is commonly not difficult to tell which way the ice flowed, by noting toward which point the striæ run, and the rough faces look. Long exposed, the peculiar ice-worn surface is apt to be effaced by the disintegrating action of the weather, though it retains its hold with extraordinary pertinacity. Along the fjords of Norway and the sea-lochs of the west of Scotland, it may be seen slipping into the water, smooth, bare, pol-

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[3] C. Reid, Horizontal Section, No. 127 of Geol. Survey, and "Geology of the Country around Cromer" (sheet 68 E), in Memoirs of Geol. Survey, 1882.

ished and grooved, as if the ice had only recently retreated. Inland, where a protecting cover of clay or other superficial deposit has been newly removed, the peculiar ice-worn surface may be as fresh as that by the side of a modern glacier.

From the evidence of these striated rock-surfaces and the scattered blocks of rock that were transported to various distances, it has been ascertained that the whole of northern Europe was buried under one continuous mantle of ice. The southern edge of the ice-sheet must have lain to the south of Ireland, whence it passed along the line of

Fig. 454.—Arctic Plants found in Glacial Deposits.
a, Salix polaris, Wahlenb. (2/3); *b*, Betula nana, Linn.; *c*, Leaf of same, showing the size to which it grows in more southern countries.

the Bristol Channel, and thence across the south of England, keeping to the north of the valley of the Thames. The whole of the North Sea was filled with ice down to a line which ran somewhere between the coast of Essex and the present mouths of the Rhine, eastward along the base of the Westphalian hills, and round the projecting promontory of the Harz, whence it swung to the base of the Thuringerwald and struck eastward across Saxony, keeping to the north of the Erz, Riesen and Sudeten mountains; thence across Silesia, Poland and Gallicia by way of Lemberg, and circling round through Russia by Kieff and Nijni Novgorod northward by the head of the Dvina to the Arctic Ocean. The total area of Europe thus buried under ice has been computed to have been not less than 770,000 square miles.

Owing mainly to the direction of the prevalent moisture-bearing winds, the snowfall was greatest toward the west and northwest, and in that direction the ice-sheet attained its greatest thickness. Over Scandinavia, which was probably entirely buried beneath the icy covering, it was perhaps between 6000 and 7000 feet thick. Thence the sheet spread southward, gradually diminishing in thickness. But from the striæ left by it on the Harz, it is computed to have been at least 1470 feet thick where it abutted on that ridge. The Scandinavian ice joined that which spread over Britain, where the dimensions of the sheet were likewise great. Many mountains in the Scottish Highlands show marks of the ice-sheet at heights of 3000 feet and more. If to this depth we add that of the deep lakes and fjords which were filled with ice, we see that the sheet could not have been less than 5000 feet thick in the northern parts of Britain.

This vast icy covering, like the Arctic and Antarctic ice-sheets of the present day, was in continual motion, slowly draining downward to lower levels. Toward the west, its edge reached the sea, as in Greenland now, and must have advanced some distance along the sea-floor until it broke off into bergs that floated away northward. Toward the south and east it ended off upon land, and no doubt discharged copious streams of glacier-water over the ground in its front. In North America the southern edge of the ice-sheet is sometimes marked by a "terminal moraine"—a feature well displayed from Pennsylvania to Dakota.

The directions of movement of the ice-sheets can be followed by the evidence (1st) of striæ graven on the rocks over which the ice passed, and (2d) of transported stones ("erratic blocks") which can be traced back to their original sources.

In Europe the great centre of dispersion for the ice-drainage was the table-land of Scandinavia. As shown by the rock-striæ in Sweden and Norway, the ice moved off that area northward and northeastward across northern Finland into the Arctic Ocean; westward into the Atlantic Ocean, southwestward into the basin of the North Sea; southward, southwestward and southeastward across Denmark and the low plains of Holland, Germany and Russia, and the basins of the Baltic, Gulf of Bothnia, and Gulf of Finland. The evidence of the transported stones coincides with that of the striation, and is often available when the latter is absent.

United with the Scandinavian ice, but having an independent system of drainage, was the ice-sheet that covered nearly the whole of Britain. The rock-striæ show that while it probably buried the country even over its highest mountain-tops, it moved outward from each chief mass of high ground. Thus, from the Scottish Highlands, which were the main gathering ground, it drained northward to join the Norwegian ice, and move with it in a northwesterly direction across the Orkney and Shetland Islands. Westward it descended into the Atlantic; eastward into the basin of the North Sea, to merge there also into the Scandinavian sheet and that which streamed off from the high grounds of the south of Scotland, and to move as one vast ice-field in a south-southwest direction across the northeast and east of England. Southward it flowed into the basin of the Clyde and the Irish Sea, to unite with the streams moving from the southwest of Scotland and the northwest of England and Wales. The centre of Ireland appears also to have been an area from which the ice moved outward, passing into the Atlantic on the one side and joining the British ice-fields on the other.

It is when we follow the direction of the ice-striæ, and see how they cross important hill ranges, that we can best realize the massiveness of the ice-sheet and its resistless movement. As it slid off the Scottish Highlands, for instance, it went across the broad plains of Perthshire, filling them up to a depth of at least 2000 feet, and passing across the range of the Ochil Hills, which at a distance of twelve miles runs parallel with the Highlands, and reaches a height of 2352 feet. Mountains of 3000 feet and more, with lakes at their feet, 600 feet deep, have been well ice-worn from top to bottom. It has been observed that the striæ along the lower slopes of a hill-barrier run either parallel with the trend of the ground or slant up obliquely, while those on the summits may cross the ridge at right angles to its course, showing a differential movement in the great ice-sheet, the lower parts, as in a river, becoming embayed, and being forced to move in a direction sometimes even at a right angle to that of the general advance. On the lower grounds, also, the striæ, converging from different sides, unite at last in one general trend as the various ice-sheets must have done when they descended from the high grounds on either side and coalesced into one common mass. This is well seen in the great central valley of Scotland. Still more marked is the deflection of the striæ in the basin of the Moray Firth.

Northward they are deflected in a N.N.W. direction across Caithness and the Orkney Islands, pointing to the influence of the Scandinavian ice-sheet. On the south side of the basin, they run E. by S., and at last S.E., on the northeast of Aberdeenshire, showing that the ice there turned southward into the North Sea, until it met the N.E. stream from Kincardineshire and the valleys of the Dee and Don, with which and with the ice from Scandinavia it turned southward into the basin of the North Sea. The great mass of ice which crept down the basin of the Firth of Clyde was joined by that which descended from the uplands of Carrick and Galloway, and the united stream filled up the Irish Sea and passed over the north of Ireland. At that time England and the northwest of France were probably united, so that any portion of the North Sea basin not invaded by land-ice would form a lake, with its outlet by the hollow through which the Strait of Dover has since been opened.

When this glaciation took place the terrestrial surface of the northern hemisphere had acquired the main configuration which it presents to-day. The same ranges of hills and lines of valley which now serve to carry off the rainfall served then to direct the results of the snowfall seaward. The snow-sheds of the Ice Age probably corresponded essentially with the water-sheds of the present day. Yet there is evidence that the coincidence between them was not always exact. In some cases the snow and ice accumulated to so much greater a depth on one side of a ridge than on the other that the flow actually passed across the ridge, and detritus was carried out of one basin into another. A remarkable instance of this kind has been observed in the north of Scotland, where so thick was the ice-sheet that fragments of rock from the centre of Sutherland have been carried up westward across the main water-parting of the country and have been dropped on the western side.[4]

In North America also abundant evidence is afforded of a northern ice-sheet which overrode Canada and the Eastern States southward to about the 39th parallel of latitude in the valley of the Missouri. Some details regarding the area which it covered and the traces it has left of its presence are given at p. 1723.

Beyond the limits of the northern ice-sheet, the European continent nourished snow-fields and glaciers wherever the ground was high enough and the snowfall heavy enough to furnish them. As already mentioned, the precipitation of moisture during the Ice Age, as at present, was greatest toward the west, and consequently in the western tracts the independent snow-fields and glaciers were most numerous and extensive. Even at the present time, the glaciers of the western part of the Alpine chain are larger than those further east. At the time of the northern ice-sheet a similar local difference existed. The present snow-fields and glaciers of these mountains, large though they are, form no more than the mere shrunken remnants of the great mantle of snow and ice which then overspread Switzerland. In the Bernese Oberland, for example, the valleys were filled to the brim with ice, which, moving northward, crossed the great plain, and actually overrode a part of the Jura Mountains; for huge fragments of granite and other rocks from the central chain of the Alps are found high on the slopes of that range of heights. The Rhone glacier swept westward across all the intervening ridges and valleys, and left its moraine-heaps in the valley of the Rhone where Lyons now stands.

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[4] Peach and Horne, Brit. Assoc. 1892, p. 720.

At the same time the high grounds of the Lyonnais, Beaujolais, and Auvergne (lat. 45° S.) had their glaciers. Others flourished on the Iberian table-land, at least as far south as the basin of the Douro (lat. 41°). Eastward in corresponding latitudes glacier relics become scantier and disappear. The Vosges possessed a group of glaciers which have left behind them some beautifully perfect moraines. Less extensive were those of the Black Forest, Sudetengebirge, and Carpathians. No trace of glaciation has been detected in the Balkans. A similar relation between snowfall and glaciation is traceable in North America, but there it is the eastern area which supported the massive ice-sheets, while the western plateaus and mountain-ranges, which were probably then, as now, comparatively arid, had only valley-glaciers.

That the ice in its march across the land striated even the hardest rocks by means of the sand and stones which it pressed against them, is a proof that, to some extent at least, the terrestrial surface must have been at this time abraded and lowered in level. How far this erosion proceeded, or, in other words, how much of the undoubtedly enormous denudation everywhere visible over the glaciated parts of Europe is attributable to the actual work of land-ice, is a problem which may never be even approximately solved. There seems good ground for the belief that a thick cover of rotted rock—the result of ages of previous subaerial waste—lay over the surface, and that the "glacial deposits" consist in great measure of this material, moved and reassorted by ice and water (pp. 597, 724). The land, as above remarked, had the same general features of mountain, valley and plain as it has now, even before the ice settled down upon it. But the prominences reached by the ice were rounded off and smoothed over, the pre-glacial soils and covering of weathered rock were in large measure ground up and pushed away, the valleys were correspondingly deepened and widened, and the plains were strewn with ice-borne débris. It is obvious that the influence of the moving ice-sheets has been far from uniform upon the rocks exposed to it, this variation arising from the differences in powers of resistance of the rocks on the one hand, and in the mass, slope and grinding power of the ice on the other. Over the lowlands, as in central Scotland and much of the north German plain, the rocks are for the most part concealed under deep glacial débris. But in the more undulating hilly ground, particularly in the north and northwest, the ice has effected the most extraordinary abrasion. It is hardly possible, indeed, to describe adequately in words these regions of most intense glaciation. The old gneiss of Norway and Sutherlandshire, for example, has been so eroded, smoothed, and polished, that it stands up in endless rounded hummocks, many of them still smoothed and curved like dolphins' backs, with little pools, tarns, and larger lakes lying between them. Seen from a height the ground appears like a billowy sea of cold gray stone. The lakes, each lying in a hollow of erosion, seem scattered broadcast over the landscape. So enduring is the rock, that, even after the lapse of so long an interval, it retains its ice-worn aspect almost as unimpaired as if the work of the glacier had been done only a few generations since.[5] The abundant smoothed and striated rock-basin lakes of the northern parts of Europe and North America are a striking evidence of ice-action (p. 723, and Book VII. "Watersheds"). The phenomenon of "giants'

[5] Some of these roches moutonnées may be of Palæozoic age (Nature, August, 1880).

kettles," characteristic of glaciated rock-surfaces in Sweden, Silesia, and Switzerland (p. 722), is another mark of the same process of erosion.

Ice-crumpled Rocks.—Not only has the general surface of the land been abraded by the ice-sheets, but here and there more yielding portions of the rocks have been broken off or bent back, or corrugated by the pressure of the advancing ice. Huge blocks 300 yards or more in length have been bodily displaced and launched forward on glacial detritus. Such are some of the enormous masses of chalk displaced and imbedded in the drift of the Cromer cliffs, and the transported sheets of Lincolnshire Oolite found in Leicestershire.[6] The laminæ of shales or slates are observed to be pushed over or crumpled in the direction of ice-movement. Occasionally tongues of the glacial detritus which was simultaneously being pressed forward under the ice have been intruded into cracks in the strata, so as to resemble veins of eruptive rock.[7]

Detritus of the Ice-sheet—Bowlder-clay—Till.—Underneath the great ice-sheet, and probably partly incorporated in the lower portions of the ice,[8] there accumulated a mass of earthy, sandy, and stony matter (till, bowlder-clay, "grundmoräne," "moraine-profonde," "older diluvium") which, pushed along and ground up, was the material wherewith the characteristic flowing outlines and

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[6] Mr. Fox Strangways has noticed one such sheet near Melton which measures at least 300 yards in length by 100 in breadth, but may extend beneath the bowlder-clay to a greater distance. Report of Geological Survey of the United Kingdom, Science and Art Report for 1892, p. 249.

[7] On the disruption of the Chalk below the Till of Cromer see C. Reid on Geology of Cromer, Mem. Geol. Surv. 1882. For analogous phenomena at Möens Klint, off the coast of Denmark, see Johnstrup, Zeit. Deutsch. Geol. Ges. xxvi. 1874, p. 533. Compare also H. Credner, op. cit. xxxii. 1880, p. 75. F. Wahnschaffe, op. cit. xxxiv. 1882, p. 562.

[8] Brückner, Penck's Geographische Abhandl. Band I. Heft 1.

smoothed striated surfaces were produced.[9] This "glacial drift" spreads over the low grounds that were buried under the northern ice-sheet, resting usually on surfaces of rock that have been worn smooth, disrupted, or crumpled by ice. It is not spread out, however, as a uniform sheet, but varies greatly in thickness and in irregularity of surface. Especially round the mountainous centres of dispersion, it is apt to occur in long ridges ("drums," or "drumlins"), which run in the general direction of the rock-striation, that is, in the path of the ice-movement. It may be traced up many valleys into the mountains, underlying the moraines of the later glaciation. In other valleys, it has been removed by the younger glaciers. In most glaciated countries the bowlder-clay is not one continuous deposit, but may be separated into two or more distinct formations, which lie one on the other, and mark distinct and successive periods of time.

In those areas which served as independent centres of dispersion for the ice-sheet, bowlder-clay partakes largely of the local character of the rocks of each district where it occurs. Thus in Scotland, the clay varies in color and composition as it is traced from district to district. Over the Carboniferous rocks it is dark, over the Old Red Sandstones it is red, over the Silurian rocks it is fawn-colored. The material of the deposit is generally an earthy or stony clay, which in the lower parts is often exceedingly compact

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[9] As already suggested, the materials of the till may have consisted largely of a layer of decomposed rock due to prolonged pre-glacial disintegration (pp. 597, 724). It is difficult to explain by any known glacial operation the accumulation of such deep masses of detritus below a sheet of moving land-ice. Another problem is presented by the occasional and sometimes extensive preservation of undisturbed loose pre-glacial deposits under the till. The way in which the "Forest-bed" group has escaped for so wide a space under the Cromer cliffs, with their proofs of enormous ice movement, is a remarkable example.

and tenacious. The higher portions are frequently loose in texture, but alternations of hard tough clay and more friable material may be met with in the same deposit. In general, bowlder-clay is unstratified, its materials being irregularly and tumultuously heaped together. But rude traces of bedding may not infrequently be detected, while in some cases, especially in the higher clays, distinct stratification may be observed.

The great majority of the stones in bowlder-clay are of local origin, not always from the immediately adjacent rocks, but from points within a distance of a few miles. Evidence of transport can be gathered from the stones, for they are found in almost every case to include a proportion of fragments which have come from a distance. The direction of transport indicated by the percentage of travelled stones agrees with the traces of ice-movement as shown by the rock-striæ. Thus, in the lower part of the valley of the Firth of Forth, while most of the fragments are from the surrounding Carboniferous rocks, from 5 to 20 per cent have come eastward from the Old Red Sandstone range of the Ochil Hills—a distance of 25 or 30 miles—while 2 to 5 per cent are pieces of the Highland rocks, which must have come from high grounds at least 50 miles to the northwest. The further the stones in the till have travelled, the smaller they usually are. As each main mass of elevated ground seems to have caused the ice to move outward from it for a certain distance, until the stream coalesced with that descending from some other height, the bottom-moraine or bowlder-clay, as it was pushed along, would doubtless take up local débris by the way, the detritus of each district becoming more and more ground up and mixed, until of the stones from remoter regions only a few harder fragments would be left. In cases where no prominent ridges interrupted the march of the ice-sheets, and where the ground was low and covered with soft loose deposits, blocks of hard crystalline rocks might continue to be recognizable far from their source. Thus in the stony clay and gravel of the plains of northern Germany and Holland, besides the abundant locally-derived detritus, fragments occur which have had an unquestionably northern origin. Some of the rocks of Scandinavia, Finland, and the Upper Baltic are of so distinctive a kind that they can be recognized in small pieces. The peculiar syenite of Laurwig, in the south of Norway, has been found abundantly in the drift of Denmark; it occurs also in that of Hamburg, and has been detected even in the bowlder-clay of the Holderness cliffs in Yorkshire. The well-known rhombenporphyr of southern Norway has likewise been recognized at Cromer and in Holderness. Fragments of the Silurian rocks from Gothland, or from the Russian islands Dago or Oesel, are scattered abundantly through the drift of the North German plain, and have been met with as far as the north of Holland. Pieces of granite, gneiss, various schists, porphyries, and other rocks, probably from the north of Europe, occur in the till of Norfolk.[10] These transported fragments are an impressive testimony to the movements of the northern ice. No Scandinavian blocks have been met with in Scotland, for the Scottish ice was massive enough to move out into the basin of the North Sea, until it met the northern ice-

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[10] These erratics, from their petrographical characters, appear to me to be certainly not from Scotland. Had that been their source they could not have failed to be accompanied by abundant fragments of the rocks of the south of Scotland, which are continuously absent. See V. Madsen, Quart. Journ. Geol. Soc. xlix. 1893, p. 114.

sheet streaming down from Scandinavia, which was thereby kept from reaching the more northerly parts of England.

The stones in bowlder-clay have a characteristic form and surface. They are usually oblong, have one or more flat sides or "soles," are smoothed or polished, and have their edges worn round (Fig. 160). Where they consist of a fine-grained enduring rock, they are almost invariably striated, the striæ running on the whole with the long axis of the stone, though one set of scratches may be seen crossing and partially effacing another, which would necessarily happen as the stones shifted their position under the ice. These markings are precisely similar to those on the solid rocks underneath the bowlder-clay, and have manifestly been produced in the same way by the mutual friction of rocks, stones, and grains of sand as the whole mass of débris was being steadily pushed on in one general direction.

As above remarked, bowlder-clay is not always one continuous deposit. On the contrary, when a sufficiently large extent of it is examined, evidence can commonly be found of two distinct divisions, sometimes even of more than two. These are separable from each other by differences of color, composition, and texture. An attentive study of them shows that they have been formed successively under ice-sheets moving often from different directions and transporting different materials. Their limits of distribution also vary, the lower and older subdivisions extending further south and spreading over a wider area than the upper.

Interglacial Beds.—That the deposition of bowlder-clay in Britain was interrupted by milder intervals, when the ice, partially at least, retreated from the land and allowed trees and other vegetation to grow up to heights of 800 or 900 feet above the sea, was first proved by observations at Chapel Hall, Lanarkshire.[11] During the thirty years which have intervened since these observations were published, a large amount of additional information on this subject has been collected in the British Islands, on the continent of Europe, and in North America. The bowlder-clays are now well known to be split up with inconstant and local stratifications of sand, gravel and clay, often well stratified, pointing to conditions quite distinct from those under which ordinary bowlder-clay was accumulated. These intercalations have been recognized as bearing witness to intervals when the ice retired from some districts and when ordinary water-action came into play over the ground-moraine thus exposed. Much controversy, however, has arisen as to the chronological value to be assigned to these intervals. To some geologists the intercalations in the bowlder-clay appear to indicate little more than seasonal variations in the limits and thickness of the ice-sheets, such as now affect the glaciers of Scandinavia and the Alps. To others, again, they furnish proof of successive interglacial periods by which the long Ice Age was broken up. Thus Prof. James Geikie, recently reviewing the whole evidence on the subject, has come to the conclusion that there were really five glacial intervals embraced within what is called the Glacial Period, separated from each other by four interglacial periods of mild temperature.[12]

Much difficulty in forming definite conclusions as to the importance of these obvious interruptions in the deposition of the bowlder-clay arises from the absence of continuous sections wherein the order of succession of the several stages

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[11] A. G., Trans. Geol. Soc. Glasgow, vol. i. part. ii. 1863.
[12] Trans. Roy. Soc. Edin. xxxvii. part i. 1893, p. 146.

of the glacial history can be demonstrated by visible relations of superposition. A section at one locality has to be correlated with another at a greater or less distance, and assumptions have to be made as to the identity or difference of the various deposits. The evidence of fossils can hardly be said to be available, for it is so fragmentary as to give little aid in determining the chronology of the deposits in which it occurs.

The existence of two distinct deposits of bowlder-clay, with an intervening group of sands, gravels, clays, and peat-beds, may be taken to afford good proof of two advances and retreats of the ice-sheets, with an interval of non-glacial conditions between them. The oldest bowlder-clay marks the greatest extent of the ice. The upper bowlder-clay shows that though the ice on returning attained huge dimensions and formed continuous ice-sheets over much of northern Europe, it did not descend as far as at first. Yet while these two main epochs of maximum cold can be satisfactorily established there appears to be no reason to doubt that each of them may have had fluctuations in temperature or in snowfall, so that the ice-sheets may have alternately or intermittently advanced and retreated over considerable tracts of country. The ground-moraine, when thus laid bare, may have been reassorted by water, so that, as the ice once more moved forward, it here and there pushed its detritus over the aqueous deposits of the milder interval. But the marked contrast between the lower and upper bowlder-clay in composition and extent shows that the interval which separated them was probably of prolonged duration. We have here evidence of at least one important interglacial period. The occurrence of such interludes of more genial climate is what might be expected to be traceable on the astronomical theory of the cause of the Ice Age, which has been already discussed (p. 51). The deposits which record the passage of an interglacial period consist of layers of sand and gravel, such as, over a wide area of central England, separate the two bowlder-clays, also deposits of clay and beds of peat found elsewhere in a similar position. To this age also have been assigned the older alluvial terraces which have been preserved chiefly beyond the limits of the second glaciation, and from which

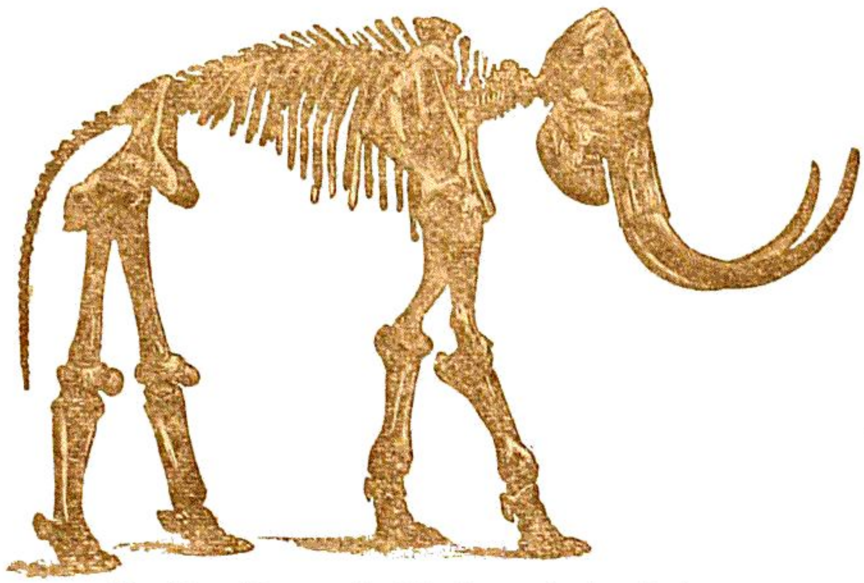

Fig. 455.—Mammoth (*Elephas primigenius*).
From the Skeleton in the Musee Royal, Brussels (much reduced).

a considerable number of mammalian remains as well as stone implements of human workmanship have been disinterred.

During interglacial conditions the climate in the northern hemisphere was probably much more equable and mild than at present, with a higher mean temperature, and at certain intervals a greater precipitation of moisture.[13] From the general aspect of the flora and fauna preserved in interglacial deposits in Britain it may perhaps be inferred that

[13] J. Croll, Phil. Mag. 1885, p. 36.

there was then more sunshine than now. Mr. Reid suggests that the scarcity of thoroughly aquatic mollusks and of fish indicates that during some stages, at least, the climate was dry rather than moist. As a result of more favorable meteorological conditions vegetation flourished even far north where it can now hardly exist. The frozen tundras of Siberia appear then to have supported forests which have long since been extirpated, the present northern limit of living trees lying far to the southward. Indications of a more equable and milder climate are likewise supplied by the plant-remains found in Pleistocene tufas of different parts of Europe, where species now restricted to more southern countries were then able to flourish together with those which are still native there.[14]

The fauna of the northern parts of our hemisphere was then an extraordinary one. It was marked more especially by the presence of the last of the huge pachyderms, which had for so many ages been the lords of the European forests and pastures. The hairy mammoth and woolly rhinoceros roamed over the plains of Siberia and across most, if not the whole, of Europe. These animals were probably driven southward by the increasing cold, and they appear to have survived some of the advances of the ice, returning into their former haunts when a less wintry climate allowed the vegetation on which they browsed once more to overspread the land.[15] Some of the mammals now restricted to the far

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[14] Nathorst, Engler's Botanische Jahrb. 1881, p. 431; C. Schröter, "Die Flora der Eiszeit," Zürich, 1883.

[15] The mammoth lived in the neighborhood of the extinct volcanoes of central Italy, which were then in full activity. From discoveries in Finland, it has been inferred that the extinction of this animal may not have been much before historical times. A. J. Malmgren, Oefv. Finsk. Vet. Soc. Forh. xvii. p. 139. Consult Boyd Dawkins on the range of the mammoth in space and time: Q. J Geol. Soc. xxxv. 1879, p. 138; and Howorth, Geol. Mag. 1880; "The Mammoth and the Flood" and "The Glacial Nightmare."

north likewise found their way into countries from which they have long disappeared. The reindeer migrated southward into Switzerland,[16] the glutton into Auvergne, while the musk-sheep and Arctic fox travelled certainly as far as the Pyrenees. As the climate became less chilly, animals of a more southern type advanced into Europe: the porcupine, leopard, African lynx, lion, striped and spotted hyænas, African elephant, and hippopotamus. With each

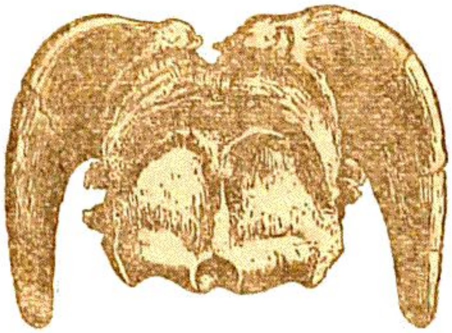

Fig. 456.—Back View of Skull of Musk-sheep (*Ovibos moschatus*, ⅙), brick-earth, Crayford, Kent.

oscillation of climate there would be a corresponding immigration and emigration of northern and southern types.

Evidences of Submergence.—After the ice had attained its greatest development, some portions of northwestern Europe, which had perhaps stood at a higher level above the sea than they have done since, began to subside. The ice-fields were carried down below the sea-level, where they broke up and cumbered the sea with floating bergs. The heaps of loose débris which had gathered under the ice, being now exposed to waves, ground-swell, and marine currents, were thereby more or less washed down and reassorted. Coast-ice, no doubt, still formed along the shores, and was broken up into moving floes, as happens every year now in northern Greenland. The proofs of this phase of the

[16] On the distribution of the reindeer at present and in older time, see C. Struckmann, Zeitsch. Deutsch. Geol. Ges. xxxii. 1880, p. 728.

long glacial period are contained in shell-bearing sands, gravels, and clays which overlie the coarse older till, and are perhaps, to some extent, furnished by erratic blocks.[17] It is difficult to determine the extent of the submergence, for, when the land rose, the more elevated portions continued to be seats of glaciers, which, moving over the surface, destroyed the deposits that would otherwise have remained as witnesses of the presence of the sea, while at the same time the great bodies of water discharged from the retreating glaciers and snow-fields must have done much to reassort the detritus on the surface of the land. From the evidence of marine shells, southern Scandinavia is believed to have sunk about 600 feet below its present level. In Britain the submergence was probably not less than 500 feet. If indeed we take the beds of marine shells which have been found in North Wales, Cheshire, and elsewhere as marking actual sea-bottoms, the depression which they would then indicate must have been at least 1350 feet. But these shelly deposits are probably not conclusive proofs of submergence.[18]

That ice continued to float about in these waters is shown by the striated stones contained in the fine clays, and by the remarkably contorted structure which these clays occasionally display. Sections may be seen (as at Cromer) where, upon perfectly undisturbed horizontal strata of clay and

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[17] For an account of the dispersion of the "erratics" of England and Wales, see Mackintosh, Q. J. Geol. Soc. xxxv. 1879, p. 425; and Reports of the Committee appointed to investigate this subject by the British Association, 1872 *et seq.* For those of Scotland much information has been gathered by the Bowlder Committee of the Royal Society of Edinburgh; Proc. Roy. Soc. Edin. 1872–84. Erratic blocks have probably in the vast majority of cases been dispersed by land-ice and not by floating ice.

[18] Mere fragments of marine shells in a glacial deposit need not prove submergence under the sea; for they may have been pushed up from the sea-floor by moving ice, as in the case of the shelly till of the west of Scotland, Caithness, Holderness and Cromer. How far this may have been the origin of the shelly deposits found at high levels in Britain is still a disputed question.

sand, other similar strata have been violently crumpled, while horizontal beds lie directly upon them. These contortions may have been produced by the horizontal pressure of some heavy body moving upon the originally flat beds, such as ice in the form of an ice-sheet or of large stranding masses driven aground in the fjords or shallow waters where the clays accumulated; or possibly, in some cases, sheets of ice, laden with stones and earth, sank and were covered up with sand and clay, which, on the subsequent melting of the ice, would subside irregularly. Another indication of the presence of floating ice is furnished by large scattered bowlders, lying on the stratified sands and gravels. Though these blocks probably belong as a rule to the time of the chief glaciation, they may in some cases have been shifted about by floating ice during the submergence.

Second Glaciation—Re-elevation—Raised Beaches.—When the land re-emerged from its depression, the temperature all over central and northern Europe was again severe. The northern ice-sheet once more advanced southward, but did not again attain nearly the same dimensions. From the direction of the striæ, it would appear sometimes to have moved differently from its previous course, occasionally even at right angles to it. In the basin of the Baltic, for example, the later direction of the ice-stream appears to have been southwestward and westward. Besides the evidence of this direction furnished by striated rock-surfaces, abundant fragments of the fossiliferous Silurian rocks of Gothland are strewn over the Germanic plain even as far as Holland. There seems no reason to doubt that during this second advance of the ice the Scottish and Scandinavian ice-sheets were again united over what is now the floor of the North Sea. It was then that the upper bowlder-clay of Britain was formed. The glaciers of the Alps once more marched outward over the lower grounds, but without descending so far as before. Their limits are marked by an inner group of moraines.

From its second maximum the ice-sheet gradually shrank backward, though probably not without occasional pauses and even advances. As it retreated from the lower grounds it lost the aspect of a continuous ice-sheet, and when it reached the bases of the mountains it eventually separated into valley-glaciers radiating from each principal mass of high ground. In this condition also there was probably a long period of oscillation, the glaciers alternately descending and shrinking backward with variations in the seasons. In Britain there is abundant evidence of this stage in the history of the Ice Age. The Scottish Highlands, being the largest area of high ground in the country, was the chief seat of the ice. Not only did every group of mountains nourish its own glaciers; even small islands, such as Arran and Hoy, had their snow-fields, whence glaciers crept down into the valleys and shed their moraines. It would appear indeed that some of the northern glaciers continued to reach the sea-level even when the land had there risen to near or quite its present elevation. On the east side of Sutherlandshire, at Brora, and on the west side of Ross-shire, at Loch Torridon, the moraines descend to the 50-feet raised beach; at the head of Loch Eriboll, they come down to the sea-level and even extend underneath the water, showing that the glacier at the head of that fjord actually pushed its way into the sea, and no doubt calved its icebergs there.

Another proof of the magnitude of some of the ice-streams that filled the valleys of the Scottish Highlands during the later stages of the Glacial Period is supplied by the proofs that here and there among the loftier or broader snow-fields of the time they accumulated in front of lateral valleys, the drainage of which was in consequence ponded back and made to flow out in an opposite direction by the *col* at the head (p. 713). In these natural reservoirs, the level at which the water stood for a time was marked by a horizontal ledge or platform, due partly to erosion of the hillside, but chiefly to the arrest of the descending débris when it entered the water. The famous "Parallel Roads of Glen Roy" are the most familiar examples. In some instances, as at Achnasheen in Ross-shire, the detritus of the glacial streams was arrested and spread out in broad platforms across the valleys.

The gradual retreat of the glaciers toward their parent snow-fields is admirably revealed by their moraines, perched blocks, and *roches moutonnées*. The crescent-shaped moraine-mounds that lie one behind another may be followed up a glen, until they finally die out about the head, near what must have been the edge of the snow-field. The highest mounds, being the last to be thrown down, are often singularly fresh. They frequently inclose pools of water, which have not yet been filled up with detritus or vegetation, or flat peaty bottoms where the process of filling up has been completed. Huge blocks borne from the crags above them are strewn over these heaps, and similar erratics perched on ice-worn knolls on the sides of the valleys mark some of the former levels of the ice. The Scottish Highlands, the southern uplands of Scotland, the hills of the Lake district and of North Wales present admirable examples of all these features.

On the continent of Europe also similar evidence remains of the gradual retreat of the ice. In many tracts of high ground glaciers no longer exist. In the Vosges, for example, they have long since vanished, but fresh moraines remain there as evidence of their former presence. The Alpine glaciers are the lineal descendants of those which filled up the valleys and buried the lowlands of Switzerland and the Lyonnais.

Before the retiring ice-sheet had shrunk into mere valley glaciers, and while it still occupied part of the lower ground, there would doubtless be a copious discharge of water from its melting front. As the ice had overridden the land and buried its minor inequalities, there would be great diversity in the level of the bottom of the ice, and consequently the escaping water would at first flow with little relation to the present main drainage lines. Streams of water might be let loose over the plateaus and hilly ridges as well as over the plains. There could hardly, therefore, fail to be much rearrangement of the detritus left by the ice. Possibly to this part of the Ice Age and to this kind of action we should attribute the masses of gravel and sand which, over so much of northern Europe, rest on bowlder-clay. Among these accumulations are the sheets of coarse, well-rounded gravel (plateau-gravel), which, with no recognizable relation to the present contours of the ground, are spread over the plains and low plateaus, and fill up many valleys. These gravels rest sometimes on bowlder-clay, sometimes on solid rock, and are older than the valley alluvia. They have evidently not been formed by any ordinary river-action, nor is it easy to see how the sea can have been concerned in their formation. They are well developed in Norfolk and adjacent tracts of the southeast of England, where they consist mainly of well-rounded flints (cannon-shot gravel).

Still more remarkable are the accumulations of sand and gravel to which the name of "Kame group" has been given. Covering the lower ground in a sporadic manner, often tolerably thick on the plains, these deposits rise up to heights of 1000 feet or more. In some places, they cannot be satisfactorily separated from the sands and gravels associated with the bowlder-clay, in others they seem to merge into the sandy deposits of the raised beaches, while in hilly tracts it is sometimes hard to distinguish between them and true moraine-stuff. Their most remarkable mode of occurrence is when they assume the form of mounds and ridges, which run across valleys and plains, along hillsides, and even over water-sheds. Frequently these ridges coalesce so as to inclose basin-shaped hollows, which are often occupied by tarns. Many of the most marked ridges are not more than 50 or 60 feet in diameter, sloping up to the crest, which may be 20 or 30 feet above the plain. A single ridge may occasionally be traced in a slightly sinuous course for many miles, as in the case of the famous mound which runs across the centre of Ireland. These ridges, known in Scotland as Kames, in Ireland as Eskers, and in Scandinavia as Oesar, consist sometimes of coarse gravel or earthy detritus, but more usually of clean, well-stratified sand and gravel, the stratification toward the surface corresponding with the external slopes of the ground, in such a manner as to prove that the ridges are usually original forms of deposit, rather than the result of the irregular erosion of a general bed of sand and gravel. Some writers have compared these features to the submarine banks formed in the pathway of tidal currents near the shore. But they appear rather to be of terrestrial origin, due in some way to the melting of the great snow-fields and glaciers, and the consequent discharge of large quantities of water over the country. But no very satisfactory explanation of their mode of formation has yet been given.

Over the tracts from which the ice-sheet retired, lakes are usually scattered in large numbers. Some of these lie in ice-worn basins of rock. Where the detritus has been strewn thickly over the ground, however, they rest in hollows of the clay, earth, sand, or gravel. The origin of these depressions in the drifts cannot be found in any denuding operation since the ice left. They are obviously original features of the surface, dating back to the time when the various drifts were laid down. In some cases they may be due to irregular deposition of the detritus, as where successive moraines are thrown across a valley. The small pools may sometimes have been originated by the melting of portions of ice which had become detached from the main mass, and were surrounded by or buried under detritus. Many small rock-basins may have had their place and form determined by that prolonged deep subaerial rotting already referred to, while others may be referable to underground movements. But the glaciers, in smoothing and polishing the rocks, wore them down unequally, hollowing them into rock-basins, leaving them in prominent smoothed domes, and carrying the same characteristic sculpture over all the durable rocks exposed in the areas of intenser glaciation.

The uprise of the land in Scandinavia and Britain took place interruptedly. During its progress it was marked by long pauses when the level remained unchanged, when the waves and floating ice cut ledges along the sea-margin, and when sand and gravel were accumulated below high-water mark in sheltered parts of the coast-line. These platforms of erosion and deposit (raised beaches) form conspicuous features at successive heights above the present level of the sea (p. 484). The coast of Scotland is fringed with a succession of them (Fig. 457). Those below the level of 100 feet above the sea are often remarkably fresh. The 100-feet terrace forms a wide plateau in the estuary of the Forth, and the 50-feet terrace is as conspicuous in that of the Clyde. In Scandinavia, especially in the northern parts of Norway, the successive pauses in the last uprise of the land are impressively revealed by long lines of terraces which wind around the hill-slopes that encircle the fjords (p. 487).

The records of the closing ages of the long and varied Glacial Period merge insensibly into those of later geologi

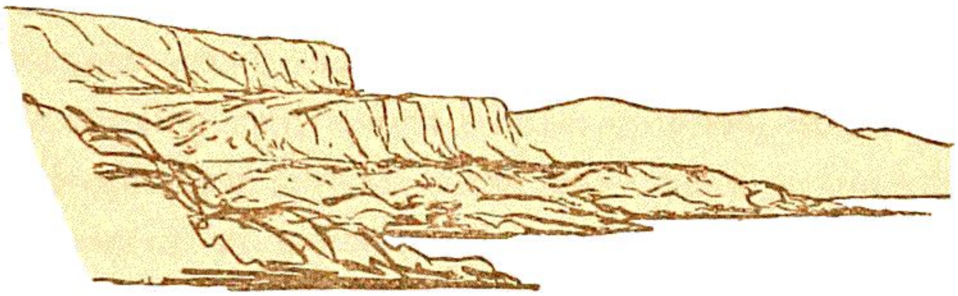

Fig. 457.—Terraces of erosion, marking ancient shore-lines. South coast of Island of Mull.

cal times. It is obvious that besides the effect of a general change of climate operating over the whole of the northern hemisphere, we must remember the influence which the natural features of different countries had upon the climate. From the plains, the ice and snow would retire sooner than from the hills. In fact, we may regard some parts of Europe as still retaining the conditions of the Glacial Period, though in diminished intensity, the present glaciers of the Alps being, as above remarked, the representatives in continuous succession of the vaster sheets that once descended into the lowlands on all sides from that central elevated region. And even where the ice has long since disappeared, there remain, in the living plants and animals of the higher and colder uplands, witnesses to the former severity of the climate. As that severity lessened, the Arctic vegetation, that hitherto had peopled all the lower grounds of central and western Europe, was driven up into the hills before the advance of plants loving a milder temperature, which had doubtless been natives of Europe before the period of great cold, and which were now enabled to reoccupy the sites whence they had been banished. On the higher mountains, where the climate is still not wholly uncongenial for them, and likewise here and there at lower levels, colonies of the once general Arctic flora still survive. The Arctic animals have also been mostly driven away to their northern homes, or have become wholly extinct. But the remains of the Arctic plants and to some extent also of the animals occur in the lacustrine clays, peat-mosses and other deposits of the glacial series, even down into the heart of Europe.

It has been forcibly pointed out by Mr. Wallace that the present mammalian fauna of the globe presents everywhere a striking contrast to the extraordinary variety and great size of the mammals of the Tertiary periods. "We live," he says, "in a zoologically impoverished world, from which all the largest, and fiercest, and strangest forms have recently disappeared." [19] He connects this remarkable reduction with the refrigeration of climate during the Glacial Period. The change, to whatever cause it may be assigned, is certainly remarkably persistent in the Old World and in the New, and not merely in the temperate and northern regions, but even as far south as the southern slopes of the Himalaya Mountains.

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[19] "Geographical Distribution of Animals," i. p. 150. Consult also Asa Gray, Nature, xix p. 327 (363).

§ 2. Local Development

Britain.[20]—Though the generalized succession of phenomena above given is usually observable, some variety is traceable in the evidence in different parts of the British area. In Scotland, where the ground is generally more elevated, and where snow and ice were most abundant, the phenomena of glaciation reached their maximum development. In the high grounds of England, Wales and Ireland there was likewise extensive accumulation of ice. The ice-worn rocks of the low grounds are usually covered with bowlder-clay, which in Scotland is interstratified with beds of sand, fine clay, and peat, but has never yielded any marine organisms except near the coast, where they are sometimes common, and in one locality in Lanarkshire. In England, marine shells, usually fragmentary, occur in the bowlder-clays both in the eastern and western counties. The ice-sheet no doubt passed over some parts of the sea-bottom, and ground up the shell-banks that happened to lie in its way, as has happened, for example, in Caithness, Holderness, and East Anglia, where the shells in the bowlder-clay are fragmentary, and sometimes ice-striated. The "Bridlington Crag" of Yorkshire, according to Messrs. Sorby, Lamplugh and Reid, is a large fragment torn from a submarine shell-clay, and imbedded in the bowlder-clay.[21] With the exception of such marine inclosures, the organic contents as well as the physical characters of the Scottish Till point to terrestrial conditions of deposit under the ice-sheet.

The depth, extent and movements of the great ice-sheet which covered Britain have already been referred to. The proofs of the former presence of the ice are scattered abun-

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[20] Besides the general works and papers already cited, the following special papers in the Quarterly Journal of the Geological Society may be consulted: Wales, Mackintosh, 1882, p. 184; I. W. E. David, 1883, p. 39. N.W. England, Mackintosh, 1879, p. 425, 1880, p. 178; T. M. Reade, 1874, p. 27, 1883, p. 83; A. Strahan, 1886, p. 369. S.E. England, Searles V. Wood jun., 1880, p. 457, 1882, p. 667; A. J. Jukes-Browne, 1879, p. 397, 1883, p. 596; Rowe, 1887, p. 351. Scotland (Long Island), J. Geikie, xxix. 1873; xxxiv. 1878; (Shetlands) Peach and Horne, 1879, p. 778; (Orkneys) 1880, p. 648; (Aberdeenshire) T. F. Jamieson, 1882, pp. 145, 160. The student will find a useful digest of the literature for England up to 1887 in Mr. H. B. Woodward's "Geology of England and Wales." The Memoirs of the Geological Survey will be found to contain much local detail on this subject.

[21] Lamplugh, Quart. Journ. Geol. Soc. xl. 1884, p. 312. C. Reid, "Geology of Holderness" in Mem. Geol. Survey.

dantly over the country north of a line drawn from the Bristol Channel to the estuary of the Thames. South of that line the ground is free from bowlder-clay, though various deposits, possibly of contemporary date, serve to indicate that, though not buried under ice, this southern fringe of England had its own glacial conditions.[22] Among these is the "Coombe-rock" of Sussex—a mass of unstratified rubbish which has been referred by Mr. C. Reid to the action of heavy summer rains at a time when the ground a little below the surface was permanently frozen. In the glaciated tract one of the most striking features in showing the Green-

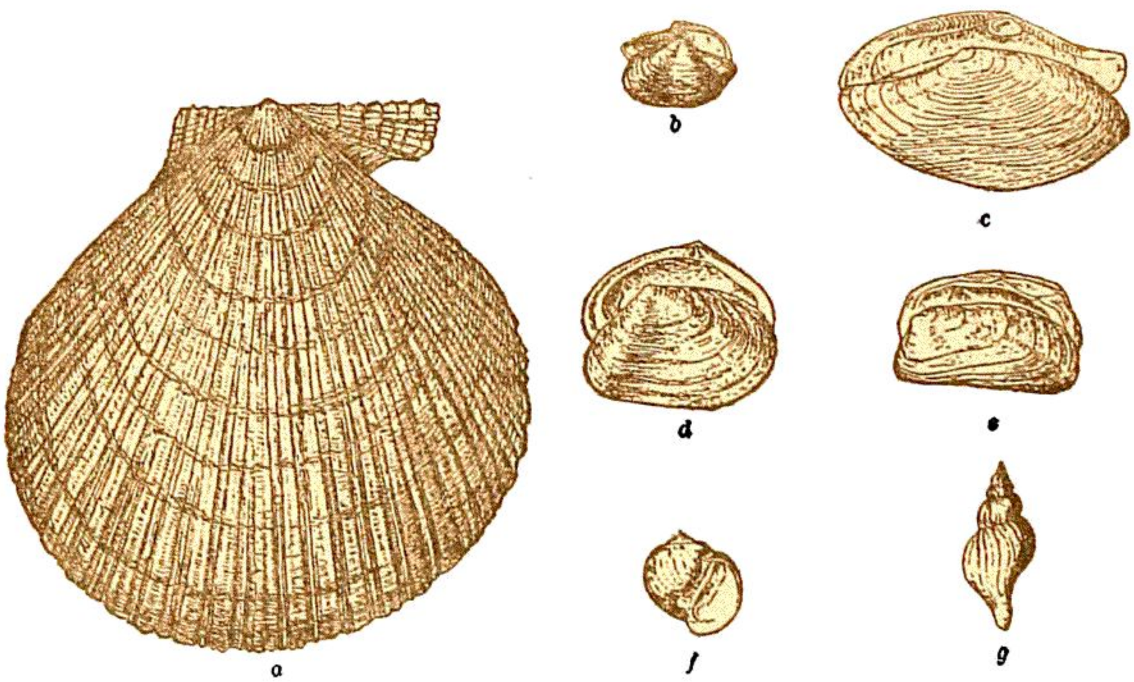

Fig. 458.—Group of Shells from the Scottish Glacial Beds.

a, Pecten islandicus, Mull. (½); *b*, Leda truncata, Brown (½); *c*, Leda lanceolata, Sow. (½); *d*, Tellina lata, Gmelin (T. calcarea, Wahl.) (½); *e*, Saxicava rugosa, Pennant (½); *f*, Natica clausa, Brod. and Sow. (½); *g*, Trophon scalariformis, Gould (T. clathratus) (½).

land-like massiveness of the ice-sheet is furnished by the south of Ireland, where the hills of Cork and Kerry have been ground smooth and striated down to the sea, and even under sea-level, detached islets appearing as well ice-rounded roches moutonnées. There can be no doubt from this evidence that even in the south of Ireland the ice-sheet continued to be so massive that it went out to sea as a great wall of ice, probably breaking off there in icebergs.

The records of the submersion of Britain are probably very incomplete. If we rely only on the evidence of un-

[22] C. Reid, Quart. Journ. Geol. Soc. xiii. 1887, p. 364.

transported marine shells, we obtain the lowest limit of depression. But, as above remarked, the mere presence of marine shells cannot always be accepted as conclusive. Again, the renewed ice and snow, after re-elevation, may well have destroyed most of the shell-beds, and their destruction would be most complete where the snow-fields and glaciers were most extensive. Beds of sand and gravel with recent shells have been observed on Moel Tryfaen, in North Wales, at a height of 1350 feet, but the shells are broken, and show such a curious commingling of species as to indicate that they are probably not really in place. In Cheshire marine shells occur at 1200 feet. In Scotland they have been obtained at 524 feet in the bowlder-clay at the Lanarkshire locality already referred to; but the layer containing them may have been transported by the ice-sheet. Subsequent elevation of the land has brought up within tide-marks some of the clays deposited over the sea-floor during the time of the submergence. In the Clyde basin and in some of the western fjords these clays (Clyde Beds) are full of shells. Comparing the species with those of the adjacent seas, we find them to be more boreal in character; nearly the whole of the species still live in Scottish seas, though a few are extremely rare. Some of the more characteristic northern shells in these deposits are Pecten islandicus, Tellina lata (T. calcarea), Leda truncata, L. lanceolata, Yoldia arctica, Saxicava rugosa, Panopæa norvegica, Trophon scalariformis (T. clathratus), and Natica clausa (Fig. 458).

Of the later stages of the Glacial Period, the records are much the same all over Britain, allowance being made for the greater cold and longer lingering of the glaciers in the north than in the south, and among the hills than on the plains.

In Scotland the following may be taken as the average succession of glacial phenomena in descending order:

Last traces of glaciers, small moraines at the foot of corries among the higher mountain groups. The glaciers, no doubt, lingered longest among the higher mountains of the northwest (Highlands, Galloway, Lead Hills, Hartfell and Loch Skene, Arran, Mull, Skye, Harris, Orkney, Shetland).

Marine terraces (50 feet and higher). Clay-beds of the Arctic sea-bottom (Clyde Beds) containing northern mollusks. The marine terraces prove a submergence of at least 100 feet beneath the present level of the land; how much beyond that limit the submergence reached has still to be determined.

Large moraines, showing that glaciers descended to the line of the present sea-level in the northwest of Scotland. Some of the moraines rest upon the 50-feet marine terrace.

Erratic blocks, chiefly transported by the first ice-sheet, but partly also by the later glaciers, and partly by floating ice during the period of submergence.

Sands and gravels—Kame or Esker series, sometimes containing terrestrial organisms, sometimes marine shells.

Upper bowlder-clay—rudely stratified clays with sands and gravels.

Till or lower bowlder-clay (bottom moraine of the ice-sheet)—a stiff stony unstratified clay, varying up to 100 feet or more in thickness. Bands of fine sand, finely laminated clays, layers of peat and terrestrial vegetation, with bones of mammoth and reindeer, also in some places fragmentary or entire Arctic and boreal marine shells, occur either in the till or between it and the upper bowlder-clay. Till spreads over the lower grounds, often taking the form of parallel ridges or drums.

Ice-worn rock surfaces.

Over a great part of England and Ireland the drift deposits are capable of subdivision as follows:

4. Moraines (North Wales, Lake District, etc.) and raised beaches.
3. Upper bowlder-clay—a stiff stony clay or loam with ice-worn stones and intercalations of sand, gravel, or silt. It occasionally contains marine shells. It possibly does not come south of the Wash.
2. Middle sands and gravels, containing marine shells. At Macclesfield (1200 feet above the sea) there have been found Cytherea chione, Cardium rusticum, Arca lactea, Tellina balthica, Cyprina islandica, Astarte borealis, and other shells now living in the seas around Britain, but indicating perhaps by their grouping a rather colder climate than the present. Corbicula fluminalis abounds in some gravels which underlie the upper bowlder-clay. South of the Wash it is found in similar deposits overlying the lower or "chalky bowlder-clay." In

Ireland marine shells of living British species occur at heights of 1300 feet above the sea. But, for the reason already assigned, the submergence may not have been nearly so great as these high-lying shelly deposits might be supposed to indicate.

1. Lower bowlder-clay—a stiff clayey deposit stuck full of ice-worn blocks, and equivalent to the till of Scotland. On the east coast of England (Holderness, Lincoln and Norfolk) it contains fragments of Scandinavian rocks; in particular, gneiss, mica-schist, quartzite, granite, syenite, rhombenporphyr; also pieces of red and black flint, probably from Denmark, and of Carboniferous limestone and sandstone, which have doubtless travelled from the north. Along the Norfolk cliffs it presents stratified intercalations of gravel and sand, which have been extraordinarily contorted. As in Scotland, the true lower bowlder-clay in the north of England and Ireland is often arranged in parallel ridges or drums in the prevalent line of ice-movement. As above mentioned, the "crag" of Bridlington, Yorkshire, is probably a fragment of an old marine glacial shell-bearing clay, torn up and imbedded in the bowlder-clay of the first ice-sheet. Its shells are strikingly Arctic.

The southern limit of the ice has been already mentioned (p. 1683). No "terminal moraine" has been observed, the ground to the south of the ice-limit being free from glaciation, though erratic blocks, probably brought by drift-ice, are found on the Sussex coast. The Coombe-rock has been already referred to (p. 1711). Deep superficial accumulations of rotted rock occur where the rock has decomposed *in situ* in the southern non-glaciated region, as may be well seen over the Palæozoic slates and granites of Devon and Cornwall. In the non-glaciated chalk districts, a thick cover of flints and red earth partly represents the insoluble parts of the chalk that remain after prolonged subaerial decay, but from the frequent presence of fragments of quartz, which does not occur in the chalk, this mantle of "clay with flints" seems to indicate also a certain amount of transport, though the agent by which this was effected is not obvious. The high moorlands of eastern Yorkshire appear to have risen as an insular tract above the ice-sheet; for the bowlder-clay advances up the valleys that indent the northern face of the Jurassic table-land, but ceases about a height of 800 feet, and the tableland itself is entirely free of drift, but its rocks are much decayed at the surface.

Scandinavia.[23]—The order of Pleistocene phenomena is generally the same here as in Britain. The surface of the country has been everywhere intensely glaciated, and, as already stated, the ice-striæ and transported stones show that the great ice-sheet probably exceeded 3000 feet in thickness, for the hills are ice-worn for more than 5000 feet above sea-level, and that moving outward from the axis of the peninsula it passed down the western fjords into the Atlantic, and southward and southeastward into the Baltic. The subsequent partial submergence of the country is proved by numerous shell-bearing clays. The fossils in the higher littoral shell-beds indicate a more Arctic climate; they include, as in the Scottish glacial clays, great numbers of thick-shelled varieties of Mya truncata and Saxicava rugosa; also Balanus porcatus, B. crenatus, Mytilus edulis, Pecten islandicus, Buccinum grœnlandicum, Trophon scalariformis (T. clathratus), Natica clausa. The clays of deeper water contain Leda lanceolata, Yoldia arctica, Y. intermedia, Y. pygmæa, Dentalium abyssorum, etc. The fossiliferous deposits of lower levels point to a climate more nearly approaching the present, for the more thoroughly Arctic species disappear, and the thick-shelled varieties of Mya and Saxicava pass into the usual thin-shelled kinds. The remarkable terraces that fringe the coast of Norway from the southern or Christiania region to the North Cape mark pauses in the re-elevation of the land (Fig. 78). The eastern plains of Sweden and the lower grounds of southern Norway are covered with great accumulations of sand and gravel (oesar) like the kames of Scotland and the eskers of Ireland.

Germany.[24]—Since the year 1878 an active exploration of

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[23] See G. de Geer, Zeitsch. Deutsch. Geol. Ges. xxxvii. 1885, p. 177.

[24] There is now an ample though recent literature devoted to the glacial phenomena of Germany. The volumes of the Zeitsch. Deutsch. Geol. Gesellschaft for 1879 and subsequent years contain papers by G. Berendt, H. Credner, A. Helland, A. Penck, R. Richter, F. Noetling, F. Wahnschaffe, F. E. Geinitz, F. Schmidt, etc. See also the Jahrb. Preuss. Geol. Landesanstalt for 1880 and following years; the Maps and Explanations of the same Survey for the neighborhood of Berlin, 27 sheets, and the memoirs of the Geological Survey of Saxony.

the earlier memorials of the glacial period has been carried on in northern Germany, with the result of bringing out more clearly the evidence for the prolongation of the Scandinavian and Finland ice across the Baltic and the plains of Germany even into Saxony. The limits reached by the ice are approximately fixed by the line to which northern erratics can be traced. Beneath the oldest members of the glacial drifts, deposits are found in a fragmentary condition containing shells now living only in southern Europe, such as Paludina diluviana and Corbicula fluminalis. Above the glaciated rocks comes a stiff, unstratified clay, with ice-striated blocks of northern origin—the till or bowlder-clay (Geschiebelehm, Blocklehm). Two distinct bowlder-clays have now been recognized—the older or till separated by interglacial deposits from the newer. Terminal moraines marking the limits of the ice-sheet have been found in the form of ramparts of Scandinavian blocks and gravel, which have been traced for many miles along the coast-line and across the plains of northern Germany.[25] The sources of the various ice-streams which united to form the great ice-sheet that crept over the Germanic plain are well shown by a study of the stones in the moraine material. The Scandinavian rocks are found toward the west and the Finnish toward the east of the glaciated area. Among the intercalated materials that separate the two bowlder-clays are layers of peat, with remains of pine, fir, aspen, willow, white birch, hazel, hornbeam, poplar, holly, oak, juniper, ilex, and various water-plants, in particular a water-lily no longer living in Europe. With this vegetation are associated remains of Elephas antiquus, mammoth, rhinoceros, elk, megaceros, reindeer, musk-ox, bison, bear, etc. Some of the interglacial deposits are of marine origin on the lower grounds bordering the Baltic, for they contain Cyprina islandica, Yoldia arctica, Tellina solidula, etc. Among the youngest glacial, and probably in part interglacial, deposits are the upper sands and gravels (Geschiebedeck-sand), which spread over wide areas of the Germanic plain, partly as a more or less uniform but discontinuous sheet, and partly as irregular hillocks and ridges strewn with erratic blocks, and inclosing pools of water and peat-bogs. These mounds and ridges, with their accompanying sheets of water, form

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[25] G. Berendt, Jahrb. Preuss. Geol. Landesanst. 1888, p. 110; K. Keilhack, op. cit. 1889, p. 149.

a conspicuous feature of the low tract of country from Schleswig-Holstein eastward to the Vistula.

In some of the mountain groups of Germany there is evidence that probably at the height of the Ice Age glaciers existed. Reference has already been made to the moraine mounds of the Vosges[26] and Black Forest,[27] and to the fact that the glaciers of the western hill-groups were more extensive than those to the east. In the Carpathian range, a series of moraines, sometimes inclosing lakes, is distributed in the valleys that radiate from the Hohe Tatra.[28] On both sides of the Riesengebirge, moraines occur. At the sources of the Lomnitz, on the southern side, they inclose two lakes at the foot of high recesses and cliffs.[29] No certain traces of glaciers appear to have been met with in the eastern part of the Sudeten range, nor in the Erzgebirge or Thuringerwald. Further north, in the Harz, mounds of detritus which resemble moraines have been referred by Kayser to glacier-action.[30]

France.—As France lay to the south of the northern ice-sheet, the true till or bowlder-clay is there absent, as it is for the same reason from the south of England. It is consequently difficult to decide which superficial accumulations are really contemporary with those termed glacial further north, and which ought to be grouped as of later date. The ordinary sedimentation in the non-glaciated area not having been interrupted by the invasion of the ice-sheet, deposits of pre-glacial, glacial, and post-glacial time naturally pass insensibly into each other. The older Pleistocene deposits (perhaps interglacial) consist of fluviatile gravels and clays which, in their composition, belong to the drainage systems in which they occur. There is generally no evidence of transport from a great distance, though, in the Champ de Mars at Paris, blocks of sandstone and conglomerate nearly a yard long sometimes occur, as well as small pieces of the granulite of the Morvan. Erratics at Calais and on the coast of Brittany may also have been carried a long way.[31] The rivers, however, were probably much larger during some part of the Pleistocene period than they now are, and the transport of their stones may have been

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[26] H. Hogard, "Terrain erratique des Vosges," 1851.
[27] J. Partsch, "Gletscher der Vorzeit," 1882, p. 115.
[28] Ibid. p. 9. [29] Ibid. p. 55.
[30] Lossen and Kayser, Zeitsch. Deutsch. Geol. Ges. xxxiii. 1881.
[31] Ch. Velain, Bull. Soc. Geol. France, xiv. 1886, p. 569.

sometimes effected by floating ice. They have left their ancient platforms of alluvium in successive terraces high above the present watercourses. Each terrace consists generally of the following succession of deposits in ascending order: (1) A lower gravel (*gravier de fond*), the pebbles of which are coarsest toward the bottom and are interstratified with layers of sand, sometimes inclined and contorted. (2) Gray sandy loam (*sable gras*). (3) The foregoing strata are covered by yellow calcareous loess (p. 566), or with an overlying dark brown loam or brick-earth. The upper exposed parts of the gravels and sands are commonly well oxidized, and present a yellowish-brown or deep reddish-brown tint, while the lower portions remain more or less gray. Hence the old names *diluvium gris* and *diluvium rouge*. The gravels and brick-earths have yielded terrestrial and fresh-water shells, most of which are of still living species, and numerous mammalian bones, among which are Rhinoceros antiquitatis (tichorhinus), R. etruscus, R. leptorhinus, Hippopotamus amphibius, Elephas antiquus, E. primigenius, wild boar, stag, roe, ibex, Canadian elk, musk-sheep, urus, beaver, cave-bear, wolf, fox, cave-hyæna, and cave-lion. Palæolithic implements found in the same deposits show that man was a contemporary of these animals (see p. 1733).[32]

It is in the centre and east of France that the most unequivocal signs of the ice of the Glacial Period are to be met with. The mountain groups of Auvergne, which even now show deep rifts of snow in summer, had their glaciers whereby moraine heaps and large blocks of rock were strewn over the valleys; not only so, but there is evidence in that region of a retreat and redescent of the ice, for above the older moraines lie interglacial deposits containing abundant remains of land-plants with bones of Elephas meridionalis, Rhinoceros leptorhinus, etc., the whole being covered by newer moraines.[33]

The much lower grounds of the Lyonnais and Beaujolais (rising to more than 3000 feet) likewise supported indepen-

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[32] A detailed study of the Quaternary deposits of the north of France has been made by J. Ladrière, who divides them into three stages, each marked off by a gravelly layer at the base and terminating above in a loam with terrestrial vegetation and fresh-water and terrestrial shells. The lowest is the assise, with Elephas primigenius and Rhinoceros tichorhinus. Ann. Soc. Geol. Nord, xviii. 1890, p. 93.

[33] Julien, "Des Phenomènes glaciaires dans le Plateau central de la France," 1869. Rames, Bull. Soc. Geol. France, 1884.

dent snow-fields.[34] The glacier of the Rhone and its tributaries at the time of the maximum glaciation was so gigantic as to fill up the hollow of the Lake of Geneva and the vast plain between the Bernese Oberland and the Jura. It crossed the Jura and advanced to near Besançon. It swept down the valley below Geneva, and then, joined by its tributaries, spread out over the lower hills and plains until the whole region from Bourg to Grenoble was buried under ice. The evidence of this great extension is furnished by rock-striæ, transported blocks and moraine stuff.[35]

Belgium.—The Quaternary deposits of this country, like those of northern France, belong to a former condition of the present river-basins. In the higher tracts, they are confined to the valleys, but over the plains they spread as more or less continuous sheets. Thus, in the valley of the Meuse, the gravel-terraces of older diluvium on either side bear witness only to transport within the drainage-basin of the river, though fragments of the rocks of the far Vosges may be detected in them. The gravels are stratified, and are generally accompanied by an upper sandy clay. In middle Belgium, the lower diluvial gravels are covered by a yellow loam (Hesbayan), probably a continuation of the German loess, with numerous terrestrial shells (Succinea oblonga, Pupa muscorum, Helix hispida). In lower Belgium, this loam is replaced by the Campinian sands, which have been observed lying upon it. The Belgian caverns and some parts of the diluvium have yielded a large number of mammalian remains, among which there is the same commingling of types from cold and from warm latitudes so observable in the Pleistocene beds of England and France. Thus the Arctic reindeer and glutton are found with the Alpine chamois and marmot, and with the lion and grizzly bear.

The Alps.[36]—Reference has already been made to the vast extension of the Alpine glaciers during the Ice Age. Evi-

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[34] Falsan and Chantre, "Anciens Glaciers," ii. p. 384.

[35] Falsan and Chantre, op. cit.

[36] Besides the works of Falsan and Chantre, Penck and Partsch, cited on p. 1679, the student may consult Morlot, Bib. Univ. 1855; Bull. Soc. Vaud. Sci. Nat. 1858, 1860; Heer, "Urwelt der Schweiz"; the map of the ancient glaciers of the north side of the Swiss Alps, published in four sheets by A. Favre, Geneva, 1884; C. W. Gümbel, Sitzb. Akad. Wien, 1872; R. Lepsius, "Das westliche Süd-Tirol," Berlin, 1878; A. Heim, "Handbuch der Gletscherkunde," 1885; Baltzer, Mittheil. Naturf. Ges. Berne, 1887; Renevier, Bull. Soc. Helv. 1887; A. Böhm, Jahrb. k. k. Geol. Reichsanst. xxxv. 1885, p. 429.

dence of this extension is to be seen both among the mountains and far out into the surrounding regions. On the sides of the great valleys, ice-striated surfaces and transported blocks are found at such heights as to show that the ice must have been in some places 3000 or 4000 feet thicker than it now is. The glacier of the Aar, for instance, which was a comparatively short one, being turned aside by and merging into the large stream of the Rhone glacier near Berne, attained such dimensions as not only to fill up the valley now occupied by the Lakes of Thun and Brienz, but to override the surrounding hills. The marks made by it are found at a height of 930 metres above the valley, which with 305 metres for the depth of Lake Brienz gives a depth of at least 1235 metres or 4000 feet of ice moving down that valley. Judging from the evidence of the heights of the stranded blocks, the slope of this glacier varied from 45 in 1000 in its upper parts to not more than 2 in 1000 toward its termination.[37] From the variation in the direction of the striæ, as well as in the distribution of the transported blocks, there can be little doubt that the Alpine glaciers varied from time to time in relative dimensions, so that there was a kind of struggle between them, one pushing aside another, and again being pushed aside in its turn.

Turning to the regions beyond the mountains, we find that proofs of glaciation reach to almost incredible distances. The Rhone glacier has already been referred to as overwhelming the mountainous and hilly intervening country, and throwing down its moraines with blocks of the characteristic rocks of the Valais where Lyons now stands, that is, 170 miles in direct distance from where the present glacier ends. The same ice-sheet, swelled from the northern side of the Bernese Oberland, overflowed the lower ridges of the Jura, streaming through the transverse valleys, even as far as Ornans near Besançon. Turning northeastward, it filled up the great valley of Switzerland, and, swollen by the tributary glaciers of the Aar, the Reuss, and the Linth, joined the vast stream of the Rhine glacier above Basel. This enormous *mer du glace* poured over the Black Forest and down the valley of the Danube at least as far as Sigmaringen, where blocks of the rocks of the Grisons occur. Eastward it was joined by the great glacier that descended from the Swabian and Bavarian Alps, and of which the moraine-heaps are strewn over the lowlands as far as Munich. The

[37] A. Favre, Arch. Ann. Sci. Phys. Nat. Genève, xii. 1884.

Tyrolese and Carinthian Alps were likewise buried under an icy covering which sent a huge glacier eastward down the valley of the Dran. On the south side of the Alps, the glaciers advanced for some way out into the plains of Lombardy, where they threw down enormous moraines, which sometimes reach a height of more than 2000 feet (Ivrea). These vast accumulations, to which there is no parallel elsewhere in Europe, rise into conspicuous hills and crescent-shaped ridges round the lower ends of the upper Italian lakes. At some of these localities the moraine stuff rests on marine Pliocene beds. It is possible that the glaciers actually reached the sea-level.[38] There appears to be no doubt, at least, that they descended to a lower level on that side than on the northern side of the Alps.

By tracing the distribution of the transported blocks, the movements of the ancient glaciers can be satisfactorily followed. These blocks are not dispersed at random over the glaciated area. Each glacier carried the blocks of its own basin, and, where these are of a peculiar kind, they serve as an excellent guide in following the march of the ice. Not only were the blocks in each drainage area kept separate from those of adjoining basins, but those on the left sides of the valleys do not, except along the junction lines, mingle with those of the right sides. As a rule, the blocks lie along the slopes of the valleys rather than on the bottoms, and are often disposed there in groups or lines. In the Arve valley, near Sallanches, for example, a zone comprising several thousand granitic bowlders runs for a distance of more than three miles. The blocks of Monthey have long been famous. On the flanks of the Jura near Solothurn, the bowlders of Riedholz, stranded there by the ancient Rhone glacier, still number 228, though they have been reduced by the quarrying operations now happily interdicted (see Figs. 151, 152, 153).[39]

That the Ice Age in the Alps, as in northern Europe, was interrupted by at least one warmer interglacial period, when the ice retreating from the valleys allowed an abundant vegetation to flourish there, is shown by the lignites of Dürnten (Canton Zurich), Utznach (St. Gall), Hotting (near Inns-

[38] The surface of the Lago di Garda, round the lower end of which glacier moraines extend, is little more than 200 feet above the sea-level.

[39] Favre, Arch. Sci. Phys. Nat. Genève, xii. 1884, p. 399. Penck, "Vergletscherung der Deutschen Alpen," believes that he can trace evidence of at least three distinct periods of glaciation in the Alps.

pruck), and several other places. These deposits can here and there be seen to overlie ancient moraine stuff; they are interstratified with fluviatile gravels and sands, which again are surmounted with scattered erratic blocks belonging to a later period of glaciation. Among these interglacial vegetable accumulations Heer recognized several pines or firs (Pinus abies, P. sylvestris, P. montana), larch, yew, oak, sycamore, hazel, mosses, bog-bean, bulrush, raspberry, and Galium palustre, as well as bog-mosses, all still growing in the surrounding country. With the plants there occur the remains of Elephas, Rhinoceros etruscus, Bos taurus, var. primigenius or urus, red-deer, cave-bear, likewise traces of fresh-water shells and insects, chiefly elytra of beetles.

The succession of main events in the history of the Ice Age in Switzerland is thus tabulated:[40]

Post-glacial. Ancient lacustrine terraces (150 feet above present level of Lake of Geneva), deltas, and river gravels with Limnæa stagnalis, and other fresh-water shells, bones of mammoth (?).

Second extension of the glaciers. Erratic blocks and terminal moraines of Zurich, Baldegg, Sempach, Berne, with an Arctic flora and fauna.

Interglacial beds. Gravels, lignites, and clays of Utznach, Durnten, etc., covered by the moraine stuff of the second glaciation and overlying the oldest glacial deposits—Elephas antiquus, Rhinoceros leptorhinus.

First glaciation. Striated blocks found under the interglacial beds.

Russia.—A vast extent of Russia was buried under the first great ice-sheet, the southward limits of which across the country have already been stated (p. 1684). There appears to be evidence that the second advance of the ice not only affected the western lowlands that were covered by the Baltic glacier, but even the centre of the country. Recently proofs have been obtained of an interglacial period in central Russia marked by lacustrine deposits intercalated between glacial clays. They have yielded an abundant flora, including alder, birch, hazel, willow, fir, water-lilies, and remains of mammoth, etc.[41]

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40 Heer, "Urwelt der Schweiz."

41 N. Kirschtafowitsch, Bull. Soc. Imp. Nat. Moscou, No. 4, 1890. On the glaciation of the Urals see Nikitin, Neues Jahrb. 1888, i. p. 172.

North America.[42]—The general succession of geological change in Post-Tertiary time appears to have been broadly the same all over the northern hemisphere. In North America, as in Europe, there is a glaciated and non-glaciated area; but the line of demarcation between them has been much more clearly traced on the western side of the Atlantic. The glaciated area extending over Canada and the northeastern States presents the same characteristic features as in the Old World. The rocks, where they could receive and retain the ice-markings, are well smoothed and striated. The direction of the striæ is generally southward, varying to southeast and southwest according to the form of the ground. The great thickness of the ice-sheet is strikingly shown by the height to which some of the higher elevations are polished and striated. Thus the Catskill Mountains, rising from the broad plain of the Hudson, have been ground smooth and striated up to near their summits, or about 3000 feet, so that the ice must have been of even greater thickness than that. The White Mountains are ice-worn even at a height of 5500 feet. G. M. Dawson has found glaciated surfaces in British Columbia 7000 feet above the sea.[43]

As in Europe, the glacial deposits increase in thickness and variety from south to north, spreading across Canada, over a considerable area of the northeastern States, and rising to a height of 5800 feet among the White Mountains. From the evidence of the rock-striæ and the dispersion of bowlders, it appears that, though the glaciated region was buried under one deep continuous *mer de glace* like that of Greenland at the present time, moving steadily down from the north, there were considerable variations in the direction of motion, mainly, no doubt, owing to inequalities in the general slope of the ground underneath. Nothing, however, is more striking than the apparent indifference with which the ice streamed onward, undeflected even by considerable

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[42] See J. D. Whitney, "Climatic Changes of later Geological Times," Mem. Mus. Compar. Zool. Harvard, vol. vii. 1882; and papers by J. D. Dana, T. C. Chamberlin, R. D. Salisbury, W. Upham, George M. Dawson, H. Carvill Lewis, G. F. Wright, and others in Amer. Journ. Sci., American Geologist, Canadian Naturalist, Canadian Journal, Ann. Reports of U. S. Geol. Survey, and Canadian Geol. Survey, Second Geol. Surv. of Pennsylvania. J. W. Dawson, "Acadian Geology," 1878; "Handbook of Canadian Geology," 1889; G. M. Dawson, Trans. Roy. Soc. Canada, viii. sect. iv. 1890, p 25; G. F. Wright, "Man and the Glacial Period," "The Ice Age in America."

[43] Geol. Mag. 1889, p. 351; see also W. Upham, Appalachia, v. 1889, p. 291.

ridges and hills. The line of the southern margin of the ice can still be followed by tracing the limits to which the drift deposits extend southward. From this evidence we learn that the ice-sheet ended off in a sinuous line, protruding in great tongues or promontories and retiring into deep and wide bays. In the Eastern States, the southern limit of the glaciated region is marked by one of the most extraordinary glacial accumulations yet known, and to which in Europe there is no rival. It consists of a broad irregular band of confused heaps of drift, or more strictly of two such bands, which sometimes unite into one broad belt and sometimes separate wide enough to allow an interval of twenty or thirty miles between them, each being from one to six miles in breadth and rising several hundred feet above the surrounding country. The surface of these ridges presents a characteristic hummocky aspect, rising into cones, domes, and confluent ridges, and sinking into basin-shaped or other irregularly-formed depressions, like the kames or oesar of Europe. The upper part of the material composing the ridges generally consists of assorted and stratified gravel and sand, the stratification being irregular and discordant, but inclined on the whole toward the south. Below these rearranged materials is a bowlder-drift—a mixture of clay, sand, and gravel, with bowlders of all sizes, up to blocks many tons in weight and often striated. Though sometimes indistinguishable from ordinary till, it presents as a rule a greater preponderance of stones than in typical till, but contains also fine stratified intercalations. A large proportion of the material of the ridges has been derived from rocks lying immediately to the north, and the nature of the ingredients constantly varies with the changing geological structure of the ground. There is also always present a greater or less amount of detritus representing rocks that lie along the line of drift-movement for 500 miles or more to the north. The band of drift-hills lies sometimes on an ascending, sometimes on a descending slope, crosses narrow mountain ridges and forms embankments across valleys, showing such a disregard of the topography as to prove that it cannot have been a shore-line, and has not been laid down with reference to the present drainage system of the land.[44]

To this remarkable belt of prominent hummocky ground the name of "terminal moraine" has been given by the

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[44] H. C. Lewis, "Report on the Terminal Moraine," Second Geol. Surv. Pennsylvania, Z, 1884, p. 45, with Preface by J. P. Lesley.

American geologists who have so successfully traced its distribution and investigated its structure. The conditions, however, under which the drift rampart in question was formed certainly differed widely from those that determine an ordinary terminal moraine. The constituent materials can hardly have travelled on the surface of the ice, but must rather have lain underneath it or have been pushed forward in front of it. But the mode of formation is a problem which has not yet been satisfactorily solved.

There seems good reason to believe that there are at least two "terminal moraines" belonging to two distinct and perhaps widely separated epochs in the Ice Age. The most southerly and therefore oldest of them begins on the Atlantic border off the southeastern coast of Massachusetts, where it is partially submerged. Rising above the level of the sea in Nantucket Island, Martha's Vineyard, No Man's Island and Block Island, it is prolonged into Long Island, of which it forms the backbone, and where it reaches heights of 200 to nearly 400 feet. A second or later and less prominent line of drift-hills runs along the north shore of Long Island, and is prolonged by Fisher's Island into the southern edge of the State of Rhode Island, whence, striking out again to sea, it forms the chain of the Elizabeth Islands, passes thence into the State of Massachusetts, and runs nearly east and west through the peninsula of Cape Cod. The distance between these two bands of hummocky ridge varies from five to thirty miles. From the western end of Long Island the moraine passes across Staten Island and the northern part of New Jersey, enters Pennsylvania a little north of Easton, and follows a sinuous northwesterly course across that State and for some miles into the State of New York, where, forming a deep indentation, it wheels round in a southwesterly direction, re-enters Pennsylvania, and passes into Ohio. Throughout this long line, the moraine coincides with the southern limit of the drift and of rock-striation, though in western Pennsylvania, in front of the ridge, scattered northern bowlders are found over a strip of ground which gradually increases southwestward to a breadth of five miles.[45] Beyond central Ohio, however, the drift extends far to the south. Taking its limits as probably marking the extreme boundary

[45] This strip of ground, called by the late Prof. H. C. Lewis the "fringe," widens out southwestward, as stated above, to a breadth of five miles, in which, though there are no rock-striæ or drift, scattered northern bowlders occur. Op. cit. p. 201.

of the ice-sheet (then at its largest), we find that it goes southward, perhaps nearly as far as the junction of the Ohio with the Mississippi, sweeping westward into Kansas, and then probably turning northward through Nebraska and Dakota, but keeping to the west of the Missouri River.

The inner or second terminal moraine is well developed in the southern part of the State of New York, lying well to the north of the first moraine, and much more irregularly distributed. Southwestward the two series of ramparts unite at the sharp bend of the older ridge just mentioned, and continue as one into the centre of Ohio. This junction probably indicates that the southern edge of the ice at the time of the second moraine, though generally keeping to the north of its previous limit, reached its former extent in northwestern Pennsylvania, and united its débris with that left at the time of the greatest extension of the ice-sheet. From the middle of Ohio, the younger moraine pursues an extraordinarily sinuous course. One of its most remarkable bends incloses the southern half of Lake Michigan, which was the bed of a great tongue of ice moving from the north. Immediately to the west of this loop there lies an extensive driftless area in Wisconsin and Minnesota. The course of the moraine bears distinct witness to the independent direction of flow of the united glaciers that constituted the great ice-sheet. It sweeps in vast indentations and promontories across Wisconsin, Minnesota, and Iowa, forming probably the most extensive moraine in the world, and strikes northwestward through Dakota for at least 400 miles into the British Possessions, where its further course has been partially traced. The known portion of the moraine thus extends with a wonderful persistence of character for 3000 miles, reaching across two-thirds of the breadth of the continent.[46]

In the non-glaciated regions evidence of the presence and influence of the ice-sheet is probably furnished by high alluvial terraces, which could not have been formed under the present conditions of drainage. From this kind of evidence it is believed that when the ice-sheet crossed the Ohio River near Cincinnati, it ponded back the drainage of the entire

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[46] T. C. Chamberlin, "Preliminary Paper on the Terminal Moraine," Third Ann. Rep. U. S. Geol. Survey, 1883. Every student of glacial geology ought to make himself familiar with this admirable summary. Consult also G. M. Dawson, "Report on 49th Parallel"; F. Wahnschaffe, Zeitsch. Deutsch. Geol. Ges. 1892, p. 107; J. B. Tyrrell, Bull. Geol. Soc. Amer. i. 1890, p. 395, describes the terminal moraines in Manitoba and the adjacent territories of N.W. Canada.

water-basin of east Kentucky, southeast Ohio, West Virginia, and western Pennsylvania, up to a height of perhaps 1000 feet, forming a lake at that level.[47] Similar indications of a lake, caused by an ice-dam ponding back the drainage, are found at the head of the Red River in Minnesota.[48] The largest sheet of fresh water which has left its records in that region has been called "Lake Agassiz." It occupied the basin of the Red River of the North and Lake Winnipeg. It is computed to have covered an area of 110,000 square miles, thus exceeding the total area of the five great existing lakes—Superior (31,200), Michigan (22,450), Huron with Georgian Bay (23,800), Erie (9960), Ontario (7240), which have a united area of 94,650 square miles.[49] Many other "glacial lakes," which no longer exist because their ice-barriers have disappeared, have been found scattered over Canada.[50]

The deposits left by the ice-sheet within the limits of the terminal moraines so resemble those of Europe that no special description of them is required. The lowest of them, resting on ice-worn rocks, is a stiff, unstratified bowlder-drift or till, full of polished and striated stones. Occasional intercalations of sand and clay, which at Portland, in Maine, have yielded many existing species of marine organisms, and in some places land-plants and fresh-water shells, separate the lower from an upper bowlder-clay, which is looser, and more gravelly and sandy than the older deposit, contains larger rough and angular blocks, and has acquired a yellow tint from the oxidizing influence of surface waters. The bowlders vary up to 10 feet (sometimes even 40 feet) in diameter, and have seldom travelled more than 20 miles. The bowlder-clays over wide areas are distributed in lenticular hills or drums from a few hundred feet to a mile in length, from 25 to 200 feet high, and with a persistent smoothness of outline and rounded tops.[51] As in Europe, the longer axes of these drums is generally parallel with that of the striation of the underlying rocks.

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[47] H. C. Lewis, "Report on the Terminal Moraine," cited on p. 1724.

[48] W. Upham, Proc. Amer. Assoc. xxxii. 1883, p. 214.

[49] For a full account of this vanished lake (now represented only by scattered sheets of water in the hollows of its basin), with its terraces, dunes, deltas and other features, see W. Upham, Rep. Geol. Surv. Canada, vol. iv. for 1888–89.

[50] W. Upham, Bull. Geol. Soc. Amer. ii. 1891, p. 243.

[51] W. Upham, Proc. Bost. Soc. Nat. Hist. xxiv. 1889, p. 228. See on Till, W. O. Crosby, op. cit. xxv. 1890, p. 115.

At the height of the Ice Age there were large glaciers in the Rocky Mountains, of which the small glaciers found some years ago among the Wind River Mountains in Wyoming are some of the last lingering relics.[52] But though the ice filled up the valleys to a depth of 1600 feet or more, and transported vast quantities of detritus which now remains in prominent moraines and scattered bowlders, it never advanced into the plateau of the prairie country to the east. Whether or not the glaciers at the north end of the Rocky Mountains merged into and were turned aside by the southward-moving ice-sheet has still to be ascertained. Even far to the west, the Sierra Nevada nourished an important group of glaciers.[53]

The loose deposits or drifts overlying the lower unstratified bowlder-clay belong to the period of the melting of the great ice-sheets, when large bodies of water, discharged across the land, levelled down the heaps of detritus that had formed below or in the under part of the ice. This remodelled drift has been called the "Champlain group."[54] Lower portions are sometimes unstratified or very rudely stratified, while the upper parts are more or less perfectly stratified. Toward the eastern coasts, and along the valleys penetrating from the sea into the land, these stratified beds are of marine origin, and prove that during the Champlain period there was a depression of the eastern part of Canada and the United States beneath the sea, increasing in amount northward from a few feet in the south of New England to more than 500 feet in Labrador. The marine accumulations are well developed in eastern Canada, where the drift-deposits show the following subdivisions:

Post-glacial accumulations.

Saxicava sand and gravel, often with transported bowlders (Upper Bowlder deposits, St. Maurice and Sorel Sands). Shallow-water boreal fauna, Saxicava rugosa, bones of whales, etc.

Upper Leda clay (and probably "Sangeen clay" of inland); clay and sandy clay with numerous marine shells, which are the same as those now living in

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[52] F. V. Hayden's Twelfth Report, U. S. Geol. and Geog. Survey of the Territories.

[53] J. Leconte, Amer. Journ. Sci. (3) ix. 1875, p. 126. See Amer. Naturalist, 1880, for a paper on the ancient glaciers of the Rocky Mountains.

[54] See J. D. Dana, Amer. Journ. Sci. x. 1875, p. 168, xxvi. 1883, xxvii. 1884; Winchell, op. cit. xi. 1876, p. 225.

northern part of Gulf of St. Lawrence; also in some districts fresh-water shells and plants.[55]

Lower Leda clay, fine clay, often laminated, with a few large travelled bowlders (probably equivalent to "Erie Clay" of inland; "Champlain Clay," Lower Shell-sand of Beauport); contains Leda arctica, Tellina grœnlandica; probably deposited in cold ice-laden water.

Bowlder-clay or Till; in the Lower St. Lawrence region contains a few Arctic shells, but further inland is unfossiliferous.

Peaty beds, marking pre-glacial land-surfaces.[56]

The Leda clays rise to a height of 600 feet above the sea. On the banks of the Ottawa, in Gloucester, they contain nodules which have been formed round organic bodies, particularly the fish Mallotus villosus or capeling of the Lower St. Lawrence. Sir J. W. Dawson also obtained numerous remains of terrestrial marsh-plants, grasses, carices, mosses, and algæ. This writer states that about 100 species of marine invertebrates have been obtained from the clays of the St. Lawrence valley. All except four or five species in the older part of the deposits are shells of the boreal or Arctic regions of the Atlantic; and about half are found also in the glacial clays of Britain. The great majority are now living in the Gulf of St. Lawrence and on neighboring coasts, especially off Labrador.[57]

Terraces of marine origin occur both on the coast and far inland. On the coast of Maine they appear at heights of 150 to 200 feet, round Lake Champlain at least as high as 300 feet, and at Montreal nearly 500 feet above the present level of the sea.[58] In the absence of organic remains, however, it is not always possible to distinguish between terraces of marine origin marking former sea-margins, and those left by the retirement of rivers and lakes. In the Bay of Fundy evidence has been cited by Dawson to prove subsidence, for he has observed there a submerged forest of pine and beech lying 25 feet below high-water mark.[59]

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[55] For a list of Canadian Pleistocene plants see D. P. Penhallow, Bull. Geol. Soc. Amer. i. 1890, p. 321.

[56] J. W. Dawson, Supplement to "Acadian Geology," 1878; Canadian Naturalist, vi. 1871; Geol. Mag. 1883, p. 111: Bull. Geol. Soc. Amer. i. 1890, p. 311.

[57] Dawson, "Acadian Geology," p. 76.

[58] On terraces of Lake Ontario see Amer. Journ. Sci. (3) xxiv. p. 409.

[59] "Acadian Geology," p. 28.

Inland, the stratified parts of the "Champlain group" have been accumulated on the sides of rivers, and present in great perfection the terrace character already (p. 669) described. The successive platforms or terraces mark the diminution of the streams. They may be connected also with an intermittent uprise of the land, and are thus analogous to sea-terraces or raised beaches. Each uplift that increased the declivity of the rivers would augment their rate of flow, and consequently their scour, so that they would be unable to reach their old flood-plains. Such evidences of diminution are almost universal among the valleys in the drift-covered parts of North America, as in the similar regions of Europe. Sometimes four or five platforms, the highest being 100 feet or more above the present level of the river, may be seen rising above each other, as in the well-known example of the Connecticut Valley.

The terraces are not, however, confined to river-valleys, but may be traced round many lakes. Thus, in the basin of Lake Huron, deposits of fine sand and clay containing fresh-water shells rise to a height of 40 feet or more above the present level of the water, and run back from the shore sometimes for 20 miles. Regular terraces, corresponding to former water-levels of the lake, run for miles along the shores at heights of 120, 150, and 200 feet. Shingle beaches and mounds or ridges, exactly like those now in course of formation along the exposed shores of Lake Huron, can be recognized at heights of 60, 70, and 100 feet. Unfossiliferous terraces occur abundantly on the margin of Lake Superior. At one point mentioned by Logan, no fewer than seven of these ancient beaches occur at intervals up to a height of 331 feet above the present level of the lake.[60] The great abundance of terraces of fluviatile, lacustrine, and marine origin led, as already stated, to the use of the term "Terrace epoch" to designate the time when these remarkable topographical features were produced. The cause of the former higher levels of the water is a difficult problem. In some cases it has doubtless arisen from dams formed by tongues of ice during the retreat of the ice-sheet.

India.—There is abundant evidence that at a late geological period glaciers descended from the southern slopes of the Himalaya Mountains to a height of less than 3000 feet above the present sea-level. Large moraines are found in

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[60] Logan, "Geology of Canada," p. 910. Consult also the paper by Gilbert on Lake Shores cited ante, p. 686.

many valleys of Sikkim and eastern Nepal between 7000 and 8000 feet, and even down to 5000 feet, above sea-level. In the western Himalayas perched blocks are found at 3000 feet, and in the Upper Punjab very large erratics have been observed at still lower elevations. No traces of glaciation have been detected in southern India. Besides the physical evidence of refrigeration, the present facies and distribution of the flora and fauna on the south side of the Himalaya chain suggest the influence of a former cold period.[61]

Australasia.—The present glaciers of the New Zealand Alps had a much greater extension at a recent geological period. According to Sir J. Haast they descended into the plains, and, on the west side of the island, probably advanced into the sea, for along that coast-line their moraines now reach the sea-margin; huge erratics stand up among the waves, and the surf breaks far outside the shore-line, probably upon a seaward extension of the moraines.[62] Captain Hutton, however, points out that there is no evidence from the fauna of any general and serious refrigeration of the climate during this glacier period.[63] He believes that the principal part of the sub-tropical flora and fauna of New Zealand was introduced before the Miocene period, and has flourished ever since, and that any serious diminution of the temperature of the islands would have exterminated all but the more cold-loving species of plants and animals. He maintains that the cause of the former greater extension of the glaciers is to be sought in the fact, of which there are other independent proofs, that the land then stood at a far higher level than it does at present, an additional 3000 to 4000 feet being estimated to suffice for restoring the glaciers to their former maximum size. He likewise adduces grounds for believing that the glacier epoch (which he declines to regard as a *glacial* epoch) in New Zealand dates back to a much earlier time than the Ice Age of the northern hemisphere, probably to the Pliocene period.

To the Upper Pliocene and Pleistocene periods are assigned the wide terraced gravel-banks and alluvial flats which occur in the main valleys of Australia, and the

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[61] Medlicott and Blanford, "Geology of India," p. 586.

[62] "Geology of Canterbury and Westland," p. 371. This, however, as above stated, is not admitted by Captain Hutton (N. Zealand Journ. Sci. 1884).

[63] "Geology of Otago," p. 83. See for a fuller statement of his views on this subject his address on the Origin of the Fauna and Flora of New Zealand, N. Zealand Journ. Sci. 1884; also Proc. Linn. Soc. N. S. Wales, x. part 3.

great alluvial plains which in some of the colonies form such marked features. These deposits vary up to 300 feet in depth, and are a great storehouse of alluvial gold. They may possibly indicate that a greater rainfall was concerned in their formation than now characterizes the same regions. If the glaciers of New Zealand advanced into the sea, and the great Antarctic ice-sheet ever crept north toward the Australian shores, during some part of this cold period, the rainfall may have been so augmented that the rivers spread out far beyond the limits within which they are now confined. Evidence indeed has been adduced in favor of true glaciation in the Australian Alps. What are described as ice-worn surfaces have been observed on Mount Cobboras at elevations of between 4000 and 6000 feet, and on Mount Kosciusko in New South Wales. Erratic blocks and moraines are likewise cited.[64]

Section ii. Recent, Post-glacial or Human Period

§ 1. General Characters

The long succession of Pleistocene ages shaded without abrupt change of any kind into what is termed the Human or Recent Period.[65] The Ice Age, or Glacial Period, may indeed be said still to exist in Europe. The snow-fields and glaciers have disappeared from Britain, France, the Vosges, and the Harz, but they still linger among the Pyrenees, remain in larger mass among the Alps, and spread over wide areas in northern Scandinavia. This dovetailing or overlapping of geological periods has been the rule from the beginning of time, the apparently abrupt transitions in the geological record being due to imperfections in the chronicle.

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[64] J. Stirling, Trans. Roy. Soc. Vict. 1884, p. 23; Nature, xxxv. 1886, p. 182; Dr. von Lendenfeld, Proc. Linn. Soc. N.S. Wales, 1885, p. 45.

[65] See for general information Lyell's "Antiquity of Man," Lubbock's "Prehistoric Times," Evans's "Ancient Stone Implements," Boyd Dawkins's "Cave Hunting" and "Early Man in Britain," J. Geikie's "Prehistoric Europe."

The last of the long series of geological periods may be subdivided into subordinate sections as follows:

Historic, up to the present time.	
Prehistoric	Iron, Bronze and later Stone.
	Neolithic.
	Palæolithic.

The Human Period is above all distinguished by the presence and influence of man. It is difficult to determine how far back the limit of the period should be placed. The question has often been asked whether man was coeval with the Ice Age. To give an answer, we must know within what limits the term Ice Age is used, and to what particular country or district the question refers. For it is evident that even to-day man is contemporary with the Ice Age in the Alpine valleys and in Finmark. There can be no doubt that he inhabited Europe after the greatest extension of the ice. He not improbably migrated with the animals that came from warmer climates into this continent during interglacial conditions. But that he remained when the climate again became cold enough to freeze the rivers and permit an Arctic fauna to roam far south into Europe is proved by the abundance of his flint implements in the thick river-gravels, into which they no doubt often fell through holes in the ice as he was fishing.

The proofs of the existence of man in former geological periods are not to be expected in the occurrence of his own bodily remains, as in the case of other animals. His bones are indeed now and then to be found, but in the vast majority of cases his former presence is revealed by the implements he has left behind him, formed of stone, metal, or bone. Many years ago the archæologists of Denmark, adopting the phraseology of the Latin poets, classified the early traces of man in three great divisions—the Stone Age, Bronze Age, and Iron Age. There can be no doubt that, on the whole, this has been the general order of succession in Europe, where men used stone and bone before they had discovered the use of metal, and learned how to obtain bronze before they knew anything of the metallurgy of iron. Nevertheless, the use of stone long survived the introduction of bronze and iron. In fact, in European countries where metal has been known for many centuries, there are districts where stone implements are still

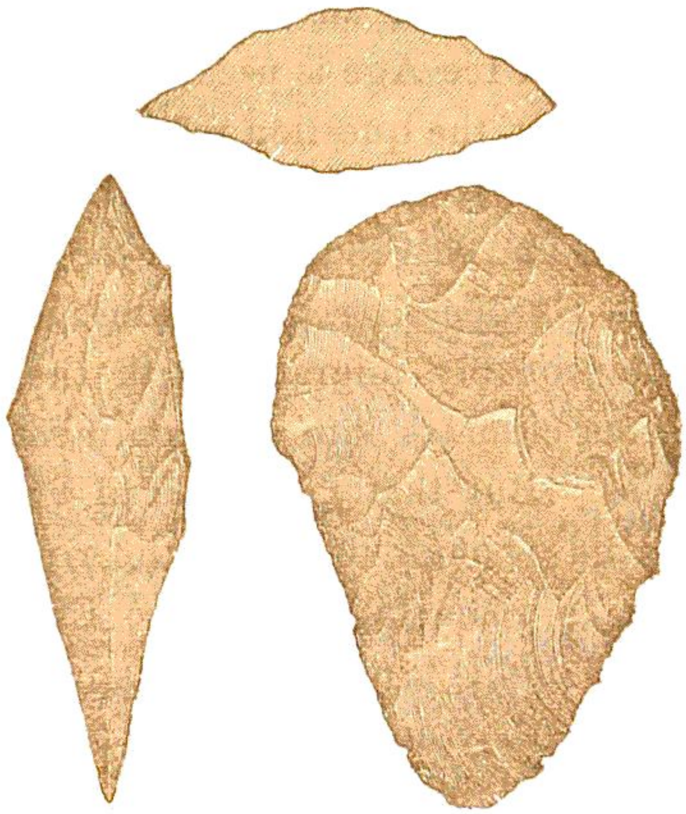

Fig. 459.—Palæolithic Flint Implements.

employed, or where they were in use until quite recently. It is obvious also that, as there are still barbarous tribes unacquainted with the fabrication of metal, the Stone Age is not yet extinct in some parts of the world. In this instance, we again see how geological periods run into each other. The material or shape of the implement cannot therefore be always a very satisfactory proof of antiquity. We must judge of it by the circumstances under which it was found. From the fact that in northwestern Europe the ruder kinds of stone weapons (Fig. 459) occur in what are certainly the older deposits, while others of more highly finished workmanship (Figs. 462, 463) are found in later accumulations, the Stone Age has been subdivided into an early or Palæolithic and a later or Neolithic epoch. There can be no doubt, however, that the latter was in great measure coeval with the age of bronze, and even, to some extent, with that of iron.[66]

The deposits which contain the history of the Human Period are river-alluvia, brick-earth, cavern-loam, calcareous tufa, loess, lake-bottoms, peat-mosses, sand-dunes, and other superficial accumulations.

PALÆOLITHIC.[67]—Under this term are included those deposits which have yielded rudely-worked flints of human workmanship associated with the remains of mammalia, some of which are extinct, while others no longer live where their remains have been obtained. An association of the same mammalian remains under similar conditions, but without traces of man, may be assigned to the same geological period, and be included in the Palæolithic series. A satisfactory chronological classification of the deposits

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[66] The student may profitably consult Sir Arthur Mitchell's "Past in the Present," 1880, for the warnings it contains as to the danger of deciding upon the antiquity of an implement merely from its rudeness.

[67] This term has been further subdivided into minor sections according to the degree of "finish" in the instruments and their presumed chronological order. Thus, deposits containing the very rude type of worked flints found at Chelles near Paris and at St. Acheul have been called Chellean or Acheulian. Those with implements like the scrapers of Moustier (Dordogne) have been named Mousterian. Those where the flints have been more deftly worked, like the implements found at Solutré in Burgundy, have been called Solutrian; while those which contain well-finished implements associated with carved bone and ivory, as at the caves of La Madelaine (Périgord), have been called Magdalenian. But this classification does not rest on the evidence of superposition and is probably of little chronological value, though some weight may be attached to the presence of different mammals with the different types of instrument.

containing the first relics of man is perhaps unattainable, for these deposits occur in detached areas and offer no means of determining their physical sequence. To assert that a brick-earth is older than a cavern-breccia, because it contains some bones which the latter does not, or fails to show some which the latter does yield, is too often a conclusion drawn because it agrees with preconceptions.

River-Alluvia.—Above the present levels of the rivers, there lie platforms or terraces of alluvium, sometimes up to a height of 80 or 100 feet. These deposits are fragments of the river-gravels and loams laid down when the streams flowed at these elevations, and therefore after the excavation of the valleys. The subsequent action of the running water has been to clear out much of the old alluvial material then accumulated, so as to leave the valleys widened and deepened to their present form. River-action is at the best but slow. To erode the valleys to so great a depth beneath the level of the upper alluvia must have demanded a period of many centuries. There can therefore be no doubt of the high antiquity of these deposits. They have yielded the remains of many mammals, some of them extinct (Elephas antiquus, Hippopotamus amphibius, Rhinoceros megarhinus—Merckii), together with flint-flakes made by man. From the nature and structure of some of the high-level gravels there can be little doubt that they were formed at a time when the rivers, then possibly larger than now, were liable to be frozen and to be obstructed by accumulations of ice. We are thus able to connect the deposits of the Human Period with some of the later phases of the Ice Age in the west of Europe.

Brick-Earths.—In some regions that have not been below the sea for a long period, a variable accumulation of loam has been formed on the surface from the decomposition of the rocks *in situ*, aided by the drifting of fine particles by wind and the gentle washing action of rain and occasionally of streams. Some of these brick-earths or loams are of high antiquity, for they have been buried under fluviatile deposits which must have been laid down when the rivers flowed far above their present levels. They have yielded traces of man associated with bones of extinct mammals.

Cavern Deposits.—Most calcareous districts abound in underground tunnels and caverns which have been dissolved by the passage of water from the surface (p. 623). Where these cavities have communicated with the outer surface, terrestrial animals, including man himself, have made use of them as places of retreat, or have fallen or been washed into them. The floors of some of them are covered with a reddish or brownish loam or cave-earth, resulting either from the insoluble residue of the rock left behind by the water that dissolved out the caverns, or from the deposit of silt carried by the water which in some cases has certainly flowed through them. Very commonly a deposit of stalagmite has formed from the drip of the roof above the cave-earth. Hence any organic remains which may have found their way to these floors have been sealed up and admirably preserved.

Calcareous Tufas.—The deposits of calcareous springs have in various parts of Europe preserved remains of the flora and fauna contemporaneous with the early human inhabitants of the Continent. Among the more celebrated of these deposits are those of Cannstadt in Würtemburg, which have yielded specimens of twenty-nine species of plants, consisting of oaks, poplars, maples, walnuts and other trees still living in the surrounding country, but with the remains of the extinct mammoth; and of La Celle, near Moret, in the valley of the Seine.

Loess.—The physical characters and probable æolian origin of this remarkable deposit having been already mentioned (p. 566), we may now consider it in reference to its place in geological history. In central Europe it covers a wide area. Beginning on the French coast at Sangatte, it sweeps eastward across the north of France and Belgium (Hesbayan loam), filling up the lower depressions of the Ardennes, passing far up the valleys of the Rhine and its tributaries, the Neckar, Main and Lahr; likewise those of the Elbe above Meissen, the Weser, Mulde and Saale, the Upper Oder and the Vistula. Spreading across Upper Silesia, it sweeps eastward over the plains of Poland and southern Russia, where it forms the substratum of the Tschernosem or black-earth. It extends into Bohemia, Moravia, Hungary, Gallicia, Transylvania and Roumania, sweeping far up into the Carpathians, where it reaches heights of 2000 and, it is said, even 4000 or 5000 feet above the sea. It has not been observed on the low Germanic plains south of the Baltic, nor south of central France and the Alpine chain. Though thickest in the valleys (100 feet or more), it is not confined to them, but spreads over the plateaus and rises far up the flanks of the uplands. Near its edge, where it abuts against higher ground, it contains layers or patches of angular débris, but elsewhere it preserves a remarkable uniformity of texture.

The loess is sometimes found resting on gravels containing remains of the mammoth. It may be observed to shade off into more recent alluvial accumulations. It is probably not all of one age, having been deposited during a prolonged period and at many different altitudes. The older portions may not impossibly belong to the later part of the Glacial Period. Though on the whole not rich in fossils, the loess has yielded a peculiar fauna, which singularly confirms Richthofen's view that the deposit was a subaerial one. In the first place, the shells found in it are almost without exception of terrestrial species. Out of 211,968 specimens from the loess of the Rhine, Braun found only one brackish and three fresh-water forms, Linnæa and Planorbis, of which there were only 32 specimens in all. Of the rest, there were 98,502 examples of two species of Succinea, an amphibious genus, and 113,434 specimens belonging to 25 species of Helix, Pupa, Clausilia, Bulimus, Limax and Vitrina—unquestionable terrestrial forms.[68] It is worthy of note that Helices and Succineas abound at present in the steppe-regions of central Asia, and that many of the species of loess mollusks are now living in east Russia, southwest Siberia, and on the prairies of the Little Missouri in North America.[69]

From various parts of the European loess, Dr. Nehring has described a remarkable assemblage of animals, which included a jerboa (Alactaga jaculus), marmots (Spermophilus, several species), Arctomys bobac, tailless hare (Lagomys pusillus), numerous species of Arvicola, Cricetus frumentarius, C. phœus, porcupine (Hystrix hirsutirostris), wild horses and antelopes (Antilope saiga). This fauna, excepting some extinct or extirpated species, is identical with that which now lives in the southeast European and

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[68] Zeitsch. für die gesammt. Naturwiss. xl. p. 45, as quoted by H. H. Howorth, Geol. Mag. 1882, p. 14.

[69] A. Nehring, Geol. Mag, 1883, p. 57; Neues Jahrb. 1889, p. 66.

southwest Siberian steppes.[70] Besides these distinctively steppe animals the loess contains numerous remains of the mammoth and woolly rhinoceros, likewise bones of the musk-sheep, hare, wolf, stoat, etc. It has also yielded flint implements of Palæolithic types. The bones of man himself were claimed many years ago by Ami Boué to have been found in the loess, and his opinion has been in some measure strengthened by more recent observations.

The origin of the loess is a problem which has given rise to much discussion. It has been regarded by some writers as the deposit of a vast series of lakes; by others as the mud left by swollen rivers discharged from melting ice-fields; by others as a sediment washed over the surface of the land by an abundant rainfall. The remarkably unstratified character of the loess as a whole, its uniformity in fineness of grain, the general absence of coarse fragments, except along its margin, where they might be expected, its singular independence of the underlying contour of the ground, and the almost total absence in it of fluviatile or lacustrine shells, seem to prove conclusively that it cannot have been laid down by rivers or lakes. On the other hand, its internal composition, the thoroughly oxidized condition of its ferruginous constituent, its distribution, and the striking character of its inclosed organic remains, point to its having been accumulated in the open air, probably in circumstances similar to those which now prevail in the dry steppe regions of the globe. It appears to mark some arid interval after the height of the Glacial Period had passed away, when, while the climate still remained cold and the Arctic fauna had not entirely retreated

[70] Nehring, op. cit. p. 51, where a reference to this author's numerous memoirs on the subject will be found.

to the north, a series of grassy and dusty steppes swept across the heart of Europe and Asia."[71]

Palæolithic Fauna.—The mammalian remains found in Palæolithic deposits are remarkable for a mixture of forms from warmer and colder latitudes similar to that already noted among the interglacial beds. It has been inferred, indeed, that the Palæolithic gravels are themselves referable to interglacial conditions. On the one hand, we meet with a number of species of warmer

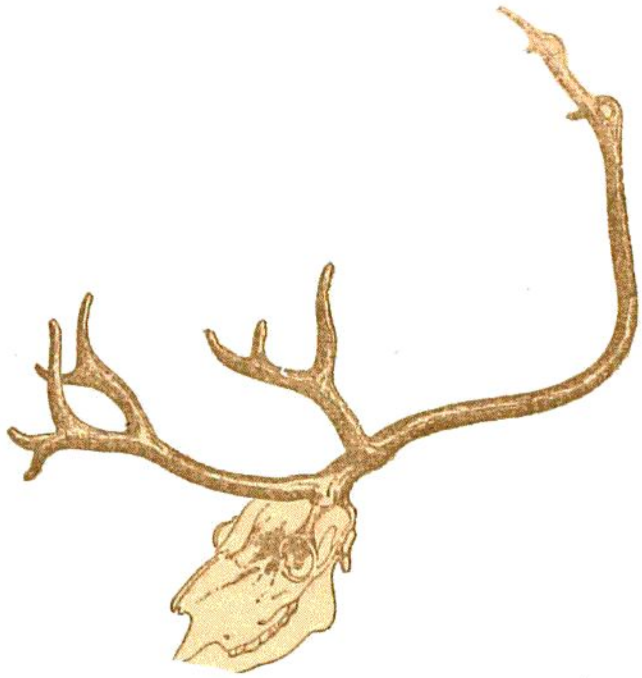

Fig. 460.—Antler of Reindeer ($\frac{1}{12}$) found at Bilney Moor, East Dereham, Norfolk.

habitat, as the lion, hyæna, hippopotamus, lynx, leopard and caffer cat; and, in the loess, the assemblage of forms above referred to as that which still characterizes the warm dry steppes of southeastern Europe and southern Siberia.

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[71] The views propounded by Richthofen for the loess of China and applied by Nehring to that of Europe have been widely adopted by geologists (see, for example, T. F. Jamieson, Geol. Mag. 1890, p. 70). But they have not been universally received, some geologists contending that water in different ways has been concerned in the formation of the loess. See J. Geikie, "Prehistoric Europe," p. 244; Rep. Brit. Assoc. 1889; Address to Geol. Sect.; Wahnschaffe, Zeitsch. Deutsch. Geol. Ges. xxxviii. 1886, p. 533; F. Sacco, Bull. Soc. Geol. France, xvi. 1887; p. 229.

But, on the other hand, a large number of the forms are northern, such as the glutton (Gulo luscus), Arctic fox (Canis lagopus), reindeer (Cervus tarandus), Alpine hare (Lepas variabilis), Norwegian lemming (Myodes torquatus), Arctic lemming (M. lemmus, M. obensis), marmot (Arctomys marmotta), Russian vole (Arvicola ratticeps), musk-sheep (Oribus moschatus), snowy-owl (Stryx nyctea). There is likewise a proportion of now wholly extinct animals, which include the Irish elk (Cervus giganteus or Megaceros hibernicus), Elephas primigenius (mammoth), E. antiquus, Rhinoceros megarhinus, R. antiquitatis (tichorhinus) (woolly rhinoceros), R. leptorhinus and cave-bear (Ursus spelæus). The Palæolithic fauna has been divided into three sections, each supposed to correspond with a distinct period of time: 1st, the Age of Elephus antiquus, with which species are associated Rhinoceros megarhinus (Merckii) and Hippopotamus amphibius (major). 2d, The Age of the mammoth, with the woolly rhinoceros, cave-bear and cave-hyæna. 3d, The Age of the reindeer, when that animal passed in great numbers across central Europe. But, as already stated, such subdivisions are admittedly artificial, and should only be used as provisional aids in the comparison of deposits which cannot be tested by the law of superposition.

That man was contemporary with these various extinct animals is proved by the frequent occurrence of undoubtedly human implements, formed of roughly chipped flints, etc., associated with their bones. Much more rarely, portions of human skeletons have been recovered from the same deposits. The men of the time appear to have camped in rock-shelters and caves, and to have lived by fishing and by hunting the reindeer, bison, horse, mammoth, rhinoceros, cave-bear, and other animals. That they were not without some kind of culture is shown by the vigorous incised

Fig. 461.—Figure of the Mammoth.
Engraved on ivory by Cave-men, La Madelaine, France (Lartet, "Reliquiæ Aquitan").

sketches and carvings which they have left behind on reindeer antlers, mammoth tusks (Fig. 461), and other bones, depicting the animals with which they were daily familiar. Some of these drawings are especially valuable, as they represent forms of life long ago extinct, such as the mammoth and cave-bear. The men who in Palæolithic time inhabited the caves of Europe must have had much similarity, if not actual kinship, to the modern Eskimos.

NEOLITHIC.—The deposits whence the history of Neolithic man is compiled must vary widely in age. Some of them were no doubt contemporaneous with parts of the

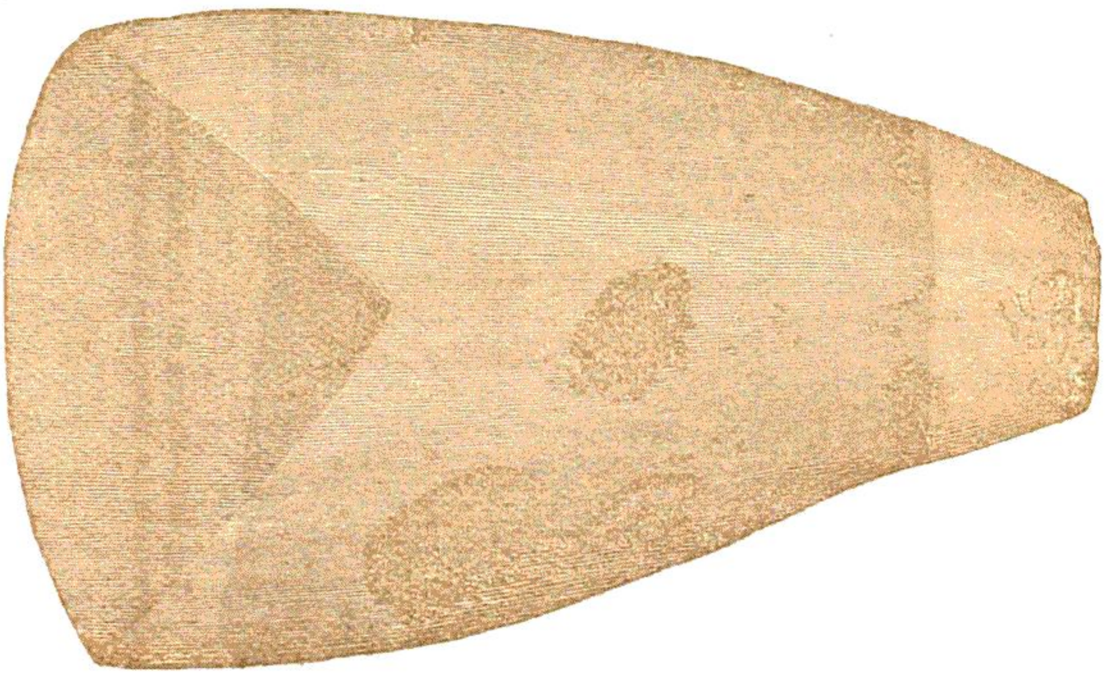

Fig. 462.—Neolithic Stone Implement.

Palæolithic series, others with the Bronze and Iron series. They consist of cavern deposits, alluvial accumulations, peat-mosses, lake-bottoms, pile-dwellings, and shell mounds.

The list of mammals, etc., inhabiting Europe during Neolithic is distinguished from that of Palæolithic time by the absence of the mammoth, woolly rhinoceros, and other extinct types, which appear to have meanwhile died out in Europe. The only form now extinct which appears to have survived into Neolithic time was the Irish elk, which may have continued to live until a comparatively late date.[72] The general assemblage of animals was probably much what it has been during the period of history, but with a few forms which have disappeared from most of Europe either within or shortly before the historic period, such as the reindeer, elk, urus, grizzly bear, brown bear, wolf, wild boar, and beaver. But besides these wild animals there are re-

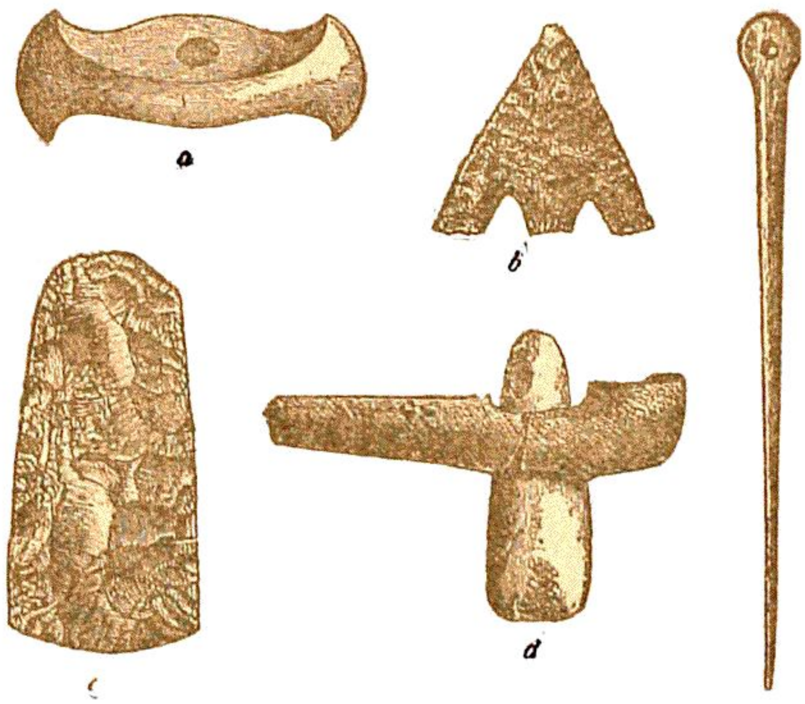

Fig. 463.—Neolithic Implements.

a, Stone axe-head (⅓); *b*, Barbed flint arrow-head (natural size); *c*, Roughly-chipped flint celt (⅓); *d*, Polished celt (⅛), with part of its original wooden hand still attached, found in a peat-bog, Cumberland; *e*, Bone-needle (natural size), Swiss Lake Dwellings; *a*, *b*, *c*, *d*, reduced from Sir J. Evans's "Ancient Stone Implements."

mains of domesticated forms introduced by the race which supplanted the Palæolithic tribes. These are the dog, horse, sheep, goat, shorthorn, and hog. It is noteworthy that these domestic forms were not parts of the indigenous fauna of Europe. They appear at once in the Neolithic deposits, leading to the inference that they were introduced by the human tribes which now migrated, probably from Central Asia, into the European continent. These tribes were like-

[72] Geol. Mag. 1881, p. 354; Nature, xxvi. p. 246.

wise acquainted with agriculture, for several kinds of grain, as well as seeds of fruits, have been found in their lake-dwellings; and the deduction has been drawn from these remains that the plants must have been brought from southern Europe or Asia. The arts of spinning, weaving, and pottery-making were also known to these people. Human skeletons and bones belonging to this age have been met with abundantly in barrows and peat-mosses, and indicate that Neolithic man was of small stature, with a long or oval skull.

The history of the Bronze and Iron Ages in Europe is told in great fulness, but belongs more fittingly to the domain of the archæologist, who claims as his proper field of research the history of man upon the globe. The remains from which the record of these ages is compiled are objects of human manufacture, graves, cairns, sculptured stones, etc., and their relative dates have in most cases to be decided, not upon geological, but upon archæological grounds. When the sequence of human relics can be shown by the order in which they have been successively entombed, the inquiry is strictly geological, and the reasoning is as logical and trustworthy as in the case of any other kind of fossils. Where, on the other hand, as so often happens, the question of antiquity has to be decided solely by relative finish and artistic character of workmanship, it must be left to the experienced antiquary.

§ 2. Local Development

A few examples of the nature of the deposits of the Palæolithic and Neolithic series will suffice to show the general character of the evidence which they supply.

Britain.—Palæolithic deposits are absent from the north of England and from Scotland. They occur in the south of

England, and notably in the valley of the Thames. In that district, a series of brick-earths with intercalated bands of river-gravel, having a united thickness of more than 25 feet, is overlain with a remarkable bed of clay, loam, and gravel ("trail"), three feet or more in thickness, which in its contorted bedding and large angular blocks probably bears witness to its having been accumulated during a time of floating ice. The strata below this presumably glacial deposit have yielded a remarkable number of mammalian bones, among which have been found undoubted human implements of chipped flint. The species include Rhinoceros leptorhinus, R. antiquitatis (tichorhinus), R. megarhinus, Elephas antiquus, E. primigenius, Cervus giganteus (Megaceros hibernicus), Felis leo, Hyæna crocuta, Ursus ferox, U. arctos, Ovibos moschatus, Hippopotamus amphibius (major), and present another example of the mingling of northern with southern, and of extinct with still living forms, as well as of species which have long disappeared from Britain with others still indigenous. Other ancient alluvia, far above the present levels of the rivers, have likewise furnished similar evidence that man continued to be the contemporary in England of the northern rhinoceros and mammoth, the reindeer, grizzly bear, brown bear, Irish elk, hippopotamus, lion, and hyæna.

The caverns in the Devonian, Carboniferous, and Magnesian limestones of England have yielded abundant relics of the same prehistoric fauna, with associated traces of Palæolithic man. In some of these places, the lowest deposit on the floor contains rude flint implements of the same type as those found in the oldest river-gravels, while others of a more finished kind occur in overlying deposits, whence the inference has been drawn that the caverns were first tenanted by a savage race of extreme rudeness, and afterward by men who had made some advance in the arts of life. The association of bones shows that when man had for a time retired, some of these caves became hyæna dens. Hyæna bones in great numbers have been found in them (remains of no fewer than 300 individuals were taken out of the Kirkdale cave), with abundant gnawed bones of other animals on which the hyænas preyed, and quantities of their excrement. Holes in the limestone opening to the surface (sinks, swallow-holes) have likewise become receptacles for the remains of many generations of animals which fell into them by accident, or crawled into them to die. In a fissure of the limestone near Castleton, Derbyshire, from a space measuring only 25 by 18 feet, no fewer than 6800 bones, teeth, or fragments of bone were obtained, chiefly bison and reindeer, with bears, wolves, foxes, and hares.[73]

France.—It was in the valley of the Somme, near Abbeville, that the first observations were made which led the way to the recognition of the high antiquity of man upon the earth. That valley has been eroded out of the Chalk, which rises to a height of from 200 to 300 feet above the modern river. Along its sides, far above the present alluvial plain, are ancient terraces of gravel and loam, formed at a time when the river flowed at higher levels. The lower terrace of gravel, with a covering of flood-loam, ranges from 20 to 40 feet in thickness, while the higher bed is about 30 feet. Since their formation, the Somme has eroded its channel down to its present bottom, and may have also diminished in volume, while the terraces have, during the interval, here and there suffered from denudation. Flint implements have been obtained from both terraces, and in great numbers, associated with bones of mammoth, rhinoceros and other extinct mammals (p. 1718).

The caverns of the Dordogne and other regions of the south of France have yielded abundant and varied evidence of the coexistence of man with the reindeer and other animals either wholly extinct or no longer indigenous. So numerous in particular are the reindeer remains, and so intimate the association of traces of man with them, that the term "Reindeer period" has been proposed for the section of prehistoric time to which these interesting relics belong. The art displayed in the implements found in the caverns appears to indicate a considerable advance on that of the chipped flints of the Somme. Some of the pictures of reindeer and mammoths, incised on bones of these animals, are singularly spirited (Fig. 461).

Germany.—From various caverns, particularly in the dolomite of Franconia (Muggendorf, Gailenreuth) and in the Devonian limestone of Westphalia and Rhineland, remains of extinct mammals have been obtained, sometimes in great numbers, including cave-bear (of which the remains of 800 individuals have been taken out of the Gailenreuth cave), hyæna, lion, rhinoceros, and others. From the cavern of

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[73] Boyd Dawkins, "Early Man in Britain," p. 188. The reindeer has yet not been found in such abundance in the English caverns as in those of Southern France.

Hohlefels in Swabia remains of elephants, rhinoceroses, reindeer, antelopes, horses, cave-bears and other animals have been found, together with interesting proofs of the contemporaneity of man, in the form of rude flint implements, axes of bone, or teeth and bones which he had bored through, or split open for their marrow. At Schussenried in the Swabian Saulgau, not far from the Lake of Constance, beneath a deposit of calcareous tufa inclosing land-shells, there is a peaty bed containing Arctic and Alpine mosses, together with abundant remains of reindeer, also bones of the glutton, Arctic fox, brown fox, polar bear, horse, etc. While this truly Arctic assemblage of animals lived near the foot of the Alps, man also was their contemporary, as is shown by the presence, in the same deposit, of his flint implements, stones that have been blackened by fire, bones of the reindeer and horse that have been broken open for their marrow, needles of wood and bone, and balls of red pigment probably used for painting his body.[74]

Switzerland.—The lakes of Switzerland, as well as those of most other countries in Europe, have yielded in considerable numbers the relics of Neolithic man. Dwellings constructed of piles were built in the water out of arrow-shot from the shore. Partly from destruction by fire, partly from successive reconstruction, the bottom of the water at these places is strewn with a thick accumulation of débris, from which vast numbers of relics of the old population have been recovered, revealing much of their mode of life.[75] Some of these settlements probably date far back beyond the beginning of the historic period. Others belong to the Bronze, and to the Iron Age. But the same site would no doubt be used for many generations, so that successive layers of relics of progressively later age would be deposited on the lake-bottom. It is believed that in some cases the lacustrine dwellings were still used in the first century of our era.

Denmark.—The shell-mounds (Kjökken-mödding), from 3 to 10 feet high, and sometimes 1000 feet long, heaped up on various parts of the Danish coast-line, mark settlements of the Neolithic age. They are made up of refuse, chiefly shells of mussels, cockles, oysters, and periwinkles, mingled with bones of the herring, cod, eel, flounder, great auk,

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74 O. Fraas, Archiv für Anthropologie, Brunswick, 1867.
75 Keller's "Lake Dwellings of Switzerland."

wild duck, goose, wild swan, capercailzie, stag, roe, wild boar, urus, lynx, wolf, wild cat, bear, seal, porpoise, dog, etc., with human tools of stone, bone, horn, or wood, fragments of rude pottery, charcoal, and cinders.

The Danish peat-mosses have likewise furnished relics of the early human races in that region: they are from 20 to 30 feet thick, the lower portion containing remains of Scotch fir (Pinus sylvestris) and Neolithic implements. This tree has never been indigenous in the country within the historic period. A higher layer of the peat contains remains of the common oak with bronze implements, while at the top come the beech-tree and weapons of iron.[76]

North America.—Prehistoric deposits are essentially the same on both sides of the Atlantic. In North America, as in Europe, no very definite lines can be drawn within which they should be confined. They cannot be sharply separated from the Champlain series on the one hand, nor from modern accumulations on the other. Besides the marshes, peat-bogs, and other organic deposits which belong to an early period in the human occupation of America, some of the younger alluvia of the river-valleys and lakes can no doubt claim a high antiquity, though they have not supplied the same copious evidence of early man which gives so much interest to the corresponding European formations. From the peat-bogs of the eastern States, and from the older alluvium of the Missouri River, the remains of the gigantic mastodon have been obtained. There have likewise been found bones of reindeer, elk, bison, beaver, horse (six species), lion and bear; while southward those of extinct sloths (Mylodon, Megatherium) make their appearance. In California, from the deep auriferous gravels remains of mastodon and other extinct animals have been met with, also human bones, stone spear-heads, mortars and other implements. Prof. Whitney has described the famous Calaveras skull as occurring at a depth of 120 feet in undisturbed gravel which is covered with a sheet of basalt.[77] Heaps of shells of edible species, like those of Denmark, occur on the coasts of Nova Scotia, Maine, etc. The large

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[76] See Steenstrup on "Kjökken Möddinger"; Nathorst, Nature, 1889, p. 453.

[77] Mem. Mus. Compar. Zool. Harvard, vi. 1880. But the age of this relic is the subject of dispute. The evidence adduced in support of the great antiquity of man in America, and his contemporaneity with the Mastodon and other extinct animals, is summarized by the Marquis de Nadaillac in his "L'Amérique Prehistorique" (translated by N. d'Anvers, 1885).

mounds of artificial origin in the Mississippi valley have excited much attention. The early archæology of these regions is full of interest.

In South America, the loams of the Pampas have furnished abundant remains of horses, tapirs, lamas, mastodons, wolves, panthers, with gigantic extinct sloths and armadilloes (Megatherium, Glyptodon).[78]

Australasia.—No line can be drawn in this region between accumulations of the present time and those which have been called Pleistocene. The modern alluvia have been formed under similar conditions to those under which the older alluvia were laid down, though possibly with some differences of climate. In New South Wales, ossiferous caverns contain bones of the extinct marsupial animals mentioned on p. 1676, mingled with those of some of the species which are still living in the same places. In one locality in the same colony, in sinking a well, teeth of crocodiles were found with bones of Diprotodon, etc. No human remains have yet been found associated with those of the extinct animals; but a stone hatchet was taken out of alluvium at a depth of 14 feet.[79]

In New Zealand, the most interesting feature in the younger geological accumulations is the presence of the bones of the large bird Dinornis, which has become extinct since the Maoris peopled the islands. The evidences of the human occupation of the country are confined to the surface-soil, shelter-caves, and sand-dunes.[80]

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[78] See Florentino Ameghino, "La Antiquedad del Hombre en el Plata," where a good account of the Pampas country will be found.

[79] C. S. Wilkinson, "Notes on Geology of New South Wales, 1882," p. 59.

[80] Hector, "Handbook of New Zealand," p. 25.

BOOK VII

PHYSIOGRAPHICAL GEOLOGY

AN investigation of the geological history of a country involves two distinct lines of inquiry. We may first consider the nature and arrangement of the rocks that underlie the surface, with a view to ascertain from them the successive changes in physical geography and in plant and animal life which they chronicle. But besides the story of the rocks, we may try to trace that of the surface itself—the origin and vicissitudes of the mountains and plains, valleys and ravines, peaks, passes, and lake-basins which have been formed out of the rocks. The two inquiries traced backward merge into each other; but they become more and more distinct as they are pursued toward later times. It is obvious, for instance, that a mass of marine limestone which rises into groups of hills, trenched by river-gorges and traversed by valleys, presents two sharply contrasted pictures to the mind. Looked at from the side of its origin, the rock brings before us a sea-bottom over which the relics of generations of a luxuriant marine calcareous fauna accumulated. We may be able to trace every bed, to mark with precision its organic contents, and to establish the zoological succession of which these superimposed sea-bottoms are the records. But we may be quite unable to explain how such sea-formed limestone came to stand as it now does, here towering into hills and there sinking into valleys. The rocks and their contents form one subject of study; the history of their present scenery forms another.

The branch of geological inquiry which deals with the evolution of the existing contours of the dry land is termed Physiographical Geology. To be able to pursue it profitably, some acquaintance with all the other branches of the science is requisite. Hence its consideration has been reserved for this final division of the present work; but only a rapid summary can be attempted here.

At the outset one or two fundamental facts may be stated. It is evident that the materials of the greater part of the dry land have been laid down upon the floor of the sea. That they now not only rise above the sea-level, but sweep upward into the crests of lofty mountains, can only be explained by displacement. Thus the land owes its existence mainly to upheaval of the terrestrial crust, though it may have been to some extent increased and diminished by other causes (ante, pp. 479, 494). The same sedimentary materials which demonstrate the fact of displacement, afford an indication of its nature and amount. Having been laid down in wide sheets on the sea-bottom, they must have been originally, on the whole, level or at least only gently inclined. Any serious departure from this original position must therefore be the effect of displacement, so that stratification forms a kind of datum-line from which such effects may be measured.

Further, it is not less apparent that sedimentary rocks, besides having suffered from disturbance of the crust, have undergone extensive denudation. Even in tracts where they remain horizontal, they have been carved into wide valleys. Their detached outliers stand out upon the plains as memorials of what has been removed. Where, on the other hand, they have been thrown into inclined positions, the truncation of their strata at the surface points to the same universal degradation. Here, again, the lines of stratification may be used as datum-lines to measure approximately the amount of rock which has been worn away.

While, therefore, it is true that, taken as a whole, the dry land of the globe owes its existence to upheaval, it is not less true that its present contours are due largely to erosion. These two antagonistic forms of geological energy have been at work from the earliest times, and the existing land with all its varied scenery is the result of their combined operation. Each has had its own characteristic task. Upheaval has, as it were, raised the rough block of marble, but erosion has carved that block into the graceful statue.

The very rocks of which the land is built up bear witness to this intimate co-operation of hypogene and epigene agency. The younger stratified formations have been to a large extent derived from the waste of the older, the same mineral ingredients being used over and over again. This could not have happened but for repeated uplifts, whereby the sedimentary accumulations of the sea-floor were brought within reach of the denuding agents. Moreover, the internal characters of these formations point unmistakably to deposition in comparatively shallow water. Their abundant intercalations of fine and coarse materials, their constant variety of mineral composition, their sun-cracks, ripple-marks, rain-pittings, and worm-tracks, their numerous unconformabilities and traces of terrestrial surfaces, together with the prevalent facies of their organic contents, combine to demonstrate that the main mass of the sedimentary rocks of the earth's crust was accumulated close to land, and that no trace of really abysmal deposits is to be found among them. From these considerations we are led up to the conclusion that the present continental areas must have been terrestrial regions of the earth's surface from a remote geological period. Subject to repeated oscillations, so that one tract after another has disappeared and reappeared from beneath the sea, the continents, though constantly varying in shape and size, have yet, I believe, maintained their individuality. We may infer, likewise, that the existing ocean-basins have probably always been the great depressions of the earth's surface.[1]

Geologists are now generally agreed that it is mainly to the effects of the secular contraction of our planet that the deformations and dislocations of the terrestrial crust are to be traced. The cool outer shell has sunk down upon the more rapidly contracting hot nucleus, and the enormous lateral compression thereby produced has thrown the crust into undulations, and even into the most complicated corrugations.[2] Hence, in the places where the crust has yielded to the pressure, it must have been thickened, being folded or pushed over itself, or being perhaps thrown into double bulges, one portion of which rises into the air, while the

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[1] See J. D. Dana, Amer. Journ. Sci. (2) ii. 1846, p. 352; "Geology" in "Wilkes' Exploring Expedition," 1849; Amer. Journ. Sci. (2) xxii. 1856; "Manual of Geology," 1863, 2d edit. 1874, 3d edit. 1880; Darwin, "Origin of Species," 1st edit. p. 343; L. Agassiz, Bull. Mus. Comp. Zool. 1869; vol. i. No. 13; J. D. Whitney, Mem. Mus. Comp. Zool. Harvard, vii. No. 2, p. 210. See also Proc. Roy. Geograph. Soc. new ser. i. 1879, p. 422. The contrary view that land and sea have continually changed places over the surface of the globe was held by Lyell, and is still maintained by some geologists. For a statement of geological evidence in favor of this interchange of terrestrial and marine areas the student may consult the memoirs of the late Prof. Neumayr, cited on p. 1477.

[2] The Rev. O. Fisher in his "Physics of the Earth's Crust," maintains that the secular contraction of a solid globe through mere cooling will not account for the observed phenomena. See ante, p. 105.

corresponding portion descends into the interior. Mr. Fisher believes that this downward bulging of the lighter materials of the crust into a heavier substratum underneath the great mountain-uplifts of the surface is indicated by the observed diminution in the normal rate of augmentation of earth-temperature beneath mountains,[3] and by the lessened deflection of the plumb-line in the same regions.

The close connection between upheaval and denudation on the one hand and depression and deposition on the other has often been remarked, and striking examples of it have been gathered from all parts of the world. It is a familiar fact that along the central and highest parts of a mountain-chain, the oldest strata have been laid bare after the removal of an enormous thickness of later deposits. The same region still remains high ground, even after prolonged denudation. Again, in areas where thick accumulations of sedimentary material have taken place, there has always been contemporaneous subsidence. So close and constant is this relationship as to have suggested the belief that denudation by unloading the crust allows it to rise, while deposition by loading it causes it to sink (ante, pp. 500, 501).[4]

It is evident that in the results of terrestrial contraction on the surface of the whole planet, subsidence must always have been in excess of upheaval—that, in fact, upheaval has only occurred locally over areas where portions of the crust have been ridged up by the enormous tangential thrust of

[3] The rate observed in the Mont Cenis and Mont St. Gothard tunnels was about 1° Fahr. for every 100 feet, or only about half the usual rate.

[4] This belief has been forcibly urged by American geologists who have studied the structure of the Western Territories. See especially the geological Reports of Mr. Clarence King, Major Powell and Captain Dutton; also Mr. T. Mellard Reade's "Origin of Mountain-Ranges," and Phil. Mag. June, 1891.

adjacent subsiding regions. The tracts which have thus been, as it were, squeezed out under the strain of contraction have been weaker parts of the crust, and have usually been made use of again and again during geological time. They form the terrestrial regions of the earth's surface. Thus, the continents as we now find them are the result of many successive uplifts, corresponding probably to concomitant depressions of the ocean bed. In the long process of contraction, the earth has not contracted uniformly and equably. There have been, no doubt, vast periods during which no appreciable or only excessively gradual movements took place; but there have probably also been intervals when the accumulated strain on the crust found relief in more or less rapid collapse.

The general result of such terrestrial disturbances has been to throw the crust of the earth into wave-like undulations. In some cases, a wide area has been upheaved as a broad low arch, with little disturbance of the original level stratification of its component rocks. More usually, the undulations have been impressed as more sensible deformations of the crust, varying in magnitude from the gentlest appreciable roll up to mountainous crests of complicated plication, inversion, and fracture. As a rule, the undulations have been linear, but their direction has varied from time to time, having been determined at right angles, or approximately so, to the trend of the lateral pressure that produced them. As the crust has thickened, and in consequence of the structure imparted to it by successive subsidences, certain tracts even of the land have acquired more or less immobility, and have served as buttresses against which surrounding areas have been pressed and dislocated by subsequent movements. Suess has pointed out various areas of the earth's surface, named by him "Horsts," which seem to have served this purpose in the general rupture and subsidence of the terrestrial crust.

Considered with reference to their mode of production, the leading contours of a land-surface may be grouped as follows: 1. Those which are due more or less directly to disturbance of the crust. 2. Those which have been formed by volcanic action. 3. Those which are the result of denudation.[5]

1. Terrestrial Features due more or less directly to Disturbance of the Crust.—In some regions, large areas of stratified rocks have been raised up with so little trace of curvature that they seem to the eye to extend in horizontal sheets as wide plains or table-lands. If, however, these areas can be followed sufficiently far, the flat strata are eventually found to curve down slowly or rapidly, or to be truncated by dislocations. In an elevated region of this kind, the general level of the ground corresponds, on the whole, with the planes of stratification of the rocks. Vast regions of Western America, where Cretaceous and later strata extend in nearly horizontal sheets for thousands of square miles at heights of 4000 feet or more above the sea, may be taken as illustrations of this structure.

As a rule, curvature is more or less distinctly traceable in every region of uplifted rocks. Various types of flexure may be noticed, of which the following are some of the more important:

(*a*) *Monoclinal Flexures* (p. 896).—These occur most markedly in broad plateau-regions and on the flanks of large broad uplifts, as in the table-lands of Utah, Wyo-

[5] For a sketch of the physiography of the British Isles see Nature, xxix. 1884, pp. 325, 347, 396, 419, 442.

ming, etc. They are frequently replaced by faults, of which indeed they may be regarded as an incipient stage (p. 916).

(*b*) *Symmetrical Flexures*, where the strata are inclined on the two sides of the axis at the same or nearly the same angle, may be low gentle undulations, or may increase in steepness till they become short sharp curves. Admirable illustrations of different degrees of inclination may be seen in the ranges of the Jura[6] (Fig. 464) and the Appalachians (Fig. 246), where the influence of this structure of the rocks on external scenery may be instructively studied. In many instances, each anticline forms a long ridge, and each syncline runs as a corresponding and parallel valley. It will

Fig. 464.—Symmetrical Flexures of Swiss Jura (the ridges coinciding with anticlines and the valleys with synclines).

usually be observed, however, that the surface of the ground does not strictly conform, for more than a short distance, to the surface of any one bed; but that, on the contrary, it passes across the edges of successive beds, as in Fig. 464. This relation—so striking a proof of the extent to which the surface of the land has suffered from denudation—may be followed through successive phases until the original superficial contours are exactly reversed, the ridges running along the lines of syncline and the valleys along the lines of anticline (Figs. 244, 245). Among the older rocks of the earth's crust which have been exposed alike to curvature and prolonged denudation, this reversal may be considered to be

[6] On the geology of the Jura see C. Clerc. "Le Jura," Paris, 1888; G. Boyer, "Remarques sur l'Orographie des Monts Jura," Besançon, 1888; and the older work of Thurmann, "Esquisses Orographiques de la Chaine du Jura," 1852.

the rule rather than the exception. The tension of curvature may occasionally have produced an actual rupture of the crest of an anticline along which the denuding agents would effectively work.

The *Uinta type* is a variety of this structure seen to great perfection in the Uinta Mountains of Wyoming and Utah. It consists of a broad flattened flexure from which the strata descend steeply or vertically into the low grounds, where they quickly resume their horizontality. In the Uinta Mountains, the flat arch has a length of upward of 150 and a breadth of about 50 miles, and exposes a vast deeply trenched plateau with an average height of 10,000 to 11,000

Fig. 465.—Uinta Type of Flexure.
a, Palæozoic rocks; *b*, Mesozoic; *c*, Tertiary; *f*, fault.

feet above the sea, and 5000 to 6000 feet above the plains on either side. This elevated region consists of nearly level ancient Palæozoic rocks, which plunge below the Secondary and Tertiary deposits that have been tilted by the uplift (Fig. 465). Powell believes that a depth of not less than three and a half miles of strata has been removed by denudation from the top of the arch.[7] In some places, the line of maximum flexure at the side of the uplift has given way, and the resulting fault has at one point a vertical displacement estimated by him at 20,000 feet.

Another variety of more complex structure may be termed the *Park type*, from its singularly clear develop-

[7] "Geology of Uinta Mountains," p. 201. There is in this work a suggestive discussion on types of mountain structure. See also Clarence King's "Report on Geology of 40th Parallel," vol. i.

ment in the Park region of Colorado. In this type, an axis of ancient crystalline rocks—granites, gneisses, etc.—has been as it were pushed through the flexure, or the younger strata have been bent sharply over it, so that after vast denudation their truncated ends stand up vertically along the flanks of the uplifted nucleus of older rocks (Fig. 466).

There may be only one dominant flexure, as in the case of the Uinta Mountains, the long axial line of which is truncated at the ends by lines of flexure nearly at right angles to it. More usually, numerous folds run approximately parallel to each other, as in the Jura and Appalachian chains. Not infrequently, some of them die out or coalesce. Their axes are seldom perfectly straight lines.

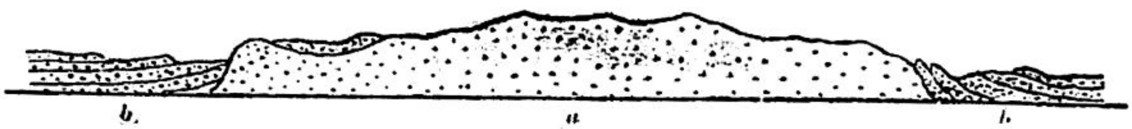

Fig. 466.—Park Type of Flexure.
a, Crystalline rocks; *b*, Mesozoic rocks.

(*c*) *Unsymmetrical Flexures*, where one side of the fold is much steeper than the other, but where they are still inclined in opposite directions, occur in tracts of considerable disturbance. The steep sides look away from the area of maximum movement, and are more sharply inclined as they approach it, until the flexures become inverted. Instructive examples of this structure are presented by the Jura Mountains and the Appalachian chain. In these tracts, it is observable that in proportion as the flexures increase in angle of inclination, they become narrower and closer together; while, on the other hand, as they diminish into symmetrical forms, they become broader, flatter, and wider apart, till they disappear (Figs. 246, 467).

(*d*) *Reversed Flexures*, where the strata have been folded over in such a way that on both sides of the axis of curvature they dip in the same direction, occur chiefly in districts of the most intense plication, such as a great mountain-chain like the Alps. The inclination, as before, is for the most part toward the region of maximum disturbance, and the flexures are often so rapid that after denudation of the tops of the arches the strata are isoclinal, or appear to be dipping all in the same direction (p. 900). A gradation can be traced through the three last-named kinds of flexure. The inverted or reversed type is found where the crumpling of the crust has been greatest. Away from the area of maximum disturbance, the folds pass into the unsymmetrical type,

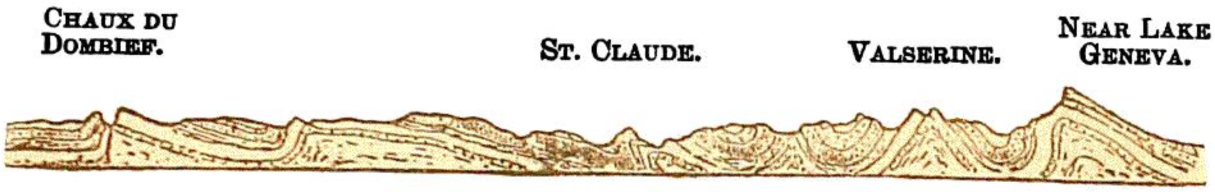

Fig. 467.—Section across Western Part of Jura Mountains.
(After P. Choffat, $\frac{1}{250000}$, A. Heim, "Mechanism. Gebirgsb." pl. xiii.).

then with gradually lessening slopes into the symmetrical, finally widening out and flattening into the plains. If we bisect the flexures in a section of such a plicated region we find that the lines of bisection or "axis-planes" are vertical in the symmetrical folds, and gradually incline toward the more plicated ground at lessening angles.[8]

Fractures not infrequently occur along the axes of unsymmetrical and inverted flexures, the strata having snapped under the great tension, and one side (in the case of inverted flexures, usually the upper side), having been pushed over the other, sometimes with a vertical displacement of several thousand feet, or a horizontal thrust of several miles. It is

[8] H. D. Rogers, Trans. Roy. Soc. Edin. xxi. p. 434.

along or parallel to the axes of plication, and therefore coincident with the general strike, that the great faults of a plicated region occur. As a rule, dislocations are more easily traced among low grounds than among the mountains. One of the most remarkable and important faults in Europe, for example, is that which bounds the southern edge of the Belgian coal-field (p. 1383). It can be traced across Belgium, has been detected in the Boulonnais, and may not improbably run beneath the Secondary and Tertiary rocks of the south of England. The extraordinary thrust-planes of the northwest of Scotland (pp. 1037, 1179) are notable examples of gigantic horizontal displacement. It is a remarkable fact that faults which have a vertical throw of many thousands of feet may produce little or no effect upon the surface. The great Belgian fault is crossed by the valleys of the Meuse and other northerly flowing streams, yet so indistinctly is it marked in the Meuse valley that no one would suspect its existence from any peculiarity in the general form of the ground, and even an experienced geologist, until he had learned the structure of the district, would scarcely detect any fault at all. The Scottish thrust-planes are eroded like ordinary junction-planes between strata, and produce no more effect than these do on the topography (see Figs. 311, 334).

In some regions of intense disturbance, such as the Alps, the rocks have been plicated rather than fractured. The folds have been so compressed that their opposite limbs often lie parallel to each other at a high inclination. In other regions, such as the northwest of Scotland, where the gigantic pressure has encountered the resistance of a "horst" or solid buttress of immovable material, the rocks have been ruptured by innumerable thrust-planes and faults, and have been driven over each other in a kind of imbricated structure (p. 1036).

(*e*) *Alpine Type of Mountain-Structure.*[9]—It is along a great mountain-chain like the Alps that the most colossal crumplings of the terrestrial crust are to be seen. In approaching such a chain, one or more minor ridges may be observed running on the whole parallel with it, as the heights of the Jura flank the north side of the Alps, and the sub-Himalayan hills follow the southern base of the Himalayas. On the outer side of these ridges, the strata may be flat or gently inclined. At first they undulate in broad gentle folds; but traced toward the mountains these folds become sharper and closer, their shorter sides fronting the plains, their longer slopes dipping in the opposite direction. This inward dip is often traceable along the flanks of the main chain of mountains, younger rocks seeming to underlie others of much older date. Along the north front of the Alps, for instance, the red molasse is overlain by Eocene and older formations. The inversions increase in magnitude till they reach such colossal dimensions as the double fold of the Glärnisch, where Triassic, Jurassic, and Cretaceous rocks have been thrown over above the Eocene flysch and nummulitic limestone (p. 898). In such vast crumplings it may happen that portions of older strata are caught in the folds of later formations, and some care may be required to

[9] For recent information on the internal structure of the Alpine chain see especially the maps, sections and explanatory memoirs by Renevier, Heim, A. Baltzer, E. Favre, K. J. Kaufmann, C. Moesch, H. Schardt, A. Gutzwiller and others in the Beiträge zur Geol. Karte der Schweiz; also Fritz Frech, "Die Karnischen Alpen," Abhand. Naturf. Ges. Halle, xviii. (Heft i.) 1892; Zaccagna on the Graian Alps, Boll. Com. Geol. Ital. ser. iii. vol. iii. 1892, p. 175; consult also Heim's "Mechanismus der Gebirgsbildung"; Suess, "Antlitz der Erde" and "Entstehung der Alpen"; A. Favre, "Recherches Geol. dans les parties de la Savoie du Piémont et de la Suisse voisines du Mont Blanc," 1867, and "Description Geol. Canton Genève," 1880.

discriminate the inclosure from the rocks of which it appears to form an integral and original part. Some of the recorded examples of fossils of an older zone occurring by themselves in a much younger group of plicated rocks may be thus accounted for.

The inward dip and consequent inversion traceable toward the centre of a mountain-chain lead up to the fan-shaped structure (p. 901), where the oldest rocks of a series occupy the centre and overlie younger masses which plunge steeply under them. Classical examples of this structure occur in the Alps (Mont Blanc, Fig. 250, St. Gothard), where crystalline rocks such as granite, gneiss, and schist, the oldest masses of the chain, have been ridged up into the central and highest peaks. Along these tracts, denudation has been of course enormous, for the appearance of the granitic rocks at the surface has been brought about, not necessarily by actual extrusion into the air, but more probably by prolonged erosion, which in these higher regions, where many forms of subaerial waste reach their most vigorous phase, has removed the vast overarching cover of younger rocks under which the crystalline nucleus doubtless lay buried.

With the crumpling and fracture of rocks in mountain-making, the hot springs must be connected which so frequently arise along the flanks of a mountain-chain. A further relation is to be traced between these movements and the opening of volcanic vents either along the chain or parallel to it, as in the Andes and other prominent ridges of the crust. Elevation, by diminishing the pressure on the parts beneath the upraised tracts, may permit them to assume a liquid condition and to rise within reach of the surface, when, driven upward by the expansion of superheated vapors, they are ejected in the form of lava or ashes. Mr. Fisher supposes that the lower half of the double bulge of the crust in a mountain, by being depressed into a lower region, may be melted off, giving rise to siliceous lavas which may rise before the deeper basaltic magma begins to be erupted.

A mountain-chain may be the result of one movement, but probably in most cases is due to a long succession of such movements. Formed on a line of weakness in the crust, it has again and again given relief from the strain of compression by undergoing fresh crumpling and upheaval. The successive stages of uplift are usually not difficult to trace. The chief guide is supplied by uncon-

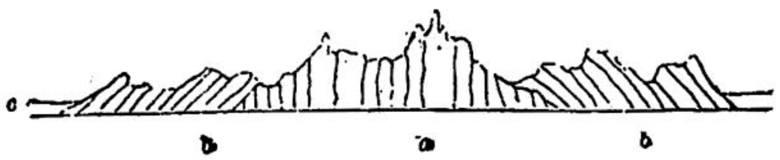

Fig. 468.—Section showing two periods of Upheaval.

formability (p. 1063). Let us suppose, for example, that a mountain range (Fig. 468) consists of upraised Lower Silurian rocks (*a*), upon the upturned and denuded edges of which the Carboniferous Limestone (*b b*) lies transgressively. The original upheaval of that range must have taken place between the Lower Silurian and the Carboniferous Limestone periods. If, in following the range along its course, we found the Carboniferous Limestone also highly inclined and covered unconformably by the Upper Coal-measures (*c c*), we should know that a second uplift of that portion of the ground had taken place between the time of the limestone and that of the Upper Coal-measures. Moreover, as the Coal-measures were laid down at or below the sea-level, a third uplift has subsequently occurred whereby they were raised into dry land. By this simple and obvious kind of evidence, the relative ages of different mountain-chains may be compared. In most great mountain-chains, however, the rocks have been so intensely crumpled, and even inverted, that much labor may be required before their true relations can be determined.

The Alps offer an instructive example of a great mountain system formed by repeated movements during a long succession of geological periods. The central portions of the chain consist of gneiss, schists, granite and other crystalline rocks, partly referable to the pre-Cambrian series, but some of which are metamorphosed Palæozoic, Secondary, and even older Tertiary deposits (p. 1032). It would appear that the first outlines of the Alps were traced out even in pre-Cambrian times, and that after submergence, and the deposit of Palæozoic formations along their flanks, if not over most of their site, they were re-elevated into land. From the relations of the Mesozoic rocks to each other we may infer that several renewed uplifts, after successive denudations, took place before the beginning of Tertiary times; but without any general and extensive plication. A large part of the range was certainly submerged during the Eocene period under the waters of that wide sea which spread across the centre of the Old World, and in which the nummulitic limestone and flysch were deposited. But after that period the grand upheaval took place to which the present magnitude of the mountains is chiefly due. The older Tertiary rocks, previously horizontal under the sea, were raised up into mountain-ridges more than 11,000 feet above the sea-level, and, together with the older formations of the chain, were crumpled, dislocated and inverted. So intense was the compression and shearing to which clays and sands were subjected, that they were converted into hard crystalline rocks. It is strange to reflect that the enduring materials out of which so many of the mountains, cliffs and pinnacles of the Alps have been formed are of no higher geological antiquity than the London Clay and other soft Eocene deposits of the south of England and the north of France and Belgium. At a later stage of Tertiary time, renewed disturbance led to the destruction of the lakes in which the molasse had accumulated, and their thick sediments were thrust up into large broken mountain masses, such as the Rigi, Rossberg and other prominent heights along the northern flank of the Alps. Since that great movement, no paroxysm seems to have affected the Alpine region except the earthquakes, which from time to time show the process of mountain-making to be only suspended or still slowly in progress.

The gradual evolution of a continent during a long succession of geological periods has been admirably worked out for Europe by Suess and Neumayr, and for North America by Dana, Dawson, Dutton, Gilbert, Hayden, King, Newberry, Powell and others. The general character of the structure of the American continent is extreme simplicity, as compared with that of the Old World. In the Rocky Mountain region, for example, while the Palæozoic formations lie unconformably upon pre-Cambrian gneiss, there is, according to King, a regular conformable sequence from the lowest Palæozoic to the Jurassic rocks. During the enormous interval of time represented by these massive formations, what is now the axis of the continent remained undisturbed save by a gentle and protracted subsidence. In the great depression thus produced, all the Palæozoic and a great part of the Mesozoic rocks were accumulated. At the close of the Jurassic period, the first great upheavals took place. Two lofty ranges of mountains—the Sierra Nevada (now with summits more than 14,000 feet high) and the Wahsatch—400 miles apart, were pushed up from the great subsiding area. These movements were followed by a prolonged subsidence, during which Cretaceous sediments accumulated over the Rocky Mountain region to a depth of 9000 feet or more. Then came another vast uplift, whereby the Cretaceous sediments were elevated into the crests of the mountains, and a parallel coast-range was formed fronting the Pacific. Intense metamorphism of the Cretaceous rocks is stated to have taken place. The Rocky Mountains, with the elevated table-land from which they rise, now permanently raised above the sea, were gradually elevated to their present height. Vast lakes existed among them, in which, as in the Tertiary basins of the Alps, enormous masses of sediment accumulated. The slopes of the land were clothed with an abundant vegetation, in which we may trace the ancestors of many of the living trees of North America. One of the most striking features in the later phases of this history was the outpouring of great floods of trachyte, basalt and other lavas from many points and fissures over a vast space of the Rocky Mountains and the tracts lying to the west. In the Snake River region alone the basalts have a depth of 700 to 1000 feet, over an area 300 miles in breadth.

These examples show that the elevation of mountains, like that of continents, has been occasional, and perhaps sometimes paroxysmal. Long intervals elapsed, when a slow subsidence took place, but at last a point was reached when the descending crust, unable any longer to withstand the accumulated lateral pressure, was forced to find relief by rising into mountain ridges. With this effort the elevatory movements ceased. They were followed either by a stationary period, or more usually by a renewal of the gradual depression, until eventually relief was again obtained by upheaval, sometimes along new lines, but often on those which had previously been used. The intricate crumpling and gigantic inversions of a great mountain-chain naturally suggest that the movements which caused these disturbances of the strata were sudden and violent. And this inference may often, if not generally, be correct. It is not so easy, however, to demonstrate that a disturbance was rapid as to prove that it must have been slow. That some uplifts resulting in the rise of important mountain ranges have been almost insensibly brought about, can be shown from the operation of rivers in the regions affected. Thus the rise of the Uinta Mountains has been so quiet that the Green River, which flowed across the site of the range, has not been deflected, but has actually been able to deepen its cañon as fast as the mountains have been pushed upward.[10] The Pliocene accumulations along the southern flanks of the Himalayas show that the rivers still run in the same lines as they occupied before the last gigantic upheaval of the chain (p. 1672).[11] A similar conclusion has been drawn from the river-valleys in the Elburz Mountains, Persia.[12]

2. Terrestrial Features due to Volcanic Action.—The two types of volcanic eruptions described

[10] Powell's "Geology of the Uinta Mountains," in the Reports of U. S. Geographical and Geological Survey, Rocky Mountain Region, 1876. The same conclusion is drawn by Gilbert from the structure of the Wahsatch Mountains. See his admirable essay on "Land Sculpture," in his "Geology of the Henry Mountains," published in the same series of Reports, 1877.

[11] Medlicott and Blanford, "Geology of India," p. 570.

[12] E. Tietze, Jahrb. Geol. Reichsanst. xxviii. 1878, p. 581.

in Book III. Part I. give rise to two very distinct types of scenery. The ordinary volcanic vent leads to the piling up of a conical mass of erupted materials round the orifice. In its simplest form, the cone is of small size, and has been formed by the discharges from a single funnel, like many of the tuff and cinder-cones of Auvergne, the Eifel and the Bay of Naples. Every degree of divergence from this simplicity may be traced, however, till we reach a colossal mountain like Etna, wherein, though the conical form is still retained, eruptions have proceeded from so many lateral vents that the main cone is loaded with minor volcanic hills. Denudation as well as explosion comes into play; deep and wide valleys, worn down the slopes, serve as channels for successive floods of lava or of water and volcanic mud. On the other hand, the type of fissure-eruption in which the lava, instead of issuing from a central vent, has flowed out from minor vents along the lines of many parallel or connected fissures, leads to the formation of wide lava-plains composed of successive level sheets of lava. By subsequent denudation, these plains are trenched by valleys, and, along their margin, are cut into escarpments with isolated blocks or outliers. Thus they become great plateaus or table-lands like those of northwest Europe, the Deccan and Abyssinia (pp. 439, 982).

The forms assumed by volcanic masses of older Tertiary and still earlier geological date are in the main due not to their original contours, but to denudation. The rocks, being commonly harder than those among which they lie, stand out prominently, and often, in course of time and in virtue of their mode of weathering, assume a conical form, which, however, has obviously no relation to that of the original volcano. Eminences formed after the type of the Henry Mountains (p. 949) owe their dome-shape to the subterranean effusion of erupted lava, but the superficial irregularities of contour in the domes must be ascribed to denudation.

3. **Terrestrial Features due to Denudation.**—The general results of denudation have been discussed in Book III. Part II. Sect. ii. Every portion of the land, as soon as it rises above the sea-level, is attacked by denuding agents. Hence the older a terrestrial surface, the more may it be expected to show the results of the operation of these agents. We have already seen how comparatively rapid are the processes of subaerial waste (p. 780). It is accordingly evident that the present contours of the land cannot be expected to reveal any trace whatever of the early terrestrial surfaces of the globe. The most recent mountain-chains and volcanoes may, indeed, retain more or less markedly their original superficial outlines; but these must be more and more effaced in proportion to their geological antiquity.

The fundamental law in the erosion of the terrestrial surfaces is that harder rocks resist decay more, while softer rocks resist it less. The former consequently are left projecting, while the latter are worn down. The terms "hard" and "soft" are used here in the sense of being less easily and more easily abraded, though every rock suffers in some measure. If, therefore, a perfectly level surface, composed of rocks exceedingly unequal in power of resistance, were to be raised above the sea, and to be exposed to the action of weathering, it would eventually be carved into a system of ridges and valleys. The eminences would be mainly determined by the position of the harder rocks, the depressions by the site of the softer. Every region of Mesozoic or Palæozoic rocks affords ample illustration of this result. The hills and prominent ridges are found to be where they are, not so much because they have there been more upheaved, but because they are composed of more durable materials, or because, by the disposition of the original drainage-lines, they have been less eroded than the valleys.

In this marvellous process of land-sculpture, we have to consider, on the one hand, the agents and combinations of agents which are at work, and on the other, the varying powers of resistance arising from declivity, composition, and structure of the materials on which these agents act. The forces or conditions required in denudation—air, aridity, rain, springs, frost, rivers, glaciers, the sea, plant and animal life—have been described in Book III. Part II. Every country and climate must obviously have its own combination of erosive activities. The decay of the surface in Egypt or Arizona arises from a different group of forces from that which can be seen in the west of Europe or in New England.

In tracing the sculpture of the land, we are soon led to perceive the powerful influence of the angle of slope of the ground upon the rate of erosion. This rate decreases as the angle lessens, till on level plains it reaches its minimum. Other things being equal, a steep mountain ridge will be more deeply eroded than one of the same elevation which rises gradually out of the plains. Hence the declivity of the ground, at its first elevation into land, must have had an important bearing upon the subsequent erosion of the slopes. It is important to observe that the depressions into which the first rain gathered on the surface of the newly upraised land would, in most cases, become the permanent lines of drainage. They would be continually deepened as the water coursed in them, so that, unless where subterranean disturbance came into play, or where the channels were obstructed by landslips, volcanic ejections, or otherwise, the streams would be unable to quit the channels they had once chosen. The permanence of drainage-lines is one of the most remarkable features in the geological history of the continents. The main valleys of a country are usually among the oldest parts of its topography. As they are widened and deepened, the ground between them may be left projecting into high ridges and even into prominent isolated hills.

A chief element in the progress of land-sculpture is geological structure—the character, arrangement and composition of the rocks, and the manner in which each variety yields to the attacks of the denuding agents. Besides the general relations of the so-called hard rocks to resulting prominences, and of soft rocks to depressions, the broader geotectonic characters have had a dominant influence upon the evolution of terrestrial contours. As illustrations of this influence, reference may be made to the marked difference between the scenery of districts composed of stratified sedimentary rocks, and that of areas of massive eruptive rocks, such as granite. In the former case, bedding and joints furnish divisional lines, the guiding influence of which upon the external forms of the mountains is everywhere traceable. In the case of eruptive masses, the rock is split open along joints only, which mainly determine the shapes of crest, cliff, and corry.

Bedding produces a distinct type of scenery which can be traced from the sides of a mere brook up into tall sea-cliffs or into lofty mountain-groups. Moreover, much of the ultimate character of the scenery depends upon whether the strata have been left undisturbed; for the position of the bedding, whether flat, inclined, vertical, or contorted,

Fig. 469.—Outlines of Mountains formed of nearly horizontal Stratified Rocks. Rocky Mountains. (Hayden's "Report of Survey of Western Territories," 1874.)

largely determines the nature of the surface. The most characteristic scenery formed by stratified rocks is undoubtedly where the bedding is horizontal, or nearly so, and the strata are massive. A mountain constructed of such materials appears as a colossal pyramid, the level bars of stratification looking like gigantic courses of masonry. Joints and faults traversing the bedding allow it to be cleft into blocks and deep chasms that heighten the resemblance to ruined architecture. Probably the most marvellous illustrations of these results are to be found in the Western Territories of the United States. The vast table-lands of the river Colorado, in particular, offer a singularly impressive picture of the effects of mere subaerial erosion on undisturbed and nearly level strata (see Frontispiece). Systems of stream-courses and valleys, river gorges, unexampled elsewhere in the world for depth and length, vast winding lines of escarpment, like ranges of sea-cliffs, terraced slopes rising from plateau to plateau, huge buttresses and solitary stacks standing like islands out of the plains, great mountain masses towering into picturesque peaks and pinnacles, cleft by innumerable gullies, yet everywhere marked by the parallel bars of the horizontal strata out of which they have been carved—these are the orderly symmetrical characteristics of a country where the scenery is due entirely to the action of subaerial agents and the varying resistance of level or little disturbed stratified rocks.

On the other hand, where stratified rocks have been subjected to plications and fractures, their characteristic features may be gradually almost lost among those of the crystalline masses which under these circumstances are so often found to have been forced through them (see Fig. 252). The Alps may be cited as a well-known example of this kind of scenery. The whole geological aspect of these mountains is suggestive of former intense commotion. Yet on every side are to be seen proofs of the most enormous denudation.

Twisted and crumpled, the solid sheets of limestone may be seen as it were to writhe from the base to the summit of a mountain, yet they present everywhere their truncated ends

Fig. 470.—Outlines of a Mountain formed of Massive Rocks. Rocky Mountains. (Hayden's "Report of Survey of Western Territories," 1874.)

to the air, and from these ends it is easy to see that a vast amount of material has been worn away. Apart altogether from what may have been the shape of the ground immediately after the upheaval of the chain, there is evidence on every side of gigantic denudation. The subaerial forces that have been at work upon the Alpine surface ever since it first appeared have dug out the valleys, sometimes acting in original depressions, sometimes eroding hollows down the slopes. Moreover they have planed down the flexures, excavated lake-basins, scarped the mountain sides into cliff and *cirque*, notched and furrowed the ridges, splintered the crests into chasm and *aiguille*, until no part of the original surface now remains in sight. And thus the Alps remain a marvellous monument of stupendous earth-throes, followed by prolonged and gigantic denudation.

In massive rocks, the structure-lines are those of joints alone, and according to the direction of the intersecting joints the trend and shape of the ridges are determined. The importance of rock-joints, not only in details of scenery, but even in some of the main features of the mountain outlines of massive rocks, is hardly at first credible. It is along these divisional lines that the rain has filtered, and the springs have risen, and the frost wedges have been driven. On the bare scarps of a high mountain, where the inner structure of the mass is laid open, the system of joints is seen to have determined the lines of crest, the vertical walls of cliff and precipice, the forms of buttress and recess, the position of cleft and chasm, the outline of spire and pinnacle. On the lower slopes, even under the tapestry of verdure which nature delights to hang where she can over her naked rocks, we may detect the same pervading influence of the joints upon the forms assumed by ravines and crags. Each kind of eruptive rock has its own system of joints, and these in large measure determine its characteristic type of scenery.

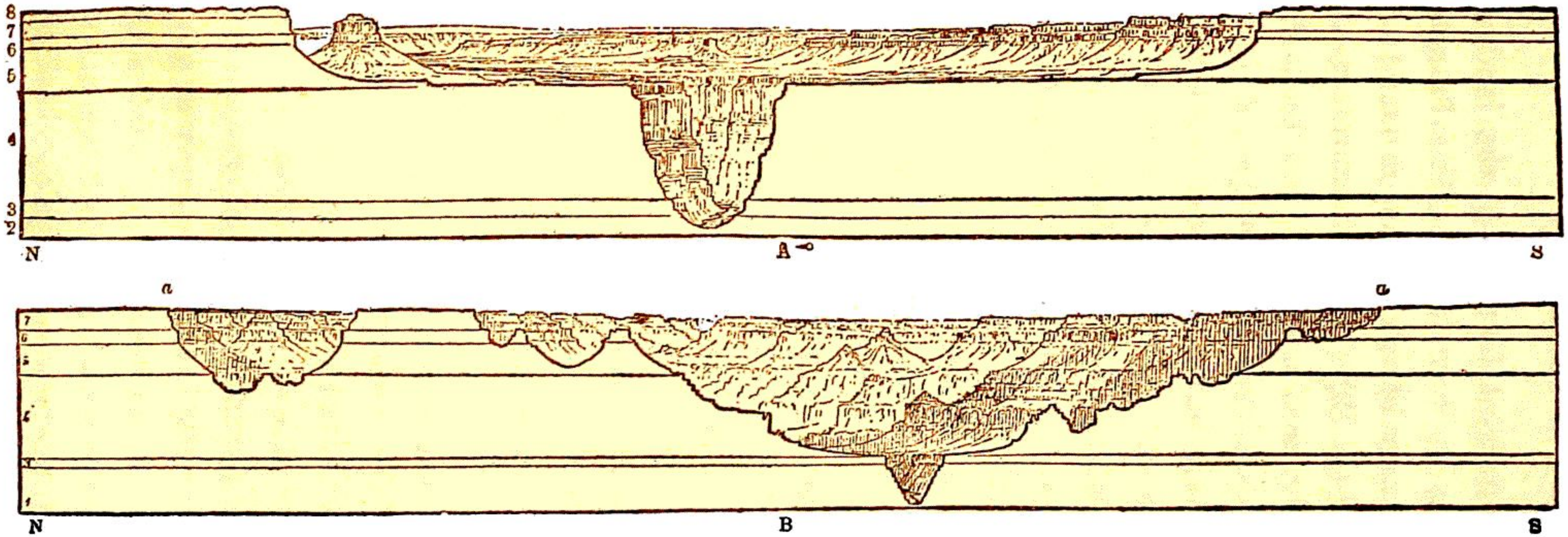

Fig. 471.—Sections across the Grand Canon of the Colorado.[13]

(Vertical and Horizontal Scale the same.)

A. Section in the Kanab division. B. Section in the Kaibab division. *a* to *a* seven miles.

		Thickness in A.	Thickness in B.
Permo-Carboniferous	8. Bellerophon beds	250 ft.	— ft.
Coal-measures	7. Cherty Limestone	350 "	500 "
	6. Cross-bedded Sandstone	200 "	400 "
	5. Aubrey red Shales, etc.	1200 "	900 "
Lower Carboniferous	4. Red Wall	2500 "	2200 "
	3. Tonto group	300 "	200 "
	2. Silurian rocks (covered unconformably by overlying rocks)	300 "	— "
	1. Granite, Schist, etc., eroded before deposition of Carboniferous rocks	— "	1200 "

[13] Drawn on a true scale for this work by Mr. Holmes, whose diagrams of the geological structure and scenery of Western America are probably at once the most artistic and instructive sketches with which geological literature has yet been enriched. To his graphic pencil also the author owes the Frontispiece to this volume.

A few of the more important features of the land may be briefly noticed here in their relation to this branch of geology. In the physiography of any region, **mountains** are the dominant features (p. 78). A true mountain-chain consists of rocks that have been crumpled and pushed up in the manner already described. But ranges of **hills**, almost mountainous in their bulk, may be formed by the gradual erosion of valleys out of a mass of original high ground. In this way, some ancient table-lands have been so channelled that they now consist of massive rugged hills, either isolated or connected along the flanks. Eminences detached by erosion from the masses of rock whereof they once formed a part have been termed *hills of circumdenudation*. Their isolation may either be due to the action of streams working round them, apart altogether from geological structure, or to their more resisting constitution, which has enabled them to remain prominent during the general degradation of the whole surface.

Table-lands (p. 83) may sometimes arise from the abrasion of hard rocks and the production of a level plain by the action of the sea, or rather of that action combined with the previous degradation of the land by subaerial waste (p. 789). Such a form of surface may be termed a *table-land of erosion*. Notable examples are to be seen in the extensive "fjelds" or elevated plateaus of Scandinavia, many of which, rising above the snow-line, form the gathering-ground of glaciers that descend almost to the sea-level. Fragments of a similar table-land may be recognized among the Grampian Mountains of Scotland. But most of the great table-lands of the globe seem to be platforms of little disturbed strata, either sedimentary or volcanic, which have been upraised bodily to a considerable elevation. These may be termed *table-lands of deposit.* But, whatsoever its mode of origin, the plateau undergoes a gradual transformation under continued denudation. No sooner are the rocks raised above the sea, than they are attacked by running water, and begin to be hollowed out into systems of valleys. As the valleys sink, the platforms between them grow into narrower and more definite ridges, until eventually the level table-land is converted into a complicated network of hills and valleys, wherein, nevertheless, the key to the whole arrangement is furnished by a knowledge of the disposition and effects of the flow of water. The examples of this process brought to light in Colorado, Wyoming, Nevada and the other Western Territories, by Newberry, King, Hayden, Powell, Gilbert, Dutton and other explorers, are among the most striking monuments of geological operations in the world. The erosion of the ancient table-lands of Scandinavia and Scotland, and their conversion into systems of hilly ridges and valleys, convey less impressive but still instructive evidence of the efficacy of subaerial waste.

Watersheds are of course at first determined by the form of the earliest terrestrial surface. But they are less permanent than the watercourses that diverge from them. Where a watershed lies symmetrically along the centre of a country or continent, with an equal declivity and rainfall on either side, and an identity of geological structure, it will be permanent, because the erosion on each slope proceeds at the same rate. But such a combination of circumstances can happen rarely, save on a small and local scale. As a rule, watersheds lie on one side of the centre of a country or continent, and the declivity is steeper on the side nearest the sea. Hence, apart from any influence from difference of geological structure, the tendency of erosion, by wearing the steep slope more than the gentle one, is to carry the watershed backward nearer to the true centre of the region, especially at the heads of valleys. Of course this is an extremely slow process; but it must be admitted to be one of real efficacy in the vast periods during which denudation has continued. Excellent illustrations of its progress, as well as of many other features of land-sculpture, may often be instructively studied on clay-banks exposed to the influence of rain.[14]

The crests of mountains are watersheds of the sharpest type, where erosion has worked backward upon a steep slope on either side. Their forms are mainly dependent upon structure, and especially upon systems of joints. It will often be observed that the general trend of a crest coincides with that of one set of joints, and that the bastions, recesses and peaks have been determined by the intersection of another set. If the rock is uniform in structure, and the declivity equal in angle on either side, a crest may retain its position; but as one side is usually considerably steeper than the other, the crest advances at the expense of the top of the gentler declivity. But, under any circumstances, it is continually lowered in level, for it may be regarded as part of a mountain where the rate of subaerial denudation reaches a maximum. An ordinary cliff is attacked only in front, but a crest has two fronts, and is further splintered along its summit. Nowhere can the guiding influence of geological structure be more conspicu-

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[14] See on this subject Mr. Gilbert's suggestive remarks in the Essay on "Land Sculpture" already cited. See also Nature, xxix. 1884, p. 325, where the history of the watersheds of the British Isles is traced.

ously seen than in the array of spires, buttresses, gullies and other striking outlines which a mountain crest assumes.

Valleys are mainly due to erosion, guided either by original depressions of the ground, or by geological structure, or by both.[15] Their contours depend partly on the structure and composition of the rocks, and partly on the relative potency of the different denuding agents. Where the influence of air, rain, frost and general subaerial weathering has been slight, and the streams, supplied from distant sources, have had sufficient declivity, deep, narrow, precipitous ravines or gorges have been excavated. The cañons of the Colorado are a magnificent example of this result (Fig. 471). Where, on the other hand, ordinary atmospheric action has been more rapid, the sides of the river channels have been attacked, and open sloping glens and valleys have been hollowed out. A gorge or defile is usually due to the action of a waterfall, which, beginning with some abrupt declivity or precipice in the course of the river when it first commenced to flow, or caused by some hard rock crossing the channel, has eaten its way backward, as already explained (p. 657).

A pass is a portion of a watershed which has been cut down by the erosion of two valleys, the heads of which adjoin on opposite sides of a ridge. Each valley is cut backward until the intervening ridge is demolished. Most passes no doubt lie in original but subsequently deepened

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[15] The student should read the suggestive essay by the late J. B. Jukes (Quart. Journ. Geol. Soc. xviii. 1862, p. 378, which was the first attempt to work out the history of the excavation of a valley system in reference to the geological history of the ground. See also Penck, Neues Jahrb. 1890, p. 165; E. Tietze, Jahrb. Geol. Reichsanst. xxxviii. 1888, p. 633.

depressions between adjoining mountains. The continued degradation of a crest may obviously give rise to a pass.

Lakes may have been formed in several ways. 1. By subterranean movements, as, for example, in mountain-making and in volcanic explosions. The subsidence of the central part of a mountain system might conceivably depress the heads of the valleys below the level of portions further from the sources of the stream. Or the elevation of the lower parts of the valleys might cause an accumulation of water in their upper parts. Or each lake-basin might be supposed to be due to a special subsidence. But these hollows, unless continually deepened by subsequent movements of a similar nature, would be filled up by the sediment continually washed into them from the adjoining slopes. The numerous lakes in such a mountain system as the Alps cannot be due merely to subterranean movements, unless we suppose the upheaval of the mountains to have been quite recent, or that subsidence must take place continuously or periodically below each independent basin. But there is evidence that the Alpine uplift is not of such recent date, while the idea of perpetuating lakes by continued local subsidence would demand, not in the Alps merely, but all over the northern hemisphere, where lakes are so abundant, an amount of subterranean movement of which, if it really existed, there would assuredly be plenty of other evidence. 2. By irregularities in the deposition of superficial accumulations prior to the elevation of the land, or, in the northern parts of Europe and America, during the disappearance of the ice-sheet. The numerous tarns and lakes inclosed within mounds and ridges of drift-clay and gravel are examples. 3. By the accumulation of a barrier across the channel of a stream and the consequent ponding back of the water. This may be done, for instance, by a landslip, by a lava-stream, by the advance of a glacier across a valley, or by the throwing up of a bank by the sea across the mouth of a river. 4. By erosion. Water keeping stones in gyration can dig out pot-holes in the bed of a river, or on the sea-shore. Unequal subaerial weathering may cause rocks to rot much more deeply in some places than in others, so that, on the removal of the rotted material, the surface of the solid rock might be full of depressions. But the only known agent capable of excavating such hollows as might form rock-basin lakes is glacier-ice (p. 719). It is a remarkable fact, of which the significance may now be seen, that the innumerable lake-basins of the northern hemisphere lie on surfaces of intensely ice-worn rock. The striæ can be seen on the smoothed rock-surfaces slipping into the water on all sides. These striæ were produced by ice moving over the rock. If the ice could, as the striæ prove, descend into the rock-basins and mount up the further side, smoothing and striating the rock as it went, it could, to a certain depth at least, erode basins.

In the general subaerial denudation of a country, innumerable minor features are worked out as the structure of the rocks controls the operations of the eroding agents. Thus, among undisturbed or gently inclined strata, a hard bed resting upon others of a softer kind is apt to form along its outcrop a line of cliff or e s c a r p m e n t. Though a long range of such cliffs resembles a coast that has been worn by the sea, it may be entirely due to mere atmospheric waste. Again, the more resisting portions of a rock may be seen projecting as crags or knolls. An igneous mass will stand out as a bold hill from amid the more decomposable strata through which it has risen. These features, often so marked on the lower grounds, attain their most conspicuous development among the higher and barer parts of the mountains, where subaerial disintegration is most rapid. The torrents tear out deep gullies from the sides of the declivities. Corries or cirques, if not originally scooped out by converging streamlets (their mode of formation is a somewhat difficult problem), are at least enlarged by this action, and their naked precipices are kept bare and steep by the wedging off of successive slices of rock along lines of joint. Harder bands of rock project as massive ribs down the slopes, shoot up into prominent peaks, or, with the combined influence of joints and faults, give to the summits the notched saw-like outlines they so often present.

The materials worn from the surface of the higher are spread out over the lower grounds. We have already traced how streams at once begin to drop their freight of sediment when, by the lessening of their declivity, their carrying power is diminished (p. 665). The great plains of the earth's surface are due to this deposit of gravel, sand and loam. They are thus monuments at once of the destructive and reproductive processes which have been in progress unceasingly since the first land rose above the sea and the first shower of rain fell. Every pebble and particle of the soil of the plains, once a portion of the distant mountains, has travelled slowly and fitfully downward. Again and again have these materials been shifted, ever moving seaward. For centuries, perhaps, they have taken their share in the fertility of the plains and have ministered to the nurture of flower and tree, of the bird of the air, the beast of the field, and of man himself. But their destiny is still the great ocean. In that bourne alone can they find undisturbed repose, and there, slowly accumulating in massive beds, they will remain until, in the course of ages, renewed upheaval shall raise them into future land, and thereby enable them once more to pass through a similar cycle of change.

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