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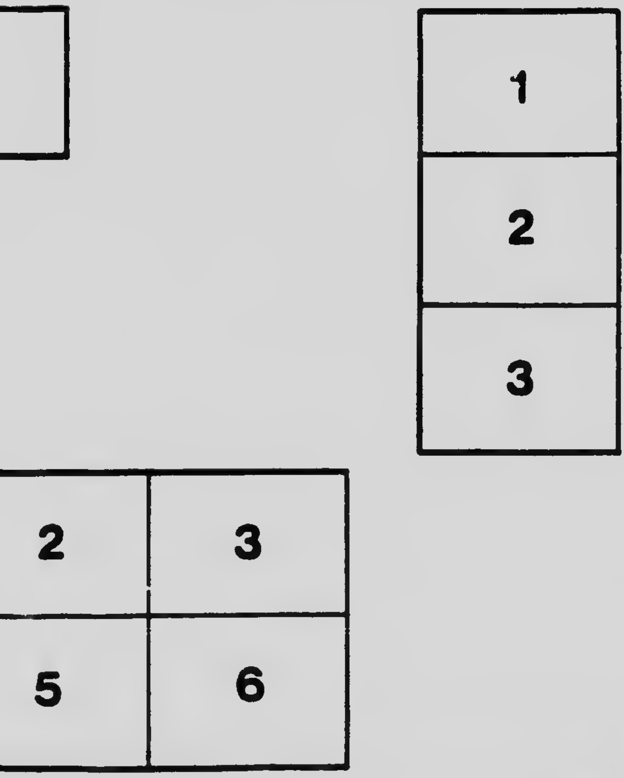
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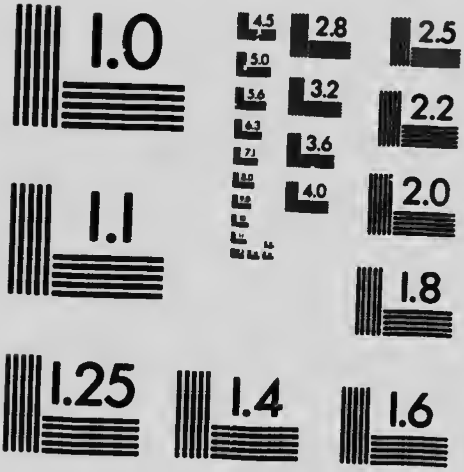

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THE GROWTH OF EUROPE

By GRENVILLE A. J. COLE

LONDON
WILLIAMS & NORGATE

HENRY HOLT & Co., NEW YORK
CANADA: WM. BRIGGS, TORONTO
INDIA: R. & T. WASHBOURNE, LTD.
1914

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NEW YORK
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THE GROWTH OF EUROPE

BY

GRENVILLE A. J. COLE

PROFESSOR OF GEOLOGY IN THE ROYAL COLLEGE OF SCIENCE FOR IRELAND; AUTHOR OF "ROCKS AND THEIR ORIGINS," "OPEN-AIR STUDIES IN GEOLOGY," "THE CHANGEFUL EARTH," ETC.

LONDON
WILLIAMS AND NORGATE

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7. Modern Geography. By M. I. Newbigin, D.Sc. (*Illustrated*)

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78. The Ocean. By Sir John Murray, K.C.B. (*Colour and other plates*)

82. Prehistoric Britain. By Dr. R. Munro. (*Illustrated*)

First Printed April 1914.

PREFACE

THIS book attempts to show how the surface-features of Europe are the result of remarkable and comparatively recent changes, in which the wearing away of the rocks and the deposition of continental waste have played a far smaller part than the actual upheaval and depression of the land. These surface-features are intimately related to the movements of man across them; and it is hoped that the traveller in familiar parts of Europe, whether a lover of scenery or a student of historical foundations, will find something of interest in these pages. The descriptive chapters may recall landscapes that have been keenly enjoyed from mountain footpaths, or from the long white highways on which imperial towns are strung like gems. The changeful sway of the earth itself, the dominance now of a great sea, and now of an uprising and unstable mountain-chain, cannot fail to prove impressive, when we read even the latest story of European lands.

The book is thus an essay both in geography and geology. My indebtedness to E. Suess's *Antlitz der Erde* and to other monumental works will be easily apparent from the bibliography. In the references, the first number, Roman or Arabic, is that used in the bibliography; a number in thick type indicates a volume; any other number indicates a page. Simple maps and diagrams have been inserted, to supplement the information that can be found in any detailed atlas. Where travel by road is suggested, the old-fashioned horse or bicycle need not be rejected as a medium. I cannot wish the reader any better fortune than my own—the memory of happy journeys and the comradeship of European friends.

GRENVILLE A. J. COLE.

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THE GROWTH OF EUROPE

CHAPTER I

SOME GEOLOGICAL CONSIDERATIONS

J. W. Gregory, in his work on *The Making of the Earth*, which is published in the Home University Library, has indicated the complex nature of the present continents. Systems of stratified rocks containing marine fossils occur so freely across areas that are now dry land as to suggest that every part of the primitive solid crust of the globe has been at some time or other under water. The more we learn of the detailed structure of the oldest rocks accessible to us, the more we are assured that they accumulated as sediments worn from still older masses. The great cycle of denudation that was clearly pointed out by James Hutton at the close of the eighteenth century has recurred so often in all regions of the globe that nothing now remains of the earliest continental land. Some parts of our continents are far older than others; but even these are young in comparison with the complete history of the region in which they form the earliest record.

Hutton in 1785, in his *Theory of the Earth*, realised that atmospheric forces acting on upstanding land must inevitably reduce that land to what we now call its "base-level," the level of the surrounding sea. The softer portions are worn away more quickly; but this allows more scope to the destructive forces in attacking the hard blocks that remain. Ultimately these blocks must also disappear. The material loosened from their flanks becomes spread out by gravitation across the lower lands. Chemical and mechanical agents break up this material into finer and yet finer particles, and these become carried away by water or by wind into the great cemetery of the sea.

This dead level condition would be the last phase in the history of a continent, were there no readjusting forces in the earth. Before, however, the general plain has been produced by denudation—while, in fact, it remains in the condition that W. M. Davis has called a *peneplain*—elevation by vertical upthrust or crumpling of the rocks sets in. The worn-down continent becomes rejuvenated; the sluggish streams meandering on its surface carve out new features, and approach the sea in rapids and in leaping falls. Broad divides, and smaller watersheds between adjacent valleys, again arise, and here and there some local folding may produce a mountain-chain.

Yet in some cases denudation may be accompanied by subsidence, and the former continent may disappear. A "transgression" of the sea then lays down marine strata across it, and the land fauna and flora migrate to some other portion of the globe. Hutton pictured the simultaneous decay of continents, and the rise of new ones, with somewhat catastrophic swiftness, to form a reconstituted world. This cycle of events, however, at any one time has reached various phases in various regions. One part of the crust, like the Russian platform, appears to have remained fairly stable for a long time; another part undergoes, within the limits of a single geological period, marked and recurrent subsidences and elevations in regard to the general level of the sea.

The continents as we now know them are of modern origin in geological time. When we try to trace back their features, we soon reach an epoch when their outlines and their surface-forms were so different from those that we recognise to-day that we can no longer refer to the land masses by their present names. The history of the European area is concerned with very ancient matters; but the growth of what we call Europe is comparatively recent. The growth of a continent includes the results of the decay of its higher lands, since the material that is swept down accumulates in basins, and forms new margins to the sea upon the coast-plains. The coming of man has set no period to the cycle of continental change, and many of the features along which we plant our towns to-day have arisen since our ancestors settled in European lands.

The relations of land and water on a continental margin depend on whether the land is rising or sinking, or on whether the sea-level is being raised or lowered in regard to the land. A general shallowing of the ocean-basins (1, 188) will spread the water across the coast-lands; a deepening, accompanied by a contraction of their width, will leave fresh areas of rock exposed. The volume of oceanic water may, moreover, change in geological time, and the solidification of a large part of it as ice during a glacial epoch may produce results equivalent to an elevation of the land. An enormous body of water may thus be transferred by evaporation to colder regions, where it falls upon the land as snow. Until milder conditions set in, no appreciable return can be made in the form of rivers to the sea. Another cause of variation in the level of the sea is merely local, but is worthy of consideration; continental land lying above the general sea-level attracts the water away from the surface that it would otherwise assume. The wearing down of the high masses of a continent allows, on the other hand, the water to slip back from the shores. The water so released rises on the sides of oceanic islands, and a removal of the attraction of the continents would swamp some of these islands altogether.

There can be no doubt, however, that the great cause of variation in the sea-level against a coast lies in the upward or downward movement of the land. Such movements have repeatedly been traced in connexion with large earthquakes. The most striking example known to us occurred at Yakutat Bay in Alaska in 1899, where the beach was raised from seven to as much as forty-seven feet. Barnacles and mussels were still clinging to the uplifted rocks when the area was investigated by R. S. Tarr and L. Martin in 1906. The *raised beaches* along many coasts, by which we may gauge such movements, are commonly warped. The top of the beach, which represents the former level of the sea during a resting stage, now lies at various heights above that level.

There has clearly been a deformation of the land-surface. Subsidences below sea-level have also occurred in recent times; but in judging of them care must be exercised, lest the mere outward slipping of delta-material be confused with movement of the firmer crust. The sea, moreover, may wear away the coast and encroach upon roads and cultivated lands; but in time such action is necessarily checked by the formation of a shelf of erosion between the high and the low water line, on the inner margin of which the waves become practically powerless. Continuous marine erosion is possible only when accompanied by a subsidence of the land.

E. Reyer has pointed out that the subsidence of land-masses is often gravitational towards the ocean-basins, and that the rocks slip outwards, becoming folded and contorted in the process. Hence there is much in common between movements of the crust and those of delta-slime. Such sliding implies the previous elevation of a mass of land, and most authors have recognised that there are tangential stresses in the crust which lead to the crumpling of rocks along certain lines. In some cases, huge blocks are thrust up above the general level, bounded by faults, that is, by surfaces along which differential movement has taken place.

E. Suess urges that the appearance of elevation may be due to subsidence of the surrounding country, which leaves such masses standing as relics of a former highland; and some mountains, formed of blocks, may owe their pre-eminence to the falling in of neighbouring lands. On the other hand, it is usually impossible to say why mountains have arisen in the form of a folded chain along a particular line on the earth's surface.

An Austrian geologist of wide outlook, O. Ampferer, believes that the movements which give rise to elongated chains originate in the plastic substratum below the outer crust, and that the surface is dragged and wrinkled by flow in this unstable layer, the physical conditions of which are only dimly known to us.

Continents must be regarded as large results of mountain-building processes. From a broad point of view, they are domes or *anticlinal* masses, while the ocean-basins are the corresponding downfolds or *synclinal* depressions. The breadth of the oceans, however, as compared with their depth, necessitates a convexity of their floors on the spheroidal surface of the earth. Hence they are, until we reach their rims, like basins turned upside down. The only way by which we can adequately realise the smallness of movements of the crust in comparison with the diameter of the earth is to attempt to draw a section of a continent or an ocean on the same vertical and horizontal scale. None the less, in view of their influence on the movements of man, a being only six feet high, across the surface, earth-wrinkles, and the features carved by denudation from them, assume immense historical importance.

The time through which we can trace the physical changes in a given area is divided into geological *periods*, the limits of which are based upon the types of animal life which successively arose, flourished, and passed away. In the earlier days of scientific observation, it seemed easier to draw the line between two periods than it does at the present time. William Smith, the English land-surveyor, who taught geologists in 1816 that strata could be "identified by organised fossils," believed that the faunas which he studied as characteristic of this or that horizon were creations special to the formations in which they were entombed. What are called *unconformities* (fig. 1), indicating uplifts of the sea-floor, and consequently gaps in the stratified series of marine deposits, are frequent in the English systems of rocks. Such apparent breaks allow of a considerable change of fauna in two successive beds, and they helped to emphasise the soundness of

William Smith's discovery. Observations in other lands, as time went on, naturally tended to fill up these gaps in our information, and something like a continuous sequence of stratified rocks is now known to us from the

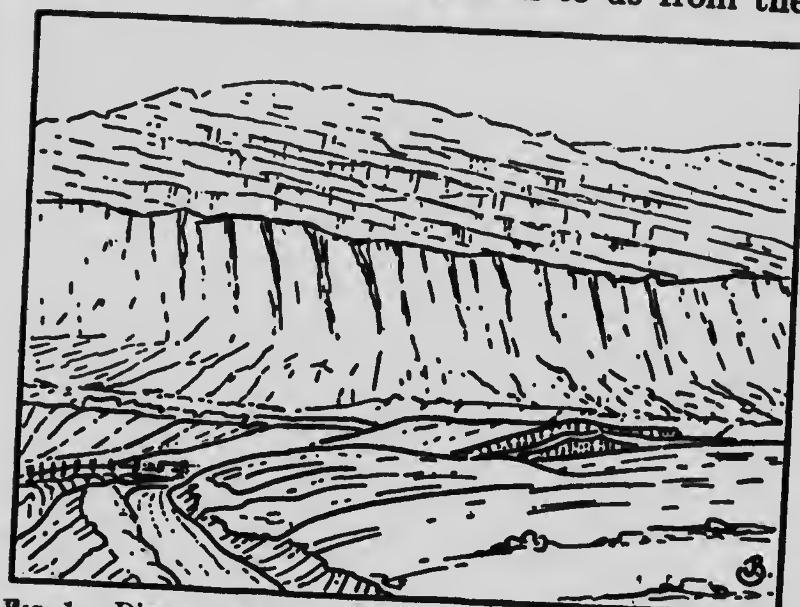

Fig. 1.—Diagrammatic sketch of unconformity between pre-Cambrian and Silurian strata, as seen on a hillside above the Joyce's River, Co. Galway.

limited European area. The line between one period and another must be based on the prevalence above or below it of some selected organic species or group of species; and the geologist and palæontologist become nowadays more concerned with discovering zoological links than in emphasising faunistic differences.

The geological periods are thus much like human dynasties, which serve us well in setting up a time-scale for past affairs. Although at each line of division continuous history cries *Le roi est mort, vive le roi*, yet association with the name of the reigning monarch sets a convenient date on a potsherd, a coat of mail, or a cathedral. By prevalent fossil remains, geological periods are subdivided into *epochs*, and special subdivisions of epochs are spoken of as *ages*.

A *system* of rocks comprises those formed during a geological period; a *series* of rocks represents an epoch of time. A *stage* corresponds to an age. Where further subdivision is required, *zones* are established, characterised by the name of some particular fossil species.

Systems have been brought together into great *groups*, each of which corresponds to a time-division styled an *era*. The terms used for the groups and eras imply the remoteness or nearness of the prevalent life-forms that characterise them as compared with those of the present-day. The earliest era is styled *Archæan*, suggesting vast antiquity; the next is *Palæozoic*, "ancient life"; then *Mesozoic*, "middle life"; and *Cainozoic*, "modern life." The names of the systems and periods have grown up somewhat casually, and suggest districts where the strata have been studied in detail, or the occurrence of some type of rock within the system, or, in the case of those included in the latest era, the relative resemblance of the molluscan species to those of modern seas.

In estimating the comparative lengths of geological periods, only a very rough approximation can be reached. If we assume that, in dealing with great thicknesses of strata, these thicknesses are proportionate to the times occupied in their deposition, we may form a time-scale based on European systems, or on those of the whole world. It is obvious that the world-wide basis, adopted by W. J. Sollas (2), will give the most logical result. Such a scale for Europe, selecting only the marine strata, indicates approximately equal duration for the Cainozoic and Mesozoic eras, and a Palæozoic era about three times as long as either. The Cainozoic era would thus represent about a fifth of the time that has elapsed since the appearance of the first well recorded fauna on the globe. Sollas's world-wide computation shows a Mesozoic era somewhat longer than the Cainozoic, and a Palæozoic era about equal to these two together. The Cainozoic era would thus fill about one quarter of the time since the opening of the Palæozoic era.

The following table shows the names adopted for the systems and periods in the present book. It must be understood that we already know in addition a very thick mass of stratified deposits, representing no doubt several systems, of pre-Cambrian or Archæan age.

Quartary Group and Era.	RECENT AND POST-PLIOCENE.
Cainozoic or Tertiary Group and Era.	PLIOCENE. MIOCENE. OLIGOCENE. EOCENE.
Mesozoic Group and Era.	CRETACEOUS. JURASSIC. TRIASSIC.
Palæozoic Group and Era.	PERMIAN. CARBONIFEROUS. DEVONIAN. GOTLANDIAN. ORDOVICIAN. CAMBRIAN.
Archæan Group and Era.	Systems classified in certain localities only.

NOTE.—The term SILURIAN for a long time covered both the Ordovician and Gotlandian systems above mentioned, and is generally used in this sense on the continent of Europe. It has been restricted in recent years, owing to the Cambridge usage, to the old "Upper Silurian" or Gotlandian only, and its retention seems likely to be a cause of considerable confusion.

CHAPTER II

THE GREAT CRETACEOUS SEA

RECONSTRUCTIONS of the outlines of sea and land in various geological periods, in the forms of "palæogeographic maps," are always unlike anything seen upon maps of the world at the present day. We can justly infer coast-lines from the nature of the deposits, or even from the characteristic fauna in certain places; but we can only draw sweeping boundaries between sea and land, and our ignorance of coastal details leaves very much to be desired. The drowned valleys and outlying islands of a sunken coast cannot be represented, nor can the bays that mark the attack of an eroding ocean upon stationary land. The resemblance of terrestrial faunas in places far apart, or the dissimilarity between marine faunas in adjacent regions of stratified rock, leads to the drawing of land-bridges between continents, which are believed to have served as passage-ways on the one hand, and on the other as barriers to migration in the seas. The absence of any geological evidence over the wide areas that are occupied by the modern oceans renders palæogeographic delineation almost hopeless; but the acceptance of Suess's Gondwanaland as a lost continent, stretching east and west across two thirds of the southern hemisphere, and abolishing both the South Atlantic and the Indian oceans, has long thrown doubt on the permanence of any existing feature. Europe as a continent cannot be traced back beyond Cainozoic times, and the greater part of its present configuration dates from the Pliocene period. Far older masses have asserted themselves in the cores of its earth-folds; or as *horsts*, that is, as upstanding blocks from which material has been faulted down on all sides; or, again, as platforms laid bare by recent denudation. But such fragmentary indications do not enable us to reconstruct a Mesozoic Europe. On the contrary, as research goes on, we become more and more impressed by the extent of the Cretaceous sea, and it is difficult to point to any considerable area of the modern continent which, with absolute certainty, escaped submergence in the waters that deposited the chalk.

The Cretaceous system may be divided into an Upper and a Lower Series, and its marine deposits represent a very general transgression of the sea over land-areas throughout the world. Through long geological periods down to Lower Cretaceous times, a continent of old and highly altered rocks (quartzites, schists, and intrusive granites) stretched over what is now the North Atlantic region. Considerable submergence of its southern edge occurred in Ordovician and Gotlandian times; but a series of folds was then set up, which produced mountainous ridges running in a north-east and south-west direction, in the cores of which granite often rose, as a further strengthening of the mass. This *Caledonian* land is still known to us in the west and north-west of Ireland, in the Scottish highlands, and notably throughout the Scandinavian peninsula, and the sandstones and conglomerates of the Old Red Sandstone series accumulated on it in Devonian times. Then came the invasion of this continental edge by the Carboniferous sea. On the schistose rocks of Mayo and Donegal, and in central Scotland, we find shore-deposits in place of the pure type of Carboniferous Limestone, and it is therefore clear that the North Atlantic continent held its own. Its borders extended far southward in Upper Carboniferous times, producing the swampy flats on which the coal-measure forests spread and flourished. A new system of crumplings preceded the Permian period in our area, and added a robust series of east and west folds to the continental edge. These have been named *Armorican* from Brittany, and *Hercynian* from their passage into central Germany. They are still conspicuous in the trend of the hill-ranges in southern Ireland and Wales, and in that of the Belgian coalfield and the Ardennes. Many modern features, moreover, have been moulded on underlying Armorican predecessors. The faulting that accompanied these movements brought several old crystalline masses to the same level as younger strata, while great intrusions of granite took place contemporaneously with the folding of the crust. The most important relics of the Armorican land are Brittany, the Ardennes-Hunsrück mass, the Black Forest and the Vosges, the plateau of Bohemia, the Central Plateau of France, and the Meseta or "table" that forms nearly the whole of Spain. The floor of Russia was probably raised by the Armorican folding, though it largely consists, like Fennoscandia, of Archæan rocks.

Even in Permian times, immediately succeeding the Carboniferous, the sea invaded parts of the new Armorican land, and spread northward and westward as far as the stubborn highlands of Tyrone. The Triassic sea, important as its deposits are in Bavaria and

Tyrol, extended only into central Germany; but the Jurassic period saw the waves beating again right across the Armorican country, and coral-banks flourished in a warm sea over the greater part of England. Some recovery took place in the edge of the northern continent at the close of this period, and the first strata of Cretaceous times in south-east England and northern Germany are lacustrine; but the sea soon reasserted itself, until the deposition of soft white foraminiferal ooze became general over the European area.

The spreading of the Upper Cretaceous seas over continental margins is so worldwide a feature that it can be best accounted for by a shallowing of the ocean depths. The white chalk, none the less, may have accumulated in places in 1500 to 2000 fathoms of water. Yet depth alone will not account for the purity of this Cretaceous limestone, since there is a rapid transition in the north of Ireland from conglomerates that mark a shore-line to white chalk of the ordinary type. The chalk near Belfast, moreover, contains pebbles of quartzite worn from the old land beneath it. We may conclude, if we please, that the continental edge furnished little clayey matter; but this is improbable, when we consider how mica-schists prevailed upon it, and how these very same rocks yield yellow soil-caps in our own day. It seems far more likely that the North Atlantic continent, despite the Caledonian folds that at one time wrinkled up its edge, was already worn down and low-lying, like eastern Canada at the present day. It was a region of small precipitation, and the rivers that flowed from it brought down little detritus from the land.

We may take our stand on the northern summit of Slieve Gallion in the county of Londonderry, and look in imagination eastward over the European area as it was in late Cretaceous times. Beneath us at the present day is a ring-like exposure of chalk, preserved under a flow of Cainozoic basalt, a mere relic of the marine limestone that once spread across the country. It is a thin representative of the massive chalk of England, for to the west of us rise the Donegal ranges which formed some portion of the Cretaceous coast-line. But the abundant flints and fragments of chalk that are found in dredgings off the west of Ireland prove that the Cretaceous sea spread far westward of the line usually assigned to it in palæogeographic maps, and probably into the mid-Atlantic region (3). A. Jukes-Browne (4, fig. 53) boldly carries it across the greater part of Ireland, and represents the British Isles in late Cretaceous time as a group of eight small islands.

The upper beds of the Chalk have, as we can see familiarly in southern England, become silicified in irregular lumps and layers, giving rise to the resisting masses known as flint. On the destruction of the beds of chalk by weathering, which is largely a matter of solution, the flints remain behind, and accumulate as gravels in beaches or on the surface of the land. They afford a striking measure of the amount of chalk that has been lost, and we learn from them that the Upper Cretaceous sea invaded the east of Aberdeen. Relics of Cretaceous strata have been dredged from far northern latitudes off the Norwegian coast, and O. Nordgaard has suggested that the abundant flint-implements in Norway were worked from a Cretaceous deposit that became lost to us in human times. The present writer has argued that many immature features on the surface of the Irish uplands are due to the fact that the region was protected by overlying chalk almost down to the Glacial epoch.

The blocks of chalk recognised by J. W. Judd under the basalt of the west of Mull, where flints are common in gravels of Cainozoic age, probably lie near the northern limit of the Upper Cretaceous sea. The Upper Cretaceous strata of the island of Eigg are sandy, and indicate a coast-line; but the ease with which such deposits are destroyed may well suggest caution in following this limit across Europe. The white headlands of the island of Möen in eastern Denmark, where the chalk rises picturesquely 125 metres above the sea, are connected with a broad development of Upper Cretaceous strata that has been traced in borings under almost the whole of Denmark. In Bornholm, however, a rocky island which resembles a geological museum in comparison with the rest of Denmark, Cretaceous beds of slightly older age include marls and sands that indicate proximity to a shore. Similar rocks occur in southern Sweden, and the presence of chalk in northern Germany shows that the sea deepened from this area southward. A large island rose in the region of the Harz Mountains, where earth-movements continued to upheave the older rocks even after the chalk sea lapped round their uptilted edges. The Upper Cretaceous beds became themselves infolded on the margin of this rising chain.

A more important mass of land, perhaps at some point connected with the Harz area, was formed by the old plateau of Bohemia, a *horst* left upstanding since the Hercynian movements of pre-Permian time. Though Upper Cretaceous strata cover much of the country between Dresden and Prague, their sandy nature shows that land was being denuded in the neighbourhood. This land was of larger extent in Lower Cretaceous times, so that even here there is evidence of the broadening of the seas which preceded the development of modern Europe.

The Upper Cretaceous ocean spread far across the east of Prussia, across Poland, and across most of Russia. The Armorican ridges running east from Brittany are held to have divided a northern from a southern basin in France; but the sea swept round this and between the Central Plateau of Auvergne and the North German island, and so into the Mediterranean area, where practically no land rose. The west of Spain may have remained uncovered; but Upper Cretaceous strata occur on the Sierra de Guadarrama north of Madrid, and the boundaries of the modern Mediterranean are of far later date. E. Haug (IV, 2, 1299) has prepared a map of the European area in the final or Maestrichtian age of the Cretaceous period, which probably errs on the side of caution, but which sufficiently indicates the extent of oceanic water.

Our white chalk along the escarpment of the Surrey hills points to an emergence of the land from a depth of some 600 fathoms; and the extent of country that lay beneath the water to the north and west becomes readily apparent when we survey the midlands from the Chiltern edge. The great masses of Cretaceous limestone that are now reared into crags on the flanks of the Alpine chain remind us still more impressively of the changes that have taken place since the departure of the Mesozoic seas. On the precipice of the Säntis in Appenzell we may see our familiar zones of Gault and Chalk, transformed by earth-pressures into compact shales and limestones, and lifted 2500 metres (8000 ft.) above the sea. The deposits of the Cretaceous ocean here form the bulwark of the most important mountain-range in Europe.

CHAPTER III

EUROPE AS A PRODUCT OF POST-CRETACEOUS TIME

It will be seen from the last chapter that the growth of Europe since the Cretaceous period involves the spread of land-masses southward and eastward from the old North Atlantic continent, and the final loss of this continent beneath the sea. The most stable masses remaining from the old land-surface that so long formed a margin to pre-European seas appear to be the Caledonian areas of north-west Ireland and Scotland, and such parts of

Scandinavia and Finland (Fennoscandia) as were not covered by the Cretaceous ocean.

Before we look into the origin of certain local features that may strike us in our journeys across Europe, it will be well to take a general view of the geological history of the region in post-Cretaceous periods. Even during Cretaceous times, upward and downward movements displaced the borders of the seas, and many districts that were submerged in the middle of the period became raised as islands before its close. During these movements, intrusions of granitoid rocks took place along the line of the Pyrenees, and these point to a certain unrest in the molten substratum or *Untergrund*, preparatory to the folding that formed the mountain-barriers of to-day.

The periods that are mainly concerned with the growth of Europe are clearly those of the Cainozoic or Tertiary era. Charles Lyell (5), in 1833, gave us names for three broad divisions of Tertiary time, based on the number of existing marine molluscan species that could be traced back into successively older strata. He viewed the beds from above downwards, seeking philosophically to explain their characters by the action of natural causes that are still in operation on the earth. His *Pliocene* (strictly written, "Pleiocæne") system includes the " more recent " molluscan forms; below is the *Miocene* (" Meiocæne "), or " less recent "; and the Cainozoic era opens with the *Eocene*, or " dawn of the recent."

Beyrich, in 1854, intercalated *Oligocene*, or " few recent," between the Eocene and the Miocene, and this well-known term will be adopted here. De Lapparent's and E. Haug's works (II and IV), however, illustrate the tendency to recombine the Eocene and Oligocene systems under some name that expresses their continuity and the similarity of their deposits, while Miocene and Pliocene are often united as the Neogene period. From the point of view of the history of our continents, which is now revealed to us in considerable detail, and also when we regard the great thicknesses of the beds concerned, the division of Cainozoic time into four periods seems convenient. The remarkable changes in mammalian life during the era also justify this view.

The prevalence and dominating influence of man after Pliocene times lead most geologists and zoologists to close the Cainozoic era with the Pliocene period, and to place Lyell's *Post-Pliocene* and *Recent* periods in a separate era, the *Quaternary*. It has been pointed out by A. Morlot and others that German authors are more correct in using the term *Quartär* or *Quartary* (IV, 2, 1760). The latest of the great ice-ages that have affected the world occurred at the beginning of the Quartary era.

The names used for subdivisions of the Cainozoic periods have varied with the judgment of successive authors, and the most important matter is to understand the relative position of the series and stages, from whatever localities their titles may be drawn. The following names will be used in the present volume :—

QUARTARY ERA

Systems.	*Series.*
RECENT AND POST-PLIOCENE.	Upper (Post-Glacial).
	Lower (Glacial).

CAINOZOIC (TERTIARY) ERA

PLIOCENE.	Upper	Sicilian Stage.
		Astian Stage.
	Middle (Placentian).	
	Lower	Pontian Stage.
		Sarmatian Stage.
MIOCENE.	Upper (Tortonian).	
	Middle (Helvetian).	
	Lower (Burdigalian).	
OLIGOCENE.	Upper (Aquitanian).	
	Lower (Tongrian).	
EOCENE.	Upper (Paris Series).	
	Lower (London Series).	

NOTE.—The places from which the above technical names are derived are, in descending order, Sicily; Asti, south-east of Turin; Piacenza (the Roman Placentia); the Black Sea (Pontus Euxinus, whence "Pontic" might be preferable); Sarmatia, the Roman name for southern Russia; Tortona, east of Asti; Helvetia, the Roman name for Switzerland; Bordeaux (the Roman Burdigala); Aquitaine, the province north of the Pyrenees; Tongres, north of Liège in Belgium; Barton in Hampshire; Paris; London.

The terms "Parisian" and "Londinian" have been used in restricted senses, and are hence not here employed for the two series of the Eocene system.

The earth's outer crust moves in a series of waves, the rising and falling of which seem slow, but which resemble those of a rough sea (fig. 2). On the open Atlantic, or even in the storm-swept Mediterranean, one may see the water swelling in great domes, and dropping again until basins are formed of corresponding depth. Similarly, across the broad surface of the globe, the dimples and bulges of the crust are continually changing places. Hence we find many areas where the Chalk or other Upper Cretaceous strata were brought within reach of denudation in early

Eocene times. We recognise, in quarries or on steep hillsides, how valleys were carved out in the limestones, similar to those that now groove the surface of our Downs. Nodules of silicified chalk (styled flint) appear locally as gravels in these hollows, and form basement-beds for the next geological series. The strata laid down on these irregular

FIG. 2.—View of a part of the earth's crust formed of stratified rocks, which have been thrown into waves, producing synclinal hollows and anticlinal upfolds. The anticlines and synclines seen on the sides of the block are evidently due to cross-sections of dimples and bulges on the surface. In nature, the surface is of course modified by denudation.

land-surfaces may be terrestrial, estuarine, or marine. By their nature and their fossils we can trace out the new geographical borderlines, and the gradual returning of the sea.

Thus the early Eocene deposits of Europe frequently contain sand and pebbles of flint derived from Cretaceous rocks. The lower beds lie, moreover, on various Cretaceous series, or overstep these series on to the surface of far older systems. In other places, the continuity of marine deposits makes it clear that the Cretaceous sea persisted into Cainozoic times.

The English chalk suffered greatly from denudation in the earliest Eocene epoch. After the Cretaceous ocean had been driven eastward, only a small portion of the British area became again submerged. Western and central England must have presented the appearance of a vastly extended Salisbury Plain, the back of the Chalk rising as a broad dome towards Lancashire and reaching far into the Irish area, if not across it. Almost horizontal Cretaceous strata thus formed a gentler border to the old rocks of the North Atlantic continent, in the same way as the unfolded Silurian limestones fringe the Archæan masses of Ontario.

Farther south, in the area where the Pyrenees were soon to rise, the Cretaceous strata were invaded in their lower part by granite veins, and underwent oscillations which allowed of the formation of fresh-water lakes; but the Eocene sea soon occupied Aquitaine. The Mediterranean region had been covered in Mesozoic times by a sea that spread westward round the Spanish plateau into the central Atlantic area and eastward over central Asia, and these conditions prevailed with little change in the Eocene period.

The great east-and-west oceanic band that Suess has named the Tethys was not yet limited and broken up. In consequence, we find in the Atlas ranges of eastern Algeria, in central Tunisia, and in Egypt, a marine passage from the Mesozoic to the Cainozoic group. The most striking feature of the fauna of the Eocene sea is the development of large foraminifera, Nummulites and Orbitoides, discoidal forms that often measure two centimetres across, while the former at times reaches ten centimetres. It is interesting to collect these essentially marine remains from limestones infolded with still more recent strata in the Alpine chain, or in the dry rock-deserts of Egypt, where they form a large part of the stone employed for building in ancient times. Nummulites are so prevalent in Eocene rocks that the system is sometimes styled "nummulitic," and E. Haug has extended this term to include the Oligocene system also.

The absence of Eocene deposits in most of the highlands north of the Ægean, and the appearance of shore-beds to the north-east, indicates that the old schistose rocks and the overlying Cretaceous strata were here uplifted so as to form a considerable island. The Cretaceous beds at present remain only in isolated patches, and no doubt suffered from denudation simultaneously with those of England.

Farther north, over the Alpine and Carpathian area, a series of sands and clays, known since 1827 as the *Flysch* formation, precedes and is intercalated with more normal marine and often nummulitic strata. While the latter contain numerous molluscs, echinoderms, and foraminifera, the Flysch is practically barren. The beds resemble those of broad estuaries, where sands and muds are laid down on the margin of continental land. In the Carpathians, they were forming as early as Cretaceous times; the series, known as the Carpathian Sandstone, has been compared by Zuber to the vast delta-deposits of the Orinoco. In the French Alps, the Flysch extends up into the Lower Oligocene. Cylindrical and branching traces of organisms, known as fucoids, often occur in the Flysch, and have commonly been regarded as due to seaweeds. O. M. Reis, after a critical study, believes that they are the burrows of worms (6).

This Flysch type of deposit occurs so suggestively along lines of country which are now marked by mountain-ranges that we must see in it a foreshadowing of upward movements of the ground. To the south of the northern Carpathian zone, the nummulitic sea occupied what is now the Hungarian plain, as is proved by the relics of Eocene strata in the hills that rise like islands to the north and south-west of Budapest. This sea formed part of the warm ocean to the south. A sea, with occasional communications southward, spread over the London and Paris areas, and across Denmark; its fauna implies somewhat colder conditions.

The OLIGOCENE period was marked in the west European area by the prevalence of lakes. We obtain from the fossils a good knowledge of the trees and shrubs that grew upon their margins, and these indicate a continuance of the generally warm conditions of Eocene times. The sea, however, was never far away from central Europe, and the well-known Fontainebleau Sandstone (Upper Tongrian) of the Paris basin is marine. South of the mass of ancient rocks forming Brittany and the Central Plateau of France, the Oligocene strata show the same variations as those round Paris; but the sea here found a southern barrier in the growing chain of the Pyrenees. Here even the Eocene beds include conglomerates of blocks worn from the uprising land, which was not a mere elevated extension of the Spanish plateaus, but an independent earth-wrinkle running east and west. In time, the conglomerates themselves became involved, as we shall see to be the case with the later shore-beds along the Alpine axis; and in the Aquitanian epoch pressure from the south crumpled up the older strata into a series of recumbent folds, broken by surfaces of thrust, so that Cretaceous limestones form conspicuous crags in the Cirque of Gavarnie and in the picturesque gorges by which one enters on the chain.

The Oligocene system of Switzerland includes much of the soft yellow sands and clays known locally as *molasse* (or *mollasse*), and also much of the flysch previously described. The Tongrian molasse is marine, while the overlying Aquitanian part is freshwater; but a long time had yet to elapse before the sea finally left the Alpine area. To the south, in a region where the sea-floor subsided until a thickness of 5000 metres of Oligocene strata were laid down, continuous marine conditions gave no suggestion of the birth of Italy.

Even the broad back of the Balkan area, which was exposed to denudation in Eocene times, sank in part beneath the early Oligocene sea (IV, 2, 1501), and the present exposures of crystalline rocks along its axis are not due to subsequent folding, but to the stripping off of marine Cainozoic sediments which were at one time extensively laid down.

In Tongrian times, moreover, the sea returned to the north German area, and formed a broad band of water that stretched eastward into Russia. We are in complete ignorance as to how far it may have invaded the lowlands of Sweden, Finland, and northern Russia, since the heavy glaciation of those countries has removed all traces of its margins.

The Oligocene sea, however, has left conspicuous traces in the basin of Mainz, a region of depression, and throughout Westphalia.

In Middle Eocene times, interesting volcanic outbursts took place in the floor of the North Sea, and ashes are found in the west of Jutland, interbedded with marine limestones and diatomaceous earths (7, 15). The far more notable eruptions of the north of Ireland and the Inner Hebrides probably began about the same time, and continued into the Oligocene period. On the surface of the Chalk downs, and of the older strata that were revealed by early Eocene denudation, lava-flow after lava-flow was poured out, until the valleys were choked, the hills were buried, and the edge of the North Atlantic continent became a region of desolate basaltic plateaus. Just as the Pyrenees mark the beginning of the

Alpine chains, so these eruptions herald a series which characterises the Miocene period in Europe as one of violent unrest.

The Lower MIOCENE strata, styled Burdigalian, from their typical occurrence near Bordeaux, are marine throughout the basin of the Garonne. The Paris basin was terrestrial at this time, providing a home for the rapidly developing mammalian life of the epoch; but a Middle Miocene (Helvetian) overflow sent an arm across it from the Atlantic. We owe to this the remarkable series of shell-beds, which are valued as agricultural marls, and are known as the *faluns* of Touraine. They repeat in the north their predecessors, the loose shelly deposits of Aquitaine. At the same time, the southern waters advanced up the depression that is now occupied by the Rhone, but retreated at the close of the Miocene period, leaving modern France dry land. The Rhone valley began to form, carved out along the line of depression by the drainage from new and old highlands lying to the north, and a temporary submergence let the sea into this narrow groove in Pliocene times. For all practical purposes, however, the surface of France has been exposed to denudation from Tortonian times.

The earth-folds that culminated locally in the Juras and the Alps raised the Mesozoic limestones sufficiently high to furnish massive conglomerates in Switzerland. These form the *Nagelfluh* beds, which are so conspicuous in the foothills near Lucerne. But the Middle Miocene (Helvetian) sea laid down a marine molasse over the lacustrine beds of the lowlands, thus carrying the rich deposits of the Vienna basin into the heart of Switzerland, and into districts that have since experienced the final crumpling of the Alps.

The southern sea lay across Vienna, and it occupied, in the Helvetian epoch, the great and now elevated plain between the Alps and the plateau of Bohemia. North, however, of the Franconian upland, brown coals, formed in swampy freshwater basins, are common in Upper Oligocene and Miocene strata. The northern sea was driven from the Mainz basin early in the Miocene period, and became more and more restricted towards the Scandinavian region as time went on. This sea was cut off from the Mediterranean area by continental land, very much as it is at the present day.

The main lines of modern Europe were decided in Upper Miocene (Tortonian) times. The falling in of the North Atlantic area, which was foreshadowed by the creeping of the Cretaceous sea up the west of Ireland, finally broke the connexion with North America. Land-bridges may have arisen in later times, as seems to be required by certain characters of the present fauna (IX); but these have been of little moment in European structure. The Atlantic border is due to down-faulting across the trend of the older mountain-chains, and the crystalline rocks of the north-west, with the volcanic load upon them, foundered in great blocks, admitting warmer waters to the confines of the Arctic Ocean. At the same time, the great mountain-chains arose, and the débris that was washed down from them began to choke the shallowing eastern seas.

The backbone of the Miocene continental land is to be found in the products of intense folding which are characterised as the Alpine chains. Heralded by the Pyrenees, these chains now rose, partly through vertical uplift, partly through tangential pressure acting mainly from the south. The huge recumbent folds that are now recognised in them appeal to some geologists as instances of overthrusting, and to others as evidence of gravitational adjustment during uplifts that were mainly vertical (8). Here and there, as in the dolomite Alps of Tyrol, block-structure locally prevails, owing to the unequal yielding of strata of very different modes of origin.

In the western Alps and northern Italy, the folding undoubtedly began at the close of the Oligocene period, and there is some evidence of older axial movements in the area; but the deposits of the Helvetian sea show how far the Alps were from being complete in Miocene times. About the Tortonian epoch, the Mesozoic limestones of the Juras, and all that overlay them, were pressed against the old crystalline masses to the west and north, and assumed their present bow-like and crumpled form. The main Alpine chain arose, sending off spurs to the north-east to join the older but still heaving ridges of the Carpathians, and to the south-east to meet the Dinaric chains. The Viennese area became faulted down, and retained its marine character into early Pliocene times; the Carpathians continued their growth, and at their south-eastern end became prolonged in the last folds of the Balkans. The Italian chain remained imperfectly developed, though its central axis now rose above the sea. Meanwhile the Mediterranean Sea was already assuming form. The antique Tethys had on one side expanded as the mid-Atlantic; on the other, it had begun to shrink away from Asia and from central Europe.

In consequence of these extensive uplifts, the PLIOCENE system in Europe is largely terrestrial in origin. The northern sea again invaded south-east England, and left shelly deposits on the surface of the Chalk, which are now lifted some 600 feet above the sea. In south-west Cornwall, and probably in places under the glacial drift of Ireland, warmer waters from the south laid down the St. Erth Beds. But in the east of Europe the sea was withdrawing into the Caspian and Mediterranean basins, and the Lower Pliocene beds (Sarmatian and Pontian) indicate increasingly brackish to freshwater conditions. The persistence of marine waters over the region south of the Alps is a remarkable testimony to the essential youth of Italy, and in Calabria the latest shell-beds of the Astian stage are found nearly 3000 feet above the present level of the sea.

The uncertainty of the borders of the Mediterranean is shown by a general shrinkage in the Pontian age, a subsequent extension, and the subsidence of the northern Adriatic region after the Po valley received its infilling of alluvium; also by the formation of the Ægean Sea at the very end of the Pliocene period, through the breaking up of a land-mass that had long connected Greece with Asia Minor. The volcano of Santorin (Thera), at the south end of the archipelago, dates from this epoch of subsidence, and it underwent catastrophic changes during the human age of copper. Its eruptions were strikingly renewed as recently as 1866–70. The active volcanoes of southern Italy similarly lead us to anticipate no persistence of the present tectonic coastal forms.

As an accompaniment to the Miocene and post-Miocene earth-movements, volcanic eruptions were widely prevalent. In the ancient plateau of Auvergne, and round Le Puy on the west flank of the Cevennes, basaltic sheets were poured out rivalling those of northern Ireland. The centres from which these flowed have now become deeply dissected. The earliest eruptions were of Lower Miocene age; but the masses of Mont Dore, the Cantal, and the Velay on the Cevennes are mainly Pliocene. Activity was revived in Auvergne in Post-Pliocene times, providing some of the freshest examples of cone-building in Europe.

The abundant volcanic centres, with broad coalescing lava-flows, that broke through the surface from the east border of Belgium to north Bohemia date from the Lower Oligocene to almost the human epoch. Their eruptions, however, were at a maximum in the greatly disturbed Miocene period. In the Eifel and the Siebengebirge in the northern Rhineland, in the Westerwald of Nassau, and in the Vogelsberg t the east in Hesse, volcanic rocks play a large part in the present landscapes. The Bohemian plateau north of Prague is set with characteristic cones, and with the remains of eruptive centres that now expose their rugged cores. These break through an Upper Cretaceous platform, and Miocene brown coals are interbedded with their exploded ashes. Within the great Carpathian ring, volcanoes have built up mountainous masses in the country north of Budapest; and the Euganean Hills in the Po basin afford another example of eruptions occurring in a region of subsidence connected with the Alpine chains.

As was pointed out in the first chapter, the surface of Europe has become greatly modified by the products of its own decay. Tectonic grooves and basins have become filled up by alluvium; coarse banks due to landslides and to the growth of taluses have obscured the flanks of mountain-chains. Large areas, moreover, have become covered by detritus brought from a distance during the last glacial epoch, which prevailed, with occasional interglacial episodes, at the time when man was seeking for a home in the new continent.

The immense changes produced by what

may be styled ice-borne alluvium will be apparent from a study of the Baltic lands (Chapter VII). Certain types of hill, and certain features due to erosion, originate during an ice-age, and in no other way. It is one of the difficulties of geographical teaching in Europe that obvious phenomena must so often be referred to causes no longer in action in this quarter of the globe. The localised glaciers of the Alps and Norway mislead rather than instruct, in regard to the huge deposits of boulder-clay and the sheets of glacial gravel that represent one of the latest phases in the complex growth of Europe.

Owing to frequent changes of level in the land, and the obstacles provided by the glacial ice, or added from it as it melted, the present drainage-system of Europe has a very recent history. Perhaps the most ancient rivers are to be found in the highlands bordering on the North Atlantic, where the axial structure of the country was determined in Devonian times.

CHAPTER IV

THE ATLANTIC BORDERLANDS

THE border of western Europe, the line along which the Atlantic water meets the land, was mainly moulded by the events of Miocene times. The central Mediterranean Sea that was indicated to geologists by Neumayr, and usefully named the Tethys by E. Suess (p. 37), lay in the Cretaceous period between the North Atlantic continent and a continent that included Africa and South America. The study of fossil marine faunas leads to the conclusion that a passage was then open into the Arctic seas somewhere west of Scandinavia. Suess points out that the Atlantic Ocean is probably an enlargement of the central part of the Tethys (I, 2, 489); and the marine overflow at the opening of the Upper Cretaceous epoch is one of the first signs of its development.

The old North Atlantic continent, however, for a long time held its own, and on it appeared some of the first signs of the Alpine movements and of the growth of Europe. In early Cainozoic times, an immense number of cracks opened in it, breaking through Archæan gneiss, through crumpled Carboniferous strata, or soft Jurassic and Cretaceous limestones, and along these cracks basaltic lava sought the surface (p. 41). These cracks, now converted into *dykes* by their infilling of lava, have a remarkably regular north-west and south-east trend, and are not accompanied by others in a cross direction. It is as if a portion of the earth's surface had been stretched, as may happen in the formation of a broad arch, without such torsion as would produce two sets of fractures.

It is noteworthy that the system of Cainozoic fractures in south-western England has the same north-west trend. These are connected with movements in the Upper Oligocene epoch (9).

It is still more important to observe that in late Cretaceous times the so-called "Saxonic" folding of central Europe led to folds and fractures that run also north-west and south-east, and that these continued to develop during the epoch of the Alpine folds. The age of the post-Cretaceous eruptions of the north-west districts is known only from certain plant-beds included in the series of lava-flows; though these are at present generally referred to the Eocene period, they are just as likely to be of Oligocene age.

The products of the eruptions that were poured out from cones established along the lines of fissure, or from great volcanic centres, such as those described by J. W. Judd in Mull and Skye, immensely modified the surface of the uplifted land. The flint gravels that occupied hollows in the Cretaceous areas are now found baked and reddened under massive flows of basalt. The country was levelled up and converted into plateaus, while here and there some huge composite cone arose, beneath which the igneous matter formed a deep-seated cauldron. The heart of Skye, with its forbidding crags of crystalline gabbro, and the granite knot that forms the Mourne Mountains, are relics of these cauldrons, now weathered out as singularly picturesque additions to regions of far older and more denuded hills. The Faroe Islands and St. Kilda and the conical relic of Rockall, nearly 200 miles farther west in the Atlantic, show how extensive the area was over which the eruptive action spread. Basaltic fragments from the surface of lost plateaus are dredged up from the seas between Scotland and Iceland, from the east of Greenland, from round Jan Mayen (10), and from Rockall Bank. Porcupine Bank, 150 miles west of Galway, consists mainly of a mass of olivine-gabbro penetrated by granite, like that of the igneous centres of Carlingford or Skye.

The basaltic flows, when of sufficient thickness, cracked during cooling into characteristic columnar forms, like those that have made the fame of Staffa and the Giants' Causeway. They weather out into steps along their vertical joints, and their grim black terraces still prevail in the county of Antrim, in the lowland of Mull and its outstanding isles, and in the rain-swept north of

Skye. But, as Sir A. Geikie has impressed upon us, these are mere fragments of the great lava-plains that occupied the North Atlantic region in Oligocene and Miocene times. The foundering of this region has left few relics above the sea, and on these denudation has been active. The basin of Lough Neagh, the largest lake in the British Isles, lies in a depression of the basalts, and is connected with the subsidences to north and west that led to the growth of the Atlantic. It was actually occupied by marine waters during some part of the Glacial epoch.

Iceland, as we now know it, represents a later stage of activity than that which produced the plateaus of the Faroes and the Inner Hebrides. But its earlier eruptions, the lavas of which lie below the present sea-level, probably began in the middle of the Cainozoic era. This large European outpost, with its impressive lava-sheets of recent date, gives us an admirable picture of the North Atlantic region prior to the great submergence.

The north-west limits of Europe were broadly defined by this submergence, though the foundering blocks may have sunk slowly and at various times. G. de Geer (10, 851) believes that the general north-west margin of the continent is not a line of fracture, but merely one of depression due to downward bending. The subsidence was accompanied or induced by a rising of the neighbouring land, as is proved by the elevation of marine Cainozoic beds both in Greenland and Spitsbergen. De Geer gives to the ocean occupying this recently depressed area the name of Scandic, his Arctic Ocean beginning north of Spitsbergen, and his true Atlantic south of the submarine barrier that runs, mostly at a depth of only 250 fathoms, from Scotland through Iceland to the Greenland coast.

The margin of the Atlantic borderlands has undergone many recent changes. By regional uplift or depression, accompanied by gentle warping rather than by folding, Europe has at one time become enlarged westward, while at another it has become reduced, with the production of outstanding islands. The "continental shelf," on which geographers lay stress (fig. 8), is usually held to terminate at about 100 fathoms, since this line is easily traceable upon charts. The more serious slope, however, to oceanic waters occurs at about 300 fathoms (550 metres); but it is difficult to invest even this with any special geological significance, except perhaps as a gentle downbending towards deeper water.

The main lines of the north-west edge of Europe are clearly due to the old Caledonian folding (p. 28). The trend of the coast of Norway down to the Indvig Fjord, of the Outer Hebrides and Kintyre, and of north-west Donegal, nearly follows that of the crumpled structure of the land. East-and-west lines seem still more potent, and may naturally be ascribed to the Armorican folding of late Carboniferous times. Yet the example of the Iberian peninsula tends to make one hesitate as to whether this or that feature is primarily of Armorican origin. In Spain we have an old mass folded at the same time as Brittany and Cornwall; but the trend of its northern and southern coasts is due to Cainozoic crumpling superposed upon the Armorican lines (p. 24). The Pyrenees thus rose in Oligocene times, and the modern sea on their northern side may be regarded as a survival, or at any rate a mere repetition, of that in which the Miocene beds of

FIG. 3.—Section showing the true slope of the continental shelf between the Porcupine Bank off the west of Ireland and the Atlantic floor. The black area indicates the water, the depth of which from point to point is stated in fathoms. Length of section forty miles. (From *Mem. Geol. Surv. Ireland*, on "Rock Specimens dredged," *etc.*)

Aquitaine were laid down. The sierras of the south, the ridges of the folded Betic chain, which form such striking landscapes as one enters the Mediterranean, are connected with the Alpine movements, and Upper Miocene marine strata are involved in them. As Macpherson and Suess have pointed out (I, 2, 198 and 207), the faulted southern border of the Spanish Armorican horst formed an impassable obstacle to the progress of the Betic folds. The new continent in many places modelled itself along lines imparted to it from that of Permian days. (See also I, 3, 886.)

Many of the east-and-west features that are conspicuous in the details of our Atlantic borderlands may, then, be due to Alpine folds and fracturing, and yet ultimately to underlying Armorican structure. The north-and-south lines, breaking right across the Armorican and even the Alpine folds, are probably connected only with the Alpine movements. A double system of fractures, approximately at right angles, is the natural accompaniment of the torsion of large sheets of the earth's crust, just as it is of restricted slabs of rock, or of glass in Daubrée's experiments in the laboratory.

The known distribution of Cretaceous rock (p. 26) shows that the west coast of Ireland, running north and south, was the edge of a depression as far back as the epoch of the Chalk. The occurrence of Middle Eocene limestone in the English Channel, and the limitation of marine Oligocene in England to the coast near Southampton, prove that the Channel existed as a marine depression before the Alpine movements, and it may never since have been dry land. The Strait of Dover, however, is doubtless a post-Pliocene feature of erosion. The north coasts of Sutherland and Caithness, of Nairn, Elgin, and Aberdeen, of Ireland from Tory Island to Ballycastle, and of the counties of Mayo and Sligo, strongly suggest fracture-lines, which are probably Alpine in origin, and are superposed on the Armorican trend. The north shore, moreover, of Galway Bay, where the granite floor of Connemara is cut off sharply against a limestone area, is continued by a lowland from Galway town to Dublin, and this line of weakness seems traceable eastward in the abrupt descent of North Wales to the Irish Sea.

The headlands of western Ireland and the massive promontories of Cornwall and of Brittany depend obviously on Armorican structure; but the Atlantic border has broken right across them, and subsidence has admitted the sea into the valleys carved on their surfaces in Cainozoic times. The irregular inlets at Padstow and Falmouth, and in the crystalline rocks near Brest and Vannes, have forms that can only be ascribed to submergence, and not to the battery of the sea.

On the other hand, the north-and-south coast-line of France south of the Gironde is not directly due to the fracture-system of the North Atlantic, but to a balance between the heavy surf of the Bay of Biscay and the growth westward of the alluvial country of the Landes. Sand-dunes accumulate on the edge of the Post-Pliocene Landes, as they do on the corresponding coast of Holland.

Farther south, below Cape Finisterre, we meet the wide-mouthed drowned valleys of Galicia, such as the Ria de Noya and the Ria de Pontevedra, which von Richthofen, followed by Suess, selected as a geographical type. The broad inlets styled *rias* are prevalent features of sunken coasts. The western edge of the Iberian mass must have been determined by recent faulting and subsidence, and not by the margin of the old Armorican horst, since in Portugal it cuts across the trend of strata that were folded in post-Miocene times.

In the more northern regions, and especially where glacial modification is apparent, the ria type of submerged valley is associated with or replaced by the narrower inlets known as *fjords*. Dingle Bay and Clew Bay may be styled rias; Killary Harbour, lying between them, is a typical fjord. The old Norsemen, who landed on the Irish shores and established the coastal commerce that flourishes to-day, were not troubled by these distinctions; and the names Waterford, Wexford, and Carlingford illustrate their general acceptance of a marine inlet as a fjord. Nowadays a fjord (or fiord) is required to have steep sides descending into water of considerable depth; its course is straighter than that of an ordinary valley; and it becomes shallower in most cases near its outlet to the open sea. Frequently a rectangular relation is noticeable between the main fjord and its lateral branches, or between sections of the same fjord.

Fjords have been dealt with from two points of view. J. W. Gregory (11), in common with many Scandinavian geologists, claims them as valleys excavated along lines of fracture. The rectangular system of fractures accompanying the Alpine movements is held to have initiated the fjords of northwestern Europe. The shallowing of the inlets at their mouths is ascribed to a backward tilting of the valleys. Such valleys, however, must have been either lowered so as to admit the sea, or excavated by glaciers until their floors lay below sea-level. If glaciers occupied them, as was clearly the case in north-western Europe, the steepness of their bounding walls may be accounted for by the fact that ice wears away the spurs, carries off débris, and allows precipices to be perpetuated. Those who connect all fjords with glaciation point out that glaciers meander far less than rivers, and produce straighter reaches in their valleys. The excavation of the floor where the ice-pressure was greatest has left a shallower reach towards the outlet.

It is evident that those who, on the other hand, lay most stress on the influence of fracture-lines, admit subsidence of the coast where fjords occur. The outlying rocky islands on such coasts, with deep sounds between them, also point strongly to submergence. The probability is that typical fjords are drowned valleys which have been modified and sometimes deepened by the passage of ice along them. Like other valleys (12, 129 and 10, 856), their courses have been in many instances determined by pre-existing fractures of the crust; and this appears to have been the case over wide areas of the north-west borderland of Europe. W. M. Davis has furnished us with a lucid explanatory diagram drawn from the faulted area of central Sweden (13, 169).

The indented west of Scotland is a typical fjord-country, and the occurrence of two crossing series of fractures is well suggested between Mull and Arisaig. Here the greatest inlet of the series, Loch Linnhe, lies along

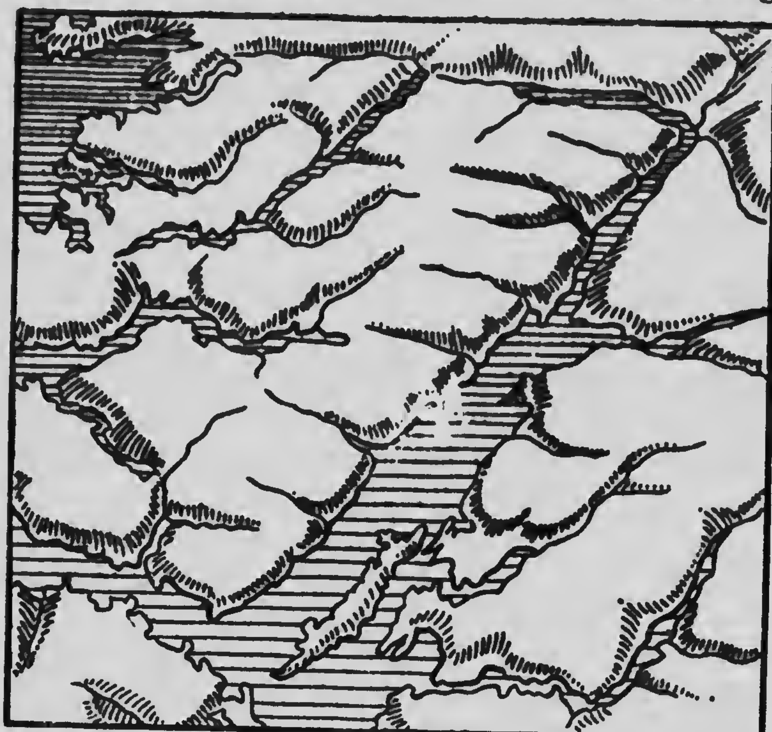

FIG. 4.—Diagrammatic view of country round Loch Linnhe, west coast of Scotland, showing the prevalence of two systems of valleys, some of which have become submerged as fjords.

the axis of Glen More, a line of weakness connected with the Caledonian structure (fig. 4). The upper branch of Loch Eil occupies a drowned valley of the Ardgour and Morven series, at some fifty degrees to the directic i of Glen More; the inland Loch Shiel lies in another valley parallel with the lower branch of Loch Eil, and a very trifling subsidence would connect it also with the sea. This system of valleys evidently existed before the gathering of the ice that modified their walls. The connexion between fjords and ordinary valleys is well seen in the inlets of the Clyde system north of Greenock, and the features of a submerged coast are nowhere more apparent than on the Atlantic border of Argyll.

The magnificent fjords of western Norway have naturally served as types for study. The chains of islands and the network of channels between them originated as features on land exposed to subaerial erosion. The fjords are continued into the highlands of the interior by valleys bounded by the same steep walls; the floors of these valleys contain rushing streams, and they sometimes retain a diminished glacier at their heads. In the Jostedalsbræ, in Svartisen, and in other ice-covered plateaus of the north, with glaciers descending from their margins down all available hollows, we realise something of the great snow-dome of Glacial times, which was generated to the east of the present watershed, and which filled all the grooves of Norway with tongues of seaward-moving ice.

Many of these tongues may have coalesced on a heavily glaciated lowland, of which mere relics now stand above the sea; but the presence of the recently born Atlantic on this side prevented any such vast extension of ice as that which spread south-eastward across the Baltic lands.

The association of raised beaches with features due to subsidence shows that oscillations of the continental margin have frequently occurred. The present contours of the coast, and the present height of any part of the coast-lands above sea-level, represent at the best merely a resting stage. The beaches mark epochs when the land was stationary for a sufficiently long time for the lapping water to spread out the detritus as a terrace, in which the remains of modern shells are found entombed. Where, in the exposed outer reaches and round the islands, the waves broke for long at the same level during a stationary stage, the shore-line is marked by a terrace of erosion, at the back of which is a line of sea-worn caves. Successive uplifts leave such shore-lines in series one above the other; nor are they necessarily parallel with the present surface of the sea. In Scandinavia the raised beaches rise towards the interior of the country, indicating a general uplift in the nature of a dome.

In the British Isles raised beaches are similarly conspicuous, even where the features of the coast as a whole are due to subsidence. As in Scandinavia, the highest traces of a shore-line represent the greatest recent submergence of the land. In many places marine clays are coming to light between tide-marks, or have been raised above high water, while under them forest-beds and peat are found, which point to a former extension of the land. As T. Hallissy shows in the Geological Survey Memoir on Clare Island, the existence of submerged peat round the whole of Ireland implies that the details of the present coastline are due to post-Glacial submergence.

Though the sea lapped round the south and west of the British Isles in pre-Glacial times, and even entered many of the valleys before they were occupied by ice (14), the British Isles as islands date from a very recent epoch. A great glacier that came down the hollow of the Irish Channel during the Ice Age, bringing stones from the Clyde area to points as far south as Waterford, left, when it melted away, a boulder-clay full of contemporary marine shells. Hence the floor over which it moved must have been previously occupied by the sea, and this shallow water may well have been thrust out before the advancing ice. The Irish Channel, however, to this day, can hardly be regarded as an arm of the Atlantic, and an uplift of some 800 feet would put an end to the greater part of it.

The North Sea is also a modern feature, though the deep channel in its floor off the Norwegian coast may be a relic of the tectonic depression which is believed to have separated Scandinavia from the lost North Atlantic continent (p. 50). The south end of the North Sea may be regarded as the reproduction of an Eocene overflow. During a large part, however, of the Cainozoic era, the North Sea was probably represented by a country of rolling downs of chalk, continuous with those of eastern England and those which then lay across Aberdeen. To the north of this region stretched a worn-down land of ancient metamorphic rocks, represented still by those of Scotland, and retaining here and there upon its surface fairly level Devonian and Carboniferous strata. Part of this continental mass survives in the relics that form Spitsbergen, where fjord-structure has now almost eaten up the land; and we see in the coal-seams of these remote arctic islands how the region formerly supported forests, which were threatened in Miocene times by incursions of the sea. It seems probable that the growth of the North Atlantic in the Pliocene period brought down a gulf between Norway and the east of Scotland; but the results of dredging on the Dogger Bank show that a great European delta occupied the southern part of the North Sea area just before Glacial times, and allowed the Thames to unite its waters with the Rhine. We cannot dogmatise about the surface over which the Scandinavian ice then proceeded to approach the eastern shores of England; but the elevation that accompanied its final melting is believed at any rate to have restored the delta land. We know that peat grew on this revived lowland, and it may now be dredged up from a depth of twenty fathoms (15). It is clear, therefore, that a very recent subsidence has occurred; but, quite apart from this, the catastrophic events known to us in the history of Holland during the Middle Ages (p. 116) sufficiently attest the rapidity with which the sea may encroach on such a shore.

The insular nature of Great Britain among the borderlands of Europe is, then, one of the latest results of earth-movement combined with denudation. The fauna of Ireland indicates recent land-connexions with both the south-western and the central portions of the Continent. The mammoth elephants that have left their remains in Irish caves and English gravel-beds doubtless entered the

Britannic area across continuous land. Their remains have, in fact, been dredged from the North Sea. Ireland became isolated before the link between England and the Netherlands was destroyed, and the sea-channel checked the ingress of certain quadrupeds, and ultimately may have prevented Ireland from falling under the dominion of the Roman emperors. The human history of our islands, however, proves that the encircling seas, in times when land-travel was fraught with peril, provided passage-ways for every adventurous tribe; and the region that was thus limited and even penetrated by the ocean has bred a composite race which regards the Atlantic as a heritage.

The expansion of England overseas, however, is only one example of the fate that has impelled the nations of the European borderlands. The Norsemen colonised Iceland and Greenland, as well as large parts of the British Isles. Their successors and relatives, the Normans, carried Latin civilisation into Ireland. The Portuguese surpassed the Phœnicians in African adventure, and followed the scarcely broken coastline to the Indian seas. The Spaniards, steering by the stars, sought a new India across the breadth of the Atlantic; and the dwellers in the shifting swamps of Holland, hemmed in by the continent on the south and east, seized on South Africa as a halting-place in their route to oriental isles. To this day, a great grey liner, appearing suddenly as a vision from the Indies along the canal at Amsterdam, epitomises the moulding of man's history by the inroad of the western seas.

CHAPTER V

THE GROUND-SWELL OF THE ALPINE STORM

When a series of strata is bent into a dome, which is the form most likely to arise during gentle movements on the spheroidal surface of the earth, denudation attacks the higher portion and tends to reduce it to a plain. The waters condensed from the atmosphere and engaged in the destructive work must run off somewhere, and it is unlikely that they will do so uniformly over the sloping margin of the dome. The plain will probably not be developed with perfect horizontality, and a weak line here and there, such as may be due to fracture, will determine the direction of a dominant stream. When a drainage-system is once started, material is carried out of the district.

Some of the strata will be more resisting than others. As denudation progresses, their upturned edges on the general plain will stand out above those of more yielding layers. They will develop a slope on their outer sides which is approximately that of the inclination of the beds to the horizontal; this is the *dip-slope.* Towards the inside of the dome they will weather along their prominent joint-planes, which are approximately perpendicular to the dipping surface, and they will send down detached blocks and heaps of débris to form taluses on the more nearly level land below. The outweathered cross-section of the bed may be called its *scarp*, a term that is applied to any steep rock-face. The whole outweathered termination of the dipping bed, that is, the scarp, the adjoining part of the dip-slope, and the edge formed by them, is usually specified as an *escarpment.* Since this word has received more popular uses, W. M. Davis has followed R. T. Hill, who, in 1896, denoted the feature as a *cuesta* (16).

The first rivers on the upraised dome will run down the marginal slopes, and their direction will thus depend on the dipping surface. They are aptly styled *consequent* streams by Davis. The scarps are developed by streams that run on the approximate plain of subaerial denudation, the *peneplain* (or peneplane) of Davis, along the lines where the strata meet the surface. These streams are thus tributaries of the consequent streams, and have been styled *subsequent*. Furthermore, comparatively short streams fall over the scarps, and tend to cut notches in them; Davis names these *obsequent* streams.

The scarps are limited in height by the thicknesses of the resisting strata, and the edges tend to become rounded as time goes on. The consequent streams, being older than the escarpments, and cutting their way downward while these develop, may run right through these prominent features of the surface (fig. 5). In time they may be found rising on land far lower than the crests of the escarpments that ring about the excavated central area. The material from the centre has been carried out by the consequent streams through the gaps maintained by them in the escarpments.

But many of the consequent streams diminish as the escarpments grow. The subsequent and obsequent streams, and the general denudation by wind and weather on the scarp, cause a continuous retreat of each escarpment. The removal of the higher portions of the uptilted strata reduces the area that once fed the streams, while they are shortened by the cutting away of ground beneath their heads. Since this process is

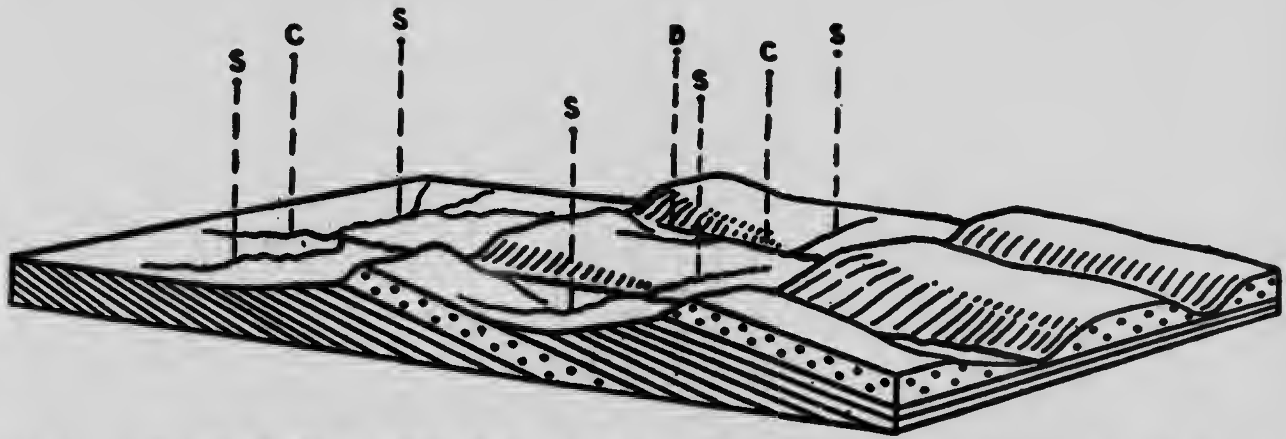

FIG. 5.—Block of the earth's crust formed of uptilted strata with unequal resistance to weathering. Two escarpments have arisen, and the consequent streams C, C, now traverse one or both of these, their valleys being steep-sided in the more resisting strata. S, S, subsequent streams. The recession of the left-hand scarp and the rapid lowering of the ground at its foot have led to the beheading of one of the consequent streams, and its former ravine appears as a dry gap at D.

due to the erosive action of the subsequent and obsequent streams, the subsequent streams and their tributaries are said to *behead* the consequent streams. The rainfall that was once distributed among a large number of consequents now goes to swell a smaller number. These survivors accordingly grow stronger, and they deepen their notches through the hills. No subsequent stream, however, can lower its valley-floor below that of the consequent into which it runs, and hence the general degradation of the district depends on the resistance offered by the most resisting of the uptilted strata in the course of the consequent streams.

As a rule, the domes reared above sea-level are so large that in any locality which is small enough for detailed study a series of escarpments appears as a series of parallel ranges of hills striking in straight lines across the country. But now and then compact instances occur, like the inlier of Woolhope, near Hereford, or the bolder domes of Old Red Sandstone overlying softer Silurian shales in southern Ireland, where the whole significance of escarpment or cuesta structure may be realised. The famous example of the Weald of south-eastern England is an elongated dome cut away at one end by the sea.

While folded mountain-chains, the most

tremendous results of crust-movement that we know, are essentially axial structures, they also must die away at their ends into less disturbed lower grounds. In their details they include many local wave-tops and wave-hollows (fig. 2), and the former give rise, on the denuded chain, to rings of escarpments with their scarps facing inwards, while the latter become weathered out as masses showing basin-structure and bounded by scarps facing outwards. It will be at once clear that the scarps are the same in both cases. Those facing outwards from tectonic basins face inwards towards the adjacent domes.

We have dwelt on this wave-structure, resembling that of a tumbled sea (p. 34), and on the effect that it has on a surface of denudation, as an introduction to the country that lies between central England and the Alps. The crustal storm which is impressively recorded in the overtoppling of the earth-waves, and their actual breaking asunder, along the line of a great mountain-chain leaves its traces as a kind of ground-swell far beyond the region of intense activity. The wave-lengths of the folded strata rapidly become longer as we pass northward from the Alps and Juras; but it is of considerable interest to trace in Champagne, Normandy, or Surrey the youthful processes of growth

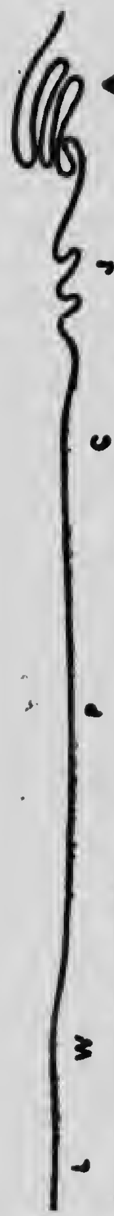

FIG. 6.—Diagram, greatly exaggerated in vertical height as compared with the length, to show the earth-wave spreading from the Alpine storm-region on the right (S.E.) to the Cotswold region on the left (N.W.). A, Alps. J, Jura range. C, Côte d'Or. P, Paris basin. W, Wealden dome. L, London basin.

that have reared the giant chains of central Europe.

Deposits of the Eocene sea remain in both the London and the Paris basins, and have been folded equally with the rocks below them. Oligocene beds may be seen uptilted on the back of the Eocene and Cretaceous of the Isle of Wight. In the Paris basin, Miocene beds are affected by the system of gentle folds, while relics of Lower Pliocene marine deposits occur on the crest of the Kentish downs. Hence the earth-movements that have given us the London, Hampshire, and Paris basins, three broad synclinal areas in which Cainozoic strata have been preserved, are of late Miocene and in part Post-Pliocene age. They are thus of the same age as the main crumpling of the Alps (fig. 6).

In a few days' journey by road, we may trace out the great waves on the swelling surface between the Severn valley and the Rhone. The dome of chalk that was formed in western England (p. 36) in late Cretaceous and early Eocene times underwent denudation thenceforward to our own day. Jurassic beds beneath it became exposed, and their limestones form an escarpment running from the Cleveland Hills of Yorkshire down to Dorset, and culminating above the Severn in the fine edge of the Cotswold Hills. The present dip-slope of these limestones, which is so noticeable when we have climbed up the scarp at Birdlip, Broadway, or Edge Hill, is a first sign in this area of the Alpine folds. We travel for fifty miles or so south-eastward, descending with the dip and here and there ascending subsidiary scarps, until, at Tetsworth on the Gloucester road, at Wendover on that from Worcester, we see rising up against us the second great escarpment, that of the Upper Cretaceous chalk, forming the Chiltern Hills. The back of this escarpment drops with the dip of the strata to sea-level at London, and then the floor of the synclinal basin rises southward, till we find the other escarpment of the Chalk in the North Downs of Kent and Surrey. Near Reading or Watford we have passed from the chalk surface, with its thin soils and pastures of short grass, to the

Eocene strata of the London basin. Outlying patches, and a widely-spread deposit known as the "clay with flints," show that these beds at one time extended much farther to the north and west. The London Clay provides an undulating country of small hills, since denudation attacks it almost equally in any direction. Here and there sandy strata of the Paris series have been preserved, giving us the plateaus of Aldershot and Weybridge, covered with dense firwoods and too dry for agricultural land.

On the other hand, the loamy and chalky Glacial boulder-clay, and the gravels washed from it at various times, ameliorate the heavy London Clay, and the gravels have contributed largely to the drainage and the health of London. The "drift" maps of the Geological Survey should be studied by any one who would appreciate the complexity of the deposits in the London basin.

The Thames, rising far west upon the dip-slope of the Cotswolds, and cutting through the edges of the Cretaceous beds between Abingdon and Goring, is clearly consequent upon the Alpine folding. It originated on a plateau of chalk that is now lost to us by the wearing back of the Chiltern scarp. The recession of the Cotswold edge, through the action of the Severn tributaries, is depriving it still further of its head-waters by the reduction of their gathering-ground. It is highly probable that the Thames once flowed from the Welsh highlands, and that it has been beheaded by the development of the Midland plain in the soft Lower Jurassic and Triassic rocks that underlie the Cotswold limestones. On the east, as was pointed out in the last chapter, it has been greatly shortened by subsidence, and by the admission of the North Sea over the former delta of the Rhine.

Though fishing folk doubtless spread along the shores of the tidal estuary of the Thames, the early inhabitants of the basin sought the hills. Beech-forests were commoner in old days than now upon the uplands; but clearings and camps could be more easily made there than in the overgrown and often marshy Eocene land. Family mistrust and tribal jealousy led men to entrench their villages on the high escarpments of the Chalk. Their ringed earthworks are still conspicuous on the edges, and the low light of sunset or of dawn picks out the mounds of their tombs across the plateaus, and even among the cultivated fields.

The reduction of centres of government, and the arrival of overlords from the continent of Europe, directed attention towards the site of London. The armed immigrants found in the Thames a passage always open towards their eastern homes. In time, those inland people who survived from the older scattered folk began to feel the call of the city and the attractions of external trade. Until the invaders came, they had long forgotten Europe to the east of them, and the arrival of their ancestors through peatland and forest where elephants and rhinoceroses browsed. The North Sea subsidence and the erosion of the Strait of Dover had cut them off from the conflicts of continental races. Hence Roman London presented as great a contrast in its primitive surroundings as Bulawayo presents in the bushland at the present day. Roads, the first requirement for stable government, began to replace the dubious woodland ways, or the trampled tracks on the chalk uplands, marked by rows of sacred thorn-trees. From that day to this, traffic has converged to the central synclinal of the Chalk, and in our time the corridor-trains from the Pictish regions of the north thunder down on London almost on the tracks of Roman roads.

We pass south from the London basin up the side of an anticlinal, from the top of which the Eocene beds have been worn away. The arch of the Chalk that lay beneath them is, however, complete in Salisbury Plain, and its south side dips down to form the complementary Hampshire basin. From Farnham and Petersfield eastward, the crest is denuded so as to expose the Lower Cretaceous strata, and even a patch or two of Upper Jurassic is revealed in the east of Sussex. This great breach in the anticlinal forms the wooded inlier of the Weald, on which the streams now rise that notch the chalk escarpments of the North and the South Downs.

These two escarpments, and the parallel edges of Lower Cretaceous sandstone within them, form the most marked features of south-eastern England. Yet they have been developed since the Pliocene sea entered on the district. The trend of the anticline from which they were evolved was determined by the older Armorican trend beneath it. Numerous borings for water and for coal have proved the existence of a ridge of folded Silurian, Old Red Sandstone, and Carboniferous rocks, an extension, in fact, from the south of Wales and Ireland, beneath the Mesozoic strata of the London basin. This ridge stood out on the land-surface in early Cretaceous times, just as the Mendip Hills, a part of the same chain, now stand out near Bristol. The sea flowed over it in the middle of the Cretaceous period, depositing the Gault Clay, succeeded by the Upper Cretaceous limestone series; and the

Alpine folding then moulded its curves upon the buried obstacle. At Guildford, the Chalk dips north at 85°; but otherwise the dips are gentle round about the Weald, and the whole arch remained sufficiently low to admit the sea over south-eastern England by a small subsidence in Pliocene times. The same subsidence allowed Pliocene strata to be deposited on the Armorican ridge of Brittany.

The traces of this sea occur in the form of iron-stained sands on the very edge of the Chalk escarpment in eastern Kent. At Lenham, between Maidstone and Ashford, they have been lowered into hollows developed by solution of the chalk, and an unmistakable marine fauna of Lower Pliocene age has been thus preserved. A. Jukes-Browne writes (*Stratigraphical Geology*, 1912, p. 593): "The Lenham Beds are mere remnants of a deposit which must originally have had a wide extension, not only in England but eastward through Belgium." The greater part of the excavation of the anticlinal inlier of the Weald by the action of rain and rivers must have occurred since Middle Pliocene times.

The crest of the original arch of chalk had no doubt been greatly thinned while terrestrial conditions prevailed here during the Miocene period. When the uplift took place that drove out the Pliocene sea, the rivers running northward washed pebbles from the Lower Cretaceous sandstones on to the broad dip-slope of chalk, and we may find them there to-day in the dry channels of beheaded streams. The subsequent streams, however, that were working out the escarpments lowered the central area so rapidly that only a few main consequent streams survived, and the Wey, the Mole, the Darent, the Medway, and the Stour, now record the former abundant flow of water down the surface of the Wealden dome. Looking across the Weald from near the Dorking gap, which has been carved out with remarkable steepness by the Mole, we note the similar notches in the South Down rampart, where the southward-running consequents flow directly to the sea.

The dry valleys that we have mentioned as representing beheaded streams are common features of the dip-slopes. Old red brick farm-houses often stand in them, sheltered by trees, which are scarce on the open uplands of the Chalk. Some of these valleys have been cut down to the usual level of the water-table in the porous limestone, and springs rise in them, fed by the general precipitation on the downs above. But these springs have not carved out the present hollows, which sometimes sweep upward, with smooth green sides, until they cut the edge of the escarpment at some point that once lay in the middle of an old river-course. Here and there the head of an obsequent hollow, one of the *combes* that form such marked recesses in the scarps, coincides with an old consequent stream-cut and a pass has developed across the ridge.

The excavation of the Weald has in itself reduced the rainfall on the anticlinal, and the surviving rivers are not engaged in serious work. Far more effective denudation is going on where the escarpments are crossed by the sea at Eastbourne and at Dover. Crescentic cracks develop on the grassy summits of the cliffs, slips of rock are common, and the Post-Pliocene passage is still being widened by the waves.

A large part of the Hampshire basin has been lost by the expansion of the English Channel, and the severe crumpling in this area doubtless laid the supporting Chalk more open to attack. The bands of black nodular flints, marking the bedding-planes along which they were developed, are seen to be steeply tilted in the Isle of Wight and along the Dorset coast. The axis of the Isle of Wight is formed by the upfolded Chalk on the south side of the Hampshire synclinal. The scarp here faces south, but the dip-slope is almost vertical, and the whole thickness of the Upper Cretaceous series is traversed in about half a mile, instead of in fifteen miles, as is the case to the south of London.

Along the line of Chalk downs that rise in grey-green rounded masses behind a fringe of crumpled Jurassic beds in Dorset, the Alpine movements have produced long faults and overthrusts (17). Some of the movements took place here in Middle Cretaceous times, before the overflowing sea came in; but we may observe in the Upper Jurassic beds of the delightful coves at Lulworth models of the contortion and recumbent overfolding that are conspicuous on a large scale in the Alps.

When we cross the narrow strait that divides us from the Continent, we find at Boulogne the eastern end of the anticlinal Wealden dome. The Paris basin repeats the features of those of Hampshire and of London, with which it was once continuous, but on a more complete and broader scale. The record of Cainozoic events is here almost perfect, up to the opening of Pliocene times, after which only land-deposits have accumulated. At Calais we enter on the great Eocene lowland that makes northern France a part of Flanders. Windmills, canals, boats that sail amid cultivated fields across the landscape, give to the Nord and Pas-de-Calais the unconfined air of Holland. To the south the Chalk rises as plateaus, almost level, and easily cut into by the streams. The local dominance of these platforms contributed to the notable successes of Crécy-en-Ponthieu and of Azincourt.

From Dieppe we enter on the Norman country, and the rolling uplands of chalk, with woods clustering in the hollows, remind us at once of southern England. The towns are set in the long valleys, beside the Somme, the Oise, or the great consequent river of the Seine. Primitive hamlets alone occupy the plateaus, where water is as scarce as it is on Salisbury Plain. On the Cainozoic beds round Paris, the State has preserved considerable forests, through which we may travel for miles along dry and often sandy roads. Elsewhere, in the wide clearings of the country, square-built farms and the church-spires of little market-centres form the only features among the unfenced fields.

The Alpine ground-swell has here been of the gentlest character. Yet we are on the downslope of a broad earth-wave, the crest of which lies 250 miles (400 km.) to the south-east. The general slope of the land is shown by the courses of the Marne and Seine, which, like the Thames, rise on Jurassic strata emerging from beneath the Chalk. If we neglect the local incident of the Wealden anticline, we may say that one great shallow synclinal (fig. 6) stretches from the Cotswold edge to that of the Plateau of Langres above the Saône (18).

This synclinal must, as we have previously pointed out, be part of a spoon-shaped downfold. The great basin that includes those of Paris, Brussels, Hampshire, and London is bounded on all sides by a ring of upturned Jurassic rocks. We can follow these round from the Cleveland plateau in Yorkshire till they are cut off by the sea at Weymouth; they reappear on the Norman coast at Caen, and stretch towards the lower Loire, where the Cretaceous sea overlapped them and spread farther than they on to the Armorican land. They swing round eastward along the north of the Central Plateau, as an upturned edge to the lowland of Touraine, and their dip forms the long descending slope, on which one may see the towers of Bourges across fifteen almost level kilometres. Thence we follow them north-eastward to Langres and Nancy, and to the plateau that was so shrewdly included in the German annexation west of Metz; and so up to the Belgian border in the Ardennes. The Cretaceous margin of the great basin probably once extended very generally beyond that of the Jurassic rocks, and it can be traced round the Ardennes, crossing an Armorican axis, to join the Chalk of Münster. We now lose the rim of this broad Alpine downfold beneath the recent incursion of the North Sea; but the discovery of numerous débris of Jurassic strata on the shore of the Skagerrak gives us a clue as to where the margin runs to join the cliffs of Scarborough.

It is of interest to note the same synclinal structure in the great basin of Aquitaine. Here the Jurassic and Cretaceous beds were upturned to form the southern margin when the Pyrenees grew in Oligocene times; but the marine Miocene faluns (p. 42), and the subsequent terrestrial Pliocene beds containing the remains of elephants, give a date for the final folding and uplift of the country. The Jurassic strata emerge above Montauban and Cahors, as plateaus of white or yellow limestone, yielding thin soils, and dry and forbidding to the farmer, who looks down their dipping surface to the tempting vineyards of Aquitaine. These strata are continued, with Cretaceous beds above them, to the sea at La Rochelle, and at Poitiers they unite with those forming the margin of the Franco-English basin. The two great plainlands of France, which were added to Europe by the Alpine movements, are thus like a pair of saddle-bags flung over the back of the Armorican substructure. From late Cretaceous times onward, the crystalline masses of the Central Plateau and Vendée have divided the deposits of the north from those of Aquitaine.

Whether we continue our journey out of the sub-basin of Paris by the valley of the Marne or of the Seine, our road lies for a long time in Cainozoic country. Level stretches of Oligocene strata, retaining ample forests, form the surface; the streams cut through them, exposing Eocene clays and sands along their shallow valleys. At Fontainebleau the Oligocene sands, recalling one of the last marine episodes in the basin, have become locally cemented by carbonate of lime, and the tumbled rocks, with their suggestion of a savage landscape, go far to console Parisians for the general flatness of their homeland. Close at hand, at Moret, which was once a frontier-town of France, we pass through the towered Porte de Bourgogne into a new country to the east; the Chalk begins to rise beneath us, and we can already picture the riders of Burgundy sweeping through this open territory from their strongholds in the valley of the Rhone.

Somewhere on the line from Auxerre to

Bar-le-Duc, we cross the margin of the Chalk, the complementary escarpment to that of the Chilterns, if we take a broad view of the Franco-English basin; and then the surface leads us upward, at twice the height of our own Cotswolds, on the long Jurassic dip-slope to the edge of the plateau above Dijon. The rivers running down on Paris dwindle on this upland, and at last a civic notice-board calls attention to the sources of the Seine. We are approaching the edge of the Langres plateau, and soon there lies below us one of the great features of Cainozoic France, the long depression of the Saône and Rhone.

In its upper part, this Saône-Rhone valley is floored with downfolded Jurassic strata. Before this folding was complete, and before the Jura range had been pressed up against the old knot of the Black Forest and the Vosges, the Miocene sea found a way here into Switzerland (I, 1, 387, and 2, 505). Farther south along the depression, its western shore-line was the faulted edge of the Central Plateau, a relic of Armorican Europe, against which the Cretaceous seas had also lapped. Its eastern shore, feebly marked at first, grew more and more definite as the Provençal Alps arose. In early Pliocene times, the whole floor of the depression became sufficiently uplifted to undergo erosion by a Pontian predecessor of the Rhone. Then it sank in the Placentian epoch, so as to admit a narrow arm of the Mediterranean to within a few miles of the site of Lyons. At this epoch, the upper part of the valley, west of the well-grown Jura chain, was occupied by a lake, which gave us the interesting deposits of the plain of Bresse, and which is still recorded in the pond-set plateau of the Dombes.

From the highland above Dijon, where walled Burgundian villages keep the edge, we see the blue ranges of the Juras, band on band, on the sky-line forty miles away. The wide pebble-filled valley below us, in which the Saône and the Doubs flow from the southern spurs of the Vosges, is continuous southward with that of the Rhone. Suess aptly calls the latter "the lower valley of the Saône." In the alluvial floor at Dôle a portion of a buried Armorican ridge remains upstanding, over which the Jurassic and Cretaceous beds were bent, and which once united the Central Plateau and the Vosges.

Between Langres and Dijon, the Jurassic beds of the high plateau are not cut off in a continuous scarp, but are folded and partly faulted down to form the floor of the Saône depression. We thus stand on the side of a synclinal, a broad and gentle earth-wave.

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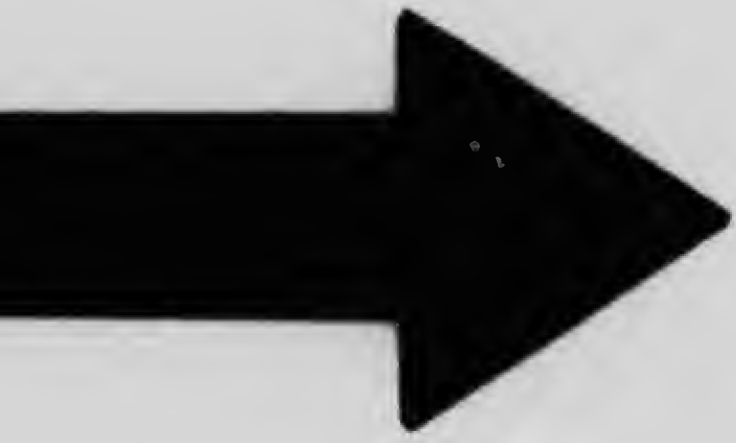

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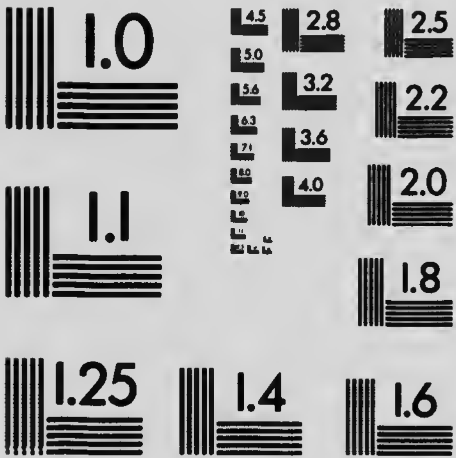

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Where shall we find the corresponding rise of the next wave?

The answer lies in the far ranges of the Juras. There we shall meet the edge of the European earth-storm. The widely spaced escarpments of the Cotswolds and the Chilterns on the one hand, and of the department of Marne and the Langres plateau on the other, are repeated again and again in the Juras in the course of a few miles (19). The Greensand ranges and the Downs of south-east England are represented by local strips of Cretaceous strata, caught in sharp synclinal folds. Dip-slope and scarp succeed one another at almost equal angles to the horizon, and the denuded folds of limestone, viewed end on from some transverse valley, have the effect of jagged mountain-peaks. Though much of the region was reared into dry land in Middle Cretaceous times, it was again covered by the Helvetian sea, and the main folding was practically Pliocene. Here once more we note the recent origin of features that dominate the European landscape.

The Saône-Rhone valley still provides the main route south to the Mediterranean. The Middle Pliocene sea has left it, and the river is again an eroding agent under the dark wall of the Cevennes. The detritus of the Vosges and Switzerland, and of the crumbling

Cainozoic beds on the foothills of the western Alps, has gathered on the Mediterranean shore as a broad delta, growing seaward in its salt lagoons. On its more stable inland edge the Roman cities of the south were seated. The tide of conquest moved up the valley, reaching even to Britain, until in turn the overlords of Paris laid claim to the imperial land. From the eighth to the tenth century the Mediterranean again made itself felt along this highway, when marauding Saracens reached as far as Besançon and Grenoble. At present the ancient transcontinental traffic to and from Britain is revived. Thousands of travellers to Africa and the East see nothing of the gate of the Mediterranean. The long trains steam out from Paris across the rising plateaus; they struggle down the dissected edge of the Côte-d'Or, amid a series of ravines that correspond with the Avon vale near Bath; and from Dijon they follow the great Pliocene stream-cut on their way to the oldest port of France.

CHAPTER VI

THE VALLEY OF THE RHINE

At the present day, the drainage of Switzerland is so largely effected by the Rhine that we are tempted to connect the detrital flats of Holland with the Alpine uplift. Napoleon Bonaparte, with characteristic acuteness, laid claim to the Netherlands as an offspring of the Helvetia which he had recently annexed to France. The Rhine valley, however, has a composite history, and the through passage from the North Sea to central Europe is one of the youngest features of the continent.

The contrasts of scenery in different parts of the course of this great river are indeed enough to raise enquiry. The higher reaches are torrential, and the valley-forms are thoroughly immature. The Hinter Rhein, rising in the glaciers of the Adula west of Splügen, at a height of 2000 metres (6500 feet) above the sea, competes, on the very crest of the Alpine core, for water that flows to the Mediterranean. Here the dissection of the frost-shattered gneissic highland provides every opportunity for river-capture. The tributaries lying to the south-east have already trenched on what may be called the Italian area, and have worked back almost into the valley of Chiavenna. This expanded fan of streamlets unites above Andeer, and the Rhine is thence clearly consequent on the Alpine chain. It is still engaged in cutting the gorges of La Rofna and the Via Mala, where the road is carried in the rock-wall high above the river, and where we can hear the water roaring in its cleft two hundred feet below.

We have here a fine example of the carving of a ravine even in a wet country, where the fall of the river is sufficiently steep to allow the deepening of the valley to keep ahead of the widening action of atmospheric water on its walls. It is noticeable that the gorge is narrowest where it traverses limestone, a rock with well developed vertical joints and capable of attack by solution as well as by abrasion. But at Thusis, under the daring castle of Hohen Rhätien, we come out on a valley widened in glacial times, into which the Rhine probably tumbled as a waterfall, when the ice had melted, and before the river cut the Via Mala gorge. Alluvium now spreads in this part of the valley, and is emphasised and added to at every flooding of the floor.

The Vorder Rhein comes in further down at Reichenau, as a tributary descending along the strike of the range from the Oberalp near Andermatt. It has been forced to cut its way through the débris of a huge prehistoric landslip, which fell from the mountains above Flims, and which added fifteen cubic kilometres of Mesozoic limestone to the Alpine waste along the valley. The magnitude of these processes, which are no longer possible among the worn-down ranges of the British

Isles, may be realised when we note that a group of hills 1800 feet in height was thus built up in the groove already carved out by the stream (20).

The flooded ravine occupied by the Walensee is thought by some to have been at one time traversed by the Rhine. At present a very slight excavation in the alluvium would turn the river at Sargans along this groove. But a wide valley, with sheer walls in places, which were doubtless undermined by glacier-ice in the cold epoch, now carries off the Rhine in a direct course to the Miocene lowland of South Germany.

The rock-floor of this valley, crossing as it does the trend of strata of various hardness, is doubtless irregular, with steps in it that were not entirely removed by glaciation. But it has become deeply covered by sheets of alluvium, which proclaim the latter-day destruction of the Alps. The Rhine meanders on this level modern surface, and, despite of correcting walls, occasionally floods across it, covering even the pebbly roads. Its entry on the Lake of Constance is across delta-land.

If these reaches among the mountains emphasise the dissection and decay of the folded Alpine chain, the youth of the chain itself is at the same time manifest. The sheer precipices and pinnacled arêtes, the cirques not yet cumbered with detritus, and often retaining glaciers in their floors, the frequent landslides from the heights, which fail to choke the deepening gorges, alike testify to the immaturity of the landscapes. The fall of rock-masses in the foothills, where the overfolded strata are still in a state of strain, may often be due to relief by fracture, and thus to the very forces that raised them to their dangerous eminence.

The lowland, which is thus profoundly modified by materials imported from the Alps, illustrates the vast amount of denudation for which glacial conditions were responsible. In Pliocene times, however, denudation by streams must have been already active, and the early Rhine flowed by some course northward, perhaps turned aside by the Armorican horst of the Black Forest. This mass controls its course to-day between Schaffhausen and Bâle. The river as it emerges from the Lake of Constance has cut boldly into the Miocene strata, for it has to drop 440 feet on its way to Bâle. At Neuhausen, just below Schaffhausen, it has been stayed by an outcrop of resisting Jurassic rocks, which it has notched back to this point, and over which it plunges vertically in a fall of fifty feet. Lower down in its swift course, it has found at Lauffenburg the gneiss of the Black Forest under a covering of Triassic beds. Unable to wear away this obstacle, it descends in picturesque rapids that give no hope for navigation. It then arrives in Bâle, still between high banks, as a great green Alpine river, flowing quickly towards the west. On its way it has been swollen by other consequent streams of Alpine origin, notably by the Reuss, which flows from the centre of the chain; but the consequent streams west of Lucerne, descending into the great depression between the limestone foothills and the Juras, fall into the Aar before they reach the Rhine. The Reuss is of interest as the survivor of a number of primitive rivers, which have been beheaded by the development of the groove of the Upper Rhone, carved out south of them almost along the axis of the Alps.

At Bâle the most casual observer will note a new phase of the Rhine valley. The river turns abruptly north in an alluvial country; the wooded highland of the Black Forest rises on the east, while soon the corresponding masses of the Vosges appear upon the west. There is room for more than one river in this wide level tract, and the Ill runs through Mülhausen parallel with the Rhine, rising in low hills west of Bâle, and pursuing its course in the great valley, the mountainous walls of which are twenty miles apart.

This remarkable groove, forming the greatest natural highway of central Europe, continues northwards as far as Mainz. There are considerable terraces of detrital matter on the west side of the valley, but they form no natural passage from the lowland to the Vosges. Above them, at Weissenburg, for instance, the hill-slopes rise as something entirely distinct, and the Alsatian roads lead up from the commercial centres in the valley to a land where deer move through the forests, and where little red-roofed villages nestle in clearings by swiftly falling streams. The Rhine alluvium extends over the east half of the valley, and the river is reached through belts of scrub, and across old swampy loops; among these the main stream flows majestically, though checked from wandering by artificial banks.

In old days, the alluvium formed very doubtful ground, though cities held their own on it. From Karlsruhe to Germersheim, the valley-floor is set with curving lakes, the relics of lost meanders, and the shifting Rhine has failed as the boundary of states. Below Worms the valley expands still further, and the broad groove that we have followed for 180 miles terminates in the basin around Mainz. The Armorican range of Hunsrück and Taunus here rises right across the river-course; but an important arm of the basin, filled with detrital deposits, spreads up past Frankfurt to the Vogelsberg.

The Rhine, however, does not turn this way. It seems to make light of the obstructing Hunsrück, and enters the plateau-edge by a gorge that exposes the tilted rocks on either side. Short lateral streamlets, running steeply from the uplands, notch the slaty walls and leave prominent bluffs between their courses. These jutting eminences have been seized on as the sites of castles, approached by zig-zag paths and practically impregnable from the river side. Except for the great bend at Boppard, the course of the Rhine is almost like a knife-cut across the Devonian hills.

At Coblenz there is a remarkable widening of the valley. Ehrenbreitstein dominates the city from a high rock-platform of the upland, a modern representative of the feudal strongholds; but beyond it a country of lower hills extends as far as Andernach. The road and railway on the left bank cut across a broad flat of alluvium. Then the gorge-feature is repeated, but remains milder in its character down to Bonn.

At Bonn the north side of the Armorican upland has been notched back widely. The valley expands into an open plain, useless for independent bandits, but suited to the dignity of walled encampments and imperial towns. A Cretaceous synclinal, its limestone floor lying partly below sea-level, opens up to left and right, and over it the Rhine meanders on what is practically delta-land.

It is clear that the most southern and energetic part of the Rhine-vale had no existence prior to the upheaval of the Alps. The marine Middle Miocene clays of St. Gallen, which come down to the Lake of Constance, and are thus included in the valley of the Rhine, are involved in the Alpine movements and also limit the date of this part of the stream. The first waters from the Rhætian Alps may have been carried by the sea that lay in the Helvetian depression eastward towards the Hungarian branch of the Tethys, or westward into the groove now occupied by the Rhone under the Central Plateau of France (p. 42). When the epoch of the marine molasse (p. 40) was over, and when lakes and dry land stretched between the Juras and the growing Alps, a good deal of the Rhætian drainage probably went somehow northwards. A portion of it may have found a river running westward, ready to carry it away (fig. 7).

The Jurassic rocks of Schaffhausen (p. 95) are part of the series that rises as broad plateaus

FIG. 7.—Sketch-map of the valley of the Rhine, showing the chief structural regions.

in central Württemberg and Bavaria, and these rocks terminate in an escarpment facing that of eastern France. It requires little imagination to unite the two plateau-regions by an arch of continuous limestone strata across the Black Forest, the Bâle-Mainz valley, and the Vosges. This broad anticline would be of the same order as the folds that we have followed from the Cotswold Hills to Langres.

There is good evidence from fragmental relics in the area intervening between the French and German scarps that " at the close of the Jurassic period a continuous sheet of marine deposits, with level structure, stretched from Regensburg to Sedan " (21, 182). The absence of Upper Jurassic and Cretaceous relics makes it probable that this region was reared into an arch by the movements that set in generally in western Europe near the end of the Jurassic period. The arch, or more correctly dome, formed a southern part of the island that included the Harz Mountains on its northern edge (p. 28).

This island persisted for a long time, and was eventually incorporated with modern Europe by the growth of dry land round it. The Jurassic and Triassic dome that concealed the Armorican horst of the Vosges and the Black Forest was continued southward, first as a chain of islands and then as a promontory, in the Upper Cretaceous sea. During Cretaceous and Eocene times, this Mesozoic cover must have been thinned by denudation; but it was by no means worn through, even in its central area.

As the unrest that was first indicated by the Hebridean eruptions and by the rise of the Pyrenees spread to the Jura region, the components of the southern promontory of the dome were perpetuated as mountain-ridges, while the long-strained arch to the north collapsed along its crown. The Armorican mass below had given way, and parallel faults lowered the surface as a great valley of subsidence from the north end of the Juras to the Taunus. This depression originated in Lower Oligocene times; but the Upper Oligocene beds laid down in it are affected by faulting, which cut up its floor into sinking blocks and caused it to deepen even in the Miocene period (22, 239). The compression accompanying the Alpine ground-swell forced up the Vosges and the Black Forest blocks, while the central band still sank between them (fig. 8). W. Salomon urges that lateral movements have also been considerable, and that the massive walls were pushed towards one another over rocks that had fallen in and that once lay above them (23). The

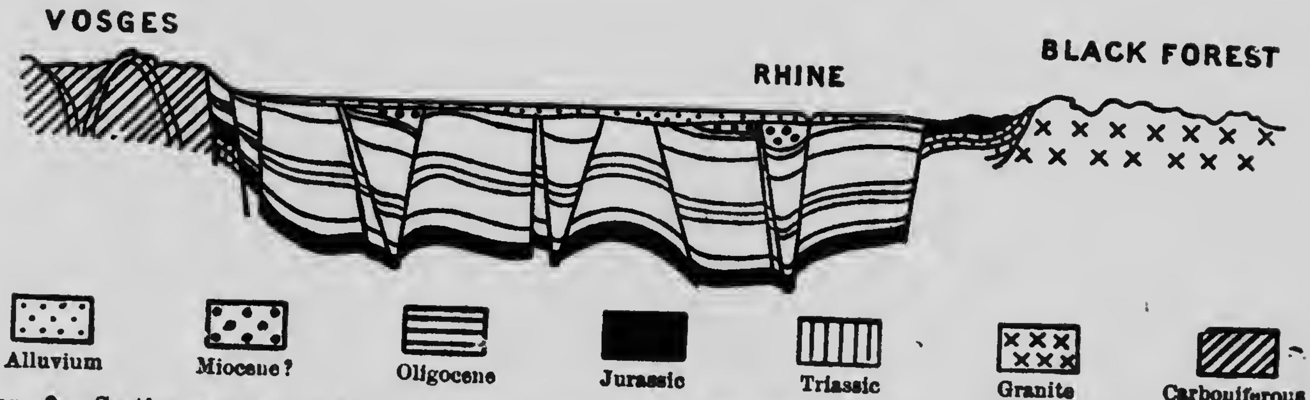

FIG. 8.—Section across the valley of the Rhine north of Mülhausen, showing its origin in downfaulting, combined with an uplift of the masses on either side. The date of the latest movements is shown by the fact that the faults affect the uppermost lacustrine beds, which are probably Miocene. The glacial and alluvial beds are not affected. The Jurassic and the underlying Triassic strata that once formed an arch across the Vosges and the Black Forest are seen to be carried down to various depths. The section (after W. Wagner and A. Tornquist) is based on numerous borings made for salt and petroleum in the Oligocene strata.

cumulative result is that along the Rhine-vale the cover of Jurassic and Triassic strata has been shifted 2500 metres (8200 feet) from the beds with which it was continuous, and now lies buried at thc bottom of a tectonic groove.

Lavas were at the same time squeezed up from below, and a volcano still forms an isolated hill, the Kaiserstuhl, rising romantically between Colmar and Freiburg above the alluvium laid down round it by the Rhine.

Local faulting also produced a basin in the heart of the upland north of Coblenz (p. 98), and the volcanoes of the Eifel and the Westerwald broke out in this weak area in the Miocene period.

The great trough-valley that is now occupied by the Rhine was thus developed in Oligocene times. By the middle of the period, the sea flowed from the North German region round the Taunus spurs into the newly formed Mainz basin, where the ground continued to sink as sediments were laid upon it. A sea also spread southward in an arm which almost communicated with that of northern Switzerland; but the Oligocene and later deposits that lie across the valley west of Bâle are freshwater or terrestrial.

E. Haug, following van Werveke, points out that the marine Oligocene series in the

Alsatian part of the Rhine depression begins with strata distinctly lower than those found near Mainz. Hence the sea in which these originated cannot have come in from the German north, but was probably an extension, round or through the Vosges, from that of the Paris basin. Present differences of level would not affect this argument, since so much warping of the region and movement along fault-planes have since gone on. In Middle Oligocene times, however, the Alsatian sea was connected with that of Mainz and northern Germany; but it was soon cut off by an uplift in the Armorican region north of Mainz, and the Rhine-groove became terrestrial, with lakes in which plants and freshwater molluscs deposited their remains. Any streams then flowing along the great depression ran southward towards the rising Jura region, and thus entered the Miocene sea of Switzerland at the same time as the embryo Rhine.

When this sea was also driven out of Switzerland by the continued and now culminating Alpine uplifts, the northward-flowing and consequent waters from the Alps fell into the depression at the foot of the Black Forest, and ran across the north end of the Juras, the surface of which appears to have been then a peneplane (E. Brückner, VIII, 479). In what is known as the Sundgau conglomerate, near Bâle, pebbles are found from the Alpine heights that are now drained by the Rhone; but nothing has been definitely traced from the more eastern highlands of the Rhine. The Rhine waters may have gone off into the Danube basin, leaving an early Rhone to cross the mouth of the present Rhine-gorge at Bâle, and to make its way thence south-westward along the valley of the Doubs. The whole surface of the Cainozoic ground of Switzerland has been so modified in Quartary times by denudation, and also by deposition of glacial drift, that it is hard to point out the precise channels of the Middle Pliocene (Placentian) streams.

Meanwhile, the Mainz-Frankfurt basin was being approached by the head of a river working back from the Cologne valley across the Armorican ridge, aided by fracturing and partial sinking of the mass. The floor of the Mainz basin, infilled with Lower Pliocene gravels, in which mammalian remains abound, at that time lay higher against the Hunsrück-Taunus hills. It was not difficult for a river across the upland to tap this basin and to carry pebbles from it down to the sea that covered Holland (24, 68). The mature valley-form indicated by W. M. Davis below Mainz (16, 106) was probably developed by this

Pliocene stream; the deep notch in its floor is due to the Post-Pliocene Rhine.

The Alpine movements had by no means come to rest. The Juras, continuing to rise in late Pliocene times, became dissected into their present ridges and valleys, and turned the early Rhone south-westward towards a low gap at Geneva. Here, in a country of fine limestone cliffs, it is still deepening its channel to the older lowland that lies under the wall of the Central Plateau of France. The crest of the Alps at the opening of the Quartary era lay far above the local snow-level, and two stages of glacial extension brought copious detritus to the lowlands. The warmer air of each interglacial age induced flooding as the ice melted away. The flanks of the Vosges and the Black Forest sent down glaciers towards the trough between them, and their deposits mingled with those that still accumulated from the lake which lay to northward and which had originated in Miocene times. On the uncertain ground near Bâle, Alpine water still flowed westward over an outwash-plain of shifting detrital beds, and so got across to the valley of the Doubs.

Soon after the close of the Pliocene period, the water that came from the limestone Alps north of the Rhone basin found itself unable to escape across the north-east portion of the Juras. It was driven eastward by the rising chain as far as Brugg, and there got into a channel at the foot of the Black Forest. This channel may have been already prepared by the backward extension of a stream running down the Jura slope to the Doubs by way of Bâle. The uplift then closed the passage to the Doubs, and the remarkable reversal of drainage occurred that has had so profound an influence on European history. The Reuss-Saône system was, in fact, cut in two by the latest movements of the Jura chain.

This critical stage in the evolution of the rivers was reached before the greatest extension of the Alpine ice. At first swampy conditions must have intervened, when the great river from the east spread out over the rising surface and some of its water slipped towards the trough to northward. But this trough soon received the full flow of the Alpine streams. It would be hard to conceive the magnitude of the change, had we not the modern example of the Salton Sink to guide us. The Colorado river runs from the cañon-country to the Gulf of California over a broad alluvial cone. In 1905, owing to some unduly effective irrigation-works, the water escaped northward into the depression of the Salton Sink, cutting its way down through old alluvium to a depth of seventy feet, and working back the head of its new valley at the rate of a third of a mile a day. If we can imagine a northward passage lying ready for the enlarged waters of the Salton Sink, at a lower level than that of the alluvial cone, we see how the Colorado might have been carried off to Los Angeles along the line now taken by the railway.

In the case of the Rhine system, the rising of the ground near Bâle corresponded with the upbuilding of the alluvial cone on which the Colorado runs. The whole stream, on some particular day, began to flow northward along the far older tectonic trough, carving away the infilling of detritus, washing back tree-stems that were floating quietly from the Lake of Mainz on their way to the Mediterranean, and finding, when it reached that lake, a notch sufficiently low for its escape across the Hunsrück-Taunus range. An enormous body of water was thus added to that which had formed in Pliocene times a mature valley across these hills. As the groove cut by the new stream deepened between its rocky walls, some of the superficial and Cainozoic deposits were carried northward out of the Mainz basin. The flank of the Armorican ridge still stood up as a barrier; but the young ravine ran like a knife-cut through it, and bore for the first time to the North Sea the water from the Alpine snows.

The Upper Rhine above Bâle was obscured and perhaps temporarily abolished by the great extension of ice that accompanied the third glacial episode in Switzerland. The valley-glaciers became confluent on their upper surfaces, through over-topping the frost-etched spurs between them. In what A. Penck calls the Riss glacial stage, the ice-front from the Bernese Oberland and the St. Gotthard reached nearly down to Bâle, and deposited its moraine-material along the southern slopes of the Black Forest. The melting of this great body of ice may have largely contributed to the excavation of the gorge of Mainz. As the ice diminished, the Upper Rhine ran along its edge; but there is no proof that it has now got back into its precise pre-Glacial channel.

About this time man came into the Rhine valley, not yet equipped for utilising its waters as a highway, but already competing with the elephants and rhinoceroses for a place on the forest-edges, and regarding with some awe the hippopotamuses bathing in shifting waters down below. Deeply covered in a pit of interglacial sand at Mauer, south-east of Heidelberg, 800 feet above the Rhine, a human mandible was found in 1907, which is probably the oldest actual relic of man in Europe. Flint implements fashioned by man, and much more durable than his bones, occur, however, in deposits of still earlier date.

We have now endeavoured to trace the history of the several sections of the valley of the Rhine. The oldest part appears to be the faulted trough, running from Bâle and Belfort to the Armorican highland above Mainz. This represents a marine inlet of the Middle Oligocene sea. As the same sea retreated from northern Germany, rivers began to spread from the Hunsrück-Taunus plateau, northward into the Cretaceous synclinal of the Antwerp-Münster basin, and southward into the Mainz basin, which was then occupied by a freshwater lake. One of the former series of streams prepared the way, as we have seen, for the Post-Pliocene Rhine-gorge through the hills.

The streams running down in late Oligocene, Miocene, and Pliocene times on Bâle can hardly be regarded as portions of the Rhine. Meanwhile, however, an Upper Rhine was forming somewhere on the Alpine ridge; but its course must have been so disturbed by the successive glaciations of its basin that we can only say that water was flowing northwestward somewhere in the lowland between the limestone foothills of the Alps and the Black Forest. During the dissection of the Alpine axis in Pliocene times, the long valley from the Oberalp to Chur was excavated, to be filled and modified by ice in successive epochs of glacier-extension. This excavation may be regarded as older than the Rhine-gorge north of Mainz, and the upper part of the Hinter Rhein system of valleys is probably contemporaneous with it.

It seems likely that the immature section of the Rhine valley from Constance to Bâle, with its waterfalls and its actual trenching on the spurs of the Black Forest, dates only from the development of the Lake of Constance, or at the earliest from the forcing of the stream northwards by the ice-front in the Riss glacial stage. The course of the Rhine below Constance, though in part indicated by the trend of Alpine water towards the Doubs valley at an earlier stage, seems to have been determined by the later stages of the Glacial epoch, and is thus an even younger feature than the gorge of Mainz.

The deeply trenched details of the Hinter Rhein valley among the mountains (p. 98) are obviously young, and afford some of the finest examples of active stream-erosion.

There remains the complex delta, which passes on the south very gradually into the level Flemish country, and on the south-east into the glacial terraces and alluvial land of Bonn. The history of this delta is the history of Holland. When the Miocene seas withdrew from the Batavian area, and volcanoes were spouting briskly in the Eifel and the Siebengebirge, the courses of streams from the Rhenish Armorican upland became lengthened northward. They deposited their alluvium over the uplifted coastal plain and perpetuated its uniform and gently sloping surface. The waste from England and the Continent, which were then united, combined to drive the sea farther and farther north in late Pliocene times, until the well-known "Forest bed" was formed in the North Sea area, as evidence of the extension of delta-lar p. 66). The outcrop of this bed at Cromer in Norfolk contains fossil plants that indicate a mild climate and the growth of woodlands like those of the district at the present day. These remains have been drifted from the more solid land on which they grew, and with them are found the bones of hippopotamuses, rhinoceroses, elephants, bisons, and hyænas, animals that were familiar to early man all down the valley of the Rhine (25).

It is tempting to picture the singular changes that took place in this shifting estuary in early Glacial times, when the Alpine water first reached it from the Mainz depression. Animals accustomed to roam freely from Germany to England found themselves cut off on treacherous islands through the development of new and rapid water-ways. The great extension of ice in Europe in the Riss stage of glaciation led to the disappearance of nearly the whole delta under a northern ice-sheet from Scandinavia. As this melted away, entirely new material was added to the emergent land, which had hitherto been built up by detritus from England or from Germany. At the same time, an increased flow from the Alpine region tended further to flood the country with muddy and pebbly deposits from the south.

The recent subsidence that has brought the North Sea down to Belgium (p. 66) threatens the present delta-front and the glacial débris heaped upon it. The Dutch maintain their country against meandering rivers behind them, and against the battery of waves in front, by the watchful care of a garrison facing out a siege. The highway of the Rhine enables them to bring stone from Germany, and their defensive dykes are now built with basalt columns, laid in cement upon their sides.

Otherwise, stone is procured from the blocks imported by the ice from northern lands. In central Holland, the passage from the modern Rhine-alluvium to the glacial sands is easily traceable by the presence of these crystalline boulders in any cutting in the heaths. But the country continues level as a whole, in spite of glacial deposition, and the tumbled forest-land near Laren on the south side of the Zuider Zee, with its mild undulations and its pleasure-resorts on tiny eminences, affords a welcome and almost romantic feature in the Netherlands.

The human interest of Holland, however, never becomes monotonous. The red brick masses of the towns and villages, against cloudy skies shot through by sudden sun-gleams, suggests the energy of men who built, with confident courage, upon the shifting edge of Europe. The uncertain soil is dredged up from watery acres to rear trading centres where citizenship is an honourable estate. The tall church-towers and turreted town-halls appeal to the traveller across miles of level land. The roads are commonly paved with brick, which develops small domes and synclinal basins as the soft ground yields beneath them. The main traffic, however, lies characteristically along the network of canals, and brown sails among lines of grey-green willows add another colour to the landscape. At the island of Dordrecht, the steamers that pass on the Merwede connect central Germany with the sea. We begin here to feel already the full force of the west winds; and the streets of Haarlem are gritty with clean sand that drifts in from the great wall of dunes. Throughout the country, windmills are used for working home-machinery as well as for larger industries. There is no need to set them, as in Pomerania, upon hills, for there is nothing here to check the wind.

Only the unfailing energy of the people, schooled by disaster on disaster, has reclaimed from the sea a land that lies below its level. The Middle Ages saw frequent inroads on the delta, and the Biesbosch south of Dordrecht still records, in its interlacing channels, the disaster of November 19, 1421, when seventy-two villages were washed away in a single storm. The Zaandam and Alkmaar area, north of Amsterdam, was devastated as recently as 1825.

The melancholy islands from Texel to Borkum, and away along the Friesland coast, which are enlivened only for a few weeks by the bathing-tents of summer-visitors, testify to older attacks of the sea upon the glacial drifts. A lake at one time occupied the centre of the Zuider Zee; the coast to the north was seriously weakened in the twelfth century, and during the next hundred years the sea worked its way southward, absorbing the lake and a large part of this perishable country (26, 4, 221). Though sea-going vessels now navigate the Zuider Zee, the Dutch engineers have long set their hearts on restoring its floor to the fluctuating delta of the Rhine.

CHAPTER VII

THE BALTIC LANDS

The most striking feature of the lands around the Baltic is the contrast between the northern and the southern groups. On the one side is the region now conveniently known as Fennoscandia, where the crystalline intrusive masses and the highly altered sediments that formed a floor to the Cambrian and Silurian seas reveal themselves over thousands of square miles, or are thinly covered in other places by glacial clays, gravels, and boulder-drift. On the south side is the great plain of northern Germany (27), expanded across Holland on the west and far into Russia on the east, where no hard rock appears upon the surface, and where Cainozoic and Mesozoic sediments are buried almost continuously under fifty to four hundred feet of drift.

Denmark is a mere level promontory, and its islands, with the exception of Bornholm, are marginal outposts of the plain. To arrive on the west of Jutland from the sea is like landing on the coast of Holland. Though many of the islands have swelling surfaces of low rounded corn-lands, and magnificent beech-woods descending to the water's edge, the scenic features are mainly due to man. An old red-roofed town, gleaming in the sunlight, is more conspicuous than the sandy hummocks of the land, and a picturesque tower, perhaps of some modern waterworks, calls attention to Laaland or to Falster from miles away across the sea. The rocky heights of Bornholm, however, are those of a peak on the submerged edge of Fennoscandia.

If we cross the Ems from Holland into Friesland, the country remains the same as that which we left behind in Drenthe. The fields are often peaty, and there are wide stretches of sandy heath. In shallow gravel-pits, we note everywhere the Scandinavian boulders. After traversing miles of level farming country, we reach a ferry on some river running northward, almost as still as a canal. It is hard to recognise the Weser, which has come down from the core of Germany. Across another gentle upland, we descend towards the broad and tidal reaches of the Elbe. Borings have here failed to penetrate the glacial covering at a depth of over 700 feet. In some cases near at hand, however, concealed hills of Miocene strata have been found within 100 feet or less beneath the surface.

On the south lies the great heath of Lüneburg, its surface swelling like a sea, a mass of irregularly heaped siliceous sands and gravels, washed by waters that long since have disappeared. Cup-like depressions and heather-covered mounds alternate across its surface. Here and there a more loamy patch invites the industrious farmer; but for the most part the country is a wild and unproductive waste. At Hamburg, arable land spreads eastward, and ten or twenty teams of horses may be seen together, ploughing in enormous fields.

To the north, Holstein repeats Friesland, and Schleswig repeats Holstein, but perhaps with fewer picturesque incidents of lakelets enclosed by wooded hills. On the east coast of these provinces, the rias of Kiel, Flensburg, and Apenrade indicate submergence and a loss of land, which took place, in one of many oscillations, about the end of the human stone-age. The northern part of Denmark shows a recent uplift, coastal plains appearing as a border to cliffs eroded by the sea.

Towards the east side of Schleswig and Holstein, a range of low hills makes an almost continuous feature, running at first north and south from the Danish border, bending south-eastward near Kiel, and traceable away to the north of Lübeck, and so into the plain of Mecklenburg. This chain of heights is composed of a great bank, as it were, of boulders, rising sometimes nearly 500 feet above the plain. It is the western part of a series of similar features that crosses the Oder between Stettin and Berlin and runs on thence to Danzig. This assemblage of mounds is known as the "baltischer Höhenrücken," or Baltic ridge. It can be traced northward through Jutland to the western coast at Bjovberg (7, 30).

Other ridges, composed of sand and water-worn pebbles, with irregular stratification, are found running approximately at right angles to the Baltic ridge. These are the same as the Swedish *åsar* and the Irish *eskers*, and are now commonly known in French literature as *oses* and in German as *oser*. They have winding forms and they occasionally branch, thus resembling rivers and their tributaries (28).

In other places elongated hills of boulder-clay rise above the plain, rounded off at their sides and along their crests, but without any particular structure when viewed in the cuttings of railway-lines or quarries. These are the *drumlins*, which are recognised now wherever continental ice has melted, and which were first appreciated by Maxwell H. Close during his investigation of the glacial phenomena of Ireland (29).

In the hollows of the interesting if monotonous landscapes of the Prussian plain, numerous lakes have gathered, mostly like large ponds. The red-brick villages cluster along their banks, under woods of birch and fir, which climb on the low hills that hem them in. In the great cultivated fields, one may see yellow sand turned up by the plough in one part, and stiff clay, full of boulders, in another. The handsome boulders of crystalline rock are carried down to the roadsides, to be broken up for the firm *Kaiserstrassen*, which bear from Emden to Memel the passage of imperial arms. The exposed portion of the largest boulder known in northern Germany, a mass of gneiss at Gross-Tychow in Pomerania, measures 3·74 metres in height, 15·90 metres (52 feet) in length, and 11·25 metres in breadth.

In the sandy stretches, fir-forests extend, perhaps for fifteen miles along the highway. The roads that lead to some clearing in their depths are deeply grooved and strewn with boulders, like those of the drift-country in Finland or New England. At times we climb, by long and scarcely noticeable slopes, to a height of 600 feet above the sea. In the north, and continuous with the great lowland, we see at times the grey-green waters of the Baltic, occupying what is merely a flooded portion of the plain.

The widely scattered boulders of crystalline rock, which cannot have been derived from any mass that is found in borings beneath the plain, have already turned our eyes to Scandinavia. The sands and loams in which they are embedded have also a northern origin. At present they are being cut into by rivers from central Germany and from the plateau of Bohemia; but a large part of the alluvium of these rivers is merely a rearrangement of the glacial drift.

The most remarkable step forward in the unravelling of the history of the North German plain is the verification of the glacial scratches that were observed by C. F. Naumann in Saxony as far back as 1844 (27, 105). Such markings, the characteristic records of the passage of land-ice, are now known on the surface of hard rocks in several places between Leipzig and Dresden, and in the Elbe valley in the neighbourhood of Magdeburg. The characteristic rounded forms of rock-floors worn by glaciers are also recognised. There is little doubt that such surfaces would be found on the resisting rocks generally beneath the plain, could we clear away the heavy load of ice-borne drift.

When we seek the cause of the surface-features of the Prussian plain, everything points to the successive stages of ice-extension that characterised the Post-Pliocene glacial epoch. But the highlands of central Europe were not in this case the source of the deposits. The chain of heights from Bjovberg in Jutland to

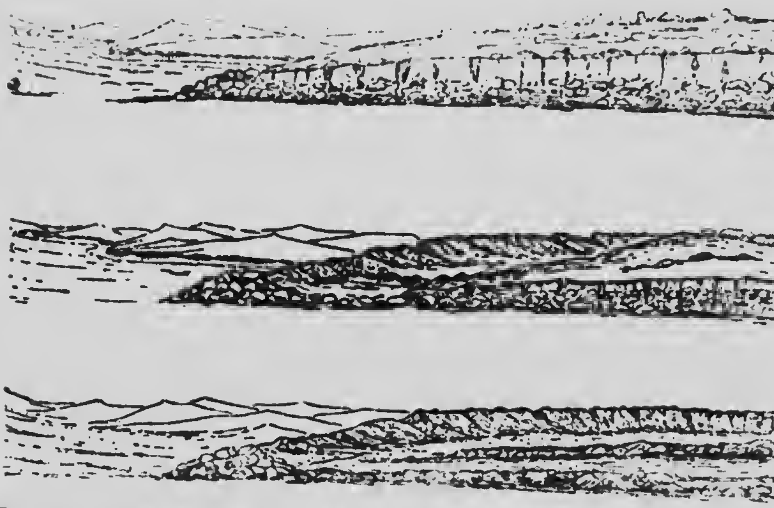

FIG. 9.—Diagrammatic views and sections illustrating the deposits left behind by a lobe of an ice-sheet of the continental type. In the uppermost view, the lobe is stationary; at its melting front it deposits a considerable terminal moraine formed from material carried on its surface and in its lower layers. In the second view, the lobe is shrinking, both horizontally and vertically, and its front now lies within the wall-like terminal moraine, through which water escapes freely into an outwash-plain. In the lowest view, the ice has melted away, leaving a thick layer of boulder-clay, on which an esker marks the course of a stream that once ran beneath the ice-sheet.

Danzig marks the margin of a mighty confluent glacier, the last ice-sheet from Fennoscandia, which remained stationary for a sufficient time to build up this terminal moraine from the débris carried in it (fig. 9). Outside the moraine-wall, level sandy deposits are common, which were washed from it and through it as it formed. Inside it, and over the country reached by a previous and maximum extension of the ice-sheet, boulder-clays and sands represent the materials borne in the ice and left behind when it was forced to melt. Such melting is not merely marginal. Over the whole surface of an ice-sheet, streams and sheets of water arise as the mass thins down in warmer times. Stones begin to appear freely on the surface. Eventually those layers are reached in which the débris has especially accumulated. The lower part of a great ice-sheet may consist of fifty per cent. ice and fifty per cent. continental waste. Even in Spitsbergen, the melting fronts of glaciers may be seen to be absolutely dark with mud and stones. When these lower layers are alone left, the transition is easy, by final melting, from the ice-sheet stage to the sheet of boulder-clay. Where distribution has been irregular in the moving ice, drumlins appear, their sides and ridges shaped by the purer ice that was pressed past and over them. Where streams run in courses melted out by them beneath the ice, the stones and mud fall into their channels from the walls. The finer part of the mud is washed away; the sand alone is left, and the stones become water-worn as they are swept along. But the floor of the inverted stream-groove may become choked, and the stream rises on its first alluvium. It cannot escape by lateral flooding, and continues to raise its channel upwards into the ice-sheet. At the same time, the ice-sheet is thinning from its surface. The sands and gravels of the sub-glacial river-course, hitherto banked up within the ice, are finally left as sinuous ridges across the country, absolutely independent of its earlier features. Where tributary streams came in, the ridges are branched. In this way the åsar or eskers arise, which geologists found so hard to account for when the glacial drift of Europe was attributed to floating ice.

In places on the melting ice-front, the débris is dropped in irregular heaps, while copious water from the ice-slopes plunges through it, carrying off the finer mud. Coarse sands and gravels then remain, as casual hills, giving rise to intractable and almost barren land. The Lüneburg heath is due to such conditions. It is a broad accumulation of the deposits known as *kames* in Scotland.

It is difficult to exaggerate the magnitude of the ice-invasion that spread in the Riss-stage over so much of northern Europe. We have mentioned (p. 66) the arrival of the

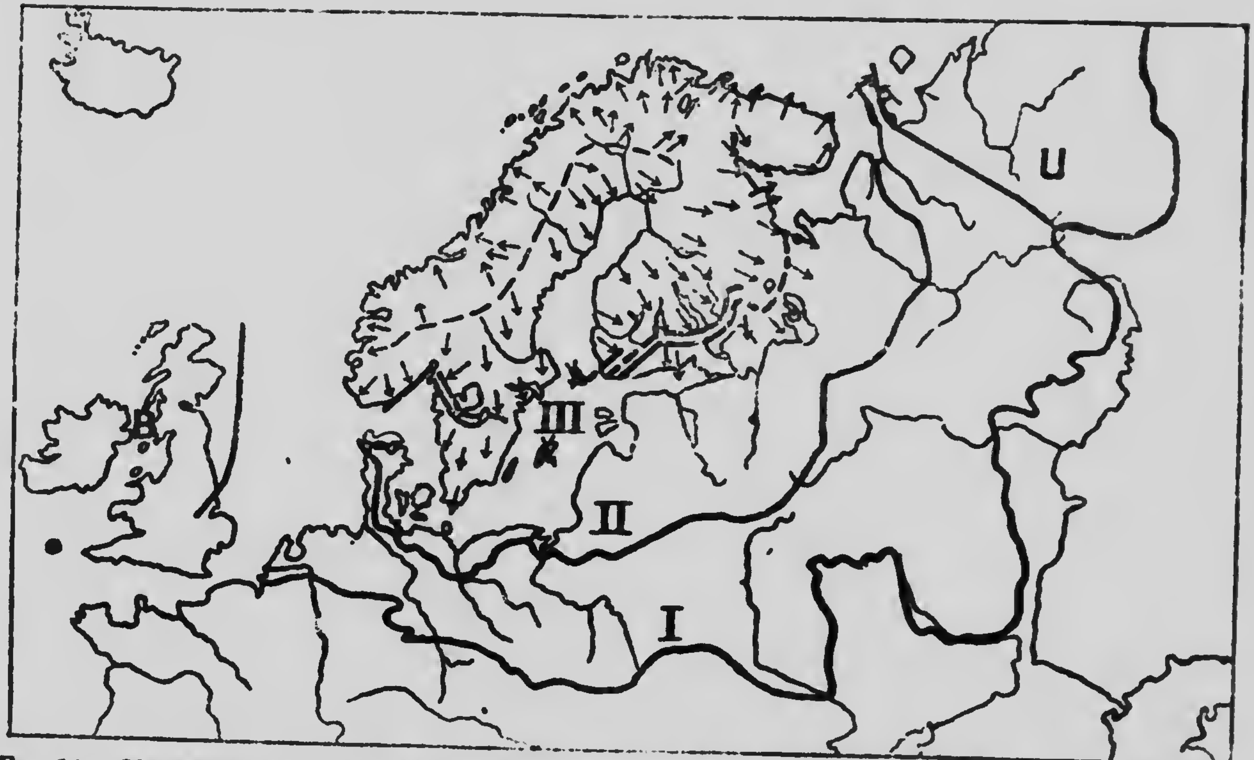

FIG. 10.—Map showing (I) the maximum extension of the Scandinavian ice in Europe, and successive halting-places of the retreating ice-front (II and III), marked by moraine-walls. U, ice of the Timan-Ural area. B, ice of the British Isles. The arrows show the direction of ice-movement. (After Wilhelm Ramsay, "Geologins Grunder.")

Scandinavian ice-sheet on the east of Britain. In the south it invaded central Saxony; in the east, possibly aided by snow-domes in northern Russia, it crossed the gathering ground of the Don, sent a long lobe down the Dnieper, and almost touched the Urals (fig. 10). The terminal moraine of Fenno-scandian boulders in the Baltic plain represents a stagnating stage, when considerable shrinkage had already taken place. Boulders from Finland are found to the south-east at Moscow and to the south in Poland (Chap. X). The distributing-area was not the same for the whole confluent ice-sheet, and the direction of its flow at any point was liable to be disturbed by variations in precipitation on the several regions of supply.

In the discussion of the Rhine valley, we have considered the modification and even the abolition of river-courses by the presence of an ice-sheet. Prior to the glacial epoch, streams ran down from the heart of Germany into a depression on the north, and probably united in one or more rivers that escaped north-westward into the Atlantic gulf off Norway. The whole of this system was thrown into disorder by the ice-invasion, and a new element was introduced by the water that poured from the melting margin of the ice-sheet. The streams consequent on the land-slope became subsequent in regard to the terminal scarp of the glacier; they ran along it, trying to escape north-westward, and were joined by others consequent on the general slope of the ice. The Rhine, in spite of the spread of Scandinavian ice in the North Sea area, seems to have preserved its northward flow, and hence the water from central Germany, much diminished by the invasion of a large part of its gathering-ground, escaped somehow from the area. Lakes must have been frequent along the ice-margin, held up on one side by the ice; but finally a stream ran down the Elbe valley to Magdeburg, and perhaps, through lakes, into the Aller valley, and so into the Weser and the sea. As the ice-sheet melted, and then stood for a long time with its front at the line marked by the Baltic ridge (fig. 10, II), the central European water could run farther northward, until blocked by the new rim of the ice. In this way the consequent courses of the Elbe, the Oder, the Warthe, and the Vistula were renewed for a certain distance, but over ground cumbered by glacial detritus and very different from that of Pliocene days.

At this stage a great river followed along the ice-front from Bromberg in Posen to the south-west of Denmark, and its course is still recorded in the Netze (the long tributary of the Oder) and in the Elbe from Havelberg to Cuxhaven. At Bromberg it was fed by the Vistula, and the passage into the Netze-Warthe valley is still easily apparent in the surface-forms. Similarly, a connexion is traceable from the Oder to the Elbe, where it bends north-west at Havelberg.

The recession of the ice left a country falling towards the depression of the Baltic, and the streams consequent on this soon worked their heads back in the soft glacial drifts, so as to capture water that ran south into the Vistula–Oder–Elbe. The Elbe valley was sufficiently deep to escape attack, but the Oder was tapped by a river working back from Stettin. On a given day—and we may note the suddenness of the change here, as in the Rhine-groove (p. 109)—the whole water of the Vistula–Oder system was turned directly towards the Baltic. The valley from Oderberg westward ran almost dry, and even the Havel was soon carried off also to the north. A little later, a river from the Danzig area tapped the Vistula near Bromberg. The result of this capture is the magnificent lower valley of the Vistula, which was excavated by the increased flow. From Fordon northward, the great river, bearing steamers and timber-rafts, and a traffic worthy of the Rhine, runs for eighty miles between steep banks of glacial drift. The stream has swung from side to side in the unconsolidated land, and the alluvial flat at Neuenburg is five miles wide. The castles of Marienwerder and Mewe, wisely planted on the upper level, guard passages across a valley-floor which is still swampy and insecure.

We need not follow the great plain eastward into Russia. The last villages on the Polish border are built on sands washed from stagnating ice, and the same country, fir-clad and sombre, seems to stretch without limit beyond the frontier. The numerous lakes of Ostpreussen may be due in part to depression of the glacial beds by superincumbent ice. A. Tornquist (30, 150) records from the boulder-clay of Georgenwalde a block of Miocene sediments 30 metres (100 feet) in thickness, which may claim to be the largest erratic in North Germany.[1] The interest of the geologist in the lands south of the Baltic becomes everywhere attracted to the vast changes, in climatic conditions and surface-configuration, that have taken place in the most recent epochs.

The melting of the ice from the western

[1] This, however, hardly compares with a glacial boulder in Huntingdonshire. A block of chalk at least half a mile in length, with springs at its base, and supporting the village of Catworth on its back.

part of Fennoscandia has left a well-scoured highland, where much of the older rock remains exposed. The lower ground of Sweden and the whole of Finland represent, however, a surface that was worn down almost uniformly in early Cambrian times. The first Palæozoic sediments were laid down on this great peneplane, which in this respect resembles the floor of eastern Canada. The removal of Palæozoic and later strata, which include the Chalk in southern Sweden, restored the ancient land-surface, and across this the ice-sheets moved in glacial times.

Finland, like Prussia, is a land of numerous lakes; but these lie in basins of hard rock, sometimes closed on one side by a barrier of glacial drift. On their margins, as along the coast, the bare glaciated granites and gneisses everywhere meet the eye, and at times a lake or a river is bounded by a considerable height of vertical rock. These abrupt features are attributed by Fennoscandian geologists, with much probability, to fracture-systems. Movement has taken place along certain of the cracks that were developed during Cainozoic stresses. These cracks are the inland representatives of those that have influenced the western fjords of Norway (p. 59). Glaciation was unable to remove the upstanding blocks. Their edges and walls are rounded, but they still remain as records of the Alpine ground-swell.

Boulders carried by the ice are scattered everywhere over Finland. In many cases they are the residues of sheets of boulder-clay, which may be found undestroyed in less exposed parts of the country. Where such clays remain, farming is happily carried on. Where the soil and subsoil consist of coarser materials, such as glacial sands and gravels, birch and fir-forests prevail. The woods extend over the most unpromising ground, and heaps of angular boulders are found amid the scanty undergrowth. The rivers from the interior descend by rapids to the coast, like those of the Uleå, the Kymmene, and the famous torrent of Imatra in Viborg. They now run in post-Glacial courses, even if they occasionally follow fault-scarps; and they have preserved their youth in consequence of a recent uplift of the land.

A huge terminal moraine, the Salpausselkä, runs from Hangö on the Gulf of Finland north-eastward to Joensuu for 600 km. (375 miles). A second wall, representing another pause in the ice-front, lies some 25 km. within it, and both form curves convex towards the south-east (fig. 11). Outside them and within them are sandy eskers (p. 120), streaming, as it were, across the country, and seeming to continue in Finland the rivers that descend from Sweden to the Gulf of Bothnia. The eskers were clearly

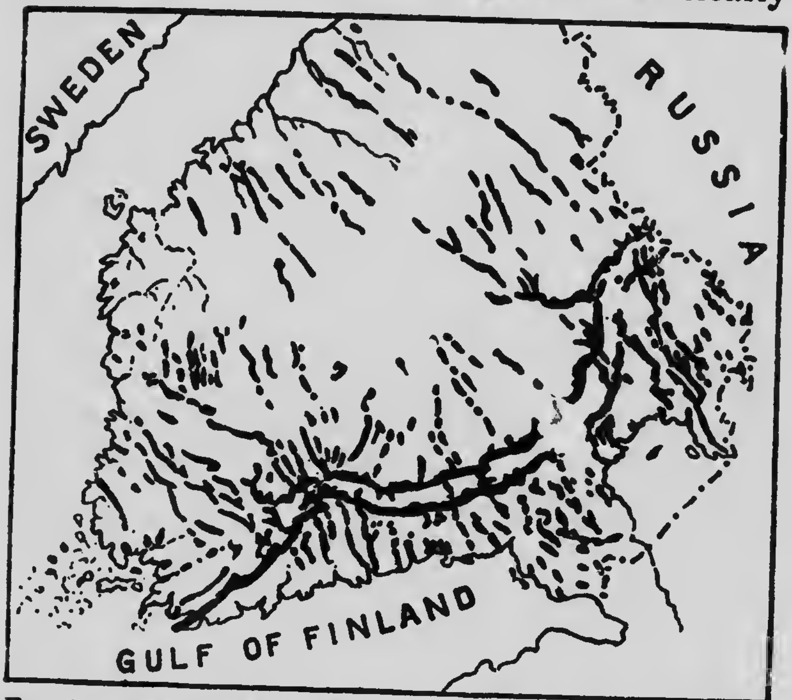

FIG. 11.—Sketch-map of southern Finland, showing in black the two great terminal moraines that record resting stages of a lobe of the Scandinavian ice-sheet, and the numerous eskers that mark the courses of streams generated beneath the shrinking ice. It will be noticed that these eskers are directed south-eastward from the Swedish coast. The floor of the country is mostly covered with boulder-deposits and marine and lacustrine strata formed from ice-borne material. (After Sederholm.)

controlled in the first instance by the course of the water beneath the Fennoscandian ice.

The Finnish eskers have proved important, like those of Ireland, for the maintenance of roads. Their elevated backs and ready drainage have made them the natural causeways above lower peaty ground. Their sides are usually covered with forest, but a track has been cleared along the crest. The great *ås* of Kangasala, which carries the road between Tammerfors (Tampere) and Tavastehus (Hamennlinna) can be traced back far to northward towards the Baltic coast. Large boulders, only partially rounded, occur in it in places; in other sections it shows a coarse gravel; in places a delicate bedding is seen in its layers of sandy clay. Many Fennoscandian geologists, with De Geer and Sederholm, regard the eskers as protruded from the ice-caves of a retreating glacier, and as formed in the sea which replaced the ice as it withdrew. The outermost end of an esker would thus be older than that farther up the country. It seems likely, however, that some of the Scandinavian eskers may have originated, as described on p. 125, in subglacial channels under stagnating ice, a view that was put forward by Hummel in Sweden and by Goodchild for the north of England.

The recent history of the Fennoscandian surface is, then, one of severe glacial denudation and considerable glacial growth. The material removed from one district has been transferred, often with an ameliorating influence, to another. In some parts of Sweden the ground is simply covered with great boulders, heaped together, forming the coarsest type of moraine-material. Forest-trees manage to spring up in the interstices, and even to gain a root-hold on the stones. Foaming streams pour down among the crevices, as if still flowing from the melting ice. The author recalls a remark of G. De Geer, as he stood at the side of the Nordenskiöld Glacier in Spitsbergen, where the ice was concealed by an immense slope of boulders shed from its surface and from its interior. "This," said De Geer, "is like a piece of Sweden." In other places the rock-floor lies bare, scoured and mammillated by the passage of continental ice. The extreme slowness with which soil forms upon a surface of glaciated crystalline rock is everywhere in evidence on the hummocks. The striations caused by stones and sand beneath the ice seem as fresh as those near existing glaciers in the Alps. The boulder-clays, however, have furnished a certain amount of arable land; and shelly sands and clays have in places been deposited from post-Glacial lakes and extensions of the sea.

H. Munthe, G. De Geer, and others have studied in great detail the shore-lines, whether beaches or terraces of erosion, that mark the limits of these marine or lacustrine overflows. De Geer observed that the finer deposits in lakes or brackish seas which received water from the melting ice-front are delicately laminated, a more sandy layer representing the summer melting, and a more clayey one that of the succeeding months, when the water could not carry coarse sediment so far. Hence, by counting the pairs of such laminæ, and tracing the deposits from point to point in ascending order, it has been possible to estimate the number of years occupied by the retreat of the ice-front over a given distance. The lower laminæ in one section of the deposits are of course not present in a section taken farther up the country over which the ice-sheet was melting back, since the ice was occupying the ground at the second point while its contents were being washed out towards the first one. The variations in the thickness of successive annual layers, due to the temperature conditions of the year, enable one series to be correlated with another, and the number of annual layers between the bottom one at the first point and the bottom one at the second point gives the time taken by the ice-front to withdraw over the distance between the selected places (81). In this way De Geer has carried back the chronology of the later stages of the Fennoscandian ice-age through some 5000 years, and, from certain seasonal laminated clays in a drained lake at Ragunda, is able to add 7000 years as the period that elapsed between the disappearance of the ice-sheet and the end of the eighteenth century.

The changes in the physical conditions of the Baltic area have been of a striking character. The axis of the Gulf of Bothnia and of the Baltic generally indicates a line of weakness in the old pre-Cambrian mass, and its parallelism with the north and south Cainozoic fracture-lines of the European coastlands cannot escape notice. We know that the Upper Cretaceous sea crossed the south of Sweden, and its deposits are found in numerous borings made through the glacial drift of Ostpreussen and far east into the interior of Russia. Oscillations in the south Baltic area drove the sea out in Eocene times and restored it in the Oligocene period; but in the Miocene and Pliocene periods only southern Denmark was submerged, and the spreading glaciers of the ice-age moved from Fennoscandia across dry land. The immense burden that they brought with them represents the loosened rock that had accumulated through long epochs on the northern surface. W. von Lozinski has pointed out how the frost-action that preceded the approach of a glacial epoch provides an exceptional quantity of boulders in readiness for transport by the ice.

It is believed that the ice-load on the Fennoscandian area during the maximum extension led to a depression of the land, for we find marine deposits formed, from the White Sea in the north of Russia down to the Baltic, along the margin of the shrinking ice-sheets. The greatest sinking of the surface occurred about the region of the Gulf of Bothnia; but oscillations are traceable at various points. When the ice had shrunk so that its front crossed the south end of the Gulf of Bothnia and the north side of the southern promontory of Sweden, the North Sea covered this promontory, and communicated with the White Sea by the Gulf of Finland. It spread gradually, following the ice-front, up the Gulf of Bothnia and over a large part of Finland; but its sheltered and calm character is clear from the fact that the moraines and eskers have suffered little from wave-action. The dissected drumlins of Clew Bay in western Ireland and of Boston Harbour tell a very different story. This marine extension is known as the "Yoldia Sea," from the prevalence in its deposits of the bivalve mollusc *Yoldia arctica*, an inhabitant of cold northern water. The lowest layers of the seasonal detritus so carefully studied by De Geer were deposited in the Yoldia Sea.

The ice continued to shrink from the north-west and south-east, and far more rapidly on the Baltic than on the Atlantic side. The ice-shed had lain persistently on a snow-dome in the north of Sweden, which overtopped the structural watershed of Scandinavia. As the ice shrank south-eastward from the watershed, merely local glaciers extended down the fjords of Norway, and long lakes were formed between the axial mountain-ridge and the ice-barrier on the east. For a time, these lakes drained through gaps in the watershed into the Atlantic. The beaches formed by them during stages when their water-level was for some time stationary have been interestingly traced throughout northern and central Sweden. The depth of the ice-covering in the latter area is impressively demonstrated when one stands on Åreskutan in Jämtland, and realises that the whole mountain is ice-scored and ice-moulded, from its base to its crest, 4000 feet above the valley-floor, while the huge boulders on its flanks and summit have been dropped there by the glacier that moved over it.

When the ice of Glacial times was reduced to a mere residual bar down the axis of Sweden, and when much of the country was assuming its present character, an uplift of southern Sweden and of the Danish isles cut off the sea on that side. The White Sea connexion also became closed, and the Baltic, restricted almost to its present area, became a lake. Peaty flats spread out into it beyond the present limits of the Prussian and South Swedish coasts. The birch and the fir, now characteristic of Fennoscandia, prevailed in northern Germany and Denmark. From the freshwater gastropod *Ancylus fluviatilis*, which with *Limnæa obovata*, abounds in the deposits left as the lake diminished, the freshwater Baltic has been styled the "Ancylus Lake."

Still later, a subsidence of some 800 feet admitted the Atlantic water by the Cattegat, after man of the early stone-age had begun to inhabit the Danish area. Families that had already formed tribal associations were no doubt thus converted into nationalistic islanders. Many of the older peat-lands became submerged, and the inflow of salt water was rather greater than it is now, the Baltic being at present the freshest sea of Europe. Oaks spread along the southern shores, and, as still milder times approached, the beech-woods that form the glory of Denmark gradually took their place. Though life in Lapland is still of a rigorous character, this is largely due to geographical position, rather than to a continuation of the ice-age.

Soon after man had established himself in Europe, he became hemmed in and driven to certain lowlands by the growing glaciers of the ice-age. No doubt this concentration of the species led many individuals to a violent death; but ultimately social qualities were fostered by the restriction of geographical range. The first settlers on the Baltic shores, facing the blasts from the high-pressure area over Sweden, were possibly poor outcasts from the tribes of happier lands. But they found in the grey-green water a hunting-field demanding all their skill. There they developed the energy that sent their descendants to the Atlantic coast of Norway, and in later years made the Hansa League a menace to the empire on the south. The salt water still appeals to the people of the Prussian shore, and they have guarded themselves against a return to the dreary conditions of the Ancylus Lake. In our own time, from the steel-blue skies and featureless coasts of Pomerania, they have carved for themselves across Holstein a passage to the places in the sun.

CHAPTER VIII

THE UPPER BASIN OF THE DANUBE

In Upper Cretaceous times, a large part of the European area lay beneath the great Chalk sea. Bohemia, however, an old lozenge-shaped Armorican horst, emerged towards the close of the period, and was added on to the large island that included the Harz Mountains and the Jurassic dome that lay above the present valley of the Rhine (p. 101). Rivers had no doubt flowed off this dome south-eastward into the Cretaceous sea that lay across Bavaria, and others now came down from the northern plateaus as the sea was driven southward. The Flysch deposits (p. 38) show that land was already rising in the Alpine area. The narrowed Eocene sea of northern Switzerland and southern Bavaria, opening eastward to the Black Sea region, may be regarded as the first sign of the Danube basin.

This band of salt-water was still further threatened by the growing Alps, which gradually involved the Flysch in their gigantic folds. It was converted into a lake-region in the early Miocene (Burdigalian) epoch, was resuscitated by the subsidence of Helvetian times, and was finally extinguished by the movements that tilted even the Helvetian strata. In the Lower Pliocene epoch, the Alps were at their full height; the Jurassic and Triassic cover was being washed off from the Black Forest; and from both uplands, the antique and the new, streams were uniting in what we may now call the Danube (fig. 7). The departure of the sea from the Vienna basin in the Pontian age allowed the river to lengthen still farther eastward over the emerging marshy lands.

We have already (p. 101) referred to the escarpment of Jurassic limestones that runs across Württemberg and Bavaria, and is the complement of that of Langres and Nancy. Its front is very noticeable as we journey southward and face the bold scarp and its jutting promontories; but in Bavaria the watershed now lies on the north side, and the consequent streams run through the escarpment (fig. 5), providing convenient passages, like those of the North Downs in England. The western part, forming the Rauhe Alb south of Stuttgart in Württemberg, presents a bolder front, rising 1500 feet above the country north of it, and its dip-slope is an almost waterless plateau, 800 metres (2600 feet) above the sea. The feeders of the Miocene sea, and later of the Danube, have been steadily reduced by the recession of the scarp; but on the other hand the waters from the Alps grew in volume as that great chain rose. This contrast in river-supply is manifest in the present features of the country.

Though the Rauhe Alb is the denuded relic of an arch reared in late Jurassic times, it bears evidences of the unrest that accompanied the Alpine folding. (Compare I, 1, 255.) Numerous volcanoes broke through it in Miocene times, and in places the basaltic necks have weathered out as craggy eminences. To the north-east, the old imperial town of Nördlingen, girt with its wall and towers, stands in a singular plain, the Ries, 25 km. (15 miles) in diameter, encircled by forest-covered hills. Miocene strata have here been dropped so as to form a circular basin in the Jurassic slope. Volcanoes burst out on the west and south sides of the ring, and the sheer rock of Wallerstein records in the lowland the calcareous cone of a hot spring. Compression has thrust up old rocks over younger ones on the margins of the ring, and a part of the granitic and schistose floor, dating at least from Armorican Europe, has come to light.

Away at the south-west end of the escarpment, and here again in a faulted Miocene area resting on the Jurassic limestone, is a fascinating group of volcanic necks in the Hegau, a district west of Constance. Here the Hohentwiel, Hohenkrähen, and a dozen or so of isolated crags, crowned with feudal castles, make a picture of almost extravagant romance. Just as on the Jurassic downfold above Dijon we found ourselves on the fringe of the Alpine earth-storm, and could picture its waves following closely on one another in the contorted region of the Juras, so here we stand on the descending slope of a broad and simple earth-wave; but, if we look southward across the Cainozoic depression of north Switzerland, we can see the breakers, and the detached rock-spray of them, in the overfolded Jurassic and Cretaceous limestones of the Alps.

The great basin extends north-eastward as the lowland of Württemberg and Bavaria. The Lake of Constance, used as a political boundary, is merely an incident in its floor. The present Rhine happens to come through it, and cannot climb over the low watershed, which rises north of Friedrichshafen some 600 feet above the level of the lake. But on the north side we soon reach streams flowing into the Danube, which have most probably been beheaded by the excavation of the basin of the Lake of Constance. Away to the east, along the continuation of the zone of limestone Alps in the highlands of South Bavaria, the consequent Alpine streams come down without hindrance to the Danube; but the Inn, carving out a long valley on the southern margin of the limestones, intercepts the water from the snow-capped central range. In its lower valley, however, it cuts right across the limestones, and thus brings this water ultimately to the Danube basin.

One of the most remarkable things in Europe is to see these rivers hurrying across Bavaria from the grey range of Alps which lies somewhere in the haze on the horizon. The fall of the Isar from the mountain-foot at Tölz to the Danube flat at Plattling is only 860 metres in a distance of 180 km., or, disregarding its meanders, 1 in 500. But this fall, six times as great as that of the Rhine from Bâle to the sea, gives it ample powers of erosion. Even north of Munich it seems to be tearing at the soft alluvial banks, and its intersecting loops force the peasantry to abandon a broad stretch on either side of the main stream. The numerous streams consequent on the falling surface cut their way down in correspondence with the rate at which the Danube lowers its floor, and they have worn out shallow valleys, widened by the swinging of their courses from side to side. In some cases, that of the Günz, for instance, east of Ulm, the present occupant, with its minute abrupt meanders, is far too small for the valley in which it runs. The wide flats of the Roth and Mindel valleys, on either side of the Günz, carry only branching streamlets that are obviously dwindling into insignificance. The abundance of streams in the Bavarian lowland points back to a time of general flooding, on a surface that had been built up by the overlapping of broad glacial and alluvial cones. As time goes on, the water is being captured by the strong survivors, such as the Iller, th Lech, and the Isar.

When this system of consequent rivers began to run over the uplifted deposits of the Miocene sea, these deposits were much thicker than they are now. The Danube, which became developed as a river by the uplift of the basin, was, moreover, pushed farther and farther north by the accumulations of its tributaries. Their confluent deltas, formed from the waste of Alpine crags and Miocene foothills, and resting on the Miocene of the lowland, were spread out in the north, where now the dip-slope of the Jurassic strata lies revealed. The Danube ran to the north of its present course, on the general plateau of Cainozoic rocks, meandering upon them, and washing them gradually away.

As the great river lowered its bed, it came down to the crystalline rocks of the Bohemian horst, and slowly worked a groove across them.

The resisting walls caused the valley to remain narrow, and the remarkable Danube gorge from Vilshofen to Linz is the result. After running in a great alluvial plain from Regensburg, the river seems wilfully to enter the hills that lie to the north-east. At Passau it is joined by the full flood of the Inn, running also between steep walls. This river has got into the crystalline highland at the quaint old frontier-town of Scheerding, and it also must have run at one time on much higher ground. The main road from Passau to Vienna climbs above the Inn to Scheerding, and struggles eastward over very hilly gneissic country, finding it impracticable to follow down the Danube gorge. The large bends in the gorge before the alluvial expansion at Linz is reached may be "entrenched meanders"; that is to say, the meandering took place on the former surface of soft Cainozoic rocks, and became perpetuated as the river-bed was lowered through this surface into the crystalline floor. At Linz the Danube escapes back into the plain, which is here rapidly narrowing as the Alps approach the antique Bohemian horst; but at Melk, where the great abbey is planted on the steep north bank, it turns off again into the highland, and makes, under the crags of Dürrenstein, a passage that surpasses the best features of the

German Rhine. Travellers in old times came down this way in open boats, at some peril of their lives; and the road and railway proceed more directly to Vienna, over a Miocene lowland and a mild pass in the Flysch beds of the wooded Wienerwald.

The present surface of the Bavarian plain is, then, only a reduced representative of what was formerly a still more extensive feature. The lowering by denudation may have been accompanied by lowering through earth-movement, since the fracture-line on the south-west of the Bohemian horst may have remained active throughout the Alpine movements. An interesting previous course of the Danube has been indicated on the Jurassic dip-slope north of Ingolstadt, and the river must have been tapped off into its present course by a . butary that was engaged in lowering the plain on its south side. The Altmühl valley, which widens considerably and rather abruptly at Breitenfurt near Eichstätt, continues in large meanders until it joins the Danube away east at Kelheim; but this noble valley, with its immature and cliff-set walls, is now occupied by a mere "misfit" of a stream. The present Altmühl, in fact, wanders in a grassy alluvial flat between steep walls of white Jurassic limestone. It is suggested (VII, 49) that this wide part of the valley was originally excavated by the waters of the Danube, which flowed in from the south by Wellheim, and ran on a surface some 25 metres (82 feet) above their present local level. The long reach of the modern Danube from Rain to Kelheim must be attributed to the Lech, and the capture of the Danube out of the Altmühl valley must have been due to the lowering of the plain near Rain.

Another solution of the Altmühl problem might be found in the Pliocene lake that occupied the volcanic depression of the Ries. This may have had an outlet eastward. There is also evidence of an old course of the Danube in the country north of the mouth of the Lech and Ingolstadt, for the remarkably broad valley in which the Roman station of Nassenfels stands was certainly not excavated by its present sluggish and tiny stream. Enough has been said to show the shifting character of the topography in the upper Danube basin.

The early Danube, then, flowed over uplifted marine Miocene strata, and the continued rise of the Alps no doubt conspired to shift it towards the north side of the basin. As we have pointed out, the delta-flats of the Alpine tributaries would have effected this movement without assistance. In the

Post-Pliocene ice-epoch, enormous deposits were added to the surface, and these underwent a more uniform distribution by the flooding rivers of interglacial ages. The last important ice-extension has left terminal moraines which lie in Württemberg 60 km. and in Bavaria 50 km. (38 and 31 miles) north of the Alpine foothills. The ice that occupied south-western Württemberg is shown by A. Penck to have been part of a great glacier-fan that expanded in the lowland, fed from the upper Rhine valley and from the Alpine foothills around Appenzell. The western lobe of this fan is traced beyond Schaffhausen, and the basin in which the Lake of Constance has gathered is attributed, with great probability, to the excavating action of the ice as it emerged on the yielding beds at the foot of the steep drop from the hills. Sections drawn to a true scale are needed to enable us to appreciate the great proportions of a continental ice-sheet in comparison with the features which it over-rides and modifies. The Lake of Constance is in most parts more than 500 feet deep, and it must be allowed that much sediment has been spread on its floor since it was occupied by the ice; but a basin 60 km. (38 miles) long need have a slope of only 53 feet in a mile to attain a depth of 1000 feet in its central portion.

The enormous denudation of the Alps, and especially of the fractured stratified ranges that flank the central chain, is evidenced once more by the deposits in the plains to northward. The depth of ice-borne material in these plains has been estimated at 2000 metres (6500 feet); but of course this thins off against protruding bosses that were not covered by the glacier-fans. In front of any line where the ice-front remained stationary for a time, outwash-plains of sand and gravel were spread more uniformly across the country, and it is these that are now being reduced in level by the action of the Alpine streams. Over a considerable area in the east of Bavaria, the underlying Miocene beds are now exposed. Behind the terminal moraines, drumlins have been formed, as is recognised by Penck in the hummocky ground in the basin of the Lake of Constance.

The products of successive ice-extensions naturally cover one another, and only those of the later ages of the Glacial epoch are likely to remain fresh upon the surface. But, where an earlier glacier-fan spread farther from the source of supply than that which followed it, its moraines and drumlins may be well preserved in advance of those of a later age. This is the case in the Bavarian plain. The greatest confluent fan appears to have been that of the Riss age, when the upper valleys of the Iller, Lech, and Isar were concealed by ice. Subsequent flooding, however, has destroyed the details of the moraine-structure. In the succeeding Würm extension, which has left such marked features round the Lake of Constance, the ice came as far north as the latitude of Munich. Deep grooves were cut in the Miocene strata of the lowland, and the Ammer See, Würm See, and the broader Chiem See, record the pressure of descending glaciers. As the Inn valley developed between the stratified foothills and the crystalline chain, an ice-capture took place, just as a water-capture takes place now (p. 146). It became necessary for ice to fill up the Inntal, if it was to cross from the 3000-metre summits over to the northern plain. A large part of the ice from the Stubai and the Zillertal Alps, where glaciers still linger at the present day, was carried off north-eastward as a long but fluctuating glacier of the Inn. When this glacier rose to a height of some 600 metres (nearly 2000 feet) above its floor, it could flood over the passes into Bavaria. A. Penck represents it as entering Bavaria during a final ice-extension, even later than the Würm age, and flowing in two streams round the craggy mass of the Wetterstein, to unite in the basin of Garmisch and override the ridge of Murnau.

This ridge of Murnau deserves attention as an example of ice-action on falling ground. From a distance, as we come out from the narrow valley of the Loisach below Partenkirchen, it looks like a huge moraine blocking the level land in front. This level land is diversified by one or two hummocks at right angles to the river-course, and these prove to be broken down barriers of harder Miocene strata. The ridge on which Murnau stands is a similar barrier that has resisted even the overriding ice; the basin behind it, in which a peaty level has now accumulated, was excavated by the Loisach glacier-tongue as it emerged abruptly from the mountains, and the river that has succeeded the ice cannot surmount the ridge, but flows along it into the next valley on the east. On the north side of the Murnau barrier, the Staffel See lies amid characteristic drumlin country; and detrital heaps and gravels, which are here and there overtopped by Miocene or Oligocene bars, cover most of the surface down to Munich.

It is impressive to realise that all the streaked out north-and-south tumbled ridges of this lower country are mere heaps of boulder-loam and gravel dropped out of stagnating ice. They rise 500 feet above the level of the lakes between them, far higher than the Surrey Downs above the Mole. They bear forests and red-roofed villages, with a life of their own well removed from the routes of daily traffic. Yet the frequent sections cut in them convince one of their recent and detrital origin. On the borders of the elongated Würm See, Miocene strata are seen on the sides of the great glacial groove; but the flanking hills that rise far higher consist of glacial boulder-beds, cut through also by the ice of the Würm extension, and final moraine-material laps over from the summits into the groove.

The lakes in the mountain-recesses differ strikingly from those that lie out in the Bavarian plain. Here also glacial excavation has been active, but the Alpine rocks form the majestic bounding walls. The Achen See, on the road from Munich to Innsbruck, lies on the very edge of the valley of the Inn, and must have been developed by ice and water that came across from the south side of the valley. The romantic König See in the extreme east of Bavaria, with its sheer cliffs descending to the water, represents a ravine that was kept free from taluses by glacial action. The Alps of the Flysch zone east of Salzburg contain a lake-district where crag and cliff are the main features. There is less room in this part of the Danube basin, between the Alpine foothills and the Hausruck (a Miocene mass extending from the plateau of Bohemia), for the formation of a plain of ice-alluvium.

The covering of the Jurassic downfold by Cainozoic and Quartary strata, from the slope of the Rauhe Alb to the crumpled ranges on the south, has produced the wealthiest lowland ground in Germany. Pebbly and stream-cut as the plain may be in places, even the rough grassy stretches have their uses, and one still sees the goose-girl of the old folk-tales driving her flock from one pool to another in the common land. The Danube is mostly too swift in its upper basin to provide a satisfactory highway, and lower down, near Straubing, the unreclaimed stretches of overgrown swamp on either side still prevent the establishment of frequent quays. But the traffic across Europe has long descended the dry dip-slope of the limestone, and has halted at Ulm, Donauwörth, Ingoldstadt, and Regensburg, as welcome cities of the plain. The route through Nürnberg to Venice in the old days enriched the burghers of Bavaria, and Augsburg (Augusta Vindelicorum) lies at the meeting of four Roman roads. Partenkirchen (Parthanum), in its drained lake-basin in the mountains, was a gateway to the north for legions out of Italy, and a Roman predecessor of Munich lay above the present city on the Isar. Lower down, the Isar gave rise to Landshut, on the highway to Carinthia and Trieste, while Salzburg and Werfen hold the crags that dominate the passage through the hills. Here, however, we are in the Alpine region, and the eastward-running rivers that we cross in the grooves below successive ranges belong to the lower basin of the Danube and lead to the Hungarian plain.

CHAPTER IX

THE FOLDING OF THE ALPS

WHEN reference is made to mountain chains in Europe, the Alps are distinctly present to the mind of every traveller. They are only a small portion of the system of earth-wrinkles that determined in Miocene, and even as recently as Pliocene times the highland axes of the central and eastern parts of the continent; but their accessibility, and their insular position amid the confluent floods of French, German, and Italian civilisation, have made them for a century and a half the field of continuous research. In the present work, we are concerned less with their structure than with their arrival on the European scene at a certain epoch, and with their presence as a highland barrier from which certain consequences have spread. The salient features of their foothills and of their central ranges at the present day are, however, so dependent on their processes of growth that a few pages may well be devoted to the development and folding of the chain.

The diversity of constituents in the Alps is easily realised as we pass from Geneva to Chamonix, or from Thun to the Rhone valley by the Grimsel, or, still more familiarly, from Lucerne to Andermatt. In each case we start across Cainozoic strata, reared, it may be, into mountains like the Niesen or the Rigi; we enter a zone of greatly folded stratified rocks, in which Jurassic and Cretaceous limestones are conspicuous; and we arrive at crystalline masses, schists, gneisses, and structureless granites, which appear to constitute the Alpine core. If we cross this core to the south side, we find the stratified ranges repeated in force from Lugano to the Dinaric region beyond Trieste. They are seen south-east of Mont Blanc in the foothills breached by the Dora Baltea at Courmayeur; but they are missing on the east side of the Piedmont Alps. Here, however, they may be supposed to lie buried under the alluvium of the tributaries of the Po.

The earliest observers very naturally concluded that the central crystalline rocks, and even the granites, were the result of the progressive alteration of strata similar to those upon their margins. Detailed surveys, however, revealed the complex structure of the chain, and a large part of the granitic material was proved to have intruded into its surroundings before anything like the modern Alps arose. The core of the chain, where such a structure definitely exists, thus represents the old floor, squeezed up along certain lines in local foldings of the crust; and the stratified foothills are marginal relics of a complex mass that once was continuous across the crystalline series.

We know little of the history of the Alpine region in Palæozoic times. Carboniferous strata are the oldest that can be recognised by their organic contents. Granites have penetrated into these, and underlying crystalline schists and gneisses have become worked up in the present chain. We have here an indication of an Armorican mass, which probably had only an accidental relation to the modern Alps. In Permian times the sea invaded the area, and the eastern Alpine district, that is, the district east of the Upper

Rhine, remained submerged during the Triassic and Jurassic periods. Though the Swiss area became uplifted as dry land in Triassic times, this movement cannot be considered as in any way foreshadowing the Alps. As is usual throughout Europe, we must come to the Cretaceous period to find the premonitory oscillations that heralded the existing features. We have seen (p. 88) how the Flysch deposits, which are mainly of Eocene age, extending, however, down into the Cretaceous and up into the Oligocene system, indicate the neighbourhood of land along the line of the Alps and the Carpathians. We have also noted the prevalence of lakes in northern Switzerland during the Aquitanian (Upper Oligocene) epoch. The conglomeratic Nagelfluh beds, which are so well seen upon the Rigi, indicate the margin of a considerable land-ridge in Lower Miocene times. The true folding of the western Alps had then begun.

Seeing that the movements were not contemporaneous throughout the area, and were not completed in the south until late Pliocene times, different kinds of deposit were formed simultaneously in different districts of the Alps. The same is true of the deposits of earlier periods, so that a great cube, as it were, cut out of any one Alpine district could be recognised as belonging to that district by the mode of development of this or that series of strata. This is the basis of some of the remarkable conclusions to which Hans Schardt, M. Lugeon, P. Termier, and other geologists have been led by their studies of Alpine structure. Vast masses of rock, amounting to whole ranges of foothills in certain places, have been found on the west and north flanks of the Alps in districts where the local type of deposit is of a different nature. Earlier workers had recognised great inversions, whereby Jurassic or Triassic strata, or even ancient crystalline masses, have been caused to overlie Eocene flysch on the upper flanks of recumbent synclines. Almost horizontal fracture-planes were seen to have become planes of movement (" thrust-planes "), along which considerable portions of the folded chain have been thrust forward, so as to override the rocks proper to the district in which they now are found. But the extent to which this transference of material has taken place was scarcely realised until the opening of the twentieth century (82). It was then pointed out that the mass styled the Fore-Alps (*Préalpes* or *Vor-Alpen*), south and north-east of the Lake of Geneva, and extending up to the Lake of Thun, possessed characters proper to the district south-east of Mont Blanc and the

Bernese Oberland. This type of Alpine beds has been styled *Lepontine*. This body of hills, the Fore-Alps, lies, then, as an outlier in a district where sedimentation has been of another type, and projects by forward thrusting into the lowland of the Swiss molasse. Smaller outlying blocks of the same nature lie on the Flysch mountains of the district round Lucerne, as if they were remnants of an overfolded sheet of strata that once covered a much wider field. Similarly, strata of a second type, known as the *East Alpine*, extend by overfolding on the back of the Lepontine type; they cross it completely near the sources of the Rhine, and form the great limestone wall of south Bavaria (fig. 18). The conclusion now reached is that in the Miocene period successive overfolds took place, whereby parts of southern districts were pushed up over northern ones, in the form of flattened recumbent folds or folded sheets. If a thick blanket is laid upon a table and ridged up into three parallel folds, running right and left, some idea may be formed of this scheme of mountain-structure. Number the folds 1, 2, 3, from back to front (in the Alpine area from north to south). Press the first fold over towards the far side of the table, to express the general structure of the country bordering the molasse-land of central and northern Switzerland, when it became influenced by the general pressures acting from the south-east and south. This fold represents the Jurassic and Cretaceous rocks, partly crumpled in place, and partly thrust northward, of the northern or *Helvetic* region. Then draw the second fold over the Helvetic, so that part of the crest of this fold actually overlaps and conceals the anticlinal edge of the first fold. This overlapping portion of the second fold represents the Fore-Alps of Chablais and Canton Vaud. Now move the third fold, the East Alpine, similarly over the second, so that at the right-hand or east side of our model it conceals the second or Lepontine mass, and very nearly reaches the anticlinal edge of the first or Helvetic fold. We have now a representation of the overfolded Alpine structure, before its dissection by denuding agents. We can conceive denudation cutting back part of the forward edge of any of the overfolds, and leaving only remnants on the exposed surface of that beneath. Or we can cut through an upper overfold, and look down, as through a window, on the preceding one, which otherwise would have remained concealed. The outlying remnants of overthrust folds or sheets, since they stand up as cliffy masses on the back of more regular ground, have been styled *Klippen*, from

"Klippe," a cliff.[1] Since a technical term is required, we may call these *klips*, meaning outlying portions of a fold or of an overthrust layer, resting on rocks which are not those on which they were originally laid down. *Klips* are thus strangers in the district where they now occur. Every grade can be traced from types like the Fore-Alps, which constitute a gigantic klip, to mere blocks ("exotic blocks") a few feet across, left where they were pressed into the beds below by the force of overfolding. Under such pressures, the advancing edges of the overfolded sheets, where they encounter more yielding strata, must spread out like glacier-fans, breaking apart and discharging detached pieces, which are now found at some distance from the

[1] The *Klippen* of the Carpathians are, however, upstanding craggy masses of pre-Cretaceous rock, surrounded by later deposits. The Cretaceous conglomerates found on their margins show that they were islets in the Cretaceous sea, and the later Flysch beds were laid down round and over them (V. Uhlig, *Bau u. Bild Osterreichs*, 1903, p. 791).

It is also fair to state that Bailey Willis, from observations in the Fore-Alps of the Rhone valley, believes that some klips, at any rate, may be explained by two systems of overthrusting. A movement from the north along a fracture-plane may carry a limestone mass over other rocks; a subsequent movement from the south, along a later fracture-plane inclined in the opposite direction, may carry back this mass as an isolated block towards its former home (33).

parent mass. In some cases it has been actually difficult to decide whether certain blocks lying in anomalous positions are the product of mountain-building processes, or are merely erratics carried into the district by ice during the glacial epoch.

This breaking apart of the overfolded and overthrust sheets was present to the mind of the writer when he used the term "rock-spray" in connexion with the northern Alp-waves (p. 145). When blocks descend from the towering limestone walls under the shocks of modern earthquakes, the mountain-building stresses are still manifest. Gravitation in other cases overcomes the cohesion of the folds, and "exotic blocks" roll into the lowlands. The forward movement of the anticlinal fronts of the great earth-waves during the maximum folding in Upper Miocene times must have been largely a matter of gravitation (p. 14). The fallen fold buried its anticlinal edge in the district into which it had slipped forward, and denudation has in places been so active that the down-turned relic of the fold-front may easily be mistaken for a local syncline belonging to the older structure of the district (fig. 12).

We must be prepared, then, in the Alps to find (i) folded masses that are in place, just as the Jura range is the crumpled floor of its

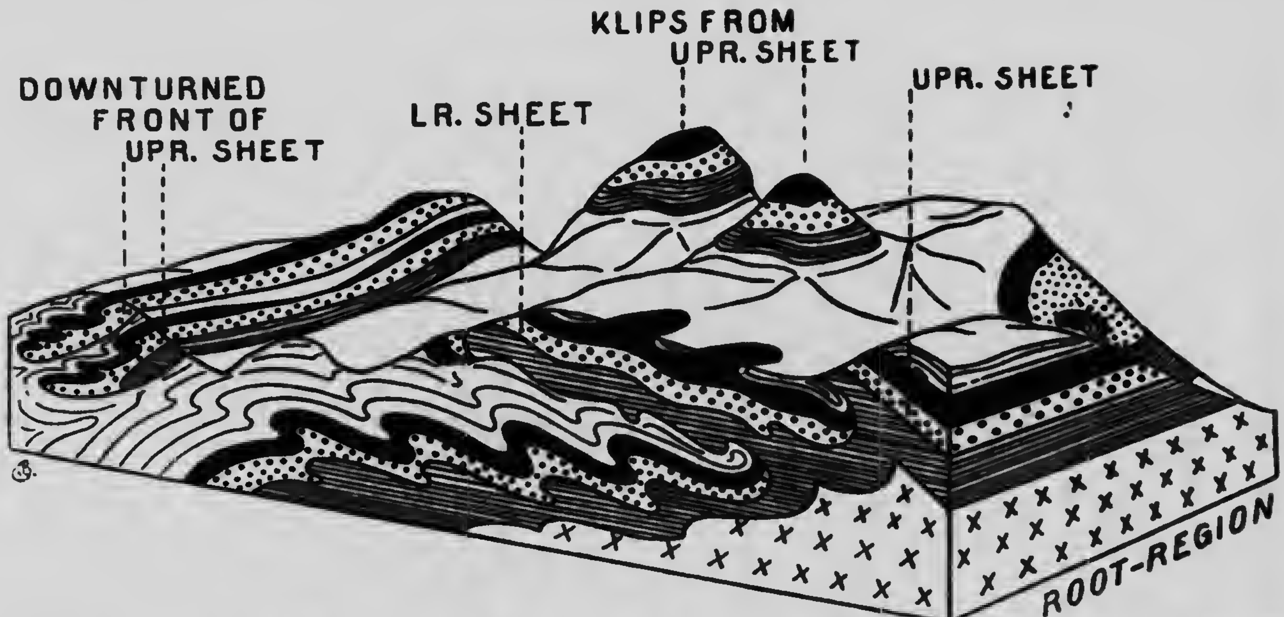

FIG. 12.—Block of the earth's crust illustrating the effects of denudation on two overfolded sheets, the upper of which is doubled along its front by an infold that includes strata of the invaded region. The root-region appears on the right, where crystalline rocks are marked with crosses. The shaded masses represent strata of Triassic, Jurassic, and Cretaceous age, thrust over into yielding beds of the Alpine Flysch type, which are marked by waving lines to show their contortion and general disturbance. Denudation has removed much of the Flysch and other Cainozoic strata from above the overfolds, and has cut through the upper one. Two klips have been left resting on Cainozoic strata as a record of the movement of the upper sheet across the country. (Drawn from a model by Stamm, based on a diagram by Lugeon, and issued by Krantz of Bonn.)

own area; (ii) folded masses that come from a distance, and that are without roots among the rocks on which they lie; and (iii) the roots of these latter masses, forming a district in which the rocks are pressed over towards the direction taken by the mighty and far-travelling overfolds.

When we conceive the Fore-Alps, including the craggy heights of the Diablerets and the serrated Alps of Chablais, as transferred from the south-east across a pass in the granitic range of the Oberland and Mont Blanc, and the superb frontier-wall of the Wetterstein above Partenkirchen (fig. 13) as weathered out from sheets of strata that have moved 100 km. (say, sixty miles) northward from their origin in the region of the Drau, we grasp to some extent the geographic changes that result from mountain-building by compression. It has been remarked that the scale of the differential movements is not vast in comparison with the huge curved surface of the earth. Yet four hundred transferences across stretches of 100 km. would carry a klip on a great circle nearly round the globe.

The folding of a district into a complex anticline, and the thrusting of this mass over in a particular direction, involves the basal rocks as well as those that lie nearer to the surface. Hence each phase in the geological history of a district may be represented in some part or other of a flattened-down and recumbent overfold. In the great precipices above Grindelwald, Jurassic limestones and gneissic rocks of the old floor are seen apparently interbedded with one another. Sections in a direction at right angles to these precipices show that we are looking at the edges of repeated folds, which are cut across by denudation on the valley-sides. We have here an example of local crumpling, the rocks being of the Helvetic type that was laid down in the Bernese district. The Lepontine overfolded sheet once covered them, since we find its rootless klips lying to northward on the Flysch beds near Lucerne.

Indeed, an example of klip-structure that is by this time classical is seen in the Klein and Gross Mythen above Schwyz. These two conical limestone masses are conspicuous as we look inland from the delta at Brunnen, a well-known port on the Lake of Lucerne. They are, for all their settled and residential air, weathered out from the edge of the Lepontine overfold, and consist of Triassic, Jurassic, and Cretaceous strata brought northward on to a mass of Flysch that is proper to the district. The more rounded Rote Fluh to the south-east is another klip from the same sheet. Hence the scenic features of a district are not necessarily carved out from material that was laid down by ordinary processes on the spot.

It is difficult to picture the condition of the Alpine surface when the overfolding was in actual progress. A. Tornquist (84) has suggested that the sea-floor was already in movement during the formation of the Flysch, and that the first rising of the Alps pushed, under a cover of water, Jurassic limestones into unconsolidated Eocene mudbanks. If there was no cover—and it is hard to see what cover could have existed when the later movements were in progress—the successive overfolded sheets moved northward on the surface of the land. The pressure came from the south and south-east, as the gigantic wrinkles were set up by some sliding motion of the mysterious *Untergrund*. Armorican or older blocks, perhaps concealed spurs of the Black Forest and the Central Plateau of France, furnished obstacles that controlled the curved form of the visible chain. The overriding of sheets northward one after another may have been merely repetitions of the first attempt of the earth-wrinkling to override these Armorican obstacles. As the pressures continued, part of the crumpled Helvetic ground was pushed a little northward of its proper area. Then a wave from the

Lepontine region rode up over the well rooted crystalline mass of the Alpine core; it brought with it from the depths the granites and gneisses that have now weathered out as the giants of the Graian and the Pennine Alps. Leaving these, as it were, stranded on the slope up which it moved, to form in due time such features as the Weisshorn and the Matterhorn, the great Lepontine mass flowed onward, carrying its limestone front through the gap of Canton Vaud, and spreading out in the Helvetic depression like the edge of a falling wave. The next earth-wave, the East Alpine, rising still farther south, found itself blocked in the western region, where the Gran Paradiso and the ranges above the Italian lakes remain fairly rooted in their place of origin; but east of the Rhine, as already stated, it rose across the Lepontine sheet, and flowed northward to the confines of Bavaria. The crystalline schists of the Hohe Tauern, south of Salzburg, with their snow-crowned heights, are believed to be a part of the Lepontine sheet exposed by denudation, a window having been cut through the East Alpine covering (fig. 18). The Niedere Tauern, which appear to continue the Hohe Tauern range in Styria, are associated, on the other hand, with the East Alpine sheet. The roots or homeland of this part of

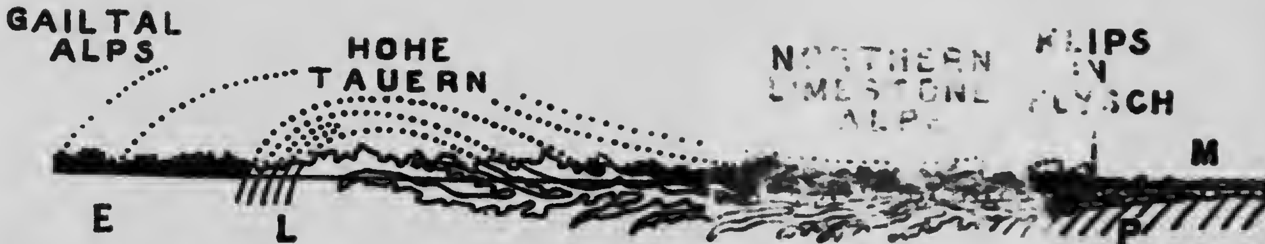

FIG. 13.—Section illustrating the two principal overfolded sheets in the [illegible] Alps. E, Root-region of the East Alpine sheet, consisting of limestones overlying crystalline rocks. This sheet is shown in black. L, Root-region of the underlying Lepontine sheet, which consists mainly of crystalline rocks, and which is exposed by denudation in the mass of the Hohe Tauern. M, Upper Oligocene and Miocene of southern Bavaria. To the left of this region, Flysch, carried forward and compressed under the East Alpine sheet. The Cainozoic strata are marked by dots. P, Crystalline rocks, probably pre-Cambrian, forming the floor of Bavaria. (Simplified from a section by V. Uhlig and O. Wilckens.)

the East Alpine overfold are to be found in the zone of east-and-west fracture along which the Drau has carved its way.

Through the occurrence of resisting bars in underlying sheets, and through the tendency of the frontal portion of an overfold to slide away from the main body, such fractures as that of the Drau valley have arisen commonly in the Alps. C. Schmidt (82) emphasises the parting asunder of stratified sheets when he considers the relation of the central crystalline masses to the lowlands on their northern flank. The front of the sheet falls into the lowland, and remains there as a crumpled range. "We know," he says, "that on the crests of Mont Blanc, the Finsteraarhorn, and the St. Gotthard, stratified rocks more than a thousand metres thick have lain across the crystalline core. Although it is still commonly held that erosion alone has removed this stratified complex, I am much more led to believe that the beds have slipped down northwards. This mass is not lying as detritus on the dark floor of the ocean, but as sun-flecked mountain ridges on the north flank of the central range. The rock-mass that once towered high above Göschenen is to-day reflected in the waters of the Lake of Uri."

These bold conceptions, which are the

result of the most patient study in the field, cannot fail to arouse enthusiasm; but the mind still returns to the question of the appearances on the surface while the over-folding was going on. So much occurred within a single epoch, the Tortonian or Upper Miocene, and probably in a few thousand years, that some of the movements must have been visible to the eye of man, had so discerning a creature appeared upon the scene. Earthquake-shocks at the present day produce perceptible undulations of the ground, and may leave permanent traces in the form of faults and dislocations. But it seems doubtful if a succession of small movements such as man has been able to record represents anything like the building of a mountain-chain at the stage when the resistance of the rocks has been overcome. There is an air of rolling and gliding about the contorted masses that carries us back to the old geological discussions, when catastrophism was the order of the day. We are bound to form some conception of the Tortonian land-surface above the rising regions of the Alps. Was time allowed for this to be shaped by continuous denudation? Did vegetation flourish on it, and animals move heedlessly across it, while the Lepontine sheet was invading the Helvetic region, and while the front of the East

Alpine mass was actually advancing from the south. The ploughing and scouring action along the front of one of these great earth-sheets appeals to us as resembling that of the glaciers of Alaska, when they are shaken out of lethargy and break up moraines and forests in their advance. Slow as the general movement may have been, the crumpling was not confined to the hidden layers of the crust. It occurred in the rocks that formed the very surface, and the final drop into the lowlands suggests the features of a landslide.

It has been very properly pointed out that many of the masses were already folded in Cretaceous times. We have noted in England and other parts of Europe an upheaval of Jurassic rocks before the return of the sea in the Upper Cretaceous epoch. But this does not detract from the magnitude of the Alpine problem. There were early axial elevations from which the flysch type of detritus was derived; by the end of the Miocene period these were converted into a series of intensely overfolded and overtowering mountain-chains. The Alpine movements remain the most amazing feature in the growth of Europe.

Some geologists still hesitate to apply to the Alps of Austria the conclusions derived from a study of the western and central Alps. There can be no doubt, however, that these conclusions have profoundly modified our conceptions of what may be expected in a mountain-chain. Wherever one-sided thrusting has produced unsymmetrical structure, we may well look for repeated overfolding and the formation of successive sheets. The older conception of a mass rising vertically along an axis, stretching the rocks along its crown and ultimately leading to their fracture, seems none the less true for certain cases. Gravitational action on both sides will then produce recumbent overfolds, and any further upward movement may well spread out the anticlinal fronts of higher sheets beyond the fronts of those below. The backsliding of the folds that is observable in the root-region on the south side of the Alps may be ascribed, with Suess, to the subsidence of the floor on that side, or, with other geologists, to the further elevation of the central region of the chain. When G. P. Scrope published his *Considerations on Volcanos* in 1825, he reasoned out the effects of the vertical uprise of the rock-floor along the axis of a mountain-range, and realised nearly all the structures, due to overfolding, fracture, and differential sliding, that are exhibited in the magnificent cliff-sections of the Alps (fig. 14).

What, finally, was the surface presented to denudation when the Alpine movements came practically to rest? Did the slowness of the movements allow of the planing away of irregularities and the production of mature hill-forms, or did their rapidity, as now seems probable, leave yawning gaps and scarps of fracture, between which the ground was cumbered with coarse taluses of fallen blocks? In either case, denudation set in, and it is generally believed that the resulting Pliocene surface of the Alps was less irregular than that

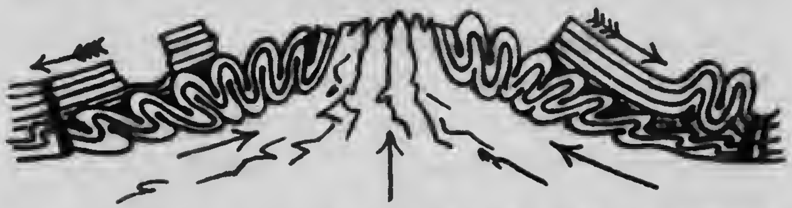

FIG. 14.—Section drawn by G. P. Scrope in 1825, to illustrate the effects of the upthrust of crystalline rocks through overlying stratified deposits, and the sliding and overfolding on the flanks of the resulting mountain-chain. The dykes shown in black are igneous intrusions spreading from the granite.

which appeals to us so powerfully at the present day. The granitic masses no doubt asserted themselves, and became, from their elevation, etched by frost-action as well as scored by swiftly falling streams. The stratified ranges gave rise to scarps, edges, and dip-slopes, much as they do in modern Switzerland. The boundaries running east-and-west between distinct rock-types, and the surfaces of faulting along which the last vertical movements had taken place, were seized on as lines of weakness by tributaries of the consequent streams. Deep valleys, like those of the Rhone or the Upper Inn, were thus excavated down the length of the chain, and they have produced in some places an apparent division of the mass into successive ranges. These modifications were effected before the Glacial epoch. During the milder ages of that epoch, the valleys were in part occupied by glacier-tongues; during the colder ages, the ice choked them, rose above their walls, and moved across them, controlled only by the general gravitational flow northward and southward from an axis of maximum precipitation. The walls of the valleys in the heart of the chain thus became sometimes moulded and in large part undercut by the ice; at other times they were protected by stagnant ice under a confluent sheet that crossed them. In the stratified masses, the plucking off of blocks along bedding-planes and joint-surfaces went on freely. When the day-temperatures on the heights were sufficiently high to melt the snow, frost-action etched out the exposed ridges, and contributed largely to the formation of the steep-walled recesses known as *cirques*. The knife-edges, or *arêtes*, set with jagged pinnacles, which attract the hardy climber, are often produced by the working back of cirques from opposite sides, whereby a rounded hill-crest may be reduced to a serrated ridge. We must also attribute to frost-action the production of outstanding peaks, like the Grivola or the Matterhorn; but these could never have attained such prominence, had not the ice been able continuously to carry off the débris from their feet. The same is true of the precipiced cirques, and the vertical walls of valleys, such as those of Lauterbrunnen or the flooded gorge of Uri, which are now deserted by the ice and liable to become modified by detrital banks. Here and there rock-basins have been excavated behind hard bands which the glaciers were unable to clear away, and the streams, originally starting in or beneath the ice, have cut ravines through the barriers down to the level of the valley-floor. The features of the higher Alps are young and ever changing; they are at present very far from geographical maturity. Yet the great days of denudation are already over, and the glaciers now shrink away between their sharp-crested lateral moraines. The last age of the Carboniferous and the earliest age of the Permian period sufficed for the rise of the Armorican chains in Europe, and the reduction of their surfaces to plains of subaerial erosion. Every landslide and the swirl of every torrent are factors in the destruction in the human epoch of the glory of the Pliocene Alps.

CHAPTER X

THE LOWER BASIN OF THE DANUBE

It has been already noticed that the folding of the Alps from south to north, and the resulting "strike" or general trend of their rock-components from east to west, have influenced the courses of rivers within the mass. In addition to a group of consequent streams flowing northward into German lands, and another group flowing southward into Italy, we find deep trenches cut along the strike by the Rhone, the Inn, and the tributaries of the Lower Danube. These, as was pointed out on pp. 96 and 146, have beheaded the original consequent streams. The Inn, however, atones for this by maintaining a consequent part of its course through the stratified ranges of Wörgl and Kufstein, whereby it reaches the Upper Danube across the Bavarian plain.

The important subsequent or strike branch of the Inn rises on the Arlberg; that of the

Salzach runs back between the Alps of Pinzgau and the Hohe Tauern almost to the valley of the Inn. The head of the Enns, rising at 860 metres (2820 feet) near Radstadt, almost intersects the valley of the Salzach. For 100 km. (say, sixty miles) the Enns flows eastward, thus continuing an excavation along the strike of the Alpine folding that is almost complete away back to the Arlberg and the upper waters of the Rhine. These elongated subsequent portions of the northern drainage-system prepare us for the grand eastward-flowing rivers that feed the Lower Danube from the region of the Carnic Alps.

Suess has connected the Drau and Gail valleys with fracture-systems, and the fault-movement along the latter was manifested as recently as 1846 in the great earthquake and landslip of the Dobratsch, which scarred the northern wall near Villach. The two rivers rise close to one another near Sillian in the Pustertal; the Drau a little to the west, on one of the most interesting watersheds in the Alps, and the Gail across a small rise a little to the south-east. The Drau reaches Villach, some sixty miles east, after two notable northward bends near Lienz and Sachsenburg; the Gail keeps almost straight along a band of ancient crystalline schists. Between the two rivers, along the general Alpine strike, a zone of Triassic limestone produces splendid pinnacles and scarps.

The development of marine limestone in Triassic times in this region, while Switzerland remained dry land, has added a number of wildly fantastic forms to the scenery of the Eastern Alps. The Dolomite Alps of Tyrol are known to rock-climbers as presenting some of the most defiant precipices. The massive limestone was developed side by side with more normal sediments in the Triassic sea, and the transition from one type to the other is so abrupt that von Richthofen and many later observers see in the Dolomites upraised coral-reefs some 4000 feet in thickness. The fact that modern coral-reefs are converted into dolomite, by the substitution of magnesium for calcium through the agency of percolating sea-water, greatly supports this view as to the origin of the masses in Tyrol. Their upper layers are often distinctly stratified, as if, in shallowing lagoons, the reef-building corals weakened and ordinary sedimentation was resumed.

The present pre-eminence of the craggy dolomites is due to two causes. They weather, like other limestones, down great vertical joints, which widen by solution, and provide the hazardous "chimneys" by which their summits are attained. Brown scars may be seen upon their walls, with fresh talus-heaps below them, indicating the vertical flaking that is going on every day. The neighbouring sediments, of varied character, wear down into far gentler forms. Where the two types come into sharp contrast at their meeting-ground, the sediments wash away from the limestone wall, which becomes more and more dominant as time goes on. But in many cases the dolomite masses are bounded by planes of fracture. They have refused to yield in the general stress of the Alpine movements, and have become broken up into huge blocks, which have been shifted this way and that, and have sometimes sunk into their weaker surroundings. The region extending into Italy, south of Toblach and the source of the Drau, is set with the most magnificent rock-pinnacles and serrated walls, which owe their present position to Miocene disturbance, equally with the crystalline rocks of the Matterhorn or Mont Blanc.

As we descend the torrent of the Drau from the level watershed of Toblach, we plunge at the scattered village of Abfaltersbach into the great gorge of Lienz. The limestone on its south-east side, contrasting with the old schists on the north-west, forms a succession of notched and serrated spurs. The crags on both sides send down huge taluses, and landslides have often blocked the groove. These ten miles present a scene of destruction that is characteristic enough, and yet always impressive, among the limestone Alps. During a thunderstorm, you may see the water oozing from some treacherous rift; then presently the stones begin to grind on one another; the hill-side gives way, the whole talus moves down towards the valley, and thousands of tons of mud and crumbling rock are added to the burden of the stream. A rainy evening among the Austrian Alps goes far to explain the infilling of the plains to eastward.

The Pustertal, of which the Lienzer Klause is the closing episode on the east, is a noble example of a "through valley," in which the watershed is hardly perceptible between the Rienz, flowing to the plain of Verona, and the Drau, flowing to the Danube. At Toblach the flat of cultivated land, 4000 feet above the sea, seems to belong to both drainage-basins. It forms a pleasant interlude among sombre wooded hills, with the Rienz coming down on it from the dolomite towers on the south, and the Drau rising quietly close at hand in the forest-slope below the Gant Spitze. In the Glacial epoch it was buried deep in ice which came over from the north, flowed out east and west, and also penetrated south towards the Dolomites.

MICROCOPY RESOLUTION TEST CHART

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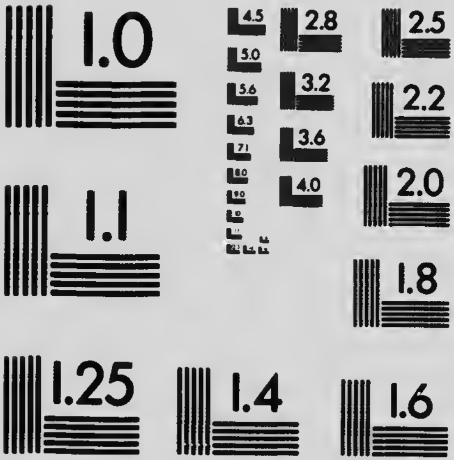

E. Suess (I, 3, 452 and 469) regards the Triassic region south of Toblach, of which we obtain such romantic glimpses up the Rienztal, as belonging to the Dinaric ranges rather than to the Alps. In these ranges, farther to the east, the prevalent thrusting has been from north-east to south-west (I, 1, 659), arising, therefore, from a sub-crustal movement distinct from that which has formed the Alps. Movements to the south are indicated in the Marmolata among the dolomites of Tyrol; but these may be due to the general backward slip of the southern Alps as the Po depression developed and the northward thrusting came to rest.

The Triassic ranges south of the Gailtal may still more reasonably be classed as Dinaric. Between them and the Gail, the ridge of the Carnic Alps consists of an old Armorican mass squeezed up in the general folding, and it interestingly includes Silurian and Devonian strata, as well as Carboniferous, reminding us of the old ranges far away in southern Ireland. A similar outcrop of the older floor occurs to the north of Graz in Styria. But all the mountains in this complex region owe their present prominence as European features to the crumpling and uplift of late Cainozoic times, and the slipping down from them of faulted basins and of plains.

The Drau, carving at its valley-floor, has long formed a highway into Hungary, until it becomes the Drava in soft Slavonic speech, and meanders largely in the plain at Varasdin. As we descend through Ober Drauburg and Greifenburg, and other villages with wooden roofs and bulbous spires, we may note how the road clings to the sunnier side of the deep valley, and to the gentler northern slope, mountainous though it is, formed by the smooth weathering of the schists. On the south side, the limestones rise in frequent scarps; but all along the valley one may find milder episodes, caused by relics of the last marine Miocene strata, or of the freshwater Pontian zones that replaced them as the sea was driven to the east.

From south of Sachsenburg to Villach, however, the river cuts into the northern schists, much as the Danube does on the edge of the plateau of Bohemia; the valley in part shows broad terraces of alluvium and glacial drift, the level top of which is used for hay-fields. The bridges across the rapid stream are made for flood-time; if parts of their timber structure are swept away, they can easily be repaired by local carpenters, who carve on them a date and a pious symbol, with considerable knowledge of man's futility in face of the destruction of the Alps. Then the valley narrows before Villach; the hamlets stand on cliffs above the river, or are hidden in forest, echoing to the roar of water-mills; and suddenly we emerge on a great Cainozoic basin, stretching away beyond Klagenfurt, and cumbered with the fresh moraine-material of the Würm-age glaciers of the Eastern Alps. On the south again, as at Toblach, above bare local cones of stratified rock, the dolomite masses tower, crag after crag, along the wall of Italy.

The clear green Gail, which has clung to its straight route along the northern border of the Carnic Alps, comes here into the Drau. Its valley preserves a distinctive population, and the short-skirted brilliantly dressed women, with their Slavonic sense of colour, offer as great a contrast to the citizens of Villach as the Carnic highland offers to the Quartary hummocks along the Wörther See.

The glacial deposits within the terminal moraine of the Drau glacier form irregular forest-covered land before Bleiburg. The river cuts through them down into the rock, and villages are banished from its romantic gorges as it dissects the schistose floor of Styria. The log-rafts swirling down upon the rapids, between cliffs and pine-clad hills, have still the grand air of the Alps; and then the Alps themselves sink away beneath us, as we come out on the Pliocene land of Marburg, and find, on the Pettauer Feld, the once heroic river of Carinthia wandering in its own alluvium. Thenceforward to Varasdin and Eszék, wide stretches on its banks are abandoned to marsh and pebbly flats, set with grey-green willows, and with a rough vegetation, which furnishes pasture for long-horned Hungarian cattle and the dark imported buffalo. The official boundary between Hungary and Croatia follows lost loops of the stream, and at the present day makes on the map a series of quaint and meaningless meanders. We are here only some 500 feet above the sea, which lies at Varna, as the crow flies, 600 miles away.

The Mur to north of it and the Sava to the south, though less significant, have much the same history as the Drava. At one time they also fell into the last Miocene sea of central Europe. Their waters spread out in the Pontian lakes, and finally became restricted features of the vast alluvial plain. The Mur rises in the mountainous ground produced by the resistance of the Tauern mass. We see it flowing innocently through St. Michael at the north side of the Katschberg Pass; but soon it becomes a destructive agent, washing away the bases of frequent landslides, and carrying the revived mud of antique strata far down for the building up of Hungary. The Mur cuts southward across the Armorican land at Graz, and emerges promptly on a basin that was faulted down in late Miocene times, where its broad alluvium now forms a tongue of the plain, stretching back across the fractured and buried Alpine spurs. The Sava has its sources in the white crags of the Mangart, which towers like a fortress of Austria above the Predil road. On the south of it is the Slavonic country that merges naturally into Italy, and the triple names of the villages, as Karfreit, Kobarid, Caporetto, reflect the passage from the Alpine edge into Dinaric regions on the east and into the Adriatic downfold on the south. But the Sava, sheltered on the northern Dinaric slopes, runs away eastward to Belgrade; it keeps along the Triassic strike in a wonderfully straight course for 30 km. (19 miles), then cuts across the beds into the glacial basin above Laibach, and escapes east again from this, with episodes of gorges, into the inlet of the plain near Agram. At Agram it traverses an Alpine spur, which is so sunken and insignificant that the alluvial valley on its back is 8 km. (5 miles) wide. The river now shows a tendency to work against the soft Cainozoic hills on its southern bank; but it has produced in its wanderings a flat from 8 to 12 km. (5 to

7 miles) across. Long before its junction with the Danube, the Sava has become a sluggish river of the open plain, and even near Sisek we feel ourselves in the unsheltered lowland that has swallowed up the last spurs of the Alps. Oak-forests, dark and primeval, spread across the unfenced country. The villages cling to the straight military highway, or to the loopings of the stream as best they can. The country is unfinished, the very soil is still unsettled, and Budaševo on its curving marsh, or Ivaniskibak, following a bend that has run dry, illustrate the continuous building of the plain at the expense of the mountains to the west.

Storms in this Croatian lowland are very different from those familiar in the Alps. The writer has elsewhere described a flight before one on the road (35). "As we turn round, kilometre after kilometre, we can feel the sunlight being swept from the face of heaven; the earth lies still; even the great oak-forest, from which we have emerged, is only just beginning to tremble in its topmost leaves. But now the first wind touches us, the first drops begin to fall; the whole life of the country is at once in motion, fleeing along the road, where the dust is whirled up strangely amid the rain. Hailstones descend, at least an inch across, and break themselves to pieces on the ground. Horses, cows, poultry, white-kerchiefed girls, and men in black coats, their sleeves flying out behind them, hurry into the nearest villages from the blank and stricken fields. A hand, as it were, at first gentle, then imperious, pushes you forward from behind. In the air there are resistless spirits; in the oak-forest there are strange whisperings, and the cry of frightened birds. The herd-boy, with his rustic pipe, knows these things better than the wisest student of geography."

The Eastern Alps, then, feed the Danube, and terminate in this sudden contrast of the plain. The history of the plain can best be studied in the land south-eastward from Vienna.

Vienna, the Vindobona of the Marcomanni, occupies an inevitable site, where the Alps swing north-eastward to join the Carpathians, and where the Danube has cut the barrier, forming a gateway to Bavaria and the west. The actual gateway is at Hainburg, where the passage is too narrow for more than a couple of fortified villages, climbing on the cliffs of either bank. The alluvial level between this and the friendly uplands of the Wiener Wald belongs to whomsoever would keep the peace in central Europe.

In old times the Romans settled here at

Carnuntum, keeping watch on any tribes that might descend from the Bohemian horst towards the farmlands of Pannonia. The Middle Ages saw the struggle changed to one between east and west, and the passage cut by the Danube was best defended by a city with its back against the hills. The western suburbs of Vienna spread up into the forest-country, and the unprotected land outside the eastern wall was covered with the Turkish tents as recently as 1683.

North-west of the city, however, there is an interval of lower ground before we rise to the plateau of Bohemia. This, styled "the Vienna basin outside the Alps" (extra-Alpine), was occupied by the Upper Oligocene sea. The Alpine spurs were crumpled up soon after, and the early Miocene epoch saw a restriction of the sea, which none the less stretched north across Moravia. The extra-Alpine basin remained decidedly marine in the Helvetian (Middle Miocene) epoch, when the sea extended back over northern Bavaria and Württemberg, in a last attempt, as it were, to counterbalance the general Alpine uplift. As Europe grew in this area, and the Danube began to flow, fed by the new rivers from the rising Alps, the extra-Alpine basin shallowed; but it was not until the opening of the Pliocene period that the Danube could extend over new land eastward of Vienna. The same is true of its southern tributaries, the Mur, the Drava, and the Sava. The Upper Miocene (Tortonian) beds of Styria and Carinthia are essentially marine. The vast Hungarian plain is thus a product of the Pliocene period.

The presence of the sea at the foot of the growing Alps is beautifully revealed in the fossiliferous deposits of the "intra-Alpine" basin of Vienna (IV, 2, 1686). This triangular area, stretching south-west between the Wiener Wald and the Leitha range, is bounded by late Miocene faulting on both sides; but on the east it flows, as it were, over the Leitha gaps to join the plain of Hungary. It is now, like the corresponding basin of Graz (p. 188), largely covered by level alluvium from Alpine streams, which here run north-east, and industrial towns and villages have sprung up on it. Its lower and concealed deposits were no doubt at one time continuous with those across the Wiener Wald; but the sea remained here far longer while the basin sank amid the Alpine spurs. The site of Vienna lay on the eastern edge of Europe down to the opening of Pliocene times.

Then, in the Sarmatian and Pontian epochs, even the great depression of Hungary, ringed about by the Carpathians, began to run dry, and the Danube extended across it eastward

The strange and shallow Neusiedler See (the Fertő Tava), under the villa-gardens of the Leitha slope, occasionally disappears by evaporation, and its floor unites with the marshes of the Raba. It preserves to us a picture in little of Hungary in Pontian days. The handsome bivalve mollusc, Congeria, is characteristic of the shrinking Cainozoic sea, and the brackish water "Congeria beds" can be traced, as the typical Pontian strata, from Dalmatia across Hungary to the Caspian. The underlying Sarmatian beds are more distinctly marine; the overlying gravels and lake-deposits contain Mastodon and Rhinoceros, and Hipparion, the three-toed horse, preparing the way for a rich mammalian life in the plains newly claimed by Europe from the central sea.

The volcanoes that broke out on the margin of the great depression, when the Carpathians continued to rise in Miocene times, have added their picturesque and dissected remnants to the foothills. Where they are cut through by the Danube between Esztergom and Budapest, they prove that there has been a considerable removal of Cainozoic deposits from the plain. The gorge in the Little Carpathians, already referred to, and that of Kazan and the Iron Gates on the Rumanian frontier, tell the same tale. The floor of

Hungary may now be in course of "aggradation" by alluvial flooding; but it lay at a higher level against the mountains when the Danube first extended over it. At the same time we must remember that the eastern Carpathians continued to rise after the opening of the Pliocene period, and thus may have been pushed up against the cutting action of the rivers. The last marine strata of eastern Hungary, those of the Sarmatian stage, have been disturbed by these comparatively recent movements.

At present, however, the shifting of the rivers, and the action of the winds on the deposits of the dessicated Pontian marsh, tend to keep the surface uniform and level. In some places dunes are built up, and these were doubtless more common than they are now in the dry steppe-epoch that followed upon Glacial times. The fine wind-borne loam known as *löss* has accumulated eastward, under the influence of the prevalent winds, and a drift of minute particles still goes on in this direction from the plain towards the mountains. In summer, many of the bridges in the plain cross dry channels; the roads are mere grooved and dusty tracks, spreading out laterally into the surrounding land, since each driver of the horse-drawn country carts tries to find a firmer bottom for his wheels. In rainy seasons they are almost as impassable as those of Russia, despite the rolled pebbles from the alluvium that are liberally thrown into their grooves. The ringed camps that were necessary in early days in so open a country may account for the clustering of the houses into villages, from which it is often a considerable journey to the fields. The contrast of central Hungary in this respect with the Silesian uplands is at once remarkable. The houses in the villages are set down anyhow, and the frequent movements of the meandering streams have discouraged a respect for boundaries. The fall of the country, as shown by the Danube and the Tisza, is generally from north to south; but these rivers have swung sideways, leaving behind them marshy loops and brackish pools. The subsidence of the great basin and the continued elevation of its margins broke the eastward trend of the Danube as it came into the plain. It recovered its natural course, however, below Apatin. Here the drop from the Alpine spurs to the Sarmatian sea remains recorded in the Drava and the Sava, and it is quite fair to regard these rivers, rather than the Danube, as the makers of the gorge into Roumania.

Eastward of the Carpathian ring, the Danube moves over the former floor of the early Pliocene sea, and the Caspian may be looked on as a survival of the far larger Sarmatian waters. These, in fact, communicated with the Arctic Ocean, and it is only in recent times that the Danube has escaped to the Mediterranean. The low shores of the Black Sea have experienced many interchanges of terrestrial and marine conditions since the Pliocene period. The great swampy delta of the Danube still manifests the growth of the detritus of new Europe against the sea that so long withstood it on the east.

We are also reminded of the brackish and waning Sarmatian sea, and of the termination of the European land-mass at Vienna, by the present-day openness of Hungary to invasion from the east. The plains of Asia extend across the south of Russia; the Carpathians alone form a break between them and Vienna. On ground thus suited for the mobile tribesmen of the east, who carried as they rode from each smoking village the heads of the peasantry and food for the next day's march, any horde that crossed the mountains became a terror to the heart of Europe. The Carpathian-Dinaric ring was for them the boundary of a huge armed camp, from which the Huns in the fifth century swept on into central France and Italy. When the Huns were broken by the portent of the death of Attila, the remaining Teutons found themselves opposed by Slavs, who descended from the hills to repeople the devastated lands. Justinian, in his restoration of the empire, admitted another eastern race, the Avars, to Transylvania, whence they spread promptly over the unprotected plain. After a domination of two hundred and fifty years, they left no monument of settled rule; and the armies of Charlemagne, finding them a menace to the west, cleared the Lower Basin of the Danube in a desolating foray of seven years. The villages planted by invading Asia proved as perishable as nomadic tents. The Magyars, however, entering in the ninth century from the Volga region, showed a real capacity for occupation. They have held the plain for more than a thousand years, even though for a century and a half they had to admit their Ottoman relatives as overlords. They are still, however, apt, consciously or unconsciously, to assert their place as oriental conquerors, holding the Slavs at bay along the mountain-rim, and watching with profound suspicion the Teutonic gateway at Vienna.

CHAPTER XI

UNYIELDING RUSSIA

THE great territory known as European Russia occupies more than half the continent. At Myslowitz on its western border the traveller is nearer to Ostend than he is to Moscow; and at Moscow he is only half-way to the Urals. Except for the Urals on the east and the Caucasus and Crimean ranges on the south, the vast expanse of Russia is almost as featureless as Finland. It has not even the picturesque indentations of the sea which add variety to the coast of the Grand Duchy. The White Sea is a flooded continuation of the broad tundras of the north. The shores of the great lakes are low, like those of the Archæan region of America; and in the far interior the land seldom rises more than 1000 feet above the sea. The great drift-covered plain of Prussia (p. 121) extends through Poland, and thus connects the Baltic lands with Asia; for Russia, in its broad simplicity, is more distinctly Asiatic than any of the complex lands that lie to west of it. Even in the south-west, the lowlands of Galicia and Roumania bar out Russia from the Carpathians, and preserve the mountains for other European states. It is only in the south-east that Russia can boast of crags and snow-peaks surpassing those of the Alps, and of a " côte d'azur " which in time may attract her more prosperous citizens from the promenades of Biarritz and Monte Carlo.

The floor of this great country, which is neither a plateau nor a plain, has been described as a platform, and consists fundamentally of pre-Cambrian rocks. It is an extension of what we have already seen in Finland, a surface that records upheaval, sedimentation, subsidence into cauldrons of molten rock, and profound metamorphic changes, repeated through long periods of time. Before the Cambrian period, it was worn down to a merely hummocky condition, without important axial ranges, or even conspicuous divides. It exhibits relics of folding that strike a little west of north; but the crests and hollows of the folds are alike lost in the general degradation. We are again reminded of that remarkable epoch when denudation in the northern hemisphere remained for long unbalanced by mountain-building processes, and when the conditions postulated by Hutton were so nearly realised. A whole continent of crystalline rocks was reduced almost to the level of the sea. Where heights of three or four thousand feet remained, as in the Scottish area, the hollows between them were choked with their products of decay. Across the low shores, alike in Esthonia and Ontario, the Cambrian and Silurian seas slowly spread; and it was left for the Caledonian movements to save the sinking continent and to crumple up parts of it as European land.

In the Russian area, however, these and later folding movements were represented by broad general oscillations. Seas invaded the platform or were driven out again, and finally the Upper Cretaceous ocean so far prevailed as to deposit 1800 feet of Chalk in the south and to cover half the region (86).

The Eocene Mediterranean, occupying a wide area in which Flysch beds were just beginning to accumulate, sent an arm up the present Volga valley and spread continuously from south-eastern France to the Caspian. The Russian platform suffered a still greater [illegible]sion in Oligocene times. Communication was established with the Arctic seas, and the Alpine uplifts failed to turn the southern portion into land. On the margin of the platform, however, a chain was reared that stretched from the Balkans into Asia. Its western portion has been broken by the recent subsidence of the Black Sea area, and a merely suggestive relic remains in the hills that form the south of the Crimea. But between the Black Sea and the Caspian rises the great natural frontier of the Caucasus. Though the chain is fractured at both ends against the inland basins, it still includes some of the most magnificent mountain-crests in Europe.

Folding took place along the line of the Caucasus at the close of the Jurassic period (87). Denudation, however, reduced the highlands almost to a peneplane, and the Miocene sea spread freely across them as they sank. The present features of the Caucasus date from the great upheaval of Upper Miocene (Tortonian) times, and the range represents the culmination of the Alpine group in Europe. E. Suess (I, 1, 650) recognises in the overfolded strata an interesting combination of thrusting towards the south, which he regards as an Asiatic feature, and then towards the north, by a sort of earth-sway, in accordance with European structure.

The deposits of the Sarmatian sea, the last to leave the Hungarian plain, have been lifted on the north flank of the Caucasus to a height of 2000 metres (6500 feet) above the present sea-level, and have become actually folded in the final movements (II, 1806; I, 1, 625, 678). After rivers and frost had carved grooves and hollows in the gigantic chain, a series of fractures, traceable along its crest and across the Central Plateau of Armenia (37), served as passage-ways for extensive outpourings of lavas and volcanic tuffs. The huge cones of Elbrus (5629 metres; 18,467 feet) and Kasbek (5043 metres; 16,546 feet), cutting the snow-level, were thus piled upon the crystalline axis; and the volcanic manifestations in Armenia in historic times, and the frequent earthquakes of the present day, attest the insecurity of the European borderlines.

The Ural Mountains are contemporaneous with the Caucasus, but have adopted a completely different trend. Pushed from the east into a series of folds which subside slowly on the west into the great Russian platform, this chain has brought up Palæozoic rocks, with crystalline masses forming the crest of the divide. The steepest flank lies on the east, and the ridge is nowhere remarkable from a scenic point of view, since it rarely rises 1600 metres (5250 feet) above the sea. It has become recognised as the eastern boundary of Europe; but, until the discovery of its mineral wealth, it scarcely affected human history. The Caspian steppe to the south of it has freely admitted Asia, and to this day, for many educated Russians, Europe begins at the Carpathians.

The Timan range is a mild offshoot, stretching north-west from the wooded Ural slope to the desolate tundra of the Arctic shore. Suess sees in the general trend of the Urals an impress of the pre-Cambrian folding of the platform upon the far later earth-waves pushing in from Asia. As Ampferer indicates (p. 15), the causes of a folded chain do not lie by any means on the surface. It may represent the arrest of a progressive wave against an obstacle, or it may even point to vertical upthrust from below.

At the south end of the Urals, where the Cretaceous strata are involved, we enter the region that was occupied by the Aralo-Caspian sea even after the Glacial epoch. This sea, which is now represented by the two separated inland lakes, has an interesting history. The greatest elevation of the Caucasus took place in early Pliocene times, and the sea that was driven east from Hungary remained in South Russia as an inland sheet, cut off by the Balkan-Caucasian uplift from the Mediterranean. The present Black Sea region became in part dry land, and rivers began to flow in Pontian times on the newly raised land that connected the Balkan area and Asia Minor. One of these carved out a valley through marine Sarmatian strata where the Bosporus now lies. During Pontian times, the Aralo-Caspian sea became more and more brackish, its deposits being thenceforward characterised by species of the bivalve mollusc Dreissensia. These shells are interestingly found in various places on the floor of the Black Sea, of the Bosporus, and of the Sea of Marmora. It is clear, then, that subsidences took place, which no doubt at the same time broke up the Balkan-Crimean chain, and brought the Aralo-Caspian water back over the Black Sea region. The brackish sea crept into the river-valley on the south-west, and the Bosporus was thus established (88). R. Hoernes attributes the Dardanelles to a continuation of the Bosporus ravine; but the sea appears to have invaded the Dardanelles as recently as Post-Pliocene times, during the falling in of the Ægean area. The Black Sea was at the same time cut off from the shrinking Caspian, and became, through this narrow and insufficient channel, a portion of the Mediterranean system. Marine forms of life entered the Black Sea through the new passage, and corals are found in the Sea of Marmora that have attached themselves to the Dreissensias of Aralo-Caspian days.

While these modifications were taking place in the southern part of the great platform, the Scandinavian ice-sheet more than once invaded Russia. In an inter-glacial epoch, the sea replaced the ice in the Dvina region, as an extension of the Arctic Ocean; but these late marine deposits are insignificant when compared with the immense mantle of boulder-clay and coarse water-washed sand that was left behind by the stagnating ice. The margin of the ice-sheet (fig. 10) has been traced across the Petchora river in the north; southward by Perm to the great bend of the Don in the Cossack steppes, which it reached as a broad lobe, leaving an uncovered country on the west; and along the front of another lobe that extended to Yekaterinoslav, only two hundred miles from the Black Sea, and on the latitude of Passau and of Strassburg.

Even after the Glacial epoch, when the Scandinavian ice had withdrawn from the heart of Russia, the Aralo-Caspian water sent a broad arm up the Volga as far as the Samara loop, and brought to the central district a milder climate than it now enjoys. A large part of southern Russia may, then, be regarded as reclaimed in very recent times for Europe. Like Finland, which is still recovering from the ice-age, its surface remains practically embryonic when compared with many western lands.

The steppe-epoch, however, following on the withdrawal of the ice, was a time of marked dryness in northern and eastern Europe. The winds swept up the fine loam from the glacial outwash-sheets and from the hummocky drifts, and carried it as löss (p. 194) into the hollows of lakes and into the shifting valleys of the rivers that again began to flow. This yellow earth tended to level up the surface, from the plains north of the Carpathians to the Caspian steppe. It caught against bands of rising land, as Daniel Defoe so brilliantly conceived in his geographical romance of *Captain Singleton*,[1] and it rendered large areas suitable for agriculture when more temperate conditions were established. In Russia, the lower layers of the löss are often stratified, and were no doubt spread out by water that still flooded across the glacial plains. The upper layers are traversed by vertical shrinkage-cracks, and afford an easy passage for the roots of plants. The Black Earth district of central Russia,

[1] This foreshadowing by Defoe of part of von Richthofen's famous theory of the löss is so characteristic as to be worth quoting. Singleton's party had entered on a desert, and were glad to find that in time the sand became less deep and heavy. "This we thought might be because, for six months of the year the winds blowing west (as for the other six, they blow constantly east), the sand was driven violently to the side of the desert where we set out, where the mountains lying very high, the easterly monsoons, when they blew, had not the same power to drive it back again."

where the famous *tchernozem* soil prevails, stretches from near the mouth of the Bug in the Black Sea to the upper reaches of the Ural river. It forms a broad band intermediate between the more northern forest-zone of Russia and the barren untilled steppe. The moisture is here insufficient to encourage the growth of trees, and consequently the winds have ample scope (89). Yet the conditions allow of the growth of grasses and a variety of bushy plants, which have added black humus to the löss and have checked its free transportation by the wind. Farther south, the bushes disappear, and the green and flower-clad expanses that delight the eye at the end of spring are merely a transient feature of what is almost desert land.

The Russian platform is thus largely concealed by deposits of very recent origin. Through these deposits the rivers now cut their way, aided in the north by a progressive uplift that has been estimated at two feet in a century. Here and there we are reminded of the robuster rocks that form the platform, as when, below Yekaterinoslav, we see the granite floor in the cataracts of the Dnieper, where the "insatiable" water recalls the edge of Finland. The Volga often reveals Cretaceous limestones in its cliffs, and it notches a Permian spur above Samara. But the glacial beds and the löss allow of frequent landslides from the vertical walls above the streams, and even in the forest-region the watercourses tend to wander, while flooding is even more common than in Hungary. Though the Vistula (p. 128) is consequent on the Carpathian uplift, and the Ural in the southern forks of the Ural mountains plays the part of the Mur or the Sava in the Alps, there seems little in the surface of Russia to determine the courses of the modern streams. The systems of the Volga and the Don, and of the Dnieper from the plateau of Smolensk and the great alluvial marsh of Pinsk, indicate a general southward slope. When the snows melt in springtime, and the cart-roads in the country resemble streams, it is hard to say if this flow or that in northern Russia is going to feed the Arctic Ocean or the Mediterranean, or to pass back into the atmosphere from the desiccating Caspian steppe.

To appreciate Russia, and the difficulties of Russia, one should examine a map on a fair scale, such as the 1 : 200,000 sheets of the Austrian Military Institute. Even in Russian Poland, where conditions are more typically European, few hard roads exist, and the population is scattered in an immense number of isolated farms. As occurs in Austrian Poland also, and in most agricultural countries, there is a marked distinction between a village and a town. The latter may display surprising refinements of civilisation; but the great distances across unconsolidated plains maintain the villages in their primitive condition, and they are often mere hamlets of wooden huts and ill-provided stores. There are probably millions of Russian peasants who, but for the compulsion of military service, would never have seen a railway or a town of brick or stone. Village-life has in consequence assumed a certain significance, which is by no means unimportant in the development of character; but the interior of Russia has remained almost untouched by the music of eastern culture or the surges of European thought. The map of one of its forest-areas goes far to explain the impossibility of any such concerted uprising as that which brought the men of Marseilles to Paris, or Vespasian's legions from Jerusalem to Rome.

On the north the tundra stretches, and here the dwarf birch dies away, while the arctic willow becomes so stunted that the traveller walks upon its branches, as they lie outspread on the frost-cracked soil. South of this lies the zone of birch and conifers, forming dense woods that are occasionally swept into blackness by accidental fires; then the central district where beech and oak can flourish, and where man has profitably opened up productive clearings; and finally the steppe, merging into Asia, with its rich black soil deteriorating southward into sand. All these are practically level lands. There are no bulwarks set with watch-towers, no heights fit for prolonged resistance to attack. It was through the Russian plains that the cavalry of Batu Khan passed the Carpathians to the heart of Hungary in 1241, and the Tatars stormed the white walls of Moscow in the last years of the sixteenth century. The mixture of national costumes that enriches the annual fair of Nizhnii Novgorod reflects, even in these peaceful days, the fluctuating sway of rival tribes. It is suggestive that their meeting-ground should be trampled into dust in summer and flooded by the Volga every spring. Whole provinces could be devastated in the old times before, along rare highways through the forest, the news reached the central military power. A palace intrigue, on the other hand, might convert a town into a shambles; but it failed to agitate the empire of the steppes. The masters of Russia must master the great hordes of Asia. If a certain national uniformity exists to-day, it is based on the futility of self-reliance. Man seems so small in these vast expanses that he looks towards the domes of Moscow, and even to the imported glamour of St. Petersburg, as the Kirghis, from his shifting tent, looks towards the universal sun.

CHAPTER XII

THE RISE OF ITALY

We have pictured the ranges of the Alpine system as rising in the first instance above marine areas on either side. The Alps themselves, but more markedly the Carpathians and the Caucasus, appear as narrow barriers dividing basins of the sea. Gradually the floors of these basins become involved; in places they may be deepened by subsidence along marginal faults, but eventually they are infilled by downwash from the hills and are raised into continental land. Italy, which is almost the youngest child of Europe, remains, however, in the barrier stage. Fracture and sinking have emphasised the adjacent seas; and the main axis, which may still be rising, provides an interesting picture of the earlier phases of the Alps.

The folding of the Appennines[1] was contemporaneous with that of the Pyrenees, since there is an unconformity between crumpled Eocene strata and more horizontal Oligocene and later beds. But the marine Pliocene system, flanking the chain and conspicuous in the hills of Piedmont, shows how little of Italy, as we now know it, dates back to Oligocene times. For a brief epoch, the Oligocene sea of southern Italy received sands and pebbles from the rivers of a rising chain. Ancient schists were exposed, and a long island probably stood out above the sea. It is believed that in Middle Miocene times this island became connected, as Italy now is, with the growing Alps of Piedmont. The conditions remained much the same during the general shallowing of the Mediterranean in Sarmatian (early Pliocene) times, except that a large body of folded rocks was temporarily raised so as to connect Piedmont, by way of Corsica and Sardinia, with North Africa. This second spur of land was cut off at the south and was greatly reduced in the Placentian (Middle Pliocene) epoch, and the axis of Italy reverted to a mere narrow promontory,

[1] This spelling, adopted from Italian usage into Mill's *International Geography*, seems fully justified, on the ground that a correct form is advisable, wherever it does not conflict with the long-established English pronunciation of a familiar name.

associated in the south with islands, as it was in Miocene times. De Lapparent provides an interesting series of maps (II, 3), in which the Oligocene sea is perhaps somewhat overemphasised, but which shows how the modern land of Italy is a product of the human epoch.

If we cross the northern or central Appennines, we see very little to remind us of the crumpled Alpine chains. Cainozoic strata occupy broad areas down the axis of the country, and we find no suggestion of a schistose or granitic core until we reach the worn and rounded uplands of Calabria. Even here, the crystalline rocks are regarded as a remnant of an old mass broken up by faulting and submergence, rather than as a series brought up from below in the axial folding of the Appennines.

The high crests of the Central Appennines, including the Gran Sasso d'Italia (2914 metres; 9560 feet) near Aquila in Abruzzi, are formed of Jurassic and Cretaceous limestones, round about which there are abundant traces of a former Cainozoic covering. Doubtless somewhere far below we should find signs of intrusions and accompanying crystallisation among the rocks that have suffered more severely from the mountain-building processes. In Elba a granite is now exposed at the surface, which, like those of the Inner Hebrides (p. 52), came into place and cooled and hardened somewhere in Cainozoic times. The Eocene limestones of the island have been highly altered by an invasion of dark basic igneous rocks, and the granite of Monte Capanna, forming a circular mass more than 3000 feet above the sea, cuts through these rocks and represents one of the later cauldrons. Towards the end of the Eocene period, and before the deposition of Oligocene strata, basic rocks like those of Elba manifested themselves also in great force in the Piedmont area, and they became crushed and folded in the late Miocene movements of the Alps. These " green rocks " (*pietre verdi*), including serpentines, dolerites, and basalts, form characteristic features of the north-west Italian highlands. Though they are often associated with the older stratified series, they probably represent a general welling-up of molten matter during the birth of modern Europe. At such times the fluids of the earth's interior become pressed into every crack that opens, and they often incorporate themselves with earlier masses by a most intimate process of intermixture.

To realise Italy we should cross the Appennines, starting from one low marginal band on the Adriatic, and descending on another against the Tyrrhenian Sea. This is the journey so often made by the northern barbarians, or the oriental captors of Pannonia, in their eagerness to grasp the treasure-house of Rome. Julius Cæsar brought his legions through the mountains against a disintegrating state, and emperor after emperor found it expedient to develop the great highway that led past Aquileia to Carnuntum on the Danube. Leaving aside for the moment the alluvial plain of Lombardy, we may set out from the fortified gate of Pesaro, where the flat land ends and the Appennine foothills meet the sea. We have crossed the Rubicon in the coast-plain before Rimini, and already are in Roman lands.

We turn south-westward up the valley of one of the numerous small consequent streams, and find ourselves in a country of soft crumbling rocks, where immaturity of surface-form means genuine youth, and not resistance to decay. The valley-sides bear vine-terraces, and every acre seems to lend itself to cultivation. Here and there a cliff is formed on the eroded bank of the river, and uptilted strata show how even the Pliocene beds have been disturbed. The loamy soils are dry, and trees are scarce on the hill-sides. Now and again olive and almond orchards remind us of the corresponding Cainozoic country in Provence. When rain descends with merely moderate energy, the crumbling surface rapidly gives way. Grooves left by landslides are frequent on the larger slopes, and pebbly alluvium, on which stunted bushes grow, accumulates on the unsettled lower grounds.

The Tortonian (Upper Miocene) beds that form a long band from Bologna to Fabriano include gypsum and sulphur, and were probably formed in lagoons. Some authors have seen in the sulphur-deposits on this slope and in Sicily evidence of volcanic vapours, heralding the great activity that marked Post-Pliocene times.

When we climb up the almost barren slopes into Urbino, we find a typical hill-town, its wall and fortified palace built of brick rather than of stone, and thus in keeping with the country. The same limitations have produced the splendid brick-architecture of northern Europe, from the castle of Muiden on the Zuider Zee to Marienburg beyond the Vistula (p. 130). From the walls of Urbino we look out west towards the central range of the Appennines, its crest only some 1000 metres (say, 3000 feet) above the sea, and formed of Miocene and Eocene strata. In the south, more rugged masses rise above the foothills, where the Cretaceous and Jurassic limestones attain 1700 metres (5577 feet) on Monte Catria. These rocky edges lie on the divide, and beyond them are the head-waters of the Tiber.

Directly we reach these more resisting rocks, where the old Via Flaminia comes in at Calmazzo from the coast, we recognise that we are crossing mountains. There is a firmness of form, a dignity of crag and cliff, that reminds us of the limestone Alps of Switzerland. Our upward passage must be sought in the ravines; it is no longer easy to wander casually from crest to crest. Just as the Via Mala was carved in the Rhine-wall in 1822, to reach the southern provinces of Austria, so, two thousand years before, the Via Flaminia was developed by the Roman senate to reach the flat land of Ravenna. The tunnel through which it passes in the Burano gorge bears proudly a tablet of Vespasian.

The torrent in the Gola del Furlo is still developing the Appennines, like the tool of a graver on a plate held slantwise in his hand. Elsewhere, on the Cainozoic surface, it seems as if an acid had been sprayed. Where the rocks are of equal softness, there are no particular guiding lines, and cones and domelike hills become etched out, with deepening hollows running this way and that between them.

An interval of this kind occurs as we emerge from the Furlo gorge. The folding of the Miocene beds is seen in the layers of limestone that stand out among the crumbling shales. Cagli holds the entrance to a second ravine, where Mesozoic rocks again check erosion, and where the deep side-notches as we near the crest indicate the prevalence of limestone. It is characteristic, however, of the Appennines that the summit of this pass, the Colle di Gubbio (777 metres; 2549 feet), should lie on a brown country of upland farms, where the Eocene cover has not yet been stripped from the young chain. An abrupt episode of Cretaceous limestone, occurring as a steep inlier, drops us down on Gubbio, the first town of the Tiber basin, with its silent and closely shuttered palaces banked against the southern slope, and its deserted watch-tower dominating the road to Rome. Gubbio commands an old lake-basin, excavated along the general strike by the head-waters of a Tyrrhenian stream. The Upper Tiber, rising at 1400 metres (4600 feet) on Monte Fumaiolo, has carved out a strike-valley, and its western tributaries threaten those of the Arno above the great hollow of the Casentino. The depressions within the Appennine mass are very probably due to subsidence. While the Casentino may have been carved out of the soft strata by agents which could not clear away the jutting Cretaceous rocks on its south-west side, the neighbouring basin from Florence to Pistoja, now filled by modern alluvium, is believed to be connected with the sinking of the Tyrrhenian land (I, 3, 768). It is probably more recent than the course of the Arno, which cuts its way out of it in the gorge of Gonfolina. When the Mediterranean reasserted itself in Upper Miocene or later times over the old land-mass that included Corsica and Sardinia, the down-faulting movements reached the growing Appennines. The range lost its outlying foot-hills, which had been pressed against the Tyrrhenian obstacle, and was threatened with marine invasions along its strike-lines, like those that so freely characterise Dalmatia. The spread of marine Pliocene strata from the south-west coast almost to the central range shows how uncertain were the destinies of Italy even down to the human epoch.

The main dissection of the Cainozoic rocks along their strike, combined with their general weakness, provides a very hilly country between Gubbio and the Tiber. The towns, and even the villages, favour the hill-tops. As one looks across the tumbled ridges from Petroja, it is impossible to grasp any order or arrangement in the streams. Perugia may be described as occupying an eminence on the right bank of the Tiber, which here runs southward; but it also dominates the mouth of a far broader valley, now occupied by insignificant streams, which enter the Tiber from the south-east and are generated on a Mesozoic upland near Spoleto. To the west lies the basin of Lake Trasimeno, a great natural reservoir among rounded Cainozoic hills, with a valley stretching north-west from it that has no relation to any existing river-system. The rivers, in fact, are still finding their way upon the newly offered surface, and are hampered by local accidents of subsidence in a land of insecure foundations. One remarkable result is that people in central Italy do not live in valleys, but on hills. There is no community of interest in a tangle of small undeveloped lowlands, and the possession of a hill-fort enabled a strong family to dominate the hollows that it could see. The instability of the Cainozoic slopes has checked the extension of any one hill-town as a centre of wide authority. To this day, the railways lie far below the cities, or climb round conical hills to stations well without their walls. Communications from town to town involve miles of descent and ascent. The lack of continuous structural surface-features has kept the upland dwellers from Etruscan days through those of the Renaissance, in closely guarded and isolated camps. Their noblest efforts have been inspired by rivalry, and even in their extraordinary artistic development we often trace a jealous note. For some six centuries, the cultured discipline of the Roman civil and military services spread a sense of kinship through the hills; but the decay of the empire led to local government by dukes, on foundations as primitive as those of negro chiefs in Africa. It was the men of populous and well-ordered spaces who carried to the hill-towns the call of a united Italy.

Todi, on its cone 850 feet above the river, is an excellent type of the Umbrian hill-town. The Tiber goes off here to the south-west, the corresponding highway to Orvieto keeping characteristically to the ridges, out of reach of floods and landslides. Much of this country is carved out of beds as recent as the Pliocene "crags" of eastern England, and the extreme steepness of the street of Todi, leading to the little piazza that occupies the crest, is all the more surprising.

The truly mountainous forms of the Jurassic limestone, jutting out above Terni, point to a future aspect of the Appennines when the cover has been washed away. The village of Cesi is plastered against a great crag, the

Torre Maggiore, like a picture from the Alps of Dauphiné. At Narni, where the high bridge of Augustus once carried the Via Flaminia, a ravine has been cut by the Nera across the strike of the limestones, and the town is built upon a precipice-edge. In a few miles, however, the irregular Cainozoic country reappears, flanking the bold Sabine Hills.

And then we reach the northern Campagna, where the latest geological developments of Italy are revealed. A band of extinct volcanoes, which runs from Orvieto to the Phlegræan Fields of Naples, now lies between us and the coast. At Cività Castellana on our highway, an insignificant stream has cut a grim cleft through basaltic lavas, which in depth and gloomy colouring resembles the Batoka Gorge of the Zambesi. These lavas rest on pebble-beds, and the whole series belongs to Post-Pliocene time. The movement of the south-west edge of Italy is still evidenced by the active volcanoes of Vesuvius, the Æolian Isles, and Etna, and many of the Italian eruptions were submarine, before the coast-land of the Appennines had been raised. The volcanic action was largely explosive, and the circular lakes of Bolsena and Bracciano, some seven miles and five miles in diameter, occupy enormous crater-rings. The smaller Lago di Vico in the Monti Cimini, with its water nearly 1700 feet above the sea, records another volcano of the Quartary era which broke out on a sea-floor. The Alban Hills, a menace to the early years of Rome, afforded a natural stronghold above the undulating volcanic plain of the Campagna; they are a group of denuded cones, which include the crater-lakes of Albano and of Nemi. The tuffs that are so widely spread over the country have been cut through, with the soft Pliocene beds beneath them, to form the seven small hills of Rome. The numerous streamlets radiating over pastoral country from the Alban Hills resemble on a broad scale those that groove the flanks of Vesuvius, or any modern tuff-cone, after rain.

Rome, then, the founder of national and colonial organisation, arose on some of the most modern land in Europe. Her natural advantage lay in the difficult country to the north. She had, however, to clear from enemies the Sabine and Etruscan hills, and then to hold the Appennine passes, notably that of Scheggia and the Furlo Gorge. Contact with Cisalpine Gaul soon rendered it necessary to extend her frontier to the Alps. Italy thus became a political unit, and all beyond it was provincial land. It was not until Carthage forced her to meet ships with ships that

Rome realised her unique position as the future mistress of the Mediterranean.

Along the south-west coast of Italy, frequent and confluent deltas, from the insecure soil of Pisa to Ostia, the lost port of Rome, show how the land is extending seaward through the washing down of Cainozoic hills. The floor-materials of the mid-Pliocene sea, uplifted 3000 feet near Rome out of at least an equal depth of water, are being restored by denudation to the Mediterranean. In Calabria and Sicily, the Astian beds, full of molluscs of the most modern character, lie 1000 metres (some 3000 feet) above the sea, and even the later Sicilian series forms an important feature of the upraised coast. The frequent earthquakes of the Messinian region illustrate, like those of the Dinaric Alps, the recent origin of the Italian borderlines.

We link the Appennines with the Alpine system only through their north-west region. North of the marginal band of Pliocene strata that is traceable from Turin to Pesaro, where the foothills meet the Adriatic, lies the Quartary and largely alluvial plain of Lombardy. The dissected upland known as Monferrato, between Turin and Alexandria, has long been classical ground for the study of the Pliocene seas. As the Alps rose, they found a complement in the depression of the region to the south, and, even after the Sarmatian uplift, when limited lagoons replaced the Mediterranean, the Placentian sea laid down blue clays in Piedmont. It is interesting to find from the fossiliferous strata near the Alps that the haunts of the marine molluscs were liable to be invaded by the deltas of torrents from the chain, which resembled the great pebbly cones that unite the lowland with the foothills at the present day. Gradually terrestrial conditions set in, and the mammalian fauna that already occupied the new land in the Rhone valley or in the Hungarian plain spread also across the fertile ground of Lombardy.

This gentle uplift, which coincided with that which raised the horizontal Pliocene strata in the south, connected Piedmont with the Dinaric region, and thus with Greece and Asia Minor. The break that is at present caused by the northern Adriatic dates from an even later epoch. Into the great hollow of Lombardy, thus rescued from the sea, and largely contributing to its infilling, the detritus of the Alps was poured with increased abundance. The Appennines in comparison yielded only a small marginal fringe, and the Po, the great river of the district, consequent on the western Alps, became more and more thrust southward by the deposits of its northern tributaries. The history of the plain of Lombardy and Venetia is a reflection of that of the upper basin of the Danube (p. 147).

The Glacial epoch witnessed great erosion on the steep south face of the Alps. The Italian lakes, with their elongated forms and curious finger-like prolongations, have been ascribed by Heim to the warping of stream-eroded valleys, and by Penck to the excavating action of the latest ice-tongues. The "morainic amphitheatre" that closes in the Lago di Garda on the south represents the deposits of the southernmost lobe of a glacier that filled the Adige valley. This glacier has been traced northward as a sheet hiding much of the irregularity of the country, and was fed by ice from the Brenner-Bruneck area, as well as from the Ötztal Alps (VII, 852). The Lake of Garda has gathered behind moraines of horseshoe form, which rise in places 450 feet above the plain, and which played their part in history during the critical hour of Solferino.

The modern rivers have spread their alluvium, which is largely derived from the ice-borne material that choked the Alpine valleys, across the Glacial detritus, and have steadily levelled up the plain. Floods are as common as they are in Russia or in Hungary;

yet at the present time the terraces above the western rivers show that excavation is predominant. In Venetia, on the other hand, the streams bring down so much detritus that they build up their courses upon unstable pebbly ridges. Roads and railways ascend from swampy intervals to towns that are planted on the waterways, and the land between the rivers is abandoned to rough pasture, and is liable to be invaded by sudden runs of stones. On the more secure side of the plain, towards the Appennines, the Via Æmilia from Milan to Rimini runs with amazing straightness on almost absolutely level land. It is still one of Italy's noblest highways, and the railway has followed it closely on its route to the revived Roman port of Brindisi.

The outward growth of Italy on the shallow side of the Adriatic is seen in the marshy deltas of the Piave, the Brenta, the Adige, and the Po. Classis, now represented by a factory, a farm or two, and a huge unused sixth-century church, was the Augustan seaport of Ravenna, and now lies nearly four miles from the coast. The uncertain mudbanks of the Brenta lagoon were eagerly seized on in the fifth century by the survivors of the sack of Aquileia. The sunken land where the three-toed horse and Rhinoceros had strayed in Pliocene times was no longer practicable for mounted hordes. Fresh water could be reached in wells, which in time were deepened to some 70 metres (280 feet) in river-sand. The alluvium, lying "awash," as sailors say, was strengthened with piles, to bear the brick and marble palaces that characterise the Lombard plain. And here, driven into the sea and grasping new greatness from it, men of Roman traditions built up Venice, and laid the foundations of an oligarchy that lasted for a thousand years.

CHAPTER XIII

EAST AND WEST IN THE MEDITERRANEAN

In previous chapters, the Mediterranean has been pictured as a relic of a pre-European sea, the Tethys of Suess, which practically circled round the world. When the North Atlantic spread, by the foundering of ancient continental land, the sea to the south of Europe became at the same time reduced, and links arose connecting Spain and the Alps with Africa. These changes were coincident with the Alpine movements, and the lines of the most intense crumpling are still marked by mountain-chains.

Whether the Rif range in northern Morocco is continuous or not with the Algerian Atlas Mountains (see I, 3, 886, editorial footnote), it forms part of a loop that at one time closed the passage at Gibraltar. The Rif mountains and the Spanish Betic Chain probably rose with the Pyrenees in Oligocene times; marine invasions occurred during the Miocene period, and the Tortonian conglomerates of Granada were formed in a sea at the foot of masses already folded. The Betic mountains had been pressed up from the south against the great horst of the Spanish tableland, and were checked and controlled by it, as the Alps of Dauphiné and the Juras were by the Central Plateau of France and by the Vosges. This Betic Chain, which now forms the romantic south of Andalusia, struck north-eastward towards Corsica. Though this island is largely composed of crystalline rocks, enough remains of a Cainozoic covering in the north to show that it was concerned in the Alpine movements. "Green rocks," like those of the Western Alps, have welled up in the area and have penetrated Oligocene strata. Between Corsica and Spain lie the Balearic Isles. In Ibiza and Mallorca (Majorca) the grouping of the strata shows that we are dealing with the surviving remnants of the Oligocene range that crossed the present Mediterranean.

Horizontal beds of Helvetian (Middle Miocene) age lie in Mallorca in the hollows of this fractured chain. Similarly, in the north of Andalusia a broad lowland, in which the Guadalquivir runs, represents a Miocene strait, which preceded that of Gibraltar and gave far easier access to the Atlantic. This passage lay in the complementary depression that so often accompanies a mountain-chain. North of it rose the faulted edge of the great Spanish tableland, which sloped to the sea upon the east, and allowed lagoon-waters to occupy its surface across Murcia and Castile up to Madrid. South of it rose the folded ranges of the Betic Chain, perhaps even more serrated than they are to-day, a superb contrast to the broad and uninteresting upland with which they were ultimately connected. This chain, where it turned south towards Morocco, included the Jurassic block of Gibraltar, not yet weathered out as the guardian lion of the Mediterranean.

The Pontian uplift, which ultimately so seriously reduced the Mediterranean and drove the sea finally from the Hungarian plain, united the magnificent ranges of southern Andalusia with Spain. The "North Betic" strait became a plain; but a second passage to the Atlantic had already been found along a depression in the Moroccan region, between the Rif range of the present coast and the Atlas chain that rises south of Fez (40). As L. Gentil points out, this resulted from a depression like that of northern Andalusia, a downfold along the lines of early Miocene folding. It may well have existed contemporaneously with that of Andalusia, and it lasted somewhat longer. When, however, the Pontian uplift was complete, this strait was also closed. While Placentian (Middle Pliocene) beds were being deposited in deep water in north Italy, the Mediterranean was threatened with the fate of the Caspian, and might have become converted into a highly saline inland sea.

The critical interval, however, was a brief one. Foundering took place in the insecure Pontian land. The Tyrrhenian sea, between Italy and Sardinia, was formed as the crust-blocks sank, and the far-reaching downward movement affected the Rif-Betic barrier. This folded mass already had a warp in its north-and-south portion, which now brought it more easily beneath the sea. The narrow passage of Gibraltar opened at some date in the Placentian epoch, and it occurred at the lowest portion of the chain.

The great importance of the Strait of Gibraltar in human history lies in the fact that it saved the Mediterranean from stagnation, just as the submerged valley of the Dardanelles (p. 204) has saved the Black Sea basin. It is curious, however, to reflect that, as a passage-way for human enterprise, it had little influence until the opening of the nineteenth century. Britain found scarcely any use for the Mediterranean until Bonaparte developed his oriental schemes. St. Vincent and Trafalgar were both fought in the Atlantic. Columbus might have sailed with equal success from Cadiz as from the humbler port of Palos. The Romans reached Britain by the overland route of Gaul, and the Phœnicians who ventured through the strait made little permanent impression upon Cornwall, the Seine estuary, or the west of Africa. The Mediterranean influences which still play their part in Ireland no doubt emanated from rias on the Atlantic coast. The Strait of Gibraltar, arising by a happy accident in Pliocene times, owes most of its historic dignity to the cutting of a canal in 1869 from the Mediterranean to the Gulf of Suez.

The Moorish occupation of Andalusia restored, as it were, unity to the Rif-Betic chain. Spain, the land of Armorican plateaus, is typically the Meseta region. The Ebro valley on the north-east and that of the Guadalquivir on the south lie in depressions complementary to the Pyrenees and to the

Betic Chain. The latter is as much a part of Africa as the Pyrenees are a part of Miocene France.

The Balearic continuation of the Betic Chain must have been broken on the south-west soon after its rise, to render the north Andalusian depression effective as a waterway. The rugged and complex masses of Corsica and Sardinia also record the loss of temporary Cainozoic land, though the Pliocene subsidence that admitted the Tyrrhenian Sea on their east side has been partly compensated by the rise of Italy. We may now look eastward of the great Italian promontory, controlled in its length by the axis of the Appennines, and note the singularly recent depression between it and the Dinaric Alps.

The folding of the Dinaric Alps seems to have taken place from the north-east in Oligocene times (41). In date and direction of thrusting these ranges thus differ from the adjacent Alps. The last marine strata on their uplands are of Eocene age, a flysch type being common in the north. The Eocene system has participated in the overfolding, and it forms broad bands running south-east, overridden by Cretaceous limestone. The continuity of limestone deposits in the region through long geological periods has given the Dinaric country a marked character, especially under the influence of a climate that is often hotter and drier than that of Italy. Triassic and Jurassic limestones, whitening in the sunlight, or swept clean by sudden bursts of rain, rise round us as we descend the Isonzo from the Carinthian Alps to the marginal marshes of Monfalcone. The strike of the beds sweeps round in Carniola into the regular Dinaric south-east trend, which is traceable far away in the finger-like promontories of Greece. Cretaceous and Eocene limestones form the terraced hills of Istria, and the country becomes more and more barren as we near the blue waters of Trieste. Scattered bushes take the place of forests on the rising ground, and the plateaus are often mere deserts of inhospitable rock. The limestone, when it dissolves before the rain, yields little insoluble material to form a soil. A red earth, the *terra rossa* of Dalmatia, remains in certain hollows, as it does in the similar French region of the Causses; but on exposed surfaces this is blown away as soon as it is formed, and the bare white limestone stretches over wide areas between scanty patches of thin grass. The rain that falls is absorbed into the underlying rocks, and there forms subterranean watercourses and deepening lines of caves. Features due to solution of the limestone are everywhere apparent on the surface. Joints are widened into open grooves, and fantastically etched ridges stand up between them. The drainage is vertical rather than horizontal, and the observant Slavonic peasants have applied the word *dolina*, "a valley," to the funnel-shaped swallow-holes down which the water flows. *Terra rossa* may gather in the dolinas from the solution of the rock around. Far away, at the foot of some cliff, or half-way up the wall of a ravine, the water lost to the upper landscapes may emerge as a river ready made. The rivers of Dalmatia and Herzegovina mostly run in the floors of deep ravines, which have often resulted from the falling in of caves. The limestone region thus supports a double life; one on the plateaus, limited by lack of water, which is gathered in cisterns for the flocks; and the other along magnificent streams, coming pure out of the limestone, but limited by lack of alluvial expansions on which to develop farms and towns.

An old fortified settlement in the ravine-country seems almost part of the rock-wall. It is founded on blocks that have fallen from the crags, and rises from them like a natural growth. When the sun strikes into the valley, details are lost in the general whiteness, and tower and town seem flattened against the cliff in the great glare. In the dusk all becomes an equal grey, save for one or two frugal lamps that shine out as darkness grows. There are no sounds of bells from gathering herds, or gay voices of reapers returning from autumnal fields. Only the great torrent thunders among the opposing stones, its water stolen from the plateau four thousand feet up against the stars.

On the plateaus themselves, on these great peneplanes worn by rain and wind across the Dinaric folds, the same harmony of human structures and natural rock prevails. A farm may perhaps be picked out at a distance by some group of stunted trees; but a white town may be overlooked on a background of the terraced limestone. Streams run for a certain distance, and disappear vertically in the midst of closed basins of dry rocks.

These features, typical of the barren Karst region in Istria, prevail down the east coast of the Adriatic, across a large part of Greece, and into the desiccating lands of Syria. The term *karstland* is applied to this scenic type, which may in the past have been modified by less severe conditions of wind or rainwash, but which is found in all limestone districts where shelter cannot be offered to the soil. East of the Dinaric karstlands, very different types of landscape have arisen in the core of the folded range. The Bosnian hills are often densely clothed with forest, and successive ridges take the place of the high limestone plains. An interesting feature, both of the interior and of the Cretaceous plateaus, is the occurrence of elongated basins, with alluvium and late Cainozoic strata in their floors. Streams often flow through these, and the fertile land is set with pleasant farmsteads. The underlying floors of the hollows are, however, lower than their outlets, so that they cannot have been excavated by streams. These basins are known as *poljes* ("fields"), a term that has become adopted by geographers in place of the Croatian plural *polja*. They are the result of the warping or collapsing of the surface during the latest earth-movements, portions of a former Miocene or Pliocene covering being thus preserved. A fine example is the great Livansko polje near Livno in south-western Bosnia, which has no through drainage, but which contains a number of swamps and streams that disappear into the ground.

The characters of the Dinaric coast at once indicate a region of submergence. The Dalmatian isles are clearly portions of the folded mainland, cut off by an invasion of the sea along the strike. The inlets at

Sebenico and Cattaro have been justly compared with fjords (11, 210), and fractures have been invoked to account for their parallel reaches. The mountainous isles off the Gulf of Corinth may be regarded as the Lofodens of Greece. The sea that breaks against them has brought no amelioration of their general barrenness, and Ithaca in autumn goes far to explain the prolonged wanderings of Odysseus.

Just as the Tyrrhenian sea to the west of Italy represents a disappearance of Cainozoic land, so the Adriatic is also a result of subsidence. The Dinaric folding raised Cretaceous and Eocene strata across the region, and relics of the characteristic limestones of the oriental karstland still appear on the Italian coast (I, 1, 346). One small patch forms the promontory of Monte Conero south of Ancona, where Cretaceous rocks rise between the sea and the Pliocene fringe of eastern Italy. A larger mass, Monte Gargano, including a Jurassic core, rising in Monte Calvo to 1080 metres (3879 feet), juts out conspicuously on the north side of the Gulf of Manfredonia, for which, indeed, it is responsible. This looks like an eastern repetition of the bulges of older rock that appear in the heart of the Appennines; but it has been correlated with the Dinaric series.

The broad Cretaceous country of Apulia similarly seems to connect the upraised Dinaric land of Miocene times with southern Italy; but the whole southern area sank beneath the Pliocene sea, and marine Placentian strata are found equally on the back of Apulia and of the Ionian isles.

The northern Adriatic, however, is a still more recent feature. The gravels of the Po and Venetian estuary extend across Istria and the Dalmatian isles (42). The breaking in of the sea from Monte Gargano northward to Monfalcone occurred later than the Glacial epoch, and it continued at least into Roman times (41). E. Suess has questioned the evidence of downward Adriatic movements in the historic epoch; but allowance must be made for a certain dogmatic attitude adopted by him in regard to the importance of recent earth-movements. It is probable that the blue water, so different from that of the alluvial shore of Italy, reached Fiume and Trieste after man had settled in the plain between the Appennines and the Alps.

Greece and the Ægean isles point still more strikingly to late Cainozoic changes in the Mediterranean basin. In Pontian times, a general land-area stretched from the Dinaric range and the Balkans into Syria. The Middle Pliocene beds on some of the islets between Greece and Asia Minor indicate the presence of a lake. The downfold that made the present Ægean, and gave zest to the expeditions of Xerxes and Alexander, dates from the later Pliocene, and a partial recovery on its margins has raised marine Sicilian beds 1000 feet above the sea.

The history of mammalian life in what are now isles of the Mediterranean offers in itself a fascinating field for study. The Pontian fauna, representing animals that roamed across continuous land, is richly revealed in Samos, where we find the sabre-toothed tiger, Rhinoceros, and Mastodon, the forerunner of the elephants. *Elephas antiquus* has left its remains in the little isle of Delos, in the centre of the Ægean Sea. Dwarfed hippopotamuses of African origin occur in Sicily and in Malta, and it has been suggested that the similarly dwarfed elephants in Malta represent forms which were cut off by earth-fractures from their ancestral spaces, and became adapted in Quartary times to the limits of their island home.

CHAPTER XIV

CONCLUSION

The considerations in the foregoing chapters may present a condensed picture of the growth of Europe, somewhat in the manner of mediæval paintings of the saints, where birth occurs in one quadrant and glorious decapitation in another. Such a picture must be suggestive rather than complete; but in our case any reader with a studious mind can fill in the gaps on the lines of history or geography. The frontiers reared by the Alpine movements are obvious in the case of Spain and Caucasia; yet the Arabs stormed the meseta, and Russia has spread down to Ararat. The geographical unity of the Italian promontory, which is so trimly bounded by two recent founderings of the land, was long set at defiance by a dozen petty states; and the Austrian Empire, including as it does a large part of the Alps, the plateau of Bohemia, and a portion of the Russian platform, has little resemblance to a natural region. However logically primitive man divided himself into lake-dwellers, and foresters, and hunters of the plains, the superior person inevitably coveted the fruits of all the arts. The inhabitants of the famous Kesslerloch near Schaffhausen feasted on reindeer, horse, hare, and ptarmigan. Here are signs of the comprehensive taste that has led the English to Cyprus and Carnarvon, and the Prussians to dominate Strassburg and Munich as well as the proud fringe of Hansa Towns. The political unit nowadays is rarely due to Europe's regional growth. The eastern frontier of Holland and the meeting of the Powers at Myslowitz are absolutely inexplicable on physiographic grounds. The empire of the Visigoths and the Western Caliphate degenerated into Spain and Portugal by capricious acts of fission. Political Austria has redeemed Bosnia from the Dinaric limb, the forearm of which is Albania, and the hand of which is known as Greece. An inspection of the physical map would lead us to expect Italian soldiers in Lugano, and a sense of solidarity and common interest between all dwellers in Ireland, the European outpost. Since every nation desires factories and cornlands, coalfields and commerce of the seas, the movements of peoples are across the natural boundaries, and, in accordance with political economy, tend to the annexation of something not hitherto possessed. The Cainozoic era offered a model continent to man, on which the tremendous pageant of European history has been played. The study of its fundamental structure in relation to the wayward actions of its overlords is for most of us the very keystone of geography.

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Roman numerals are here used for works that have brought together a large body of information on the growth of Europe. E. Suess's "Antlitz der Erde" is quoted in its French form, edited by E. de Margerie, since this edition is by far the most serviceable, owing to the wealth of additional maps and illustrations and bibliographic footnotes.

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GLOSSARY

Alluvium. Material deposited in the floor of a river-valley when the stream cannot carry away the detritus supplied to it by denudation.

Alpine System of Folds. The earth-folds that arose in Cainozoic times in Europe, mostly during the great movements of Upper Miocene times.

Anticline. Strata bent up as an arch. The crown of the arch is frequently worn away by denudation, exposing the lower layers of the anticline along its crest.

Aquitanian. *See* p. 33.

Archæan. *See* p. 20.

Arête. A French term meaning a cock's comb, applied by mountaineers to a narrow ridge of rock. An arête frequently arises from the cutting back of the head-walls of two cirques from opposite sides of a mountain mass.

Armorican System of Folds. Folds set up in the European area by earth-movements that took place at the close of Carboniferous times.

Astian. *See* p. 33.

Basalt. The typical dark lava, with about 48 per cent. of silica.

Base-level. The lowest level to which, at any given time, a land surface can be reduced by denudation. This is generally the level of an adjacent sea.

Beheading of Streams. The capture of the head-waters of one stream by the cutting back of the head-waters of another into its drainage-area, and the consequent carrying off of the water into another drainage-channel.

Boulder-Clay. A loamy material containing scratched stones or boulders; it is deposited on the melting of an ice-sheet or broad glacier which has carried the materials forward in its advance.

Burdigalian. *See* p. 33.

Cainozoic. *See* p. 20.

CALEDONIAN SYSTEM OF FOLDS. *See* p. 23.
CAMBRIAN. *See* p. 20.
CARBONIFEROUS. *See* p. 20.

CIRQUE. A theatre-like recess cut by denudation in a hill-side, with a steep wall at the back and sides, an open front, and a gently sloping or even basin-shaped rock-floor.

COAST-PLAIN (or COASTAL PLAIN). The gently sloping surface formed along a coast by the deposition of material washed down from the land. The plain appears, margining the coast, if the land becomes raised.

CONSEQUENT STREAMS. Streams flowing down the general slope of the flank of an upraised mass of strata, such as a folded mountain-chain, or down the dip-slope of an escarpment.

CRAG. Properly a bare rocky mass. Locally applied in eastern England to loose shelly deposits of Pliocene age.

CRETACEOUS. *See* p. 20.

CRUST OF THE EARTH. That part of the earth which is accessible to geological study. Many masses are thus included which at one time lay at greater depths, but which have been brought by earth-movements to the surface.

DENUDATION. The wearing away of the rocks by any natural action, such as rain, river-erosion, sea-waves, wind, etc.

DEVONIAN. *See* p. 20.

DIP. The slope of uptilted strata to the horizontal; it is measured by the inclination of a line on the surface of a stratum which makes the steepest possible angle with the horizontal plane. If this line is projected on to the horizontal plane, as it might be on a map, its compass-direction is said to be the direction of dip. A bed may thus be said to dip north at 35°, south-east at 7°, and so on.

DIP-SLOPE. *See* ESCARPMENT.

DOLINA. A Slavonic term for a hollow worn in limestone by the solvent action of water running down into subterranean courses.

DOLOMITE. A mineral formed of equal molecular quantities of calcium carbonate and magnesium carbonate. The same name is commonly used for a massive rock formed of dolomite.

DRUMLIN. A somewhat elongated mound or small hill formed of boulder-clay.

DYKE. A wall-like mass of igneous rock that has consolidated in a fissure, into which it penetrated in a molten state.

EOCENE. *See* p. 20.

EROSION. The eating-away of rocks by rain, rivers, etc.

ESCARPMENT. The denuded edge of an uptilted stratum of more resisting rock in a series which contains beds more easily worn away. The escarpment has a scarp or face weathered out across the bedding, and a DIP-SLOPE which represents approximately the inclined upper surface of the stratum. *See* p. 69.

ESKER. A winding ridge of water-worn gravel associated with glacial phenomena, and in most cases arising in channels where water flows beneath an ice-sheet.

FALUNS. Shelly strata of Miocene age in France. *See* p. 42.

FAULT. A fracture in rocks along which movement has taken place, so that the rocks on one side are not continuous with their representatives on the other side.

FENNOSCANDIA. A joint name for Scandinavia and Finland.

FJORD. A narrow sea-inlet with precipitous walls, and typically with a shallow region nearer its mouth and deeper water farther in towards its head. *See* p. 58.

FORAMINIFERA. Simple organisms, mostly minute, living in great abundance in marine waters and commonly secreting a shell of calcium carbonate.

FLYSCH. Muddy and sandy strata of late Cretaceous or early Cainozoic age, formed in estuaries in the neighbourhood of rising land. *See* p. 38.

GLACIAL. Connected with cold conditions, such as favour the spread of snowfields and glaciers where precipitation is sufficient.

GLACIAL EPOCH. An epoch when cold climatic conditions prevailed, sufficient to produce a marked extension of snowfields and glaciers. The latest glacial epoch took place at the close of Pliocene times.

GONDWANALAND. A continent, named by E. Suess, which extended in Permian times across the Indian Ocean.

GOTLANDIAN. *See* p. 20.

GRANITE. The typical crystalline rock resulting from the cooling of molten highly siliceous matter within the earth's crust.

GYPSUM. Hydrous calcium sulphate in a mineral form. When massive, it forms the rock called ALABASTER.

HELVETIAN. *See* p. 33.

HORST. A resisting block in the earth's crust round which other masses have subsided, so that it stands out on the surface and may be surrounded by rocks of younger age that once lay at a higher level than its crest.

IGNEOUS ROCK. A rock that has once been in a molten state. When poured out at the surface, such rocks consolidate as LAVA; when cooled more slowly underground, they may become completely crystalline, like granite.

JURASSIC. *See* p. 20.

KARST. The name of a region in Istria, now applied to any region of bare limestone rock.

KARSTLAND. *See* KARST.

KILOMETRE. One thousand metres; 80 kilometres almost exactly equal 50 miles.

KLIP. A mass of rock carried across others by an overfold, and left stranded, as it were, through the denudation of the rocks that once connected it with its place of origin. *See* p. 164.

LAMINÆ. Unusually thin but distinct layers in a stratified deposit.

LATERAL MORAINES. The piles of débris gathered along the sides of a glacier, and left behind as sharply crested walls when the ice shrinks away in an epoch of melting.

LAVA. *See* IGNEOUS ROCK.

LIMESTONE. A rock consisting chemically of calcium carbonate.

LOESS. *See* LÖSS.

LONDON SERIES. *See* p. 33.

LÖSS. Fine clayey earth accumulated across a country by the action of prevalent winds blowing in one direction.

MASTODON. A massive predecessor of the elephants.

MEANDERS. Curving bends in the course of a stream.

MESOZOIC. *See* p. 20.

METRE. The unit of length adopted in countries where scientific studies are fully recognised in education. One metre is equal to 3·2808 feet.

MICA-SCHIST. The common type of schist (*see* SCHIST); the surfaces along which the rock splits gleam with the plates of the silicate mica, which is developed in parallel layers in the mass.

MIOCENE. *See* p. 20.

MOLASSE. Soft sandy and clayey strata of Cainozoic age in Switzerland and the Danube basin.

MOLLASSE. *See* MOLASSE.

MORAINE. Material carried on or in a glacier and deposited as it melts away.

NAGELFLUH. Conglomeratic strata associated with the uprise of the Swiss Alps.

NUMMULITIC STRATA. Beds of Eocene age formed largely of the discoidal foraminiferal shells known as nummulites.

OBSEQUENT STREAMS. *See* p. 70.

OLIGOCENE. *See* p. 20.

ORDOVICIAN. *See* p. 20.

OUTCROP. The part of a bed or mass of rock which is exposed on the surface.

PALÆOZOIC. *See* p. 20.

PARIS SERIES. *See* p. 33.

PENEPLAIN (or PENEPLANE). A surface of land reduced by denuding forces—frost, rain, rivers, wind, and so forth—almost to a uniform horizontal level. The more resisting rock-masses survive as elevations, but are in time liable to be reduced to the general base-level of the region.

PERIOD. *See* p. 16.

PERMIAN. *See* p. 20.

PLACENTIAN. *See* p. 33.

PLIOCENE. *See* p. 20.

POLJE. A Bosnian term for a level basin enclosed by hills.

PONTIAN (or PONTIC). *See* p. 33.

QUARTARY. *See* p. 33.

QUARTZITE. Sandstone cemented by crystalline silica; a very hard rock traversed by numerous small joints.

RAISED BEACHES. Beaches and wave-cut terraces of recent origin, raised above the high-water mark of the adjacent sea.

RECUMBENT FOLD. A folded mass of strata so pushed over that the flanks of the original anticline or syncline lie practically parallel with one another and approximately horizontal.

RIA. A sea-inlet, usually broad, arising from submergence of an ordinary valley.

SARMATIAN. *See* p. 33.

SCHIST. A crystalline rock with a parallel arrangement of its constituents. This arrangement commonly results from pressure, which has streaked out the mineral particles and at the same time promoted crystallisation.

SICILIAN. *See* p. 33.

SILURIAN. *See* p. 20.

STRATIFIED ROCKS. Rocks deposited in successive layers or STRATA. The strata may be formed of particles brought down from older rocks into the region of deposition, or of the shells and remains of organisms that lived and died where the rocks accumulated. Slight changes in the grain or composition of successive layers suffice to mark out the STRATIFICATION.

STRIKE. The direction of a horizontal line drawn on the plane surface of an inclined stratum. A series of inclined strata may thus be said to "strike north-east and south-west," and so on. On a horizontal surface, the emerging edges of such inclined strata will "strike" across the country in this or that direction.

Subsequent Streams. Streams flowing along the strike of uptilted strata, as tributaries to the consequent streams. *See* p. 70.

Syncline. Strata bent down, so that those on either side slope towards those on the other side.

System. *See* p. 18.

Tectonic. Connected with earth-structure, and not merely dependent on the processes of denudation acting on the earth's surface.

Terminal Moraine. The material left behind, in a more or less wall-like form, after the termination of a glacier has stood for some time at one place and then melted rapidly back.

Terra Rossa. A red earth arising as an insoluble residue from the solution of limestone in atmospheric waters.

Tethys. A name given to the sea that spread as a girdle round the globe before the formation of the North Atlantic Ocean. The present Mediterranean Sea may be regarded as a remnant of the Tethys.

Thrust-Plane. A surface only slightly inclined to the horizontal, along which fracture of rocks has taken place, and along which rock-masses have been moved by lateral pressure far from their place of origin.

Tongrian. *See* p. 33.

Transgression of the Sea. The spread of the sea over an area that has previously been dry land.

Triassic. *See* p. 20.

Unconformity. The occurrence of a series of strata lying across the denuded surface of an older series. The surface of junction thus implies the lapse of a considerable time between the laying down of the two series. Commonly there is a marked difference of dip in the two series.

Untergrund. A German term for the region, probably unstable, on which the earth's crust is held to rest.

Wave-Length of Folds. The distance from the crest of one fold in a series of contorted strata to the crest of the next fold, measured perpendicularly to the strike.

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