*Frontispiece*

Tertiary lavas, Pleaskin Head, Giant's Causeway

# THE GEOLOGY OF IRELAND

## AN INTRODUCTION

BY

J. K. CHARLESWORTH

D.Sc., Ph.D., M.R.I.A., F.R.S.E.

PROFESSOR OF GEOLOGY

THE QUEEN'S UNIVERSITY OF BELFAST

OLIVER AND BOYD

EDINBURGH: TWEEDDALE COURT

LONDON: 98 GREAT RUSSELL STREET, W.C.1.

FIRST PUBLISHED . . . . . 1953

PRINTED IN GREAT BRITAIN
BY T. & A. CONSTABLE LTD., EDINBURGH
FOR OLIVER & BOYD LTD., EDINBURGH

## ACKNOWLEDGMENTS

IN the course of many years' geological mapping over the whole of Ireland, both north and south, I have invariably met with courtesy and kindness. To all those who gave me such willing help I should like to express my warm appreciation.

I am also grateful to my friends and colleagues in Ireland, Professor E. Estyn Evans and Mr. J. J. Hartley in Belfast, Dr. Farrington, Professor H. J. Seymour and Professor L. B. Smyth in Dublin, Professor I. Swain of Cork and Professor J. Mitchell in Galway, who from time to time have given me help and encouragement in the preparation of this book.

For the drawing of text-figures I am indebted to Mr. H. S. Black (figs. 26, 27, 44 and 48), Professor Evans (fig. 99), Mr. P. Padget (fig. 95), Dr. G. L. Walker (fig. 39), Mr. H. E. Wilson (figs. 21 and 23) and Dr. A. W. Woodland (figs. 9, 11 and 13). I wish to thank Mr. A. W. Stelfox for the negative for plate XVB, Sir Edward Bailey for fig. 1, Dr. D. L. Reynolds for fig. 19 and Mr. J. Selwyn Turner for fig. 36. For permission to publish text-figures or plates my thanks are also due to the following: the Royal Dublin Society (fig. 72), the Royal Irish Academy (figs. 2, 4A and B, 65, 66, 67, 70, 74, 75, 81, 83, 84, 90, 93, 94, 96 and 97, plates IIB, XVIA, XVIIA and B, XVIIIB, XIXA and B, and table, pp. 250, 251), the Royal Society of Edinburgh (fig. 4C), the Geological Society of London (figs. 14, 56, 58, 59, 77 and 78), the Geologists' Association (figs. 2, 6 and 29), and the Geological Society of Glasgow (fig. 57): the editor of *Geography* (fig. 78), of the *Irish Naturalists' Journal* (figs. 52, 61, 86 and 98 and plate VI) and of the publications of the International Geological Congress, London, 1948 (figs. 39 and 82): the Trustees of the British Museum (plate VII): the publishers Allen & Unwin (fig. 55): D. C.

Heath & Co. (fig. 10): Edward Stanford (fig. 33): and John Wiley & Sons (figs. 12, 45 and 46): the Controller of H.M.S.O. (figs. 22, 49, 54, 60, 64, 65, 88 and 89): and the Minister of Finance of the Republic of Ireland (figs. 3, 31, 35, 79, 80, 85, 87, 90 and 92).

Irish natural history in all its branches owes much to the late R. J. Welch, and not least for his beautiful and instructive photographs. For permission to use so many of them I am grateful to the Welch Trustees and Mr. J. A. S. Stendall, Director of the Belfast Museum and Art Gallery.

# CONTENTS

# ILLUSTRATIONS

## Text Figures

PHOTOGRAPHS

INTRODUCTION

## ROCKS AND THEIR SIGNIFICANCE

GEOLOGY is the study of the Earth and its history (Gr. *ge*, earth; *logos*, discourse). It seeks to trace the evolution of the face of the Earth, of the lakes and rivers, the mountains and plains, the lands and seas, and the continents and oceans. It also attempts to discover the variations that have taken place in the climate of the world throughout time and the effect which they and the ever-changing physical features have had in the past unfolding of life, both animal and vegetable.

In reconstructing this history, the geologist uses the rocks which are laid bare in natural exposures, such as sea-cliffs, stream-courses, hillsides and mountain-scarps, or in artificial sections made in constructing roads, railways, canals or buildings, in quarrying, or in sinking wells and bores. Most of the rocks were laid down on the sea-floor as shingle, gravel, sand or mud, arranged in layers as *sedimentary* rocks. Others were originally molten and either flowed out as surface lavas, as they do to-day on Vesuvius and other volcanoes, or cooled within the earth's crust by extremely slow conduction: they are the *igneous* rocks which early writers thought had been formed by fire (L. *ignis*, fire). A third group, the metamorphic rocks, we shall consider presently.

Rocks of all kinds, either in buildings or in their place of origin in quarry or cliff-face, break down or *weather*. The daily changes of temperature which accompany the rise and fall of the sun, warm and cool the rocks at the surface and set up strains by which fragments are broken off. Water freezes in fissures or joints or in the pores of rocks and expands, as in the domestic water-pipe in winter, disrupting the rock mechanically into sharp-edged pieces. Wind abrades rocks with the aid of the grains of sand it carries with it. Rivers and streams act chemically upon the rocks and at the same time saw their way downwards through even the hardest bed by means of the muds, sands, pebbles and boulders with which they are charged. A glacier grinds the rocks by fragments frozen into its sole, and quarries or "plucks" them along joints or other planes of division. The sea also pounds against the coast and erodes its cliffs by its shingle and sand, by the weight of its breakers and by compressing the air in joints and caves.

The material set free by the ceaseless attacks of these various *subaerial* agents of erosion or denudation is deposited as sediments: by changes of temperature and frost as scree or talus at the foot of steep slopes or scarps; by wind as desert or coastal dunes; by running water as *alluvium* ("to wash together") at the mouths of rivers or on the floors of valleys and lakes; by the sea as coastal sands or shingle beaches or as muds in quieter waters. These sediments, deposited in beds or strata, for the most part in the sea, are separated by *bedding* or *stratification* planes (see Pl. IVB) which mark pauses or changes in sedimentation.

Pressure due to the weight of sediments which were subsequently piled upon them or to stresses in the earth's crust has in most cases compacted the incoherent materials into "solid" rock. This process, most noticeable obviously in older formations, has been greatly aided by such substances as calcium carbonate, silica or iron compounds which, introduced by percolating waters, have acted as cements. Thus screes have given rise to breccias, sands to sandstones, muds to clays or shales or marls, while shingle accumulated by rivers, lakes or the sea has hardened into rocks which grade from coarse to fine conglomerates (Pl. IIIA).

The clear-water deposits, which grew outside the limit of even the finest mud in deeper waters or in shallow seas where for any reason sands and muds were missing, consolidated into limestone (Fig. 28, p. 81). This contains the remains, namely the hard parts, of marine organisms, such as corals or crinoids (sea-lilies), which lived in the seas and at death were incorporated in the growing accumulation.



The layers which were originally almost or quite horizontal are often no longer so, but are tilted or pressed into arches or anticlines or into troughs or synclines (Fig. 37, p. 100). The grain, like that of a wooden bench or table, gives the *strike* of the folds, and the axis may be either horizontal or tilted—that is, it may have a *pitch*.

The strata have also been snapped across by *faults*. One side has been dropped down relatively to the other by an amount or "throw" which may vary between one foot and many thousands of feet. The side which we imagine has dropped down is termed the downthrow, and the other which may have remained stationary or moved upwards is named the upthrow (Fig. 62, p. 176).

The movements which produced folding and faulting (see Ch. III) were also probably responsible by compression, by tension or by torsion for the vertical divisional planes called joints. These traverse all sediments which have achieved a minimum degree of coherence. They form two sets of "master joints," arranged usually at right angles to one another and to the bedding, and parallel with the dip and strike directions.

Igneous rocks, as we have already noticed, resulted when molten matter or *magma* cooled and consolidated. The magma may have poured out over a land or a sea-floor as *lava*, or it may have cooled below the surface in the pipes or throats of volcanoes as *vents* or *necks* (Pl. XA), in vertical fissures as *dykes* (Pl. XIIA), between bedding planes as *sills* (Pl. XB), or deep within the crust in *plutonic* bosses. Where the volcanic activity was accompanied by much steam and gas and was explosive, the igneous matter was broken up into volcanic ash or *tuff* or into the coarser *volcanic breccia* or *agglomerate*.

Igneous rocks differ markedly in the size of their crystals and consequently in their appearance. When the magma cooled at great depth, for example in a great plutonic mass beneath a blanket of sedimentary or other rock, hundreds or thousands of feet thick, its crystals had time to grow: they may be readily recognised by the naked eye, as in the coarse-grained granite (L. *granum*, a grain) in which the pink or white crystals with glistening surfaces are respectively orthoclase and plagioclase, the transparent bluish glassy spots are quartz, and the glistening scales are biotite (dark mica) or muscovite (white mica). If it cooled less slowly as in necks, dykes or sills, the crystals are medium sized as in a dolerite (see below). If, on the other hand, it cooled very rapidly as a surface lava by the radiation of heat and the loss of water and gases which at lower levels acted as fluxes, the individual crystals are only recognisable in thin sections under a microscope. Such *volcanic* rocks may indeed cool so quickly that even the smallest crystals are unable to grow: the lava then consolidates as a glass which looks and breaks like a dark bottle-glass. Examples of these *pitchstones* or *obsidians* occur in the town of Newry and at Sandy Braes, Tardree, Co. Antrim. Larger crystals set in a finer grained ground-mass are termed *porphyritic*. If the porphyritic crystals are orthoclase the rock itself is named a *porphyry*, if plagioclase, a *porphyrite*.

Igneous rocks may also be classified according to their chemical or mineral composition. *Acid* igneous rocks, such as the lava called *rhyolite* ("flow stone") or *quartz-porphyry* or the plutonic granite, are light-coloured: they contain the colourless mineral *quartz*, the pink or red mineral *orthoclase*, or the white mineral called *plagioclase*. *Basic* rocks, such as the basalt lavas of Co. Antrim or the dolerite sills which cooled more slowly within the crust, are dark-coloured: they contain minerals such as *augite* which have iron in their composition. The lavas of intermediate composition, that is between the acid and the basic, include the andesites.

Sedimentary or igneous rocks may, by earth-movements (see Ch. III), be pressed down into the crust where they are acted upon by great heat and pressure and become changed. The original minerals, unstable at high temperatures and pressures, break down into minerals of different and often simpler composition. In the course of this *dynamic* or *regional metamorphism* flat or linear crystals are rotated into planes more or less at right angles to the maximum pressure. By this rotation and by developing new flaky minerals (mica, chlorite, talc) which grow from the indeterminate clayey substance and set themselves as they grow and flake or cleave very readily, the rock assumes a *foliation* or schistose structure along which it splits easily.



The commonest metamorphic rocks are gneiss and schist, alike characterised by a banding or foliation. *Gneiss* is a rock of coarse texture and often of granitic composition and appearance in which the banding or parallel structure is on a large scale. *Schist* designates those rocks, in most cases originally sandy muds, which are generally fissile and frequently contorted. Schists often have lustrous surfaces owing to new minerals, such as sericite (silvery white), chlorite (green) or talc (apple-green or greenish-grey). They are named after the most abundant mineral, e.g. hornblende-schist, mica-schist, sericite-schist, garnet-schist and albite-schist.

Other metamorphic rocks are *phyllite*, a rock silvery in appearance which owes its silky glossy lustre to minute spangles of white mica or chlorite; *quartzite*, a metamorphosed sandstone in which the quartz grains interlock; *marble*, a crystalline limestone in which the extremely fine-grained calcium carbonate has been converted into a mosaic of closely fitting grains of crystalline calcite; and *slate*, such as the ordinary roofing slate, which has in most cases descended from clay or shale, and splits along new close-set structural or *cleavage* planes and not along the original bedding planes. These are generally almost obliterated and only recognisable by slight differences in grain, texture or colour.

*Contact* or *thermal* metamorphism takes place because of the heat and hot gases and liquids associated with magmas. For reasons which will be readily understood, it is well seen in the *contact aureole* around granite bosses (see p. 53) or other large igneous masses, and on a smaller scale in connection with volcanic vents, e.g. Scawt Hill (see p. 150), dykes, e.g. in the Cave Hill quarry, Belfast (see p. 169), or sills, e.g. at Portrush (see p. 156).

We have now learned how the various kinds of rock came into existence. The remaining part of this introduction will show how the geologist applies this knowledge to fulfil his task and decipher the history of the Earth.

The geologist divides geological time into four eras in much the same way as the historian divides human history into Prehistory, Ancient, Mediaeval and Modern History. The geological eras are the Pre-Cambrian, Primary or Palaeozoic ("ancient life"), Secondary or Mesozoic ("middle life"), and Tertiary or Cainozoic ("recent life"). These eras, as in human history, are again subdivided into periods (formations or systems) which are set out in serial order in the subjoined table. Like all geological tables this one should be read up, beginning with the oldest rocks at the bottom.

It will be observed that a fifth, or Quaternary era crowns the stratigraphical column. Its creation and separation from the Tertiary are thought to be warranted by the capital fact that Man appeared during the Pleistocene period or Ice Age. For this reason the era is sometimes styled Psychozoic.

TABLE OF GEOLOGICAL FORMATIONS

| *Eras.* | *Periods.* | *Rocks in Ireland.* |
|---|---|---|
| Quaternary (1 million years) | Recent or Holocene | soils, peats, blown sand, river and lake alluvium, diatomaceous earth, raised beach. |
| | Pleistocene or Ice Age | Boulder-clay, drumlins, eskers, moraines. |
| Tertiary (59 million years) | *Pliocene* *Miocene* *Oligocene* | ALPINE MOVEMENT : *Great unconformity.* |
| | Eocene | Lough Neagh clays, Lavas, necks, dykes, sills of N.E.; Mourne and Carlingford granites. |
| Mesozoic (135 million years) | Cretaceous | Chalk or "white limestone" of N.E. |
| | *Oolites* | *Great unconformity.* |
| | Lias | Lower Lias clays of N.E. |
| | Trias | Sandstones, marls and rock salt of N.E. |



| *Eras.* | *Periods.* | *Rocks in Ireland.* |
|---|---|---|
| Palaeozoic (360 million years) | Permian | N.E., unimportant. |
| | | ARMORICAN MOVEMENT : *Great unconformity.* |
| | Carboniferous | Carboniferous limestone of Central Plain; coalfields. |
| | *Devonian* or O.R.S. | Red sandstone, etc., of S.W. and N. |
| | | CALEDONIAN MOVEMENT : *Great unconformity.* |
| | Silurian | Slates and grits of Co. Down, etc. |
| | Ordovician | Slates and grits of Co. Wicklow, Co. Down, etc. |
| | Cambrian | Slates, quartzites, etc., of S.E. |
| | | HURONIAN MOVEMENT : *Great unconformity.* |
| Pre-Cambrian (1300 million years) | Pre-Cambrian (undivided) | Gneisses and schists of Inishtrahull, Belleek, Tyrone and Connemara. Dalradian schist, etc., of W. and N.W. |

Ireland's troubled geological history is shown not only by the number of marked gaps or "unconformities" but by the repeated phases of igneous activity which occurred in Pre-Cambrian, Ordovician, Silurian, O.R.S., Carboniferous and Tertiary times.

The time-scale on the left of the table is obtained from radioactive minerals. Uraninite, monazite and other radioactive minerals are geological clocks endowed with an unfailing mechanism for keeping time by steadily ticking out atoms of helium and lead. Since the rates at which lead is generated from thorium and from each of the parental isotopes of uranium are known, the time required for the accumulation of the lead now present in any radioactive minerals can be determined.[1]

The several periods and eras are not of equal length. For example, the Tertiary era is roughly equivalent in time to the Cretaceous, the Mesozoic era to the Cambrian. The Pre-

[1] The reader interested in this problem is referred to A. Holmes, *The Age of the Earth* (Nelson).

Cambrian was longer than all succeeding time: though undivided in our table, it was not one chapter but a series of chapters, or even volumes, in the earth's history.

Several formations are unrepresented in Ireland—they are printed in italics in the above table. Ireland's geological history, like that of other countries, is imperfect: whole chapters are missing. For our knowledge of the forms of life and the physical events which are unchronicled in its pages we are indebted to other lands where sedimentation was less interrupted and a fuller sequence is both preserved and exposed.

In establishing this succession, the geologist relies in the main upon two laws. The first, the "law of superposition," merely states that as in a building the lowest layer is the oldest and the topmost is the newest. The second law is based upon the sequence of life forms and the procession of life through the ages. It is concerned with fossils. A fossil, literally something dug up, is the term given to the remains of organisms, both plant and animal, which at death were entombed in the sediments, now rocks, that were then accumulating. Since soft parts readily decay, fossils generally consist of only the hard shells or skeletons, either in the original material or replaced particle by particle by some other substance, e.g. iron carbonate, iron sulphide or silica. They are commonly merely internal or external impressions or casts. Fossils also include footprints, borings, worm-casts and other similar traces.

Since fossils are obviously not to be found in igneous rocks and are prone to be obliterated in strata that have been severely metamorphosed, the records of the past are dated by the sedimentary or stratified rocks. For this reason Historical Geology is generally called Stratigraphy. In fact, an igneous episode or a period of metamorphism is dated by relating the igneous or metamorphic rock to some sedimentary bed whose age can be ascertained by means of its enclosed fossils.

Supplementary evidence is supplied by the inclusion in one formation of fragments of another, or by differences in the degree of folding or of metamorphism.

## Chapter I

# THE PRE-CAMBRIAN: FOUNDATION STONES

Although the geologist aims at unravelling the sequence of changes stretching back beyond the dawn of life to the birth of the earth, he is unable to do this for the very beginning: this is veiled in mystery. The planet during a prolonged "Astronomical Age" cooled down from a molten state and passed through a cycle of which nothing is known though much has been surmised. Only after a long but unknown period had rolled by, and the earth had evolved its oceans and continents and wrapped itself in an atmosphere, were events chronicled in rocks which are now accessible. These most ancient rocks are the Pre-Cambrian.

The largest area of the Pre-Cambrian in the British Isles occurs in Scotland. Here it consists of (1) the Lewisian gneisses which underlie Lewis (whence their name) and the Outer Hebrides and spread through West Sutherland and Ross into Skye, Iona and Islay; (2) the Torridonian Sandstone of roughly the same area; (3) the Moine schists and gneisses which lie beneath much of the Highlands north of and about the Great Glen; and, possibly, (4) the Dalradian rocks of the rest of the Grampians which continue into Kintyre, Jura and Islay (Fig. 1).

The Lewisian gneisses have their most southerly occurrence in Inishtrahull, the island five miles north of Inishowen. The Moine schists and gneisses also are represented in Ireland; they occupy the triangular area that has its base on the river Erne between Ballyshannon and Belleek and its apex north-east of Lough Derg, Co. Donegal. Their veins of pegmatite (orthoclase and quartz) near Belleek were possibly strained off when still liquid and forcibly squeezed out of the half-consolidated gneiss—they provided the felspathic material in the form of kaolin or china-clay that was originally used in the

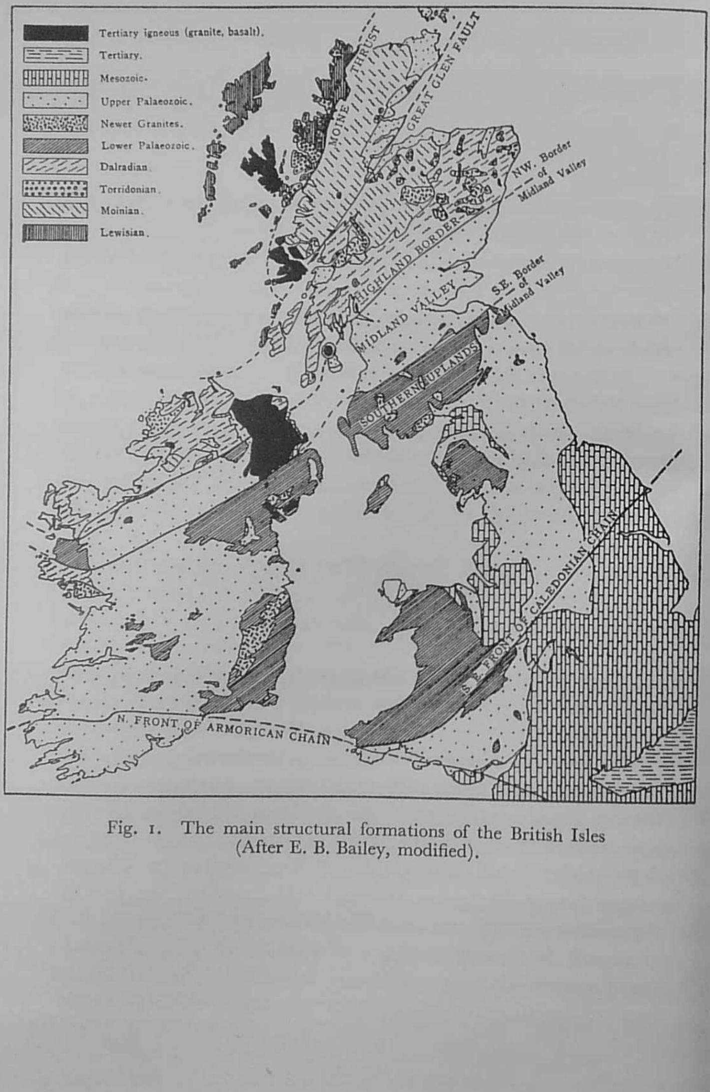



Fig. 1. The main structural formations of the British Isles (After E. B. Bailey, modified).



local pottery. The Torridonian Sandstone has no Irish representative.

Ireland's Pre-Cambrian rocks also comprise the "central inlier" of Co. Tyrone (Fig. 2); the hornblendic, micaceous gneisses about Belmullet, Co. Mayo; the gneisses of the Ox Mountains which (severely moulded by the ice of the Glacial Period) may be seen, for example, from the railway between

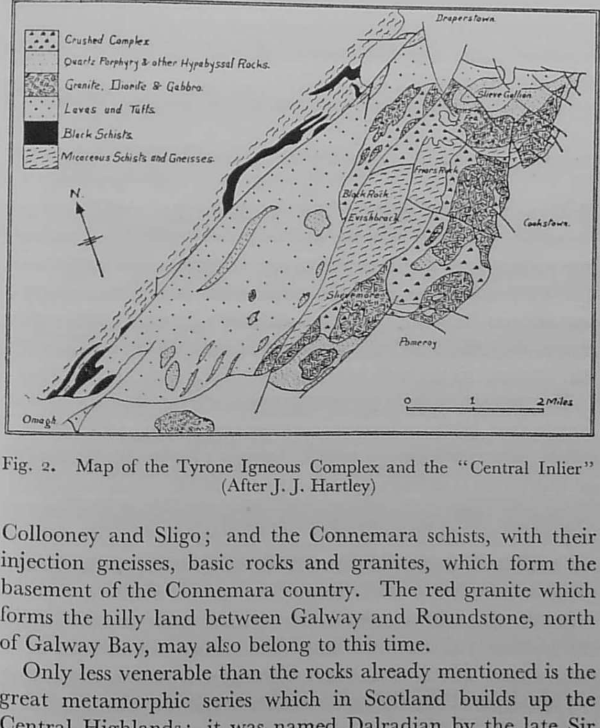



Fig. 2. Map of the Tyrone Igneous Complex and the "Central Inlier" (After J. J. Hartley)

Collooney and Sligo; and the Connemara schists, with their injection gneisses, basic rocks and granites, which form the basement of the Connemara country. The red granite which forms the hilly land between Galway and Roundstone, north of Galway Bay, may also belong to this time.

Only less venerable than the rocks already mentioned is the great metamorphic series which in Scotland builds up the Central Highlands: it was named Dalradian by the late Sir A. Geikie in 1891 because its outcrop includes the land of the ancient kingdom of Dalriada.

The Irish Dalradians, on account of their wide extent (Fig. 3), variety and persistence, and scenic features, constitute one of the most important series of rocks in the country. They form the Highland Border Ridge in north-east Antrim (Fig. 39, p. 109) and emerge from beneath the basalt-plateau in the dreary wastes of the Sperrin Mountains, culminating in Sawel (2240) [1] and Dart (2040). They also underlie the smooth, peat-covered hills of Co. Londonderry, embrace almost the whole of Co. Donegal, rise up into the narrow, rounded moorland of the Ox Mountains, and partially account for the wild scenery of Mayo and Galway.

The Dalradians in the deep glens and on the steep mountain-sides of the west and north-west are seen to comprise numerous varieties of typical metamorphic rocks, the most important being schist, gneiss, quartzite, wrinkled phyllite and granular limestone. The schists, the predominant member, are puckered, gnarled, twisted and contorted (Pl. IA), and are impregnated with strings, veins and lenticles of white quartz. These follow the crumplings of the schist and were squeezed as solutions into the planes of schistosity during earth-movements, deriving their silica from the higher silicate compounds, e.g. felspars, in the sediments among which they rest.

The schists include gleaming mica-schists, green chloritic schists, red, pink or brown garnetiferous schists, and soft and greasy talcose schists—a massive variety of talc named steatite or soapstone has been mined, among other places, at Crohy Head and Gartan Lough, Co. Donegal. North of Cushendun and at the head of Glenshesk in Co. Antrim, and in other places the micaceous matrix of the schist is studded with little square-shaped crystals of a white plagioclase named albite.

While the schists have fallen a ready prey to prolonged denudation and usually "floor" the plains and valleys, as in the Sperrin Mountains where Glenelly, Glenlark and other big glens lie along the softer schist, the intractible quartzites have withstood this onslaught. Their naked rock towers up-

[1] Figures in brackets throughout the book indicate the height of hills or mountains in feet above sea-level.



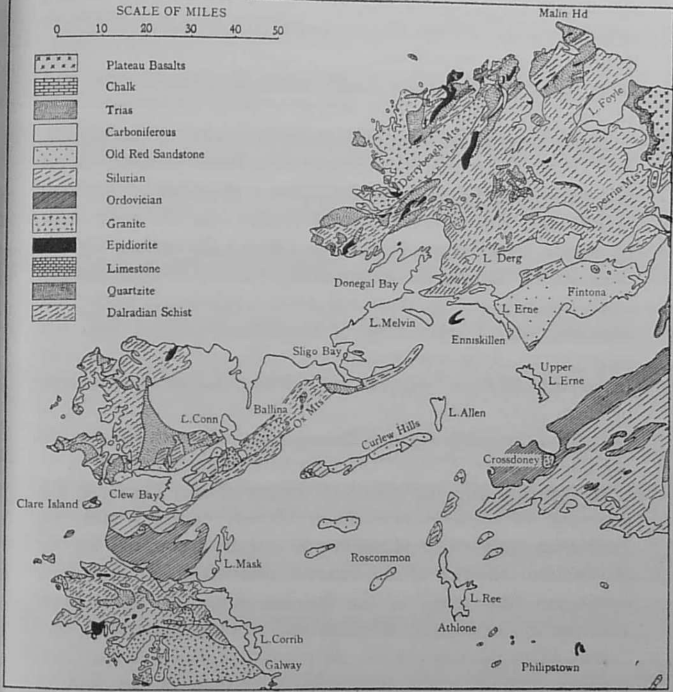



Fig. 3. Geological map of north-west Ireland (Based upon the Geological Survey). The schists south of Lough Derg and in the north of the Ox Mountains belong to the Moinian.

wards into conical peaks or gaunt ridges which glisten white, especially when the sun shines upon their wet surfaces. Their slopes are often draped with white angular scree or fine white sand, as in the "Muckish sand," which frost has formed and gathered into gullies on the north face of this mountain.

The quartzite has been etched out into some of the highest peaks in the Dalradian country, including Raghtin More (1655) and Slieve Snaght (2019) in Inishowen; the ridge of Muckish (2197) and the cone of Errigal (2462; see Pl. IB); Salt Mountain (1646) above Lough Salt; Knockalla or the "Devil's Back Bone" astride the peninsula of Fanad; Nephin (2646) in Co. Mayo; and the cluster of serrated ridges and peaks that comprises the Twelve Bens of Connemara (2395; Fig. 85, p. 223). It soars into the noblest cliffs, such as Croaghaun (2192) and Minaun (1530) in Achill Island, the precipitous face of Horn Head (*c.* 600) on the north coast, and Slieve League (1972) on the north shore of Donegal Bay where the quartzites are flaggy (Slieve Liaga, "the mountain of flaggy stones").

In contrast with the manifold variety of west Donegal, the sameness of scenery over much of east Donegal and the Dalradian part of Londonderry is largely accounted for by the general absence of the massive quartzites. It is indeed significant that much of the Sperrin summit ridge is hard schistose grit and highly siliceous rock or even true quartzite.

The crystalline limestone, very variable in its colour and texture, may be white or saccharoidal (e.g. at the foot of Errigal), dark blue (e.g. Dungiven, Torr Head) and schistose, or black and possibly graphitic. Quarried for lime in many parts, as in Co. Donegal, it is often clad in unusual verdure, including the hartsfern. It is well seen just west of Torr Head, Co. Antrim, in a quarry south of Dungiven in Co. Londonderry, and in a band running from Glenties and Lough Finn to Lough Gartan in Co. Donegal, and through Mayo and Galway.

At Recess and other localities between Galway and Clifden, the white calcite layers alternate with the mineral olivine which has been altered into light or dark green serpentine, the whole uniting in a handsome marble. This widely known Connemara marble, whose green serpentinous streaks and patches lend it infinite variety and charm, is used for internal decoration in many Irish buildings, e.g. the National Museum and National Gallery, Dublin, and the City Hall, Belfast.



Among the Dalradian rocks of the west is the remarkable "boulder-bed" which, up to 200 feet thick, can be traced almost uninterruptedly from Fanad in north-east Donegal to Glencolumbkille in the south-west and still farther south through Mayo and Galway (e.g. at Cleggan). This massive bed, the Schiehallion boulder-bed of Scotland, occurs invariably at the same horizon, namely, above the limestones and at the base of the great quartzites. It encloses rounded or subangular pebbles and blocks of pink, red or grey granite unlike any now exposed in Ireland, together with vein-quartz, schist and quartzite, the whole embedded in a green sandy matrix (see below).

The Dalradian rocks strike north-east south-west from Scotland into Ireland. The quartzites continue the trend of those conspicuous quartzite peaks of Islay and the Paps of Jura which are visible on a very clear day from the north Irish coast. The Dungiven or Torr Head limestone is the equivalent of the Loch Tay limestone which crosses Scotland from Deeside to Kintyre. In their individual groups and whole geological succession the Sperrin Mountains agree closely with north-east Antrim and with Kintyre and Cowal in Argyllshire, while Inishowen corresponds with Islay and Jura.

The age and order of succession of the Dalradian rocks are still in dispute. Some interpret them as truly Pre-Cambrian in their age and metamorphism. Others deem them to be Lower Palaeozoic rocks which have been later metamorphosed beyond all recognition (see Ch. III).

Unfortunately, fossils, the only sure means of solving the problem, are wanting. In this respect the Dalradians resemble the true Pre-Cambrian rocks of the world in which life is practically unknown. There are, it is true, Pre-Cambrian limestones, graphites, iron-ores, coals and phosphatic minerals which usually require life for their formation. Life, which was possibly at first not differentiated into plants and animals, and later consisted of one-celled protophytes and protozoa ("first animals"), had indeed evolved sufficiently in Pre-Cambrian time to yield an occasional alga, radiolarian, sponge, mollusc, crinoid, crustacean and worm (tube and trail). Though few of these memorials are known, the extraordinary variety and high degree of specialisation and organisation of the earliest Cambrian faunas in all parts of the world justify the inference that the Pre-Cambrian seas were cool and habitable and had a primitive and ancestral life. The Cambrian trilobites (Ch. II) were obviously of ancient lineage; and worms, sponges, corals, brachiopods, molluscs, crustacea, pod-shrimps, water-fleas, star-fish and hydrozoa had all been developed at this stage. While therefore Geology is silent and probably will remain silent on that great problem, the origin of life, we may be sure that the Pre-Cambrian was truly Eozoic (Gr. *eos*, dawn) and had witnessed the dawn of life: the earliest links in the great chain of life had then been forged.

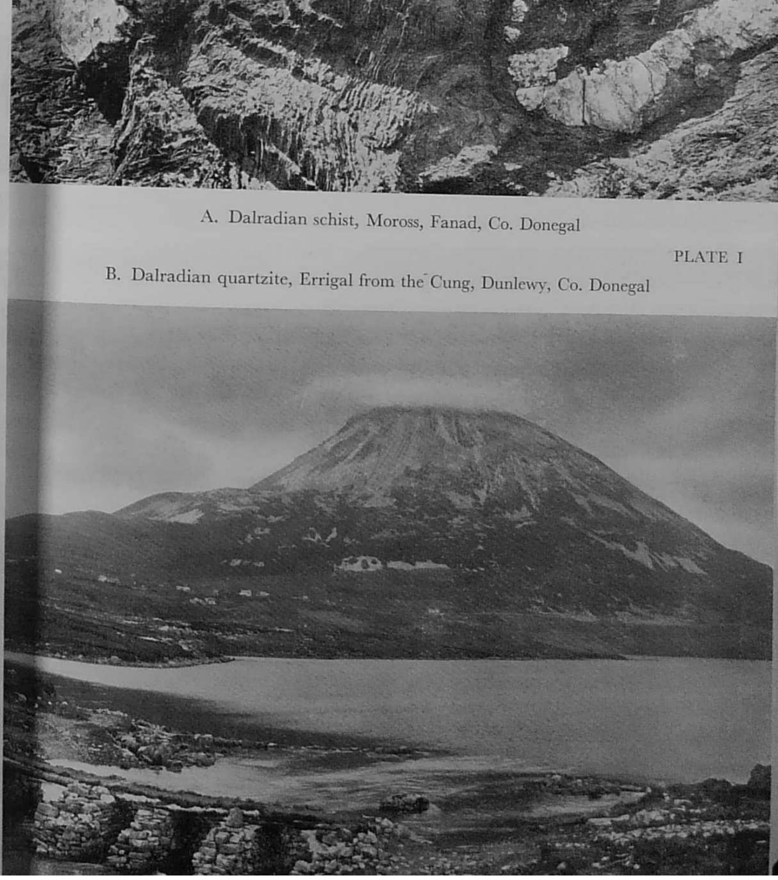
That life was already flowing as a broad stream at the beginning of Cambrian time is in seeming contradiction with the dearth of Pre-Cambrian organic remains. This problem has long been a fruitful source of discussion. It is suggested that the Pre-Cambrian life consisted exclusively of soft-bodied creatures and that skeletons were absent because the seas were then acid or had no calcium or because they had no predaceous carnivores; that the organisms were mobile and inhabited solely the surface-waters where skeletons were detrimental because of their weight; that the Pre-Cambrian strata preserved to us were deposited on land or in fresh water of low calcium content; or that life, with hard parts, did actually exist but subsequent metamorphism of Pre-Cambrian age, which attained a scale never subsequently approached, destroyed all traces of it. The true reason is difficult to find and even more difficult to prove; it may always remain a secret securely sealed within the Pre-Cambrian rocks.

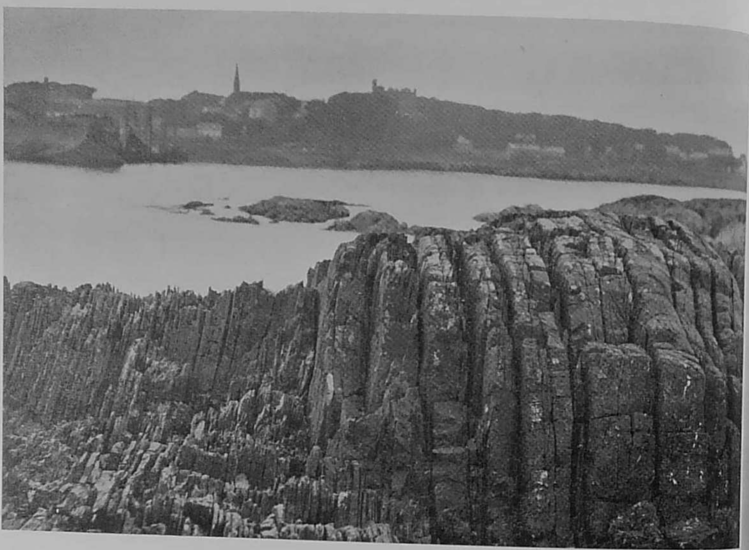
In the absence of a key to unlock this mystery the most that

A. Dalradian schist, Moross, Fanad, Co. Donegal

PLATE I

B. Dalradian quartzite, Errigal from the Cung, Dunlewy, Co. Donegal





A. Vertical Silurian strata, Ardglass, Co. Down

B. Overthrusting, Broughderg Burn, Sperrin Mountains



can at present be said is that the Dalradians show a far severer metamorphism than do the strata of Lower Ordovician (Arenig) age that rest upon them west of Lough Mask with a pronounced break or unconformity, or than the Silurian (Wenlock) beds south of the entrance of Killary Harbour whose basal conglomerate is to be seen, for example, on the coast at Gowlaun. The testimony of the igneous rocks of Co. Tyrone agrees with this conclusion (see p. 42). We therefore tentatively conclude that the Dalradians are Pre-Cambrian though some of their metamorphism may date from the Caledonian Movement (see p. 48).

In the schists, slates and quartzites we catch dim glimpses of an ocean where the detritus from unknown lands was laying the foundations of a new world. Despite their high antiquity which is too vast to be humanly apprehended, we can affirm that even at that remote time the processes of change and decay, of erosion and deposition, did not differ appreciably from those of the present. The ripple-marks of the quartzites, as on the summit of Muckish, are exact replicas of those that corrugate the sands on our modern shores. The oblique bedding in the schists, due to currents, and the graded bedding, due to periodic inwashes of fresh detritus and its gradual settling, are astonishingly reminiscent of the structures found in modern shallow-water sediments. They thoroughly justify our belief in the Doctrine of Uniformity which Sir Charles Lyell enunciated over one hundred years ago (1830) in his *Principles of Geology*. This great geologist believed that geological processes have operated on the Earth's surface throughout all time in the same way as they do now. Rocks and surface-features were not generated by sudden and violent catastrophes or cataclysms but by the steady action through millions of years of rain, frost, wind, rivers, ice, sea and other forces which are at work around us to-day.

The Dalradian sediments were spread out on the floor of a shallow sea which deepened gradually from a shore that probably ran, in general, north of the present Ireland. The bottom of the sea was slowly sinking. The extraordinary the general strike, often, as in Co. Donegal, for long distances. With the hard schistose grits, mentioned already, they build the main Sperrin watershed.

These Pre-Cambrian "foundation stones" probably extend still farther, for they peep out of the Carboniferous strata of Rosse's Point, Co. Sligo. They apparently build the Porcupine Bank, some 130 miles west of Cleggan Head, Co. Galway, where schists together with acid and basic plutonic rocks of much later age have been dredged up (see p. 167). The boulders of gneiss and mica-schist in the Old Red Sandstone conglomerates at Inch on the north shore of Dingle Bay can only have sprung from such an ancient source. Of possibly similar significance are the blocks of schist which the Carboniferous volcano at Philipstown, Offaly, has brought to the surface.

Chapter II

# THE LOWER PALAEOZOIC: A GEOSYNCLINAL SEA

With the beginning of the Palaeozic era we cross the threshold from the dimly understood Pre-Cambrian into a time about which we are more fully informed. A trough-like sea, shallow to the north-west and off the present coast to the south-east and deepest over the intervening band, crossed Ireland obliquely (Fig. 5). Its extent and relationship to the world-oceans are suggested in the map which like others of the kind given in the book is only suggestive: it ignores the effect of lateral compression due to subsequent earth-movements and the serious errors induced by continental drift, if this did in fact take place (see p. 47).

The sediments laid down in this sea were first discovered in Wales, whence their names: Cambrian, from the Latin name for Wales; Ordovician, from the ancient tribe of the Ordovices of central Wales; and Silurian, from the British tribe Silures which inhabited the Welsh marches. The Ordovician is subdivided into Arenig, Llandeilo and Bala (Caradoc), the Silurian into Llandovery, Wenlock and Ludlow, all names of localities in Wales or on its Shropshire border.

## Cambrian

While the Dalradian rocks of Ireland are found only in the west and north, the Cambrian is confined to the south-east, namely, to the Hill of Howth (560) and to Co. Wicklow and Co. Wexford (Fig. 6). It has nowhere been denuded sufficiently to uncover the Pre-Cambrian which, to judge from the evidence of Wales (Anglesey, Pembroke), is concealed beneath them.

As we might expect from their high antiquity and consequent exposure to terrestrial forces acting during a long succession

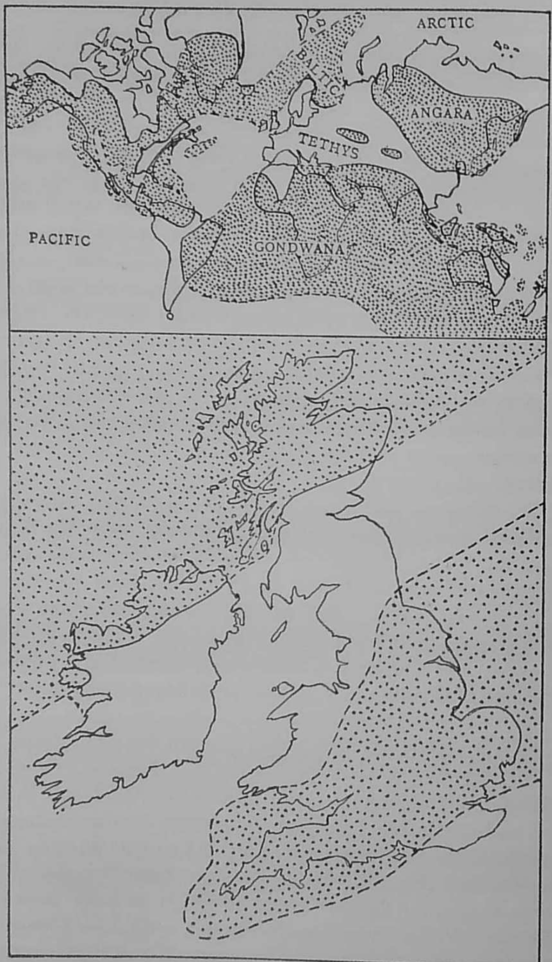



Fig. 5. Map showing the distribution of land (dotted) and sea (white) in the British Isles in Silurian time (inset: world geography).



of geological epochs, the Irish Cambrian strata have been highly disturbed; they have been sharply and steeply folded, cleaved and dislocated, and thrown into a state of confusion that has so far baffled all attempts to unravel their story. The reference to the Cambrian may itself be incorrect: the rocks may be Pre-Cambrian since they lack the typical Cambrian fauna, and the nature and behaviour of the indisputable Cambrian of Wales demand a large land-mass to the west. The absence of trilobites and of other organisms which would furnish a basis of comparison, notwithstanding repeated search, makes it impossible to fix the age of the strata with any certainty. Since they are overlain by the lowest division of the Ordovician (Arenig) they are tentatively correlated with the Cambrian.

These rocks consist of a great series of alternating purple and green sandstones ("grits"), highly cleaved and crushed slates, quartz and quartzites, together with conglomerates or breccias of local Cambrian rocks. The breccias were formed by subsequent movement—Howth, like Carrickgollogan, may have been thrust north-westwards—or more probably by slumping on the ocean floor when earlier beds, not long solidified, were shaken and broken by landslides, probably of seismic origin, before the overlying beds were laid down.

Responsible for the boldness and ruggedness about Howth and finely displayed along almost five miles of its magnificent cliffs, they are seen to be massive quartzites and grits, with well-cleaved green and variegated slates, intensely and minutely folded and crushed. They are penetrated by numerous dykes of much later age. The serrated edges of the quartzites, dipping steadily to the south, can be seen from the sea silhouetted against the western sky.

The same series, severely crumpled and contorted, emerges in Ireland's Eye, north of the Howth Peninsula: the massive quartzites give the island its wedge-shaped outline.

The "Bray Series" of the Irish Cambrian sweeps southwards from the precipitous Bray Head to about Wicklow, some

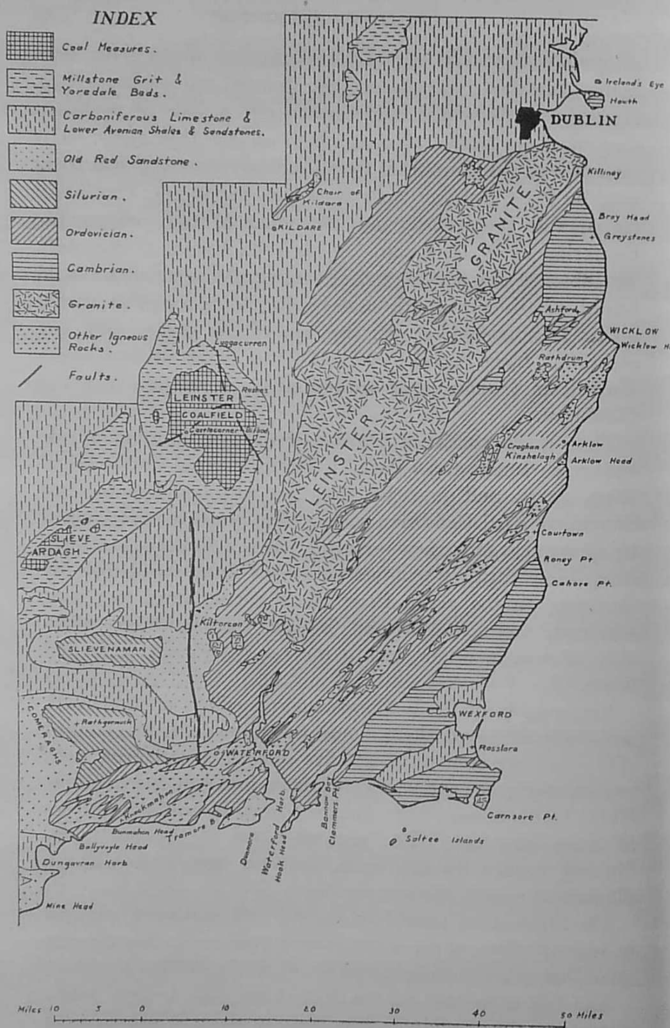



Fig. 6. Geological map of south-east Ireland (After T. T. Hallissy, reduced).



17 miles away. It is fairly well exposed, the sections at Bray Head and at Greystones being especially good. The green and purple slates and grits, fine-grained sandstones prevalently cross-bedded near Bray, and ribs of hard quartzites up to at least 500 feet thick, dip fairly regularly north-westwards at angles varying between 40° and 70°. The knobs and ridges of the quartzites diversify and dominate the landscape (Fig. 7) in Great Sugar Loaf (1659) and Little Sugar Loaf (1120). Like the Dalradian quartzites, they give rise by frost-splintering along their numerous irregular joints to white screes that mantle

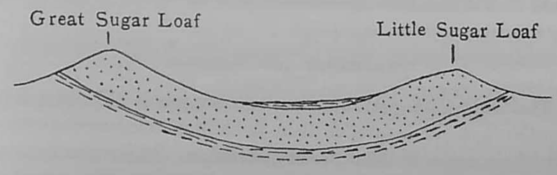



Fig. 7. Diagrammatic section through the quartzites of the Great and Little Sugar Loafs (dotted) with slates above and below.

their conical forms. Farther south, small detached masses of the quartzite build the serrated ridge of Carrick Mountain (1256), Carrickgollogan (912), Walker's Rock and Long Hill.

The Cambrian of Co. Wexford, in striking contrast, forms a low undulating country, though quartzite builds the craggy Forth Mountain (697) which is conspicuous west of Wexford town. The western boundary runs for some 36 miles from north of Cahore Point to Bannow Bay on the south coast.

Such, in brief, are the Cambrian rocks of Ireland. What picture can we form of their mode of deposition? The interpretation of past conditions is at best somewhat uncertain and is largely a matter of inference, based in part on studies of modern sedimentation and in part on the assumption, not necessarily valid, that physical and climatic causes operated much as they do to-day. In the case of the Irish Cambrian our difficulties are unusually great: the formation is incomplete; its base is nowhere exposed; and it provides no positive information of a transgressing sea or of the position of its shore-line.

In marked contrast to the succeeding Ordovician of the same area its rocks are distinctly sandy. Not only do the thick quartzites indicate sedimentation in shallow water but the slates are sandy and of shallow-water origin. The rounded grains of the quartzites and the red beds at Bray Head suggest high oxidation on a desert before deposition in shallow water. This harmonises with the fine shales of the Bray Series which seem to denote a paucity of available detritus.

## Ordovician and Silurian

The Ordovician and Silurian rocks are much alike and the conditions which controlled their deposition continued during the whole period without marked variation. Important faunal changes, however, serve to define the boundary between the two systems.

The strata of the two formations occupy an isolated outcrop of a few square miles near Pomeroy (Bala and Llandovery) in Tyrone and their igneous rocks (of Ordovician age) floor a much bigger area farther north. They also comprise the slates and grits which, excepting the granitic areas of Newry and Mourne, underlie almost all the triangular area which extends south of Belfast Lough and the Lagan valley to an apex at Longford and the watershed between the Shannon and the Erne. Encircling the base of the Mourne Mountains, they sweep beneath the low Ards Peninsula and underlie the plain of Down, appearing in its bare patches of rough country and in the Holywood and Castlereagh Hills.

Along the north of these hills, the Ordovician forms a narrow strip continuing that which crosses Scotland from Dunbar to the Rhinns of Galloway and that which passes through Armagh and Monaghan into Cavan and Longford. It emerges as inverted boat-shaped inliers trending north-east south-west in the axes of the sharp anticlinal folds where



erosion has cut sufficiently deeply to uncover them (Fig. 39, p. 109), e.g. north of Ballynahinch, at Lessan near Saintfield, at Tullygarvan and at Coalpit Bay near Donaghadee.

Ordovician strata also strike south-westwards on either flank of the Leinster granite (Fig. 6) where they furnish much of the local building stone, as in the Seven Churches, Glendalough. Silurian, consisting of dark-grey and bluish shales with intercalated bands of bluish and greenish grits, for the most part of Llandovery age, also protrudes from the O.R.S. cores of Slievenaman, Slieve Bloom, Keeper Hills and the Comeraghs. It weathers down into central bowls, dotted with farm lands and overlooked by the ringed escarpments of the truncated O.R.S. domes whose dip slopes facing outwards are barren and often forbidding. Both formations are represented in the Slieve Bernagh and Arra Mountains.

Silurian crops out too in the west of Dingle Peninsula where some shales and contemporaneous volcanic rocks accompany its calcareous flagstones. It also builds the wild mountains which range from Lough Mask to Killary along the marches of Galway and Sligo. Here it is bent into two compressed synclinal troughs which are separated by an irregular and complex anticline running roughly along Killary Harbour and exposing an almost complete Ordovician succession. A more or less single trough with Carboniferous rocks in the middle coincides with Clew Bay.

The Ordovician and Silurian strata have everywhere been thrown into sharp folds which strike with remarkable persistence from the ENE. or NE. in the direction of the belts (Fig. 17, p. 48). The dip varies considerably but is generally high and often vertical (Pl. IIa).

The rocks are thoroughly compacted, so that they have been widely used in buildings and in ancient monuments, including the ruins of Monasterboice and the Round Towers. Because of their sameness, any hills to which they give rise are generally subdued. Their dark slaty shales (frequently glossy along their planes of fracture and often splintery and crumbling) and banded slates are associated with light-coloured, purplish or greenish sandstones (grits) which, being tough and hard, have been extensively quarried for local road metal. The cleavage of the slates is in general not sufficiently fine or regular to fit them for roofing purposes, though serviceable shapes, not too thick or too heavy, have been quarried, among other places, at Carrick-on-Suir, at Kilmoganny (Co. Kilkenny), and in the famous quarries at Portroe in Slieve Arra near Killaloe—the total roofing slates quarried in Eire in 1944 totalled 2704 tons. The grits, found chiefly in thick massive beds, grade on the one hand into thinner layers of fine grain and more flaggy character and on the other into coarse breccias and conglomerates. Dark shales which constitute but a very small fraction of the total succession are occasionally of prime importance since they contain graptolites (see below). These carbon-bearing shales in the Silurian have frequently been mistaken for true coal seams, and during the last hundred years have had small pits sunk into them.

Some of the grits, more often the shales, are penetrated by numerous thin strings of calcium carbonate or by veins of white quartz. The shales are commonly speckled with brass-yellow crystals of iron pyrites (iron sulphide) which minutely bespangle the surfaces of joints or cracks (Gr. *pyr*, fire) and may be the source of the sulphur and iron of the "spa" waters of Ballynahinch.

These rocks were probably laid down under the following conditions. At the close of the Cambrian, probably after a period of uplift and erosion, the sea transgressed northwards far beyond its previous borders and covered most of Ireland during the immensely long periods of the Ordovician and Silurian. We can reconstruct in broad outline the palaeogeography of the times, although much of the Lower Palaeozoic sediment is now deeply buried beneath later strata or, if visible, has been greatly mutilated.

The Dalradian series of the west was probably alone emergent: it formed the eastern part of a vast primaeval continent or *Atlantis* which stretched over the site of the present North Atlantic Ocean and markedly influenced British



geological history, both at this time and throughout the whole span of the Palaeozoic and Mesozoic eras (Fig. 5, p. 22). Of this continent we know little, though sone indication of its relief may be gained from the stupendous pile of grits and shales which grew from its degradation: the Ordovician west of Lough Mask consists of over 10,000 feet of black shales, coarse quartzose and felspathic grits and conglomerates, while the Silurian of Dingle Bay, though the base is hidden, is apparently over 6000 feet thick. This land furnished the muds and sands of the shallow sea whose northern shore probably ran from somewhere about Cushendun to Draperstown, Omagh and the south side of the Ox Mountains. Since the Antrim Plateau, Mourne Mountains, Kerry Highlands and Wicklow Chain were then unborn, the seas spread uninterruptedly to a coast that lay about the eastern border of Wales and the present south-east corner of Ireland.

The northern shore was doubtless continually changing. Thus the Middle Ordovician sea transgressed across the Lower Ordovician strata north of Killary Harbour on to the Pre-Cambrian rocks.

The shingle beaches of this ancient sea are preserved in the west. Their massive conglomerates, of variable thickness and character, consist of blocks and pebbles of schist and quartzite, with less numerous fragments of vein-quartz and granite, all clearly derived from the waste of the Dalradian rocks of west Connaught. North-east of Clew Bay and west of Lough Mask they repose directly upon the ancient schist and include boulders of a coarse-grained granite similar to that of Galway. Dingle also lay near the ancient coast, since its Silurian beds are of vast thickness, contain layers of conglomerate throughout, and include sandy limestones.

As we depart from the old shore-line, with its shingle conglomerates and current-bedded and felspathic grits—they build, for instance, the bold and rugged mountains at the north entrance to Killary Harbour—we pass across beds which become less and less gritty and grade into a thinner series of slates, e.g. about Lough Derg, north of Killaloe, where the

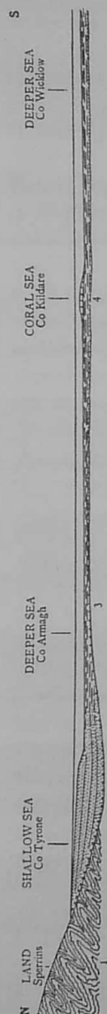



Fig. 8. Generalised section across the Lower Palaeozoic sea, showing the disposition of the depths and the various kinds of sediment. 1. Dalradian rocks; 2. sandy, trilobitic facies; 3. muddy, graptolitic facies; 4. coral facies.

deposits were least thick (Fig. 8). In the same way, the coarse rocks of the Pomeroy inlier, which represent the plentiful detritus brought down by the rivers of the period from the Tyrone igneous and metamorphic rocks, give place at a greater distance from the source of supply to the finer sediments of Down and Armagh.

The grits and coarse beds are generally barren and fossils in the finer beds are sporadic and local: they consist, in the main, of graptolites, trilobites and corals.

The graptolites, which belonged to the hydrozoa, formed feather-like colonies of very minute individuals. These lodged in cups, set like the teeth of a saw, on a very slender horny stem which was either single or branched. While the Ordovician graptolites were generally complex in character and branched (*Didymograptus*, two-branched="tuning-fork graptolite"; *Tetragraptus*, four-branched), those of the Silurian were much simpler and usually single stemmed, the cups being disposed on one side (*Monograptus*) or on both sides (*Diplograptus*). When squeezed flat and seen in profile, the fossil resembles a tiny saw or the marks made by a pencil on a slate (Gr. *grapho*, I write).

The graptolites evolved in the arrangement and shape of the branches and in the form of the cups. The tendency was apparently to abolish overcrowding and undernourishment by reducing the number of branches and the number of individuals on each branch (Fig. 9). This trend of



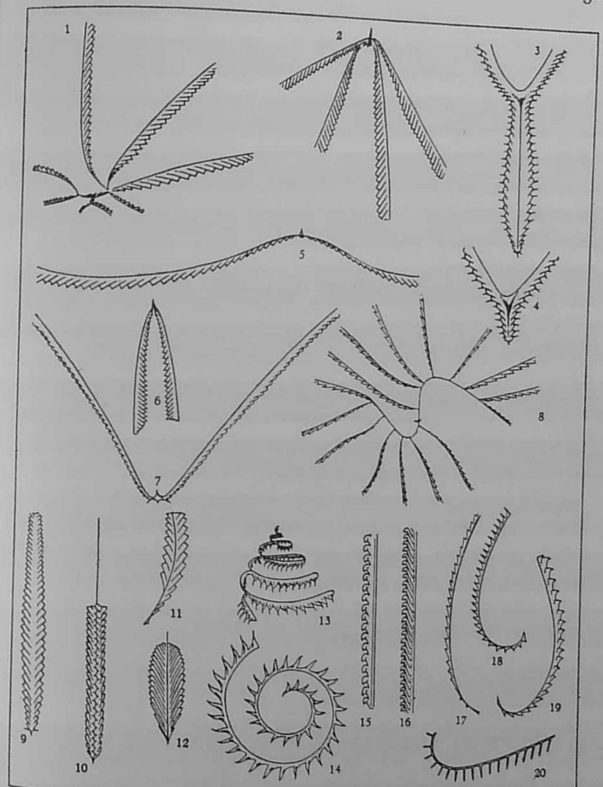


Fig. 9. Typical Irish Ordovician and Silurian graptolites (Drawn by A. W. Woodland from published sources). 1. *Dichograptus octobranchiatus;* 2. *Tetragraptus postlethwaiti;* 3. *Dicranograptus ramosus;* 4. *D. nicholsoni;* 5. *Didymograptus superstes;* 6. *D. murchisoni;* 7. *Dicellograptus forchammeri;* 8. *Nemagraptus gracilis;* 9. *Diplograptus truncatus;* 10. *Climacograptus scharenbergi;* 11. *Dimorphograptus swanstoni;* 12. *Petalograptus folium;* 13. *Monograptus furriculatus;* 14. *M. spiralis;* 15. *M. lobiferus;* 16. *M. priodon;* 17. *M. tenuis.*

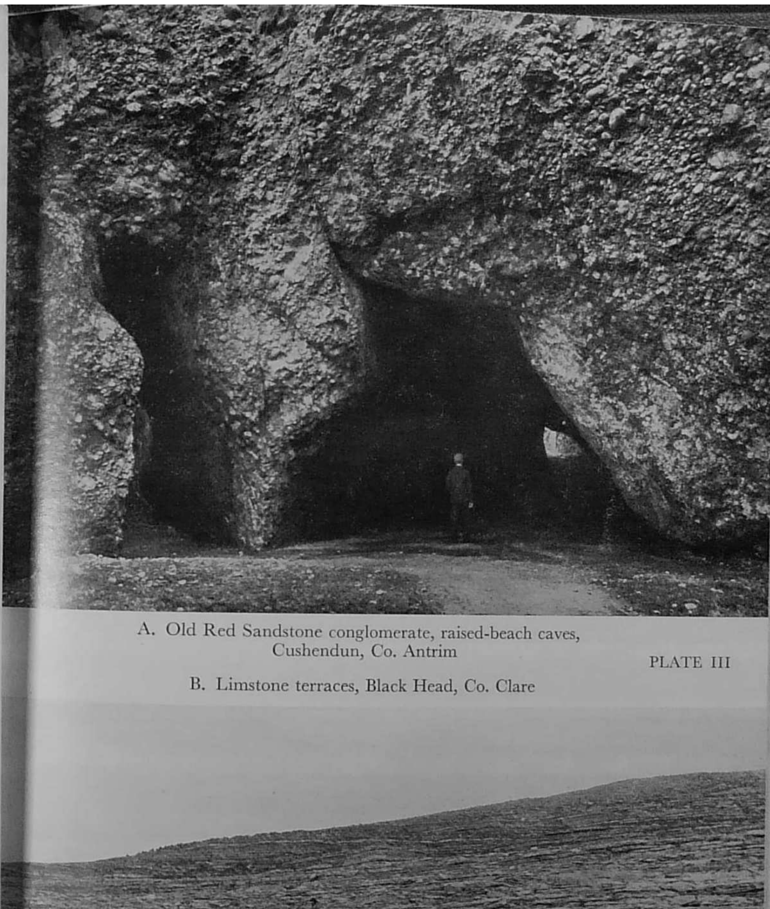
isolation was carried to an extreme in *Rastrites maximus* which, at death, fell to pieces very readily so that its fragments are frequently abundant.

The fine state of preservation of these delicate organisms points to the quietness of the waters on the sea-floor. The graptolites are preserved in chitin (a transparent horny substance), in black carbon or in shiny pyrites. They lived in surface waters, attached either to a bell-like float of their own or to floating seaweed (Fig. 10). This furnished the carbon of the dark carbonaceous shale or mudstone in which almost exclusively the graptolites are to be sought. Without means of locomotion they drifted far and wide, and when weed and graptolite died, settled to the bottom. With the aid of sulphur bacteria, they poisoned the stagnant bottom waters by giving off sulphuretted hydrogen: such badly ventilated waters exist to-day at the bottom of the Norwegian fjords and the Black Sea. The poisoning accounts for the absence of any trace of the benthos or bottom life. Such vast masses of floating algae as are here implied constituted a phenomenon which prevailed in Lower Palaeozoic times on a scale apparently not since approached.

The graptolitic shales probably accumulated in waters that were not very deep, namely, in shallow shelf-seas connected with the main ocean or in seas which were restricted and closed in by submarine barriers.

The identification of strata by their fossil contents, begun by William Smith in the early part of last century, has become more refined in its methods. Layers of rock, a few feet or few inches thick, can now be correlated from place to place. The finest life-division, the "zone," is the belt of rock which contains a particular fossil species (as well as other fossils). The zone or index fossil lends its name to the zone in which it occurs. The thickness of a zone is, so to say, a geological accident, depending upon the depth of sediment that was being laid down during the life of the particular zone-fossil (not, of course, of one individual only but of all the individuals of that species).

The graptolites were so abundant and widespread and were



A. Old Red Sandstone conglomerate, raised-beach caves, Cushendun, Co. Antrim

PLATE III

B. Limstone terraces, Black Head, Co. Clare

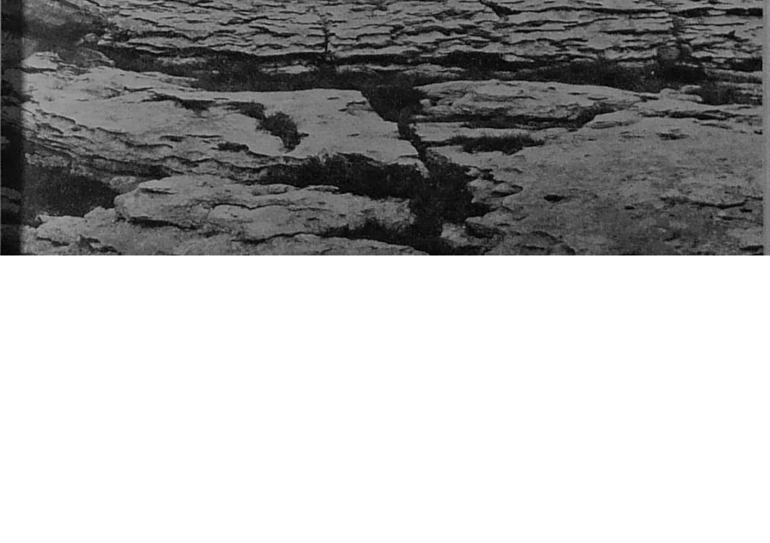
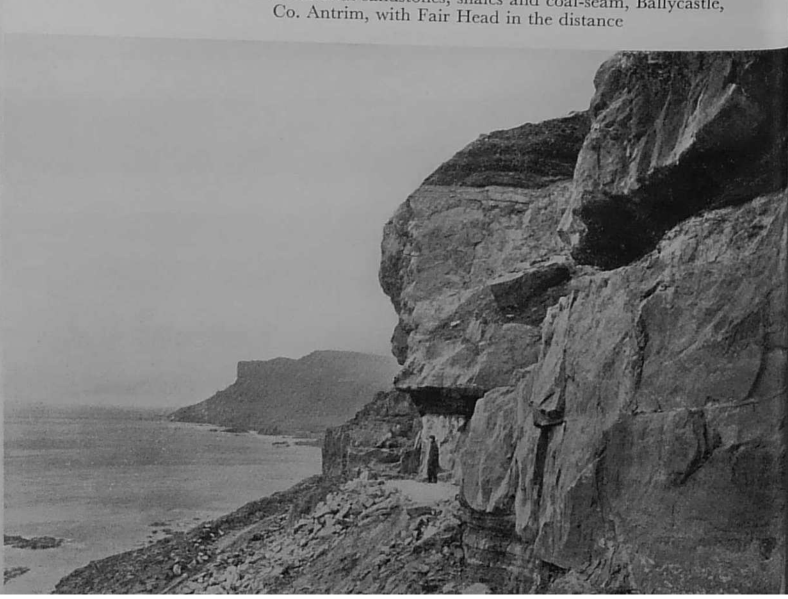


PLATE IV

A. Carboniferous Limestone plateau, with bog trees in the foreground, Ben Bulben, Co. Sligo

B. Lower Carboniferous sandstones, shales and coal-seam, Ballycastle, Co. Antrim, with Fair Head in the distance





evolving so rapidly and in such variety that they enabled the late Professor Charles Lapworth, on lines subsequently developed, to establish a standard sequence of graptolite zones

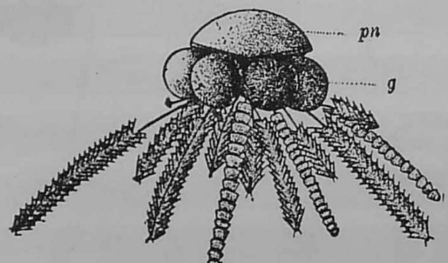



Fig. 10. A graptolite colony (*Diplograptus*) restored (After Ruedemann from A. W. Grabau).

which are indispensable in correlating one region with another. By this means, for instance, we know that the Ordovician of Down is incomplete and that the lowest division (Arenig) is either absent or not exposed.

The trilobites, which had a wide distribution and small vertical specific range, were also most suitable for zoning. Named trilobites because they are divided lengthwise into three lobes, an axial lobe and two lateral lobes (Fig. 11), they were small marine crustacea, allied probably to the scorpions and spiders and not unlike wood-lice in appearance. Their backs were protected by a horny coat or shield which was periodically cast during growth. They had a head, tail and thorax, the latter generally segmented like a modern lobster's shell to permit movement and to protect the soft underparts by curling. In life, limb and appendages were attached to the outer case but are now rarely preserved. At death, the segments usually fell apart so that whole shells, like those drawn in Fig 11, are rare. The genera and species are determined by the shape of the various parts, the number of segments, and by other variants of this kind.

The extensive shallowing and deepening of the geosynclinal sea (see p. 44) and the fluctuating boundaries of the various kinds of sediment were doubtless reflected in migrations of the graptolites and trilobites; a shoaling led to a migration of the shallow-water shelly fauna towards the centre of the geosynclinal sea, a deepening to an expansion of the area stocked with graptolites.

Clear water existed at various places and horizons, and was inhabited by corals which like the brachiopods were attached to the sea-bottom. They comprise the single or horn corals called Tetracoralla (also named rugose corals from their characteristically wrinkled outside layer) in which the septa were arranged in cycles of four, or they belonged to the group of the Tabulata which were tube-like, compound, honeycomb corals furnished with numerous, closely packed horizontal plates (*tabulae*). Typical Lower Palaeozoic corals are, among the Tabulata, *Halysites* (e.g. *Halysites catenularis*, the "chain coral," Fig. 13), *Heliolites* and *Favosites*, and among the Tetracoralla, *Acervularia*, *Omphyma* and *Zaphrentis*. Clear water prevailed, for instance, in Upper Ordovician (Bala) times in Co. Kildare where the Ordovician rocks rise in an inlier along the crest of an upfold and for seven miles project above the Carboniferous plain.

Fossiliferous limestone, with trilobites and brachiopods, of the same age occurs north of Dublin at Portraine. On Lambay it is associated with slates that were apparently deposited as muds when the local volcano (see p. 40) was dormant or quiescent and atmospheric agents were stripping the volcanic cone and carrying the ashes and lavas into the adjoining sea.

Fossiliferous limestones also enclose abundant trilobites and crinoids and occasional corals in the Ordovician of the south-east, as in the Tramore limestones of Co. Waterford.

Clear water obtained in Middle Silurian (Wenlock) times in several places. Thus at Sybil Head in Kerry, the limestones contain such typical fossils as the brachiopods *Atrypa reticularis* and *Dalmanella* (*Orthis*) *elegantula*, the trilobite *Calymene blumenbachi*, and the coral *Halysites catenularis*. True coral reefs existed in several areas.

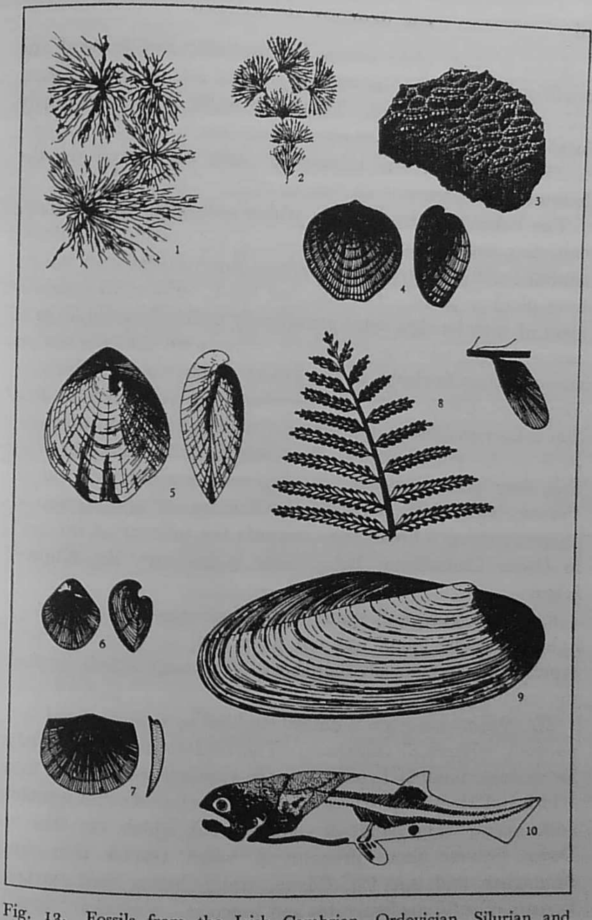



Fig. 13. Fossils from the Irish Cambrian, Ordovician, Silurian and O.R.S. (Drawn by A. W. Woodland from published sources). 1. *Oldhamia radiata*; 2. *O. antiqua*; 3. *Halysites catenularia*; 4. *Atrypa reticularis*; 5. *Pentamerus oblongus*; 6. *Adiantites hibernicus* (with one of the leaflets); 7. *Dalmanella elegantula*; 8. *Strophomena* (*Rafinesquina*) *grandis*; 9. *Anodonta jukesii*; 10. *Coccosteus decipiens* (one-seventh life size; the genus is found in Ireland).

Some of these clear waters lay probably not beyond the mudline but within it in shallows which, for various reasons, did not receive any mud. That deep water is not necessarily implied is suggested by modern calcareous echinoderms (sea-urchins), mollusca and calcareous algae discovered on the bottom of the present Irish Sea, as off the Calf of Man.

The Palaeozoic sea-floor, on which sediments were quietly collecting and enclosing the remains of the marine organisms, subsided with a movement that was intermittent and varied from place to place. The adjacent lands, subject to a movement of opposite sign, were periodically uplifted and masses of coarse shingle, now conglomerates, were swept into the sea on many distinct horizons of the Lower Palaeozoic in Galway, Mayo and Kerry. We are, therefore, not surprised to find that volcanoes arose within the geosynclinal basin and afforded relief to the crustal stresses then steadily accumulating. At first, they were restricted to a narrow marginal strip, as in Tyrone (see below). Later, the theatre of action moved progressively as a broad zone towards the interior of the sea; in Upper Ordovician (Bala) times it lay over the Kildare inlier.

Fine dust and small stones were discharged, sometimes so lightly that the fauna was not disturbed, at other times so rapidly and continuously that sheets of volcanic debris masked the marine sediments.

The Ordovician sea was indeed studded with submerged and partially submerged volcanoes. The explosions of the north, for example those of Tyrone, grew in violence southwards into Louth and Meath where lavas (andesitic), ash and other igneous rocks occur. The bands of volcanic rock which are thin in Down become more pronounced when traced into Co. Monaghan and into Co. Cavan, which has a well-marked horizon of tuffs, agglomerates and breccias. Volcanic "fires" also burned in the west; for ashes and lavas (red felsitic), associated with intrusives, are embedded in the Lower Ordovician (Arenig) sediments of Mayo, west of Lough Mask (Tourmakeady, Glensaul).

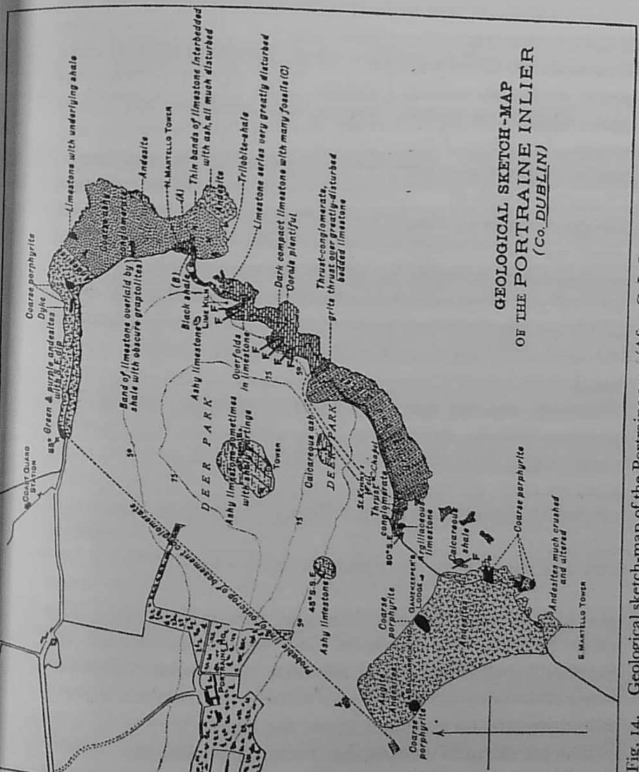



Fig. 14. Geological sketch-map of the Portraine area (After C. I. Gardiner and S. H. Reynolds, reduced. F=Fault. Scale, $3\frac{3}{16}$ inches=1 mile.

Contemporaneous amygdaloidal and porphyritic lavas of basalt and andesite were extruded in the Upper Ordovician (Bala) of Kildare, and green and purple lavas, vesicular and andesitic, and later ashes mingled with the contemporaneous limestones on the same strike-line at Portraine on the coast north of Dublin and in Lambay (Figs. 14, 15). Here the igneous rocks which have been complicated by subsequent crushing and brecciation (better seen in the limestones and shales) embrace also dykes and sills, including the ornamental "Lambay porphyry" (porphyritic andesite), with its green tabular crystals of altered plagioclase embedded in a dark green matrix: the lavas and tuffs thicken to the site of the old volcano which probably lay east of the present island. From this volcano there radiated apparently the porphyritic dykes which cut the Cambrian rocks of Howth and Bray. Some of the igneous masses near Rathdrum may also belong to this epoch.

Tyrone was the seat of prodigious igneous activity; its products underlie the country between Omagh and Draperstown (Fig. 2, p. 11) and conceal a floor of Pre-Cambrian rocks that emerges in the central inlier and has been further altered by granitic intrusions. The volcanoes, of Lower and Middle Ordovician age, emitted lavas of basic, intermediate and acid composition (in this order) which locally flowed into or were embedded in muds laid down contemporaneously along the edge of the gradually subsiding geosynclinal sea. This phase of vulcanicity was in its later stages accompanied and eventually superseded by an explosive phase when ashes and other materials were hurled out. Subsequently, thick dolerite sills insinuated themselves between the lavas.

The intrusions of magma that followed, cooled and consolidated as the blister-like masses of coarse basic rock of the area and the laccolites ("cistern stones") of granite of Slieve Gallion and Pomeroy which, injected under pressure, metamorphosed the Dalradian schists.

The Ordovician date of this igneous phase is shown by the boulders and pebbles of the granite, the latest of the igneous

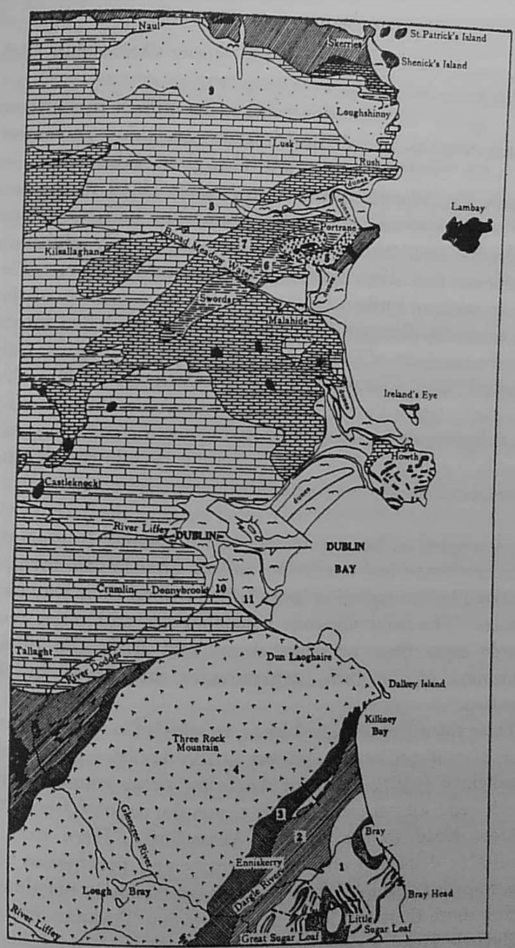



Fig. 15. Geological map of the Dublin district (After various authors, modified). 1. Cambrian, with quartzites (dotted); 2. Ordovician and Silurian, with igneous rocks (black); 3. ditto, metamorphosed in contact aureole; 4. Leinster granite; 5. O.R.S.; 6. Lower Carboniferous Shales; 7. Lower Limestones; 8. Middle Limestones and "Calp"; 9. "Millstone Grit" and "Yoredale Shales"; 10. Raised beach; 11. Alluvium.

rocks, which are found in the basal Upper Ordovician (Bala) conglomerates near Pomeroy (see p. 17).

The igneous manifestation reached its climax in south-east Ireland, namely, in two broad tracts stretching respectively from near Wicklow town past Croaghan Kinshelagh into northern Co. Waterford and from Arklow Head to the south coast at Dungarvan, and in the numerous beds of ash and porphyritic lava that seam the hills and sharply undulating terrain on the other side of the Leinster granite. These igneous rocks of Ordovician age are the counterparts of those that across St. George's Channel have been modelled into the highest mountains of Wales, e.g. the Arenig Mountains, Cader Idris and those of Snowdonia and the Carnarvon Peninsula.

In south-east Ireland, the material that was thrown out by the violent explosions varied in its fineness or coarseness with the nature and intensity of the discharge. While the fine tuffs accumulated slowly at greater distances, the coarse volcanic agglomerates and breccias were piled up near the active vents: they consisted of large rounded or subangular fragments of slate, mudstone and sandstone and of grey felsitic lavas, all shattered by the explosive forces which drilled their way to the surface. The most vigorous volcanoes are still often recognisable from their neck-like shape and from the obvious thickening of the tuffs, agglomerates and lavas in their direction.

These intrusives and hard lavas, to which Co. Wicklow owes some of its scenic beauty, project as hilly knobs, e.g. Croaghan Kinshelagh (1987), south of Aughrim, or as rounded ridges which strike almost continuously across the country from about Arklow Head to the coast of Waterford. Here they are admirably displayed and end in rocky and precipitous cliffs. The so-called Bishop's Library on this coast consists of columnar felsite, more than 100 feet thick. Between Tramore Bay and Ballyvoyle Head a remarkable number of volcanic vents are visible. The harder igneous rocks are often used as road-metal and as surface dressing for tar macadam roads.

Hot subterranean waters accompanied the igneous activity



in the south-east. Ascending through the earth's crust, they carried with them sulphur compounds which crystallised in mineral veins or as lenticles along the strike of the beds. This pyrite (iron and copper sulphides) has been heavily worked in Glenmalure, Glendalough and the Vale of Avoca, Co. Wicklow, as a source of sulphur, sulphuric acid, copper and iron, and of ochre used in paint. Sulphide ores of lead and zinc were also mined: the lead mines of the Glendalough area during the nineteenth century exceeded in scale those of any other lead mines in Ireland.

While igneous activity was rife and very widespread in the British Isles during Ordovician times, it was most unusual in British Silurian geography; the Silurian, like the subsequent Carboniferous epoch, was one of almost complete volcanic quiescence. In Ireland, however, volcanoes were active, though somewhat feebly and sporadically. They emitted lavas and ashes on a massive scale in the Slievenaman inlier and at Clogher Head at the western end of Dingle Peninsula, right on the western margin of the geosynclinal sea: they mirror those of Tortworth and the Mendips which lie on the south-eastern margin of the sea in southern England.

## Chapter III

# CALEDONIAN MOVEMENT: MOUNTAIN BUILDING

The long narrow geosynclinal sea or sag in the Earth's crust had its coastline in the north and its centre-line in the south-east, where the rocks are generally most uniform and finest in grain. The floor may have been bent down by the load of sediments and by lateral pressure working from without (Fig 16A). Alternatively, the crust may have been thinned by stretching (Fig. 16B) as the continents drifted apart or have

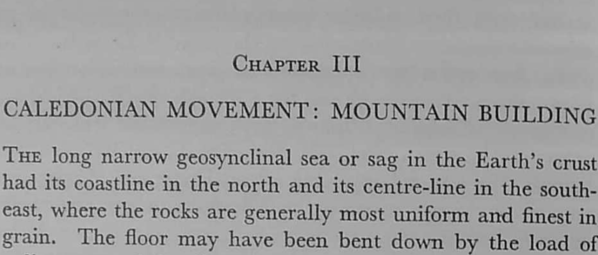



Fig. 16. Diagrams illustrating some of the theories of mountain building.

been carried down by currents beneath (Fig 16C). In each case, the geosyncline was the receptacle of detritus that was swept down from the bordering lands. Shallow-water sands and muds and coarse materials, well sorted and varying greatly from point to point, accumulated along a zone parallel with the northern shore, as in Tyrone, Galway and Kerry. Finer muds floored the deeper sea over Down and the country as far south as Co. Wicklow (Fig. 8, p. 30).

Since the many thousands of feet of Lower Palaeozoic sediment bear clear evidence throughout of deposition in no great depth of water, the floor of their receptacle was obviously sinking step by step with the accumulating sediment.





The cause of this intermittent sagging is only imperfectly understood: it may have been the weight of the sediments themselves or it may have been more or less independent of these and due to further operation of the forces which initiated the depression and made room for the accumulating load (see below).

During the periods of shallow water the coarser beds, e.g. sandstones, grits and conglomerates, were carried far from the coast. When subsidence outran deposition, the finer sediments like mudstones and shales became more extensive. At times, the floor emerged above the sea or came within the influence of the waves so that beds are missing and local gaps break an otherwise continuous sequence. One such unconformity separates the Ordovician from the Silurian in Mayo and Galway and another occurs within the Ordovician in the same area and in Tyrone.

Earthquake tremors were apparently associated with the unstable geosynclinal sea; for limestone beds were broken up and slumped, muds alternated with sands and brecciated beds came to lie between undisturbed layers.

Volcanoes rose within the mud-belt along the axial zone and bestrewed the shallow continental shelf that bordered the trough on the north-west and south-east. Their igneous rocks belong to the chemical or rock suite which is generally associated with long-continued and gentle subsidence and with lateral compression such as this region was then undergoing.

These volcanic manifestations and relatively feeble earth-movements, slow, intermittent but prolonged, were premonitory forerunners of others which assumed gigantic proportions at the close of the Silurian period. The uneasy crustal movements, marked by unconformities due to regressions and transgressions of the sea and the gentle buckling of the sea-floor, together with the igneous activity, both volcanic and deep-seated, were merely the heralds of the severe folding and igneous outburst which go under the name of Caledonian. The earth-forces slowly gathered strength and the climax supervened.

This belt of incoherent sediments, which intermittent subsidence throughout 200 million years had allowed to accumulate to the enormous depth of several miles—the Pre-Cambrian floor in Wales was depressed about 40,000 feet—was obviously a place where the earth's crust was least strong and would yield to pressure most readily: the sediments were weak and had sunk to levels of high temperature which reduced their strength still more. The floor was warped downwards and stretched so that the crust gave way under the strain and granite formed at the mountain roots. The sediments were convulsed by a lateral or horizontal pressure and the geosynclinal sea, as is usual with such seas, became the cradle of a mountain system.

The causes of this titanic tangential pressure are not certainly known, and to enquire fully into them is no part of the design of this book. Some geologists attribute the compression to a crustal shortening, owing to a decrease in the speed of the earth's rotation or to thermal and gravitational contraction of the earth and the accommodation of the solid crust to a contracting nucleus (Fig. 16D): the crust wrinkled like the skin of a shrinking apple. The crustal stresses accumulated until the strength of the rock was overcome; then earth-movement took place and continued until the stress was fully relieved. During the long stable period that ensued the stresses gathered once more. In this way are explained the well-marked periodicity and rhythm of mountain building which have given the earth its five or so great mountain-building revolutions.

Other geologists who find the contraction inadequate in amount, since the earth's radioactivity is constantly adding to the available sources of heat, account for the pressure by a thermal or expansion hypothesis, according to which the sediments of the geosyncline, in consequence of the constant sedimentation and intermittent subsidence, are carried from the cool floor of the sea to great depths where very high temperatures reign, so that the sediments expanded upwards and sidewards (Fig. 16E). Others, again, seek the force in a slow landslide of the higher, continental masses under the influence of gravity against the lower geosyncline (Fig. 16F) or in a drift of approach following the drift of separation which initiated the basin (Fig. 16A). Alternatively, the two sides approach one another like the jaws of a vice, buckling the upper sediments upwards and the deeper sediments downwards into the hotter zone of the crust where granitic magmas and granitising emanations invade the folded structure. Many also, following the late Alfred Wegener, believe that the continents are slowly wandering westwards and equatorwards and irresistibly crumpling up the weak sediments of the geosyncline in front of them (Fig. 16G). According to another interpretation, the thrust was transmitted inwards from the ocean floor (Fig. 16H). For instance, the late Professor Joly of Trinity College, Dublin, postulated thermal cycles due to the slow accumulation of radioactive heat beneath the continents and oceans, which finally led to partial or complete fusion of a deep subcrustal layer and the rapid dissipation of this heat following fusion. When the phase of consolidation and crystallisation set in, shrinking took place and the sea-floor pressed upon the continental margins and folded the geosynclinal sediments.



Lastly, the compression is attributed to vast convection currents ascending and descending in the subcrustal magmas, which drag down the crust (Fig. 16C).

Wherever the truth may lurk in this bewildering maze of conjecture, the fact remains that the geosynclinal sediments were compressed into a great orogene ("mountain birth"), as if a gigantic vice had held them. Within the resistant masses or jaws, which had already yielded to the full Pre-Cambrian deformation and metamorphism and consequently were scarcely implicated, there was a belt of thrusting and low dips and within this again a central folded belt of high dips and often intense metamorphism and igneous activity.

The closely packed isoclinal folds, eloquent testimony of the strength of the lateral pressure, took the form of an anticlinorum (fan-anticline) in the north and a synclinorum (fan-


Fig. 17. Diagrammatic section across the isoclinal folds and the Newry granite between Portadown and Warrenpoint. 1. Ordovician; 2. Silurian; 3. Newry granite; 4. Tertiary plateau-lavas.

syncline) in the south (Fig. 17). The lateral pressure converted the grits in places into quartzites, as in the Great and Little Sugar Loafs. It crumpled, crushed and shattered the rocks and bent and faulted them. The advancing earth-wave broke over the resistant Dalradians and remoulded them and worked them up into the new Caledonian range, spending itself in great dislocations or thrust planes along which whole blocks of country were pushed forward. Their "mullion" structures are especially noticeable in the quartzites, e.g. near Milford, Co. Donegal.

While the more rigid rocks were merely rucked up and faulted, the softer mudstones and shales after being crumpled had impressed upon them a new structure called slaty cleavage which resembles very closely the schistosity of the schists. The particles were flattened and together with the platy flakes of chlorite and sericite were rotated into planes at right angles to the maximum pressure. These cleavage planes, which in general trend parallel with the axial planes of the folds, are almost invariably inclined at a high angle and cut across the bedding or run parallel with it according as the beds lie along the axes or upon the flanks of the folds.

The rocks were folded into three belts: a northern belt of Ordovician strata, arranged in the form of a fan-syncline in the Holywood and Castlereagh Hills and their continuation to the south-west; a central, Silurian belt with Ordovician (mainly Llandovery grits and slates) emerging in long, narrow, inverted, boat-shaped inliers (Fig. 39, p. 109); and a belt of higher Silurian horizons which only



towards the south, near Ardree and west of Balbriggan, is again pierced by the Ordovician (Llandeilo and Bala).

A great fault, of Middle O.R.S. age, crosses Scotland from Stonehaven in the east to Loch Lomond, Bute and Arran in the west. This most striking feature in the geological and physical map of Scotland, which separates the Dalradian metamorphic rocks of the Highlands from the Upper Palaeozoic rocks of the Midland Valley (Fig. 1, p. 10), continues east of Kintyre and across the North Channel. It enters Ireland probably south of Cushendun and reappears from beneath the plateau-basalts along the southern edge of the Sperrin Mountains. In the bed of the Broughderg stream, on the boundary between Londonderry and Tyrone, the Dalradian schists of the Sperrins are clearly seen to be thrust at a low angle (about 10°) from the north-west (Pl. IIB). Driven with irresistible force over the ashes and lavas and other members of the Tyrone Igneous Series between Omagh and Draperstown, they have sheared these into schists of various kinds and have converted the associated sediments into graphite-schists and other metamorphic rocks.

Incidentally, it may here be noticed that the southern border of the Midland Valley which in Scotland runs from Dunbar to Loch Ryan, and is largely a fault (Southern Boundary Fault), strikes across Ireland to curve over Galway north of the Connemara schists, separating the Ordovician from the Silurian rocks south of Killary Harbour (Fig. 1, p. 10).

These movements, which by the thermal expansion of the roots elevated the Lower Palaeozoic strata into a mountain system thousands of feet high, rivalling possibly the modern Alps in their height and grandeur, contributed more than any single episode to the control of the country's relief. As the geological map shows, the geological grain and main physical features of most of Ireland conform to the "Caledonian" direction. This north-east south-west trend is seen, for example, in the outcrops of the Newry granite (Fig. 39, p. 109), of the Ordovician and Silurian strata of the north-east, of the various Dalradian rocks of Donegal, including Inishowen (Fig. 3, p. 13), in the trend of the Glenveagh-Gweebarra valley, of part of Mulroy Bay and of Lough Swilly, and of the western shores of Lough Foyle; and in the alignment of the Sperrins, the Ox Mountains (Fig. 3), the mountains about Nephin, the Leinster Chain and its granite core, and in the accordant coast of Co. Wicklow (Fig. 6, p. 24).

When the forces of compression and elevation ceased—they probably acted through millions of years—the crust sagged and tension ensued. For example, a dip fault shifted the boundary between the Ordovician and Silurian three miles and initiated the Dundonald Gap that separates the Holywood Hills from the Castlereagh Hills and connects the Lagan valley with the depression of Strangford Lough (Fig. 39; Pl. XIII).

The compressive earth-movements were associated in some way with the formation of granites whose origin may now be briefly considered. The granite may have arisen by simple intrusion of liquid magma from below and its subsequent crystallisation. But what became of the material which was replaced? This, it is thought, may have been shattered by the expansion when the hot magma was intruded into it and the shattered blocks may have sunk by their own weight into the liquid magma and then been melted or assimilated—undigested patches of country rock often occur near the margins of the granites where the consolidation of the magma stopped further sinking and dissolution. Alternatively, a whole block may have subsided along a ring-shaped fracture as has been suggested for the Tertiary granites of the Mournes (Ch. X). Again, the granite may have displaced the country rocks by thrusting them aside or by forcing them down concurrently with the folding action of the earth-movements.

In recent years the view has been increasingly held that this awkward space problem is really no problem at all: the granite is merely country rock which has never been displaced but has been converted where it stood by gases, vapours or emanations from below and by the minimum addition from



deep-seated sources. In other words, granites are the product of extreme or ultra-metamorphism. At present geological opinion is keenly divided on the granite problem: it may very well be that granites originated in more than one way. In any case, granites are deep-seated phenomena and they now appear at the surface only because denudation has stripped off their covering blanket.

The Leinster granite, the largest in the British Isles, underlies about 625 square miles of the Leinster Hills. It continues for 68 miles from the shore at Dun Loaghaire to New Ross on the borders of Kilkenny and Waterford (Fig. 6, p. 24). The numerous bosses which peer out of the Ordovician strata, within five or six miles of the main eastern margin, show that the granite extends thus far with an uneven surface, and only at this distance finally plunges to any great depth: the steeper, western side has no such bosses.

Thus the great arch of the granite was asymmetrical about its longer axis, being steeper on the west than on the east where the metamorphic zone (see below) is wider and important ores of copper and zinc occur. Its top has been largely destroyed, though small Ordovician patches persist, among other places on Mount Leinster (2610) and as a dome-shaped cap of finely foliated mica-schist, penetrated by veins of granite, on Percy's Table, Lugnaquillia (3039), several miles from the main outcrop (Figs. 6, 18). It is indeed in this, the highest part of the chain, where the granite has the largest number of patches and bands and enclosures of mica-schist, that the original roof most nearly meets over the granite. The elongated strips of altered sediment which abound west of Wicklow Gap and Glenmalure may be parts of pendants from the original dome. The granite outcrop is most free from included patches where it is widest and the ground is low and drained by the Slaney.

The slow but merciless attack of the subaerial agents, which removed the roof, had achieved devastating results as early as O.R.S. and Carboniferous times: beds of each of these two formations gradually overlap the Ordovician rocks in Co.

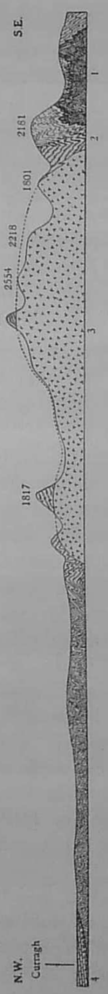



Fig. 18. Diagrammatic section across the Wicklow Mountains showing remnants of the roof of the Leinster granite and the unconformity at the base of the Carboniferous. 1. Cambrian; 2. Ordovician; 3. Leinster granite; 4. Carboniferous Limestone with basement conglomerate.

Carlow and repose finally and directly upon the eroded granite (Figs. 18, 31).

The granite varies somewhat in its composition throughout its length. Thus it is felspathic near Baltinglass and is rich in white mica towards the northern end at Killiney—this stone, with its conspicuous muscovite mica, is well seen in many buildings in and about Dublin.

The granite has been lavishly used for building purposes, e.g. sills, lintels and monoliths, and for curb stones and concrete aggregates; the biggest quarries are at Ballyknockan above the King's River, near Blessington, and at Barnacullia on the north slope of Three Rock Mountain, Dublin. It is the principal building stone in the towns adjacent to its outcrop and has provided Dublin with stone for paving and curbs and for such public buildings as Trinity College (parts of), Law Courts, Wellington Monument and Nelson's Pillar. The breakwater and piers of Dun Laoghaire Harbour, the Thames Embankment in London and various lighthouses around the coast have drawn their granite from the same source.

The cooling of the granite was not uninterrupted. Numerous cracks opened in the rock and fluid material from beneath was injected into them to solidify as veins of aplite, often containing small garnets. Gases attacking the granite near its western margin gave rise to minor masses of china-clay, and on the east formed the sulphide ores of lead,



zinc and copper. These were formerly very productive at Glenmalure, Avoca and Knockmahon.

The magma baked and indurated the country rock and sometimes fused it, locking the whole inseparably together and injecting into it veins of coarse pegmatite and fine-grained aplite or pure quartz, as is seen on the shore of Killiney Bay. In a severe form, the sediments have been changed into porcellanites or into mica-, hornblende- and especially andalusite-schists.

The Ordovician slates and grits, as we follow them towards their margin with the granite, invariably undergo a gradual but pronounced change. Although this is apparent in the grits, it is most noticeable in the slates. Remote from the granite, the slates are dull, but traced inwards through the contact aureole they begin to be distinctly lustrous and become slightly knotted in the cleavage planes. Near the granite, the slates give way to talc- or chlorite-schists and the "knots," situated at the centres of fluxing, developed into crystals of andalusite, especially at Killiney where the schists are pierced by numerous veins, dykes and sills of granite or microgranite from the parent body. Andalusite-schists are common as beach pebbles at Killiney, the andalusite being sometimes arranged in star-like groups of slate-grey, rod-like crystals. A few yards from the granite the schist consists of a felt, for the most part of minute crystals of muscovite. These grow as we approach the margin, while brown biotite appears, usually in clusters thickly strewn but not in contact, together with chlorite and crystals of andalusite. Within a foot of the granite, the muscovite felt breaks up into patches and streaks penetrated by radiating groups of chlorite and scattered crystal grains of quartz and striated felspar, evidently an intrusion from the granitic magma. The junction is well seen in the Scalp, about ten miles south-east of Dublin, and highly contorted schists are finely exposed at Glendalough.

This zone of resistant schist, encircling the granite, underlies much of the beautiful wooded scenery of Co. Wicklow which contrasts so strikingly with the rounded moorland of the granite. It also often rises into prominent ridges or hills outside the margin, as round Glen Imail near Baltinglass, Co. Carlow. When the valleys from the Leinster Hills pass through the metamorphic zone they contract, as in the outlet of Glencree on the east and in the Hollywood Scalp and the Slaney gorge at Baltinglass on the west. Since the zone is broader on the east than on the west, in conformity with the asymmetry of the granite, the ravines in the schist on the east are long, e.g. two miles near Tinahely and Shillelagh, and those on the west are short-necked, as in the King's River above its junction with the Liffey. Waterfalls also mark the points of intersection where the granite had incorporated lenses of schist within its mass. The rocky walls above the Upper Lake Glendalough, the ravines and waterfalls, e.g. at Powerscourt, at Lough Tay, and at the head of Glenmacnas, the canyon of the Doyle at Enniskerry and the Devil's Glen—all these are due to the hard schists.

The slates in contact with the smaller bosses to the south-east have likewise been altered, though the aureoles are naturally much narrower.

The Leinster granite is also interesting because of its probable association with "Wicklow gold." Unlike tin, which was used extensively with copper in the Bronze Age and was imported (since Ireland has no workable quantities of tin), the Irish gold which was utilised so plentifully in the ancient (Bronze Age) gold ornaments (accumulated over a long period by the Royal Irish Academy and now housed in the National Museum, Dublin) was native and obtained largely from Co. Wicklow. The gold was alluvial in the stream gravels ("placers") of Aughrim and Avoca, and especially on the slopes of Croaghan Kinshelagh overlooking the Gold Mines Valley. Streams eroded the sulphide veins or lodes (see above), carried away with them the lighter material such as quartz, and concentrated the precious metal with the associated tinstone (cassiterite) and wolfram in the deposits on their floors; a nugget weighing 22 oz. troy was discovered in 1795. Though the auriferous quartz-veins or "mother lodes" of the gold probably



occur near the margin of the granite, all attempts to trace their whereabouts have so far failed. The lodes are apparently buried beneath the thick drift which the Pleistocene glaciers left behind them.

A small outcrop of reddish granite, probably coeval with the Leinster granite, occupies the extreme south-east corner of Ireland at Carnsore.

A third Caledonian granite, that of Newry or Castlewellan, runs parallel to the dominant strike of the Silurian as an elongated outcrop, 26 miles long, between Slieve Croob (1775) and the country about Slieve Gullion (Fig. 39, p. 109). The roof, now but seldom preserved, as on Slieve Croob, was originally gently domed and consisted of highly inclined Silurian strata, cut off almost at right angles. Denudation has stripped off the cover so that the granite is much less imposing than its contemporary the Leinster granite, though it sometimes rises into rough and hilly country, rounded by ice and dotted with innumerable small peat bogs.

The Newry granite has been extensively quarried for building stone, for ornamental work and for paving setts, for which purpose its hardness and close texture make it eminently suitable. It was employed, for example, in the base and pedestal of the Albert Memorial, London, and for the Bank of Ireland, Belfast.

The granite is traversed by numerous joints which aid the quarrying considerably and by a regular and more or less horizontal "sheet" jointing. The former, as in other granites, are a response to tensile stress due to contraction consequent upon cooling or to tectonic causes producing torsional, tensional or compressional stresses. The sheet jointing was due to the expansion of the granite which resulted when the upper layers were removed by denudation.

The Silurian strata have not only been disturbed by the protrusion of the granite, but, as in the case of the Leinster granite, they have been severely metamorphosed. Heat and gases from the magma have baked and in places fused the slates and grits and added material from below. The meta-

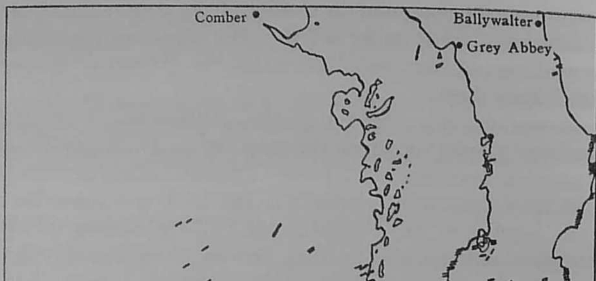



Fig. 19. Map of the Newry granite dyke-swarm (After D. L. Reynolds, modified). Scale, 1 inch=5 miles.

morphic aureole which rings the granite extends outwards for approximately one mile. As we approach the margin, the grits are transformed into quartzites and the slates become more and more micaceous until at the contact they become a typical mica-schist.

The Newry granite is associated with a dyke-swarm (Fig. 19) which runs through Down in alignment with the granite and with the strike of the Silurian rocks. The swarm extends from near Slieve Croob and Castlewellan across the Ards Peninsula



to the Irish Sea and to Bangor in the north and the Ardglass-Killough area in the south of the county, where in some instances it has yielded fragments to the Tertiary dykes. Like the Etive and Ben Nevis swarms of west Scotland, this swarm did not spread as far from its granite centre as did the Tertiary swarms (see p. 167).

The swarm represents two periods of intrusion. The dykes of the older series, which are exposed in the south of the Ards Peninsula and the neighbouring part of the mainland and are difficult to detect in the field, were intruded during a phase in the Caledonian folding and were subsequently crushed and made schistose by pressure. The younger series, which is best developed in the centre of the peninsula, was intruded after the stress. Its members are quite fresh and of greater thickness than the earlier ones.

The Donegal granite, yet another Caledonian intrusion, builds the twin-range of mountains on either side of the narrow Gweebarra fault rift which drains to the north-east by the Owencarrow and to the south-west by the Barra (Fig. 3, p. 13). Remarkable for its length, depth and straightness, the rift begins near Glen in the north and runs south-westwards for 30 miles to Gweebarra Bay and Ardara, often between bare walls of granite up to 1000 feet high. This belt of shattered rock has yielded to the disintegrating forces that have been at work in these wild mountain solitudes through untold ages.

The granite underlies the country south-west of Errigal, including The Rosses, and terminates in the coast between Gweebarra Bay and Bloody Foreland. Later than the regional metamorphism of the Dalradian schist, it varies much in appearance and texture, being red or grey in colour and finely or coarsely crystalline and often porphyritic, with crystals of orthoclase up to three inches in length. Its well-marked joints have been hollowed out along the coast into innumerable caves and chasms, frequently spanned by natural arches, while inland they control numerous ravines and steep scarps.

The granite is composed of pink or flesh-coloured orthoclase, grey plagioclase, black biotite, dark hornblende and less commonly of whitish muscovite. It is possibly sheet-like or laccolitic, i.e. it may have a lower flat plane and a convex upper surface which has long since been removed, except where the granite still underlies much of northernmost Donegal beyond its actual outcrop—it reappears in the promontories of Fanad Head, Dunaff Head and Malin Head. The reddish or grey highly porphyritic granite of Tory Island, which derives its name from the castellated crags and tors ("island of towers"), may be a further extension of the main granite.

## Chapter IV

# THE OLD RED SANDSTONE: A CONTINENTAL LANDSCAPE

The turmoil of the Caledonian Movement left behind it a new Ireland: a continental desert of high relief replaced the Lower Palaeozoic geosynclinal sea.

The continental beds form the Old Red Sandstone (often abbreviated to O.R.S.) which is immortalised in the writings of Hugh Miller, the master mason who worked last century in eastern Scotland. The beds rest unconformably upon the up-turned and worn-down edges of the Ordovician and Silurian. In very fine sections on the north bank of the Suir at Waterford, as at the railway station, the brown and red O.R.S. conglomerates dipping north-east at 10-15° are seen to overlie sharply folded Ordovician slates dipping north-west at angles of 70-80° — the actual surface of the ancient continent lies at the junction. This relationship may also be seen in Co. Tyrone and round the inliers in the Central Plain, as in Co. Kildare, where the more ancient rocks, projecting above the surface of deposition, distributed their pebbles and gravels to consolidate as the O.R.S. conglomerate.

The basal conglomerate (Pl. IIIA), which represents the initial spread of coarse material, varies with the nature of the neighbouring strata then being laid under contribution. In the south-east, where the O.R.S. rests upon the denuded edges of the Ordovician slates and sweeps across these, e.g. near Goresbridge and at Jerpoint West, on to the Leinster granite (exposed even at that early date), it encloses rounded fragments and angular blocks of slate, altered grit, Leinster granite and pebbles of white, opaque vein-quartz. At Portraine, its pebbles of purple and white quartzite and vein-quartz may have been derived from a northern extension of the Bray Series. In the Curlew Mountains, it contains local quartz, quartzite and schist; north of Clew Bay, schist and quartzite; in Slievenaman, slate and grit; and in the Waterford area, vein-quartz and quartzite, supplied probably by the local Cambrian, though the sandstones are full of large plates and scales of white mica derived from the waste of the Leinster granite. At Glenpatrick, on the northern flank of the Comeraghs, the conglomerate is 250 feet thick.

The vertical movements, which brought the Caledonian disturbance to a close, initiated broad downfolds upon which the O.R.S. accumulated. The floors continued to sink and the intervening ridges of the corresponding upfolds to rise. In this way there came into existence a number of mountain-girt lakes trending in the Caledonian direction or arid mud-flats, subject to dust-storms and swirling streams which carried iron for the staining of the deposits from the igneous and metamorphic rocks of the north and west. Torrential floods, the accompaniment of the violent rain storms that are wont to visit deserts, spread out the sun-splintered fragments and accumulated rock-waste as coarse sands and pebbles. These were arranged as deltas or detrital fans where gorges opened out upon the plains and at the foot of the lofty ranges, such as those of the Donegal Highlands and the Leinster Chain. On the floor of the shallow, seasonal lakes sudden washes laid down the finer muds which frequently exhibit rain-pits and sun-cracks.

The conditions of deposition were complex; at times the sea may have drowned the hollows so that marine and freshwater shells may have mingled in the same basin.

Yet the drainage was apparently always fresh: deposits of rock-salt or hydrous calcium sulphate (gypsum), like those of the Trias, are wanting. The O.R.S. indeed gives the impression of less aridity and more copious rainfall than does the New Red Sandstone, and suggests a land drainage with outlets to the sea. The vegetation preserved to us conjures up a picture of lakes bordered by forests and swamps while the well-rounded pebbles and boulders of the conglomerates, like those at the Cushendun caves (Pl. IIIA), point to long-continued

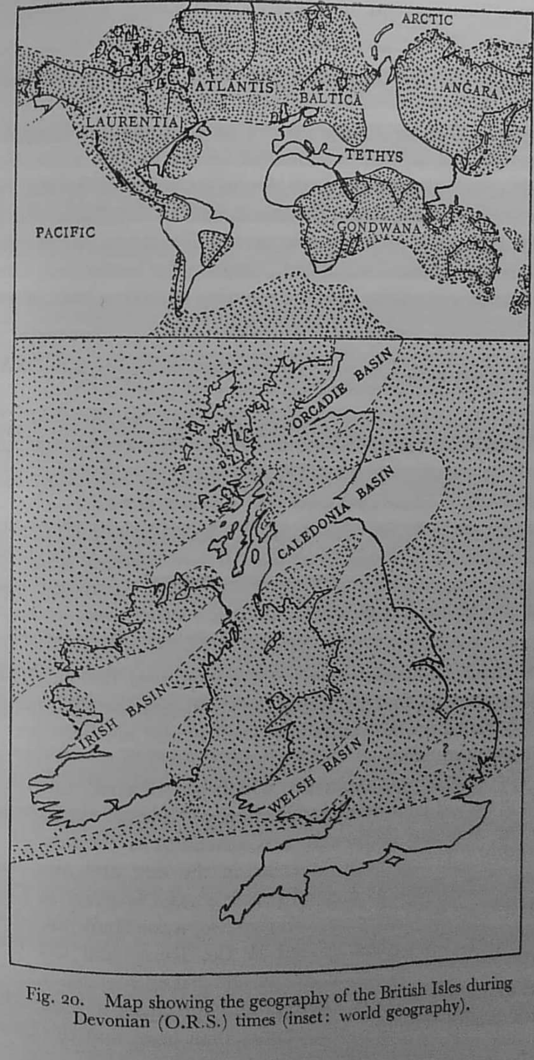



Fig. 20. Map showing the geography of the British Isles during Devonian (O.R.S.) times (inset: world geography).

attrition, and suggest that the streams that rolled them along were more or less permanent and often swollen into torrents or heavy floods.

The open geosynclinal sea which covered much of Europe at this time (Fig. 20), and was floored by the marine equivalents of the continental O.R.S. beds, lay to the south of the country. Its sediments, save where the lowest part of the Carboniferous Slate (Ch. V) is probably true marine Devonian, do not exist within the present Ireland but comprise the sandstones, slates and limestones which, with their marine trilobites, brachiopods

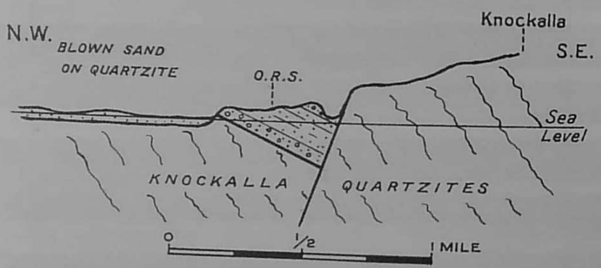



Fig. 21. Section through the O.R.S. inlier faulted down against the Dalradian quartzite, Knockalla, Co. Donegal (After H. E. Wilson).

and corals, lie beneath much of Cornwall and Devon. These Devonian rocks, first discovered in Devon (whence their name), accumulated on the continental shelf in the northern part of the Devonian sea.

The O.R.S. was originally widely distributed, since it is still preserved in out-lying patches beyond Newport and in Fanad in the west and north-west, at Cushendun in the north-east, at Rathcoole and near Portraine in the east and over wide areas as far south as Ireland's most southerly point at Cape Clear. But its outcrops are chiefly two, a southern one which constitutes the highest ground in Co. Kerry and Co. Cork (Fig. 35, p. 97) and a northern one which is entrenched between the Dalradian rocks of Donegal and the Sperrin Mountains, then doubtless loftier and grander than now, and the Lower



Palaeozoic uplands of the Newry axis which continue southwards into Co. Cavan. It forms the south-western continuation of the O.R.S. of the Midland Valley of Scotland. The O.R.S. "Fintona Beds" of Tyrone and Fermanagh, between Pomeroy and Lough Erne, contain vein-quartz, quartzite and schist from Donegal, as seen on the shores of Lough Erne, and granitic debris from the Tyrone igneous series near Pomeroy, together with boulders of contemporaneous lavas. They give to this region its strong red soils.

A relatively small though significant occurrence extends from Cushendun to Cushendall east of the basalt-plateau (Fig. 22). Resting as in Kintyre unconformably upon the Dalradian schist, it is well exposed in coastal cliffs and in the raised-beach caves at Cushendun (Pl. IIIA). Here its well-rounded boulders, some of them four feet long, are composed of quartzite (derived from Islay, their nearest visible source, or, more probably, from a south-eastern continuation at a higher level and now destroyed) and less commonly of vein-quartz, schist, gneiss and Caledonian andesite, the latter resembling the Cushendall porphyry (see below) but not identical with it.

An outlying patch of coarse conglomerate and sandstone, derived from the local metamorphic rocks (quartzite, limestone), granite and porphyry, skirts the northern base of Knockalla in Fanad (Fig. 3, p. 13). Possibly 800 feet in thickness, it lies against a fault, the contact being clearly seen about two miles from the present coast south-west of the south end of Ballymastocker Bay (Fig. 21).

The O.R.S. also peers out of detached inliers in the Central Plain to prove that a vast platform of O.R.S. underlies the widespread Carboniferous. It is brought up with the basal arenaceous horizons of the overlying Carboniferous by faults or more commonly in the axis of upfolds, the size of the inlier depending upon the length and breadth of the anticline and the depth to which it has been denuded. The O.R.S. flanks the solitary cone of Slievenaman (2363), resting unconformably on the Silurian slates which it fringes both physically and geologically, its truncated edges facing inwards as crags and rugged scarps that contrast with the smooth dip slopes which are directed outwards. In the moorlands of the broad-backed Comeraghs (2597) it likewise rests horizontally on a core of steeply inclined Ordovician and is magnificently displayed in the grand precipices of the glacial cirques which cut off this

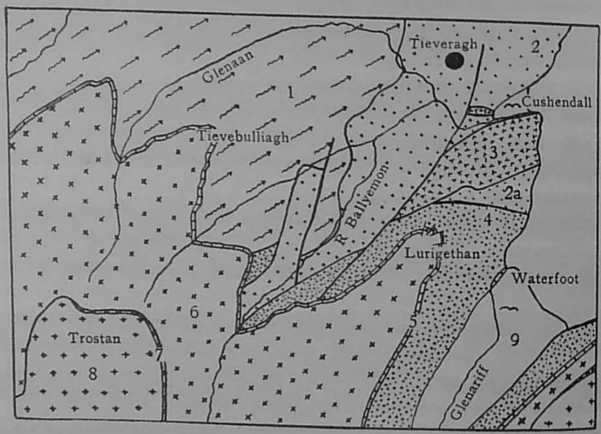


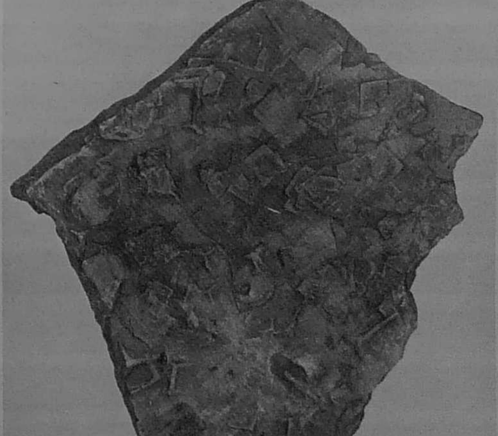

Fig. 22. Geological map of the Cushendall area (Based on Geol. Survey, with Upper O.R.S. after H. E. Wilson). 1. Dalradian; 2. O.R.S.; 2*a*. Upper O.R.S.; 3. Cushendall porphyry; 4. Trias; 5. Chalk; 6. Lower Basalt; 7. Interbasaltic Bed; 8. Upper Basalt; 9. Raised beach and Alluvium; Black, volcanic neck, Tieveragh. Scale, 1 inch=1⅓ miles.

bold mass on the east. On the margins, it plunges steeply beneath the Carboniferous carpet of the surrounding valley and plains. The O.R.S. also rises into the Curlew Mountains (818), the compact and imposing range of the Galty Mountains (3015) and the narrow serrated ridge and sharp conical peaks of the Knockmealdowns (2609, Fig. 32B, p. 92).

The O.R.S., of uniform and monotonous lithology, is prevalently tinted brown, red or purple, though the upper beds in the south are often yellow and green. Its stratification is

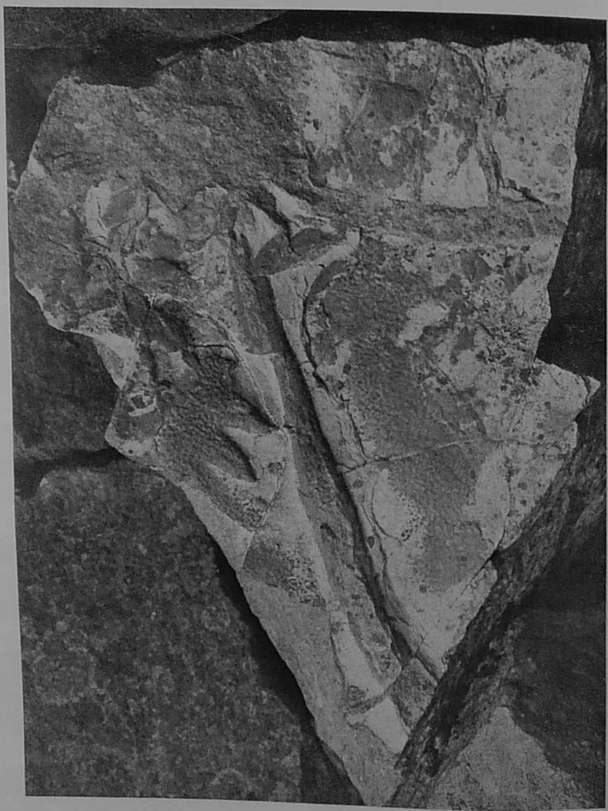
PLATE V

A. Grey Dalradian schist, red Trias and white chalk, Murlough Bay, Co. Antrim



B. Rock-salt pseudomorphs, Trias marls, Springfield, Belfast

PLATE VI



*Cheirotherium* footprint (left of centre), Trias sandstone, Scrabo Hill, Co. Down
(Photo, H. Ashley)



clearly visible, as in the terraced faces of the mountains of Kerry. Here and elsewhere it consists of coarse pebbly grits, of alternating beds of sandstone, often micaceous, and of clays, the whole possibly 10,000 feet thick. In places, as in Tyrone and at certain horizons, especially near the base, it is conglomeratic, though as we ascend the series, e.g. in the Fintona Beds, the conglomerates become thinner and fewer and grade into sandstones, these in turn passing into shales.

The Caledonian Movement and its attendant physical changes had momentous repercussions on the life of the times. The graptolites vanished from the world's seas and became extinct. The only fossils preserved to us in the great masses of practically barren rocks of this continental O.R.S. are relics of fish, molluscs and crustacea, *Eurypterus*, a sea-scorpion which resembled somewhat the modern King crab (*Limulus*) and tenanted the lakes and streams, and the plants which grew on their banks. *Archanodon jukesii*, an elongated shell with pronounced growth and hinge-lines, a close relative of the fresh-water mussel *Anodonta cygnea* common in modern lakes and rivers, points to the fresh-water origin of the deposits (Fig. 13, p. 37).

The O.R.S. is especially important for its fish remains, which indeed merit for it the title the "Age of Fish." Large numbers of bony scales or scutes of ganoid fish, belonging to the carnivorous *Coccosteus dijectus*, have been discovered in Ireland as well as other fragments of this fish, which had its head and body protected by large plates that made a rigid coat of armour (Fig. 13). The pink and greenish flaggy sandstones of the Fintona Beds near the Lisbellaw inlier have yielded fragments of the fish *Pteraspis*, which had wing-like paddles attached to each front corner of its body shield: it belonged to the Ostracoderms or most ancient order of fish, which had appeared elsewhere as early as the Ordovician.

The O.R.S. fish had a cartilaginous rod instead of vertebrae along the back and were protected by a tough skin bearing tubercles and an armour of hard plates. Their nearest living relatives are mud-fishes or lung-fishes, such as *Ceratodus* of

Australia, which has gills and air bladders, the latter acting as lungs and enabling the fish to breathe when enveloped in mud during seasons of drought.

The O.R.S. contains the earliest remains of a land vegetation in Ireland, though algae and bacteria are known from the earliest periods in other parts of the world and primitive types of plant from the Middle O.R.S. in Aberdeenshire—since we do not know of an Irish Lower Palaeozoic land we are ignorant of its land life. In the vicinity of Cork and at Hook Head in Co. Waterford, plants with fern-like foliage were washed down with the fine-grained sands. In quarries at Kiltorcan near Ballyhale, midway between Kilkenny and Waterford, the fine-grained, greenish or yellowish sandstone, the so-called "Yellow Sandstone," which is 500 to 1000 feet thick and closes the O.R.S. succession, has yielded plants whose beauty, remarkable state of preservation and great scientific interest have made this locality world famous. The commonest plant is the large tree fern, *Archaeopteris hibernica*, the fronds of which, up to five feet long and two or more feet broad, are impressed with such wonderful distinctness that even the venation can be clearly recognised. The abundance and undisturbed condition of these plants, which have large fern-like fronds bearing wedge-shaped or oval leaflets or capsules containing spores, suggest that they grew close to the place where they are now entombed, probably on the margin of a fresh-water lake.

The O.R.S. epoch in Ireland, as elsewhere in the British Isles, was one of great vulcanicity. Contemporaneous lavas, which in Scotland build the Ochils, Sidlaws and Cheviots, were widespread in Ireland, notably in the earlier part of the formation. They range from Killarney to Fintona and to Cushendall where the "Cushendall porphyry," a purplish, porphyritic rock, is exposed on the shore north of the coast-guard station (Fig. 22, p. 64). This rock was probably intruded as a sill from the volcanic vent which now forms the knob north of the Dall and just west of Cushendall (Fig. 23).

The volcanoes rose from the depressed areas of deposition



and as in Ordovician time primarily along the borders of the basins where the prevailing crustal stresses were at their highest. Thus they were active at Cushendall and Fintona in the north and in Co. Waterford and at Loo Bridge and near Lough Guitane, Co. Kerry, in the south.

Isolated or aligned in groups in the Caledonian direction, these volcanoes poured out vast sheets of lava and may have

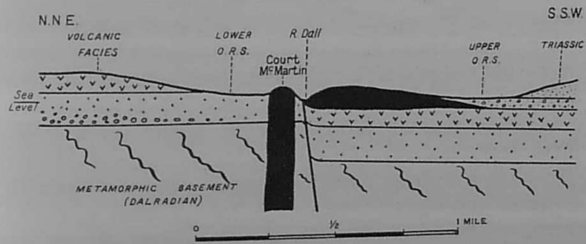



Fig. 23. Section through the O.R.S. of the Cushendall area, showing (in black) the volcanic neck and the sill of the Cushendall porphyry (After H. E. Wilson).

built up plateaus, though we can no longer reconstruct these or their vents with the detail that is possible for the Tertiary era. They were largely quiet and non-explosive since ashes, though known at Cushendall, in the Curlew Mountains and at Lough Guitane and other localities near Killarney, are relatively scarce. The purple lavas, because of their superior hardness, are striking features in the landscape, as in the Fintona area or west-south-west of Lough Allen where they cap some of the higher hills.

## Chapter V

## THE CARBONIFEROUS: CORAL SEAS AND TROPICAL SWAMPS

The Carboniferous formation is the most important geological formation of the world: it contains the most extensive and most valuable coals. In Ireland, its prominence is due less to the presence of profitable coal-seams, these being usually poor and of small extent, than to its wide distribution and agricultural value. Roughly two-thirds of the country are underlain by Carboniferous rocks (Fig. 1, p. 10), a proportion far higher than in Great Britain, since the Mesozoic strata that normally rest upon and conceal them were in Ireland either never laid down, or if deposited, were subsequently stripped off.

During O.R.S. times the Caledonian mountains succumbed to atmospheric attack and though their strike-lines persisted their relief forms largely disappeared. The close of the epoch therefore saw the hills of Ireland denuded to more or less gentle uplands and plains and the hollows largely filled in by deposition. The Yellow Sandstone of the Kiltorcan type, for instance, proves that here at least the land was low and sluggish streams transported only the finest material. The Leinster granite, as already observed, had long since lost its blanket and was freely exposed: its boulders built the Carboniferous beach and its micas much of the local Lower Carboniferous sediment in the south-east.

With the dawn of the Carboniferous epoch the sea, like an incoming tide but with extreme slowness, encroached upon this land from the south-west, between the ancient Dalradian landmass of the north and west and a large island named "St. George's Land" which stretched from the Wicklow Mountains across St. George's Channel into Wales and central England (Fig. 24). This incursion was but an insignificant part of the great Carboniferous transgression which overwhelmed vast



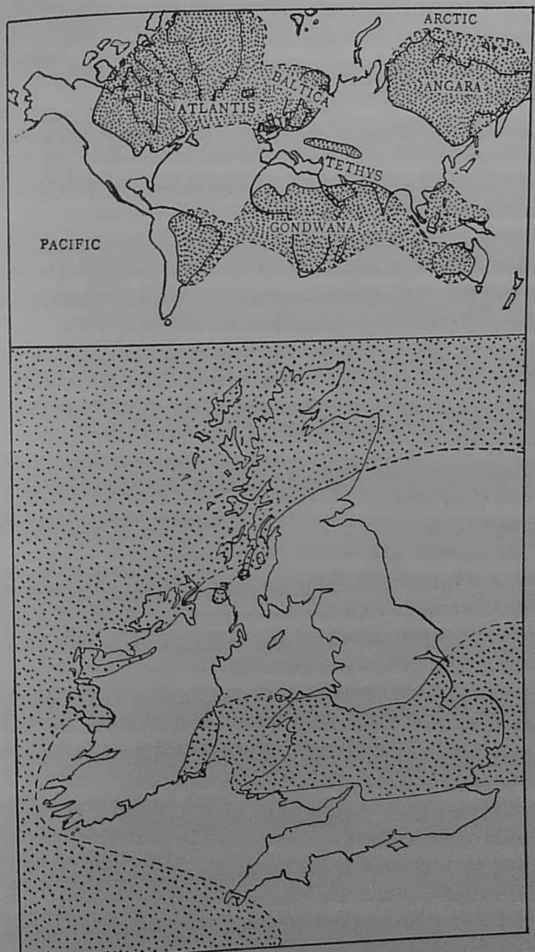



Fig. 24. Map showing the distribution of land (dotted) and sea (white) in the British Isles during Carboniferous Limestone time (inset: world geography).

areas of the world, including not only much of Europe but also large tracts of Brazil, the United States, Spitsbergen, central Asia and China, and made the distribution of land and water in the world strikingly different from that of O.R.S. time.

The sea stole round the Caledonian uplands, such as the Ox Mountains and the Dalradian Highlands of Donegal and west Connaught, and laved the shores of the small islands of Lambay, Portraine and Howth (cf. p. 23). Its waters lapped against the base of the Leinster Hills, which projected above the sea and provided the streams with much waste, including the muds and even coarse conglomerates or breccias which occur at various horizons in the Carboniferous Limestone of the Dublin district and the Barrow valley. The finest material settled still farther out, as the muds of the "Calp" (see p. 80). South of Bagenalstown in Co. Carlow they overlapped the O.R.S. and terminated against the flanks of the Leinster granite hills (Fig. 31, p. 92), so that the arable and pastoral land of the Carboniferous now skirts the granite moorlands of the Barrow valley.

The sea crept into the mountain valleys in much the same way as it follows the coastal indentations to-day. Its "fossil" shingle beach, now the basal conglomerate, moved gradually forward with the incoming surge, becoming progressively later as the lands were submerged. Higher and higher horizons overlap eastwards on to the old rocks of the Leinster Chain between Bagenalstown on the south and Naas on the north, while middle limestones rest upon the Ordovician between Naas and Dublin.

The sea extended on to various kinds of rock and all pre-existing formations. South-east of Fintona, it enclosed large angular fragments of the local O.R.S. Its low-angled beds lay on the eroded edges of the steeply inclined Ordovician and Silurian rocks, as near Dungarvan, Portraine and Dundalk, in Kildare and at Cultra (near Holywood), Co. Down. It abutted against the contorted Cambrian quartzites north-west of the Hill of Howth and even against the Dalradian rocks north of Donegal Bay, west of Lough Foyle and south of Ballycastle,



Co. Antrim. North-west of Galway City, the limestone enclosed small pebbles of quartz and at its junction with the granite developed into a breccia or conglomerate of this rock.

As the sea deepened and the shore advanced and the irregularities of the sea-bottom were filled in, the early shingle conglomerates became buried beneath off-shore deposits, namely, the pale yellow grits and sandy flags and the grey and black shales of the so-called Lower Limestone Shales which flank the Carboniferous valleys in the south and encircle as narrow frames the O.R.S. inliers in the Central Plain (Fig. 3, p. 13).

These sandy and muddy deposits gave place in turn to clear and tranquil waters of moderate depth in which countless calcareous organisms lived and died. These built up the limestones which only locally gave way to shales, for example near Dublin and Sligo, where the stiff soils betray the muds which once more temporarily invaded the sea on the horizon of the Calp.

Contemporaneous movements, heralds of those of later date (see Ch. VI), affected the sea-bottom to cause local breaks, as in Co. Kildare.

The lower Carboniferous sandstones have been widely used for scythe-stones, grindstones, door-steps, tomb-stones, and for building stones, as in the cathedrals of Armagh and the National Museum and Library, Dublin. Some of the flags have been extensively employed for pavements: the best-known quarries are at Mount Charles, north of Donegal Bay.

This wide Carboniferous sea, whose marine sediments succeeded the fluviatile and lacustrine accumulations of the O.R.S., differed markedly from the sea of Lower Palaeozoic time. While this, as we have seen, was a geosynclinal basin, the Carboniferous sea was a shallow, continental shelf-sea, resembling in some ways that which at present surrounds the British Isles.

The Carboniferous rocks may be not less than 6000 feet thick when fully developed. Of very diverse character, they

Fig. 25. Section through the Carboniferous rocks between Sligo and Lough Melvin. 1. Lower Carboniferous Shales and Limestones; 2. Carboniferous Limestone; 3. "Millstone Grit."

comprise the following series which grade almost imperceptibly the one into the other:

3. Coal Measures.
2. Millstone Grit.
1. Carboniferous Limestone.

### 1. Carboniferous Limestone

The Carboniferous Limestone is appropriately styled the "Mountain Limestone" in England where, for example, it builds the rugged Pennines with their grey scars and deep dales. In Ireland it is represented by the limestone of the Central Plain, the most conspicuous feature of the geological map and one which, with the development of the Tertiary lavas of the north-east and the almost entire absence of Mesozoic and Tertiary sediments, distinguishes Ireland from its neighbour across the Irish Sea.

Although the plain is covered with much peat (Fig. 98, p. 254) and with widespread eskers of glacial origin (Fig. 78, p. 208), the underlying limestone comes to light to-day sufficiently frequently, either in inland sections as along the northern shores of Lough Erne and at Killalagh, Co. Mayo, or in coastal cliffs, e.g. north of Donegal Bay and near Rush and Malahide in the east, to make it possible to gain an accurate idea of its lithology and behaviour. These sections, however, cannot rival those which are presented in the bold sides of Benbulben (1720) and Truskmore (2100), in the walls of Glencar and other broad glens in Co. Sligo (Fig. 25), and in the bare terraced flanks of the Burren (*borr*, great; *onn*, rock), south of Galway Bay. Here the greyish-white limestone rises in gently rounded



steps up to 1500 feet above sea-level (Pl. IIIB) or falls sheer from a height of 668 feet in the savage cliffs of Moher, Co. Clare.

The Carboniferous Limestone in these various sections is a bluish or grey compact limestone of almost pure calcium carbonate. It is well bedded, usually horizontal or only slightly inclined, but often sharply folded into broken synclines or anticlines like the anticline which constitutes the Rock of Cashel or the intense crumplings seen in the inland cliffs of the Boyne at Beauparc. The slates and limestones at Rush, for instance, have been acutely folded; even the regularly stratified conglomerates, which include pebbles of water-worn quartz, grit, slate, limestone and lava (derived from Portraine), have shared in the movement.

The limestone is traversed by innumerable well-defined joints and in places by veins of calcite—in the Aran Islands the fences of the fields are built along the lines of the joints. The thicker and more massive beds have been widely quarried for buildings all over the limestone country, both for ancient structures, e.g. many round towers and castles, and for more modern erections, e.g. St. Patrick's Cathedral, Dublin, the cathedrals of Cashel, Kilkenny, Limerick and Tuam, Muckross Abbey, Killarney, the buildings of the University Colleges of Cork and Galway, and for walls, like those round the demesnes of the south, out of which the weather has etched the shells of bivalves, pieces of coral and stems of sea-lilies. The limestone has also been worked for lime and whitewash, for agricultural purposes, and in the new cement industry of Eire, while that which takes a high polish has found an extensive use as ornamental marble. Galway provided the Black Galway marble; and beds of black limestone of the age of the Calp (see below) afford the Kilkenny marble in which the intense black (due to finely divided carbonaceous matter or iron sulphide) is relieved by white fossil (brachiopod) markings. A red marble, stained red by iron oxide, is extensively quarried at Little Island, Co. Cork, and grey marble, diversified with pink and red veins of calcite, at Midleton in the same county.

These marbles are well seen in Cork City in St. Finbar's Cathedral, in the Honan Chapel of University College and in the entrance to the Technical School. The limestone quarried in Eire in the three years 1942-44 for all purposes averaged 439,112 tons.

The strong vertical jointing and pronounced bedding cause the formation of caves with water-worn passages and emergent streams, e.g. at Marble Arch, Enniskillen, between Lough Mask and Lough Corrib, and in Co. Cork and Co. Waterford.

The limestone frequently displays an oolitic structure, so called because its minute spherical grains of calcium carbonate resemble the roe of a fish ("egg-stone"). These grains, occasionally as big as peas and named "pisolite," grew in a warm shallow sea, saturated with calcium carbonate. Concentric coats of this substance were added, either by constant wave-agitation which disengaged the carbon dioxide or by the precipitation of colloidal droplets which tended to coalesce.

More commonly, especially in the south, the limestone contains much magnesium carbonate and dolomite, the double carbonate of calcium and magnesium. This dolomite, which is often brown in colour, as on the shore between Skerries and Rush and at Sutton near Howth, may have been formed contemporaneously with the limestone. It was produced in part by leaching out the lime and concentrating the magnesia, in part by replacing the lime by magnesia derived from sea-water. In the more cavernous varieties it may have taken place after consolidation by surface-waters, containing magnesium carbonate, working down along joints and bedding planes. This is the case at Howth where the extensive dolomitisation and deposition of the manganese dioxide are connected with joints and lines of faulting.

The limestone usually contains vast quantities of black and grey chert in the form of layers, up to 40 feet thick, or of irregular or fantastically shaped nodules disposed in rows along the bedding planes. These silica concretions ("grown together") were probably deposited as a *gel* directly from the silica of siliceous organisms (radiolaria, diatoms and sponges) or from the silica in solution in the sea-water, and contemporaneously with the surrounding calcium carbonate of the limestone. The particles of the gel on settling to the bottom were aggregated into globular masses, following the general tendency of gels to assume ellipsoidal forms, and eventually became nodules of chert. These may have grown by direct additions of silica from the sea and nodules partially buried in the floor may have replaced or displaced the adjacent material. The plentiful occurrence of radiolaria, which gave rise to cherts, probably indicates a warm climate. Whether the cherts were formed in shallow or deep water is less certainly known.



The limestone has a splendid array of fossils (Figs. 26, 27), as in the narrow peninsula of Hook Head, Co. Wexford, at Bundoran, Co. Donegal, about Sligo, at Malahide, Co. Dublin, and at Black Rock, Little Island and Midleton, Co. Cork. From it have been extracted trilobites, molluscs (including the goniatites and straight or coiled ammonoids), gastropods, e.g. *Murchisonia*, *Euomphalus* and *Pleurotomaria*, crinoids, corals, and especially towards the base, remains of Elasmobranch fish (akin to the existing rays, sharks and dog-fish), and chiefly teeth, plates and spines of the Ganoid *Palaeoniscus*, as in the quarries south of Armagh.

The trilobites which were so abundant in the Welsh Cambrian and in the Irish and Welsh Ordovician and Silurian are now deposed from their former dominance and are approaching extinction. The Irish Carboniferous claims only four genera (*Griffithoides*, *Phillipsia*, *Proetus* and *Brachymetopus*). The last of the British trilobites (*Brachymetopus*), which was no bigger than the little finger-nail, failed to survive the Millstone Grit of Yorkshire.

The lamp shells or brachiopods, with their two valves hinged together, are frequently so abundant that the *Spirifer* and *Productus* make up the whole of a bed or, as at Castleknock, Feltrim Hill and at Carrick Hill, near Dublin, build irregular, rounded domes or "reef-knolls," probably representing shell-banks in the sea. Bryozoan-reefs with abundant brachiopods

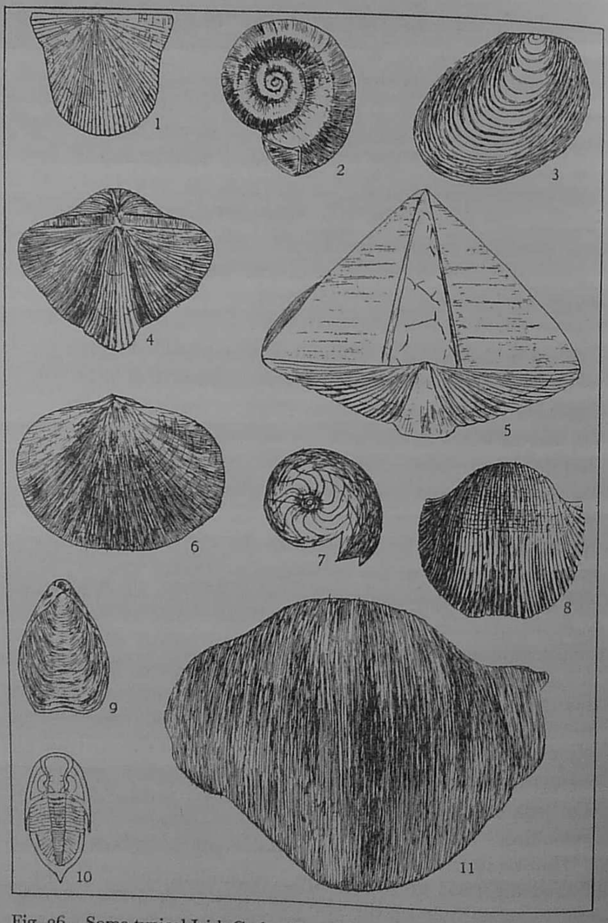


Fig. 26. Some typical Irish Carboniferous fossils (Drawn by H. S. Black to two-thirds natural size). 1. *Pterinopecten papyraceus*; 2. *Euomphalus pentangulatus*; 3. *Posidonomya becheri*; 4. *Spirifer striatus*; 5. *Syringothyris cuspidata*; 6. *Schizophoria resupinata*; 7. *Glyphioceras sphaericus*; 8. *Productus semireticulatus*; 9. *Terebratula hastata*; 10. *Phillipsia eichwaldi*; 11. *Chonetes cor.*



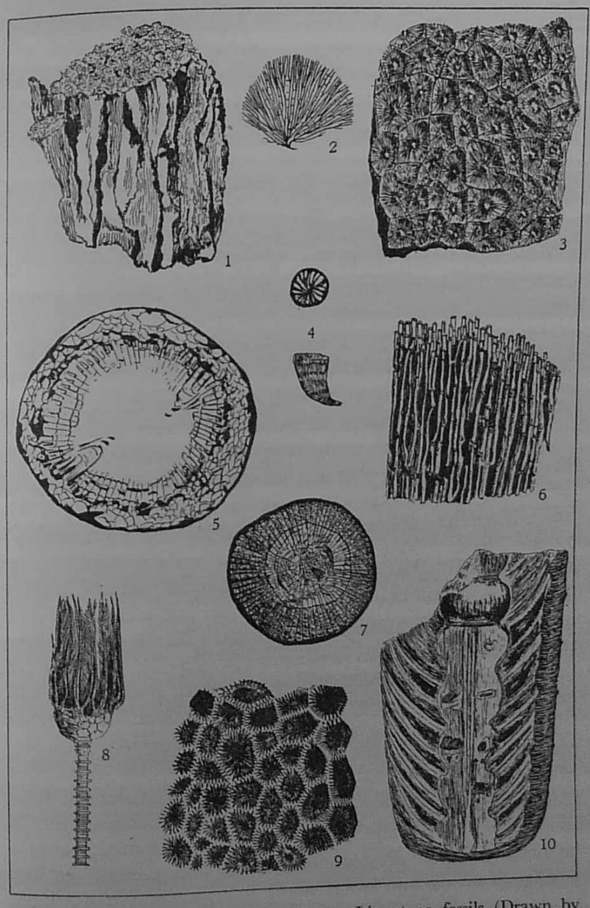


Fig. 27. Some typical Irish Carboniferous Limestone fossils (Drawn by H. S. Black to two-thirds natural size except 10, which is about one-twentieth). 1. *Lithostrotion basaltiforme*; 2. *Fenestella*; 3. *Lonsdaleia floriformis*; 4. *Zaphrentis omaliusi*; 5. *Caninia cylindrica*; 6. *Syringopora reticulata*; 7. *Dibunophyllum*; 8. *Actinoceras*; 9. *Michelinia favosa*; 10. *Actinoceras giganteum*.

and molluscs and an occasional coral extend as a barrier-reef from Cork through Limerick into Clare.

The Carboniferous Limestone epoch witnessed the last great development of the Palaeozoic cephalopods (e.g. *Nautilus* and *Orthoceras*), while in the goniatites (so called from the angular zig-zag lines or *sutures* which are the traces of the internal partitions on the shell itself—Gr. *gonia*, an angle) it chronicles the incoming of a group which during the Mesozoic era was to become predominant in the Ammonites.

*Orthoceras* ("straight horn"), a Palaeozoic nautiloid, was a thin shell simply ornamented with growth rings and almost cylindrical in shape but tapering slightly and ending in a blunt rounded apex (Fig. 27). Internally, it was divided into chambers by partitions which were convex towards the narrower end and were pierced in or near the centre by an opening round which the partition extended like a very short bottle-neck and which carried the living cord. The wider, undivided end formed the body-chamber in which the animal lodged; for the chambers, on the analogy of the modern *Nautilus* of the warm Pacific and Indian oceans, were filled with a gas secreted by the blood. During life, new shell was constantly being added to the "mouth" of the body-chamber and at intervals the animal moved forward in its chamber and secreted behind it a new septum which gave it support. The biggest of these creatures in Ireland was *Actinoceras giganteum*, the "pillars" of the quarrymen, which ranged up to 2 ft. 4 in. in the old quarries at Castle Espie, near Comber, on Strangford Lough (Fig. 27, and map, Fig. 39, p. 109), where numerous brachiopods accompanied it.

The crinoids, often termed "sea-lilies" on account of their plant-like form, had a root or organ for attachment to the sea-bottom. They also had a jointed flexible stalk, circular or pentagonal in cross-section, which was pierced for the passage of nerves and blood vessels and was formed of a large number of ossicles. In life these were united by muscular tissue which permitted of swaying in the ocean currents but at death fell apart. The stalk supported at the top a crown which is seldom preserved. This consisted of a cup which contained the body and was built up of little plates that fitted edge to edge and carried arms like tentacles formed of numerous tiny discs. Ring-shaped pieces of the jointed crinoid stems are abundant in many localities, the crinoidal limestones having been extensively used in the past for ornamental work, particularly mantelpieces.



The calcareous seaweeds or algae, persistent types which had existed in the Lower Palaeozoic seas and maintained their general plan of construction throughout the ages, had the power of extracting lime from the sea-water. They covered their soft bodies with carbonate of lime so that they resembled corals in appearance.

The corals which secreted a calcareous skeleton of lime extracted from the sea were either single or compound (Fig. 27). The single coral, such as *Zaphrentis* or *Palaeosmilia*, was conical or curved like a drinking-horn and had concentric growth rings on the external surface of its thin wall—in the Sligo area, the corals, which are up to two feet in length, have been etched out by the natural solution of the limestone around them. The cone was hollow and divided up by vertical partitions arranged radially and in cycles of four (Tetracoralla) and by horizontal floors. These corals, being sessile and fixed at the apex, grew upwards, culminating in the cup in which the polype lived. As the polype grew and moved forwards, it made additions to the outer wall of the cup and built new floors to close the cup below. Multiplication was by fission or by budding in various ways. In the compound corals, however, the individual corallites, cylindrical or polygonal in shape, did not separate but remained connected, either tightly packed together, as in *Lithostrotion basaltiforme* (Fig. 27), or as loose bundles united at intervals by short tubes, as in *Syringopora* (Fig. 27).

This clear and moderately shallow tropical sea which swarmed with life of all kinds was intermittently invaded by mud which was derived from islands that still stood above the sea and was consolidated into the thin shaly partings of the limestone. Occasionally, timber floating out from the shores, like those of the "Leinster island," rafted out boulders of granite, schist or other rock which were entangled among its roots, though recently earthquake waves have been invoked for their transport. These granite boulders are now found, up to seven feet in diameter, in the limestone near Dublin, e.g. at Donnybrook, Crumlin and Blackrock, and in the north bank of the river Dodder, near Rathfarnham.

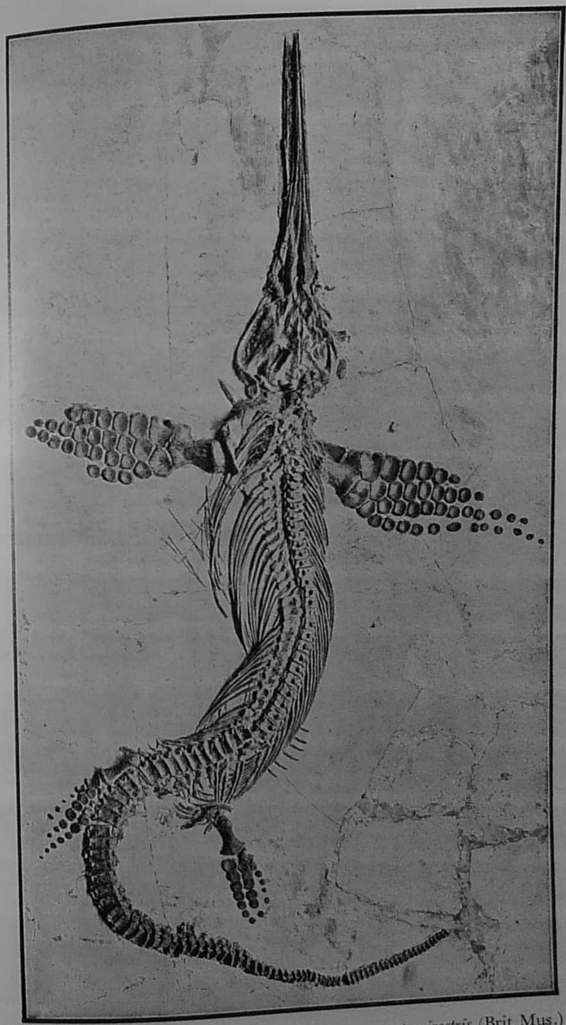
The muddy conditions were particularly prevalent while the Lower Limestone shales and the Calp were being deposited. The shales often contain flaggy limestones and sandstones and vary in thickness from 20 to 300 feet: they suggest that the sea was shallow and received continually great quantities of sand and mud from the adjacent lands. The Calp is a black, earthy limestone, shaly, flaggy and cherty, which is widely distributed throughout central Ireland in the middle of the Carboniferous Limestone. The individual bands are inconstant in character and thickness so that the Calp is represented by earthy limestones, by sandstones with plant remains, by blue, highly fossiliferous and friable shales or occasionally even by thin coal-seams. The muds of the Calp, near Dublin, were doubtless contributed by the Lower Palaeozoic slates of the south-east.

The clear-water sea extended to the vicinity of Carlingford—limestone has been worked in the quarries near the town and forms the reefs at the entrance to the Lough—and to Castle Espie (see above), where a small patch represents the last visible remnant of the limestone that originally underlay the area now submerged by Strangford Lough.

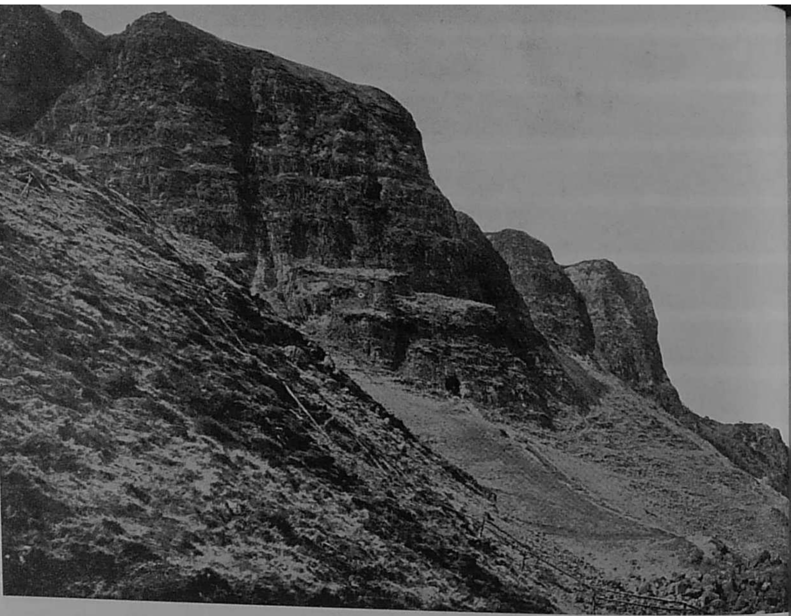
As we go farther north and approach the ancient coast and the Highland Border, against which the Silurian seas had once lapped, the clear-water limestones yield to detrital sandstones and shales, and the total thickness of the beds, with the greater coarseness of the material, naturally increases (Fig. 28).

Thus the typical coral limestones, which may be seen in the quarries about Cookstown, become thin and broken up by sandy intercalations between Magherafelt and Maghera and





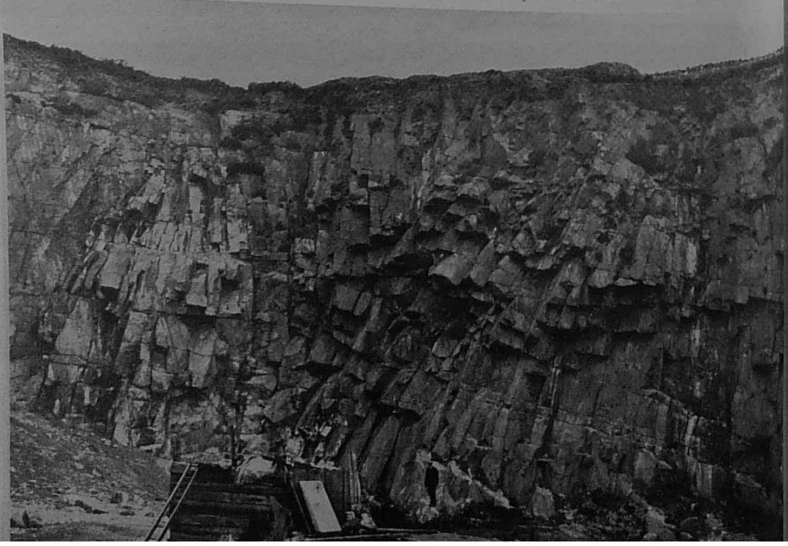
Skeleton of a marine Ichthyosaurian, *Ichthyosaurus tenuirostris* (Brit Mus.)



A. Basalt escarpment, Cave Hill, Belfast, showing successive lavas

PLATE VIII

B. Tardree rhyolite, Tardree Hill, Co. Antrim





give place to ancient shingle beaches, in the form of conglomerates, along the edge of the Sperrins, e.g. west of Dungiven, near Draperstown, and at Omagh. Farther west, similar shore-deposits of great thickness fringe the older rocks in Clew Bay and the north-east of Clare Island, and rest against their contemporaneous cliffs around Donegal Bay. Here, as we follow the Carboniferous rocks northwards to the Bluestack and Barnesmore shore-line, the bottom shales peter out, the sandstones pass into conglomerates and the overlying limestone thins and is replaced by steadily thickening sandstones.

A like transition is observed as we pass across Cork into Kerry. South of a line drawn eastwards from Kenmare River

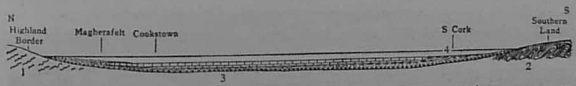



Fig. 28. Diagrammatic section across the Carboniferous Limestone sea showing the disposition of the various kinds of sediment and the position of the land-masses. 1. Dalradian rocks; 2. Lower Palaeozoic slates; 3. Carboniferous conglomerates (circles), overlain by sandstones (dots) and shales (dashes) and limestone (bricks); 4. Carboniferous Slate.

through Cobh, a remarkable change comes over the Carboniferous deposits. The Lower Limestone Shale and Lower Limestones of the Central Plain give place southwards as they appear in the recurring synclines to a thick mass of dark shales, converted by later earth-pressure into the Carboniferous Slate. This slate thickens rapidly—it may be 5000 feet thick in the south of Co. Cork, where it has provided serviceable roofing-slate at Benduff and other places—and finally becomes the dominant member. A barrier-reef which extended through Clare and Limerick to the Cork City area, e.g. at Little Island, marked the divide between the clear-water sea to the north and the mud belt to the south.

Westwards, the Carboniferous Slate itself undergoes a change. Thin and irregular grits make their appearance and thicken until, in Coomhola Glen, near Glengariff, the "Coomhola Grits," worked for road metal, reach their maximum thickness of possibly 3000 feet. The sandy and muddy waters in which they were laid down were stocked with marine creatures, including brachiopods, lamellibranchs and cephalopods.

These sands (grits) and muds (shales and slates) were doubtless swept down by rivers from a land which lay to the south and west but has now vanished by denudation and earth-movements.

Within the Dalradian terrain lies the Ballycastle coal basin, the counterpart of the small Machrihanish coalfield of west Kintyre. Its rocks, magnificently displayed in the cliffs between Ballycastle and Fair Head and in Murlough Bay, consist in the main of thick, white or reddish sandstones and grits, the latter containing fresh angular grains of quartz and pinkish felspar. Subordinate shales and a number of thin, dirty coal-seams are also visible at different horizons in the cliffs (Pl. IVB). A thin but highly fossiliferous limestone, up to 10 feet thick, and bands of ironstone, up to 15 inches thick and containing up to 30 per cent. of iron, complete the analogy with the Machrihanish succession.

The rocks dip inland at an angle of about 10° as part of a syncline which is tilted west-south-west towards Knocklayd, where a fault cuts it off against the schist (Fig. 29). The field is also traversed by several north-south faults, the net result of which, combined with the tilt of the fold, is to lower the Main Coal (see below) from its outcrop at 440 feet A.S.L. at Craigfad, south of Fair Head, to 250 B.S.L. at Bath Lodge, just east of Ballycastle.

The coalfield has ten seams of coal (Fig. 33) which are generally thin, the Main Coal alone having any appreciable thickness (4 ft.) as well as a reasonable amount of ash. The field has in the past been worked in several collieries and in numerous adits. The coals, however, are for the most part of poor quality and their accompanying strata are badly faulted and full of water—the output in the three years 1946 to 1948 averaged 1120 tons. Borings in the interior of the field show that the seams thin southwards towards the Dalradian schists against which the beds were laid down.



The fauna of the limestone and the scanty plant remains prove the coalfield to be of Lower Carboniferous age, and contemporaneous, it is important to note, not with the Coal Measures of later date, which elsewhere in Ireland carry coals, but with the Carboniferous Limestone of the south.

Carboniferous sandstones of the same age skirt Lough Foyle on the south and south-west and underlie the Roe valley.

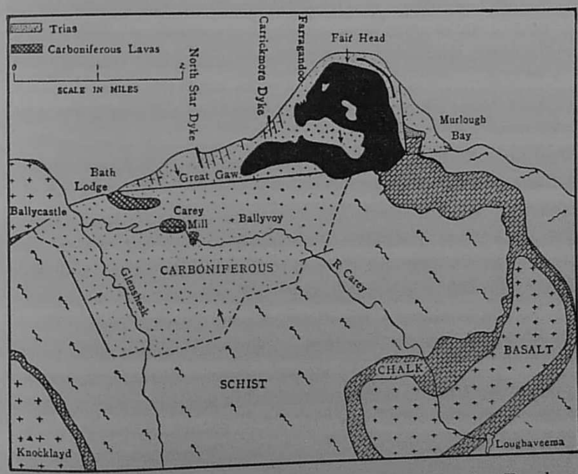



Fig. 29. Geological map of the Ballycastle area, Co. Antrim (Based on Geological Survey).

Variegated and ripple-marked, they are interbedded with sandy shales and impure, nodular limestones and pass downwards into shingle beaches of schist, quartzite and other material supplied by the neighbouring Dalradian land.

Lower Carboniferous times saw a mild and sporadic outburst of volcanic activity, more particularly in the shore-zone, as has so often been the case in geological history. Dark contemporaneous lavas are exposed in the Ballycastle coalfield in the cliff near Bath Lodge, Ballycastle, at Carey Mill, on the left bank of the Glenshesk River, and at Doon on the shore of Murlough Bay (Fig. 29). In Co. Limerick their superior hardness causes them to project above the surrounding plain in bold ridges, sometimes crowned with feudal castles.

## 2. Millstone Grit

Towards the close of the Carboniferous Limestone epoch sands and muds once again covered the sea-floor. The lands in the north and north-west of the British Isles were elevated to provide vast masses of sediment and the sea-floor was apparently no longer sinking sufficiently rapidly to keep pace with the invading sediment. This gradual shallowing and silting-up of the sea which took place in different areas at different times is recorded in the Yoredale Shale and the overlying Millstone Grit. The former was named from Wensleydale (old name Yoredale) in Yorkshire: the latter was first studied in the Pennines, where for centuries it has provided millstones and grindstones.

The Carboniferous Limestone passes upwards into black, fissile shales, massive sandstones, flagstones (especially where much mica lies in the bedding planes) and coarse yellow grits. The shales enclose interbedded limestones, which demonstrate that clear-water conditions had not wholly passed away, and lenticular layers of coal, as in the Dungannon and Lough Allen areas, which denote stages of rest in the general downward movement and presage the swamps which were to become so general in Coal Measure time. They likewise contain nodules or nodular bands of clay ironstone. These heavy, brownish nodules, often the size of cricket balls, grew from iron solutions in swamps and lagoons where water-vegetation was growing vigorously and the waters were little disturbed. They are in places extremely abundant, noticeably about Lough Allen, and, as elsewhere, weather out of the friable shales of the dark hills, e.g. in Slieve Anierin ("Mountain of Iron"), to bestrew the beds of the rivers and streams, staining them with red or brown ochre (iron oxide combined with



water). Numerous abandoned furnaces and mounds of charcoal in the Lough Allen district, e.g. at Creevelea, bear witness to the former exploitation and smelting of the nodules. Though the ores on analysis give 54·42 per cent. of iron oxide, their rather high content of phosphorus makes them unserviceable for the manufacture of iron by convenient processes. This drawback, combined with the low concentration of the nodules in the shales, renders their working uneconomic. The iron pyrites is by its decomposition responsible for the sulphur and iron springs or wells of Lisdoonvarna, Co. Clare.

The Yoredale beds, which sometimes yield remains of fossil fish and contain goniatites among the shales, are sharply distinguished lithologically and scenically from the underlying clear-water limestones. Their flat-topped plateaus, covered with dark peat and heather moor, are bounded by abrupt scarps in the resistant sandstones and grits and by gentle terraces in the more yielding shales which curve smoothly at lower levels into the limestone plains and valleys. The tablelands, conspicuous, for example, about Lough Allen, in Slieve Beagh, Co. Monaghan, in Shean North (south of Lough Erne) and in Co. Fermanagh, owe their pre-eminence to the caps of the Millstone Grit, which has slowed down the destructive processes. While reminiscent of and perhaps equally as striking as the limestone plateaus of Co. Sligo, they are perhaps less attractive and more austere.

The big change in the conditions of deposition from clear-water limestone to sandy grit and muddy shale had important repercussions on the fauna: the abundant brachiopods and corals of the limestone were rapidly extinguished or forced to migrate. In their place there throve animals adapted to a muddy environment, chiefly the lamellibranchs, e.g. *Pterinopecten* (Fig. 26), and the goniatites of the shales. The sandstones by contrast are almost wholly unfossiliferous, though impressions of drifted plants which became so abundant in the succeeding Coal Measures are sometimes discovered. The dark flagstones from the Liscannor quarries west of Lisdoonvarna which have been so widely used in the pavements of Irish towns are readily recognisable by the tortuous worm tracks which decorate their surfaces.

The shales, sandstones and grits were laid down as deltas in a very shallow sea, the bottom of which was sinking intermittently and possibly rhythmically so that the grits which the streams spread out in periods of shallow water were overlain by muds as the sea slowly deepened; the predominant shales indicate by their fine texture and well-preserved plants the shallowness and tranquillity of the waters, while the lenticular and impersistent sandstones mark the sites of sand banks.

The densely forested swamps which in Carboniferous Limestone time had been confined to the Ballycastle district now ranged southwards as the physical conditions for their growth became established: they give us on a minor scale a picture of the swamps which became so widespread in Coal Measure time, not merely in Ireland but over much of Europe.

### 3. Coal Measures

The vast deltaic flats, conterminous and low, of the Coal Measures were built out into the sea. Their forests, swamps, lagoons and river-like channels, though nowhere reproduced to-day on the same vast scale, resembled those of the modern Ganges, of eastern Sumatra and of the mangrove swamps of the Atlantic and Gulf States of North America. They were drained by sluggish streams of fresh or brackish water inhabited by fresh-water "mussels" and were colonised by forests of tall trees, viz. giant club-mosses (Lycopods), e.g. *Lepidodendron* ("scale leaf"), represented to-day in Britain by lowly plants found in bogs or the *Lycopodium* of mountain moors, greatly enlarged horse-tails or Equisetales, e.g. *Calamites,* and true ferns or Pteridosperms, tree-like in size, which bore fronds resembling those of true ferns but reproduced themselves like our modern trees by seeds and not merely by spores (Gr. *pteris* fern, *sperma* seed). Together, they provided the vegetable matter of the coal-seams and the carbon which gives its name to the whole period.



The trees, 100 feet or more in height, were like the mangroves of modern tropical swamps rooted in a muddy ooze, the grey underclay of the coal-seams. The fronds, leaves and plants died in place and fell into the swamps where bacteria converted the tissues into a jelly-like mass. The decayed vegetation lost its moisture and gases and was pressed into the coal we know by the sediments which were piled upon it.

The thickness of vegetable growth required to produce the coal of even a one-foot seam is perhaps astonishing, for it is estimated that up to 20 or even 40 feet of vegetation were so required. This great shrinkage or compression was brought about partly by biochemical and partly by geological changes after burial.

The plants accumulated where they lived since the coal to which they gave rise is almost entirely free from detritus and lies almost invariably upon a grey fire-clay or upon an intensely hard sandstone called ganister. This is used to line furnaces since it can withstand high temperatures without fusion. These clays, by their freedom from alkalies and lime and by the presence of roots and rootlets (*Stigmaria*) found beneath most coals, are known as "seat-earths" or "underclays," the exhausted soils on which the vegetation grew. Occasionally a tree with its underground limbs embedded in the fire-clay or seat-earth rises vertically through the coal, though usually the coal and its old soil are sharply divided. The stems and roots, being underground, are preserved not as wood but as casts: the decay of the plant tissue allowed sands or clays to fill the cavities. The shales often show fronds superficially like those of ferns.

The coal was formed from various plant organs belonging to several kinds of vegetation, all of which had undergone some decay before being entombed beneath the later mud (shale) or sand (sandstone). The softer tissues, naturally, were usually wholly destroyed, but the wood, roots, bark and the outer skin of the leaves, together with the resins and the seeds and spores which were blown in by the wind in immense profusion, have persisted in varying degrees. They display parts of their original structure, though biochemical action has largely replaced the original substance by new compounds. That so much is still preserved is owing to the aseptic condition of the stagnant, unoxygenated waters of the swamps which prevented the quick and complete destruction of the tissues and their conversion into the water, marsh-gas and carbon dioxide that ordinarily result from bacterial fomentation. The bright lenses of the coal originated chiefly in the wood and bark, while the dull coal consisted of the flattened leaf-cuticles and spore-cases or of an almost structureless material derived apparently from rotted and macerated vegetation.

The vegetable matter was afterwards converted into bituminous (i.e. ordinary brightly burning) coal or anthracite by the chemical and physical changes resulting from its burial beneath later sediments and its subjection to heat and pressure; though it is possible that the coal changed as the ancient plants changed and that the hard, lustrous anthracite differed in its original composition from the ordinary relatively soft and friable house coal which has less fixed carbon and more volatile hydrocarbons.

The climate was hot, moist and uniform; for the bark was smooth, seasonal growth rings were wanting and the fern-like fronds were large and drooping. The seeds had floating devices and the roots were developed horizontally along the ground.

The floor of the Carboniferous area was steadily if intermittently subsiding—this alone made it possible to heap up the great pile of sediment which now constitutes the Coal Measures—and by its rate controlled the vertical spacing of the seams. The final thickness is the measure of the accumulated total of the successive sinkings. The shales (shallow sea and lagoon), sandy shales and sandstones (deltaic flats) and coals (swamp forest) betray a well-marked sedimentary rhythm though the cycle is often not complete, one or more of its elements being omitted, while perfect regularity in the proportionate thickness of the elements is seldom observed. Each cycle marks one round in the conflict for domination between the sea and the land: it is probably connected with



intermittent sinking and isostatic adjustment but has yet to be satisfactorily explained. The coal-seams, though the most valuable economically, never total more than a very small fraction of the whole thickness of the measures.

Periodic and probably fairly rapid subsidence allowed masses of river and current-borne detritus to overwhelm the forests, and, when of exceptional amount, permitted the sea for a short time to break in and flood the whole area and introduce its marine shells, chiefly lamellibranchs and goniatites.

The Coal Measures probably buried all, or almost all, the country, for isolated patches of sandstone and conglomerate, presumedly Carboniferous, have been preserved on the summit of Slieve League (north of Donegal Bay) at 1972 feet O.D. and at Formnamore, west of Lough Mask, Co. Galway, at 2200 feet O.D. Now, however, the measures persist in only a few detached synclinal basins that originated during the Armorican folding (see Ch. VI): elsewhere the erosive forces have ruthlessly destroyed all trace of them.

The resources of the various Irish coalfields were computed by the late Professor Grenville Cole as follows:—

| | *Area (sq. miles)* | *Metric tons* |
|---|---|---|
| Tyrone coalfield . . . | 9·5 | 97,120,000 |
| Lough Allen coalfield . . | 6·0 | 8,696,000 |
| Leinster coalfield . . | 94·0 | 156,730,000 |
| Tipperary coalfield . . | 10·3 | 15,080,000 |

These figures, with the Lower Carboniferous coalfield of Ballycastle (4·5 square miles; 13,720,000 tons), give a total area of 124·3 square miles and a total tonnage of 291,346,000.

Generally speaking, the upper coals have been exhausted and only the deeper and thinner ones, which are more difficult and costly to extract, now remain. Nevertheless, though the number of working collieries has been reduced—in 1878 it was 50, in 1944 19—the output has remained fairly constant; the 1878 output was 121,975 tons, that of 1944 (in Eire) 202,263 tons, of which 74,122 tons were semi-bituminous and 128,141 tons anthracite.

One of the most important of the Irish coalfields lies north of Dungannon in Co. Tyrone and has the village of Coal Island in its centre; it bears any of these three names. It has to the north of it the Annaghone coalfield which, only about one-half a square mile in extent, is hemmed in by faults on three sides. The main coalfield is limited on the north against the Carboniferous Limestone by a fault with a throw of about 2000 feet, and plunges steeply eastwards beneath the overlying Trias (Fig. 30).

The coal-seams, some twenty-four in number and of a total thickness of 60 feet, crop out at the surface or lie beneath glacial sands and gravels, except on the east where the Coal


Fig. 30. Section through the Coal Island Coalfield and Washing Bay boring. 1. Carboniferous Limestone; 2. "Millstone Grit"; 3. Coal Measures; 4. Trias; 5. Chalk; 6. Tertiary basalt-lavas; 7. Lough Neagh Clays; f, fault.

Measures pass beneath the Trias. The Lower Coal Measures consist of alternating sandstones, grits and shales with occasional bands of limestone and excellent fire-clays. The coals include the Main Coal which is between 5 and 11 feet thick, though partings of shale and fire-clay subdivide it where the higher figure is reached. In the Middle Coal Measures, the coals are thicker and more numerous, and the sandstones become quite subordinate and are replaced by soft shales, by ironstones and by fire-clays used for tiles and coarse pottery—the fire-clay produced in the three years 1946 to 1948 averaged 10,118 tons.

The easterly dip of the beds, combined with the effect of numerous big faults, carries the Coal Measures to a great depth at a relatively short distance from the outcrop. At Washing Bay, on the south-west of Lough Neagh, where the Ministry of Munitions drilled a boring in 1919 to ascertain the depth of the coal, the top of the measures is probably

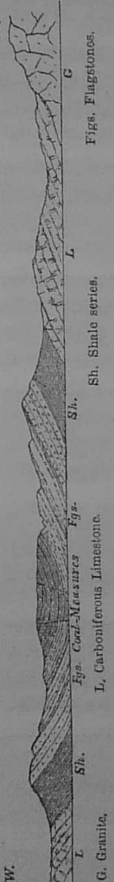


about 5000 feet underground. The great heat which may be expected at this depth (bearing in mind that as we go down into the Earth's crust the temperature rises at an average rate of 1° C. for every 100 feet) would prohibit the extraction of these coals. In this connection it may be noted that the deepest British colliery, the Pendleton Colliery of Lancashire, is 3500 feet deep.

The Tyrone coalfield is the analogue of the coalfields which lie within the Midland Valley of Scotland (Fig. 1, p. 10): other coalfields, whose exact position is not known, may lie concealed beneath the Tertiary lavas and Mesozoic sediments.

The Leinster coalfield, also named the Castlecomer coalfield, is the largest productive coalfield in Ireland. It occupies the centre of a broad and shallow synclinal basin (Fig. 31) between Slieve Bloom and the Devil's Bit Range on the west and the Leinster Hills on the east. Its bare, basin-shaped tableland, about 1000 feet high, falls abruptly on all sides in bold terraces into the highly cultivated limestone valleys of the Barrow and Nore.

The coalfield, an outlier of which is the Tipperary or Slieve Ardagh coalfield west of the Nore, consists of a thick series of black or grey shales containing shells (*Aviculopecten*, *Bellerophon*, *Euomphalus* and *Goniatites*). The shales are interstratified with grey sandstones and flagstones which become increasingly important upwards and have been quarried extensively for the "Carlow flags." Its few seams of anthracite are, generally speaking, too thin and impure to be worked profitably. One of the Kilkenny coal-seams is lenticular and has a dull, amorphous appearance. This cannel is less brittle than other coals, breaks with shell-like fracture and has a high percentage of ash. It probably did not originate *in situ* like other coals but was formed in pools and backwaters where stems and leaves, etc., fell in from the banks. Such an environment explains its relatively high percentage of ash and the not infrequent occurrence of fossil fish. The Jarrow Colliery, Kilkenny, has yielded the best collection of these fish, including some entire skeletons, as well as several skeletons, up to eight feet long, of




G. Granite, L, Carboniferous Limestone. Sh. Shale series. Figs. Flagstones.

Fig. 31. Geological section through the Castlecomer Coalfield (Based on The Geological Survey).

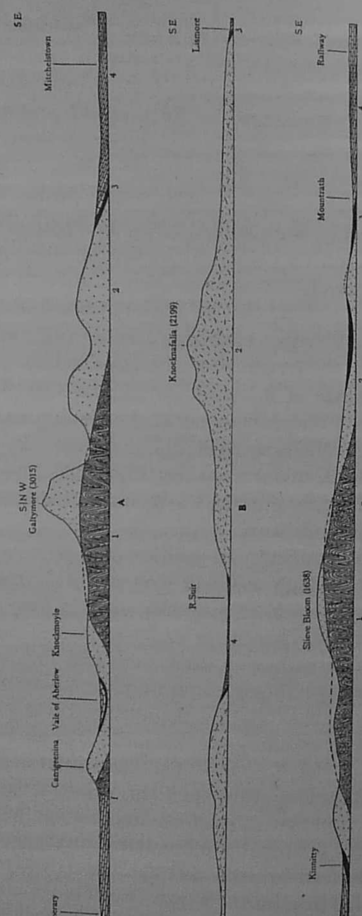



Fig. 32. Sections through (A) the Galty Mountains (showing cums in Galtymore), (B) Knockmealdowns and (C) Slieve Bloom. 1. Silurian slates (isoclinal folding diagrammatic); 2. O.R.S.; 3. Lower Carboniferous Shales; 4. Carboniferous Limestone; f, fault.



amphibians of the labyrinthodont order. The amphibia had already evolved from the fish, probably as a result of the widespread desert conditions of O.R.S. times that favoured air-breathing animals.

Of the eight or nine seams which have been explored, the upper and more accessible ones are, in general, exhausted. The No. 2 seam in both fields now provides the most suitable coal. Anthracite is at present being raised at a rate of about 100,000 tons per annum. A fire-clay beneath the Jarrow coal provides the raw material for a local ceramic industry.

Although the Leitrim field is very like the southern fields in its succession, denudation has carried away the larger part


Fig. 33. Section through the Leitrim Coalfield showing the Coal Measures resting on the "Millstone Grit" and underlying shales and, below, the Carboniferous Limestone. (After E. Hull.)

of the Coal Measures so that only the lower measures remain. Known also, for obvious reasons, as the Lough Allen, Arigna or Connaught coalfield, it consists of three detached areas separated by deep valleys in which the dark outcrops of the higher coals can be readily followed along the hillsides. The strata dip inwards like a very shallow saucer, an arrangement which as in other Irish coalfields has introduced great difficulties in working the coals on account of underground water (Fig. 33).

The coals, like those of Coal Island, are household coals of varied quality: they are thin and friable and leave much ash behind on combustion. The three chief coals in descending order are the Top Coal, Middle or Main Coal (largely worked out) and the very impure Crow Coal, respectively 1 ft. 8 in., 1 ft. 10 in. to 2 ft. 3 in. and 6 in. to 1 ft. 4 in. thick (Fig. 34). At present they are producing about 60,000 tons per annum.

The Munster coalfield underlies the dreary moorland

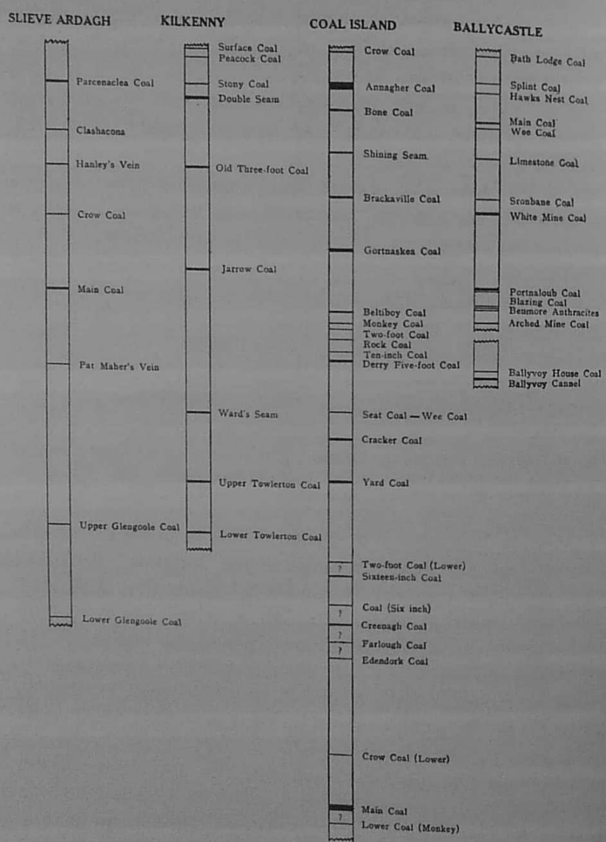



Fig. 34. Vertical sections showing the thickness and spacing of the coal seams in the chief Irish coalfields (After Dail Commission).



between the Blackwater on the south and the Shannon estuary on the north. Its gently undulating hills of relatively soft rocks, mantled with heavy wet soils, rushes and coarse grass, are composed of a marine series of alternating sandstones, flagstones, black or grey shales, fire-clays and bands of clay ironstone. Its seams of impure coal, less than one foot thick, the result of the infrequent and transitory vegetable growth, contain much sulphur. They are rarely productive, while sharp folds and shearing and thrusting at a low angle from the south, make large and systematic mining both difficult and expensive.

## Chapter VI

# THE CLOSE OF THE PALAEOZOIC ERA

### The Armorican Movement

After the long Carboniferous epoch of subsidence and deposition had come to a close, Ireland passed through the throes of yet another period of pronounced earth-movement, the third to punctuate its geological history. The earth's pent-up energy was released and reared up a mountain system to dominate the geography of Europe from southern Ireland through southern England, Belgium, France, Germany and Poland; the term Armorican, which the folding carries, comes from the ancient name Armorica (north-west Gaul or Brittany), though the movement is sometimes styled Hercynian from the forested Harz Mountains of Germany.

As in the case of the more ancient Caledonian mountains (see Ch. III), worn down stumps are all that now remain, and the structure can only be restored by continuing in imagination the lines of the crumplings or folds revealed in numerous exposures (Figs. 35, 37). The folds present their steep fronts to the north and their gentler slopes to the south. Along the northern edge of the great fold-zone, as between Dingle Bay and Dungarvan, the rocks have not infrequently been pushed over the newer rocks in front of them by strong pressure directed northwards. Such inversions, for instance, are observable in the Skibbereen anticline and its western prolongation of Clear Island and Sharkin Island; near Clogher Head where the Silurian (Wenlock) has been thrust over the O.R.S.; and in the neighbourhood of Killarney where the O.R.S. is apparently thrust on to the Carboniferous Limestone along the northern flanks of the mountains south of Muckross Lake and Lough Guitane.

The strata have been squeezed and buckled into huge



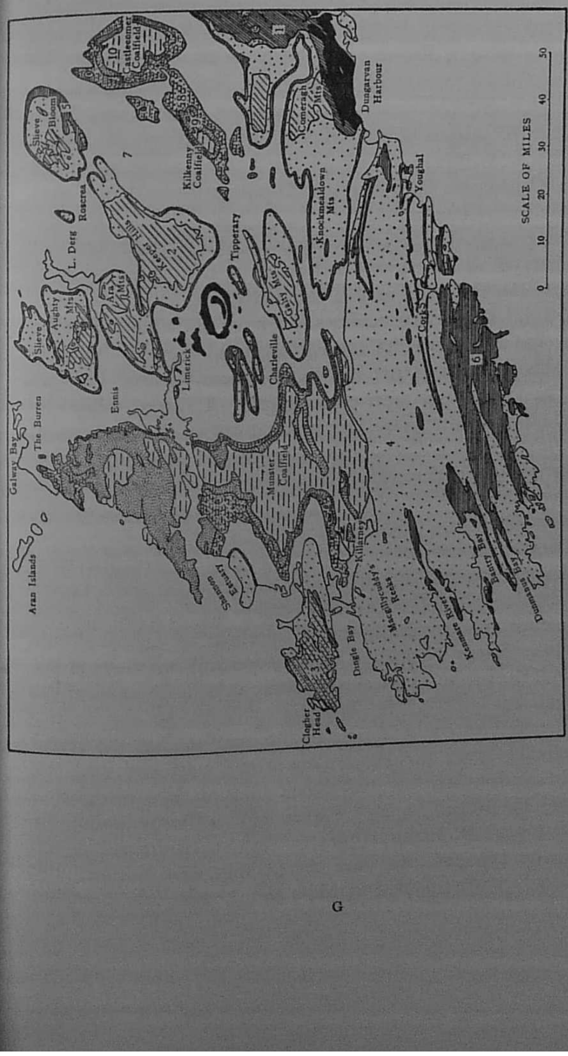



Fig. 35. Geological map of south-west Ireland (Based on Geological Survey). 1. Ordovician, with igneous rocks (black); 2. Silurian; 3. Dingle Beds; 4. O.R.S.; 5. Lower Carboniferous Shale; 6. Carboniferous Slate; 7. Carboniferous Limestone, with igneous rocks (black); 8. Yoredale Shales; 9. Millstone Grit; 10. Coal Measures.

upfolds and downfolds, the axes of which rise and fall to give the elongated domes (periclines) and spoon- or boat-shaped synclines of the outcrops. They trend roughly east-west, except in Kerry where they swing round into west-south-west. This swing in western Kerry, with the corresponding curving of the trend-lines from southern England into central France, shows that the Armorican folds, like those of the Carpathians and the Himalayas of much later (mid-Tertiary) date, were arc-shaped in plan, comparable with the curvature of the older Caledonian folds from north-east south-west into east-west folds in Mayo and Galway.

The geological structure, owing to the differentially resistant qualities of the rocks under long-continued denudation, is revealed in the relief with a simplicity and clearness rarely equalled. The O.R.S. emerges along the anticlines, as in the bare and hilly slopes of the east-west ridges, e.g. the steep cone-like features of the Knockmealdowns (2069) (Fig. 32) and in Dingle and other promontories of Kerry, while the synclines are most revealingly brought out by the outcrops of the less resistant Carboniferous strata in geological maps (Figs. 35, 36) and sections (Figs. 32, 37) and by the valleys, distinguished by their quiet pastoral beauty, of the Blackwater, Lee and Bandon.

These great parallel folds which control the broad features of the country and the pattern of the river system are not quite so simple as here suggested. They are complicated by numerous minor anticlines and synclines of an amplitude rarely sufficient to interfere with the general simplicity of the boundaries of the formations or of the various divisions of the formations.

The axes of the folds rise to the west, so that the broad synclinal valleys become shallower and narrower and the O.R.S. ridges broaden and mount upwards into Mangerton (2756), the Macgillycuddy's Reeks and into Carrauntoohil, the highest peak in Ireland (3414). Thus, notwithstanding the profound lapse of time since the foldings were finished, the anticlines have remained as ridges and the synclines as valleys

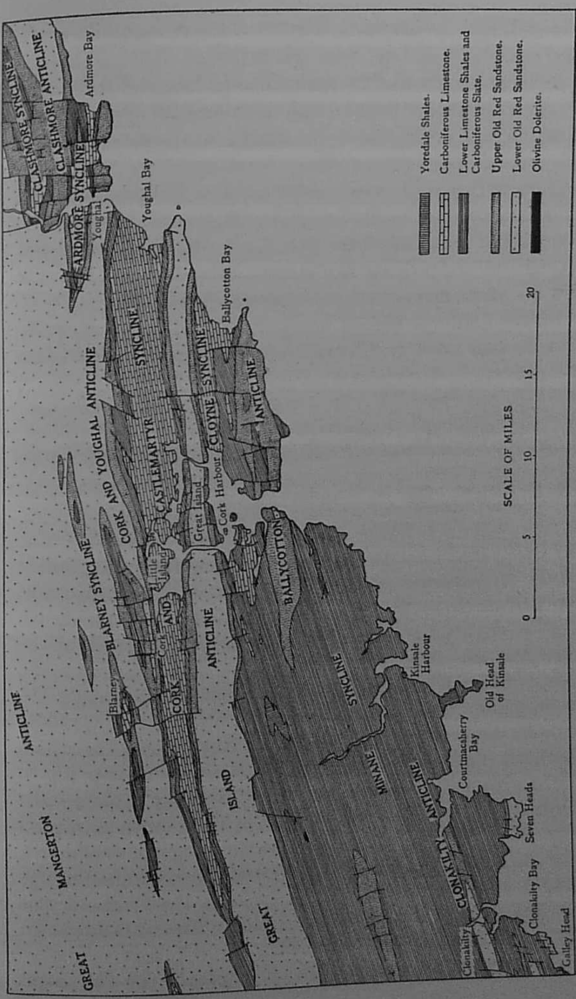



Fig. 36. Geological map of the Cork district (After Geological Survey and J. S. Turner).

(Fig. 37), and the inversion of relief which customarily results from denudation has not taken place here.

Although the front of the Armorican folding and the theatre of the most violent folding with its attendant cleavage and thrusting was in the south, movement was not restricted to that region. The "ground swell," overlapping the Caledonian country, is clearly traceable as far north as Ballyshannon and Donegal Bay in the north-west and to Ballycastle in the north-east: it has even pushed the O.R.S. over the metamorphosed rocks north of Castlebar and thrust Carboniferous Limestone at a low angle upon Cambrian quartzite at Howth.

In the northern region, however, the folds are generally broader and more gentle and were inevitably deflected into

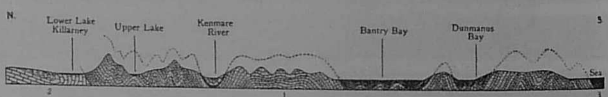



Fig. 37. Section across the Armorican folds of Co. Kerry. 1. O.R.S.; 2. Carboniferous Limestone; 3. Carboniferous Shale.

the Caledonian direction by the pre-existing folds and granitic cores. As instances we may cite the Donabate-Portraine axis, the Ballycastle coal-basin, and the anticline that builds the long, dark ridges of Slieve Bloom (1734) which stands at the northern end of an uplifted mass that is parallel with the Leinster Chain. Further examples include the Devil's Bit, the synclines of the Castlecomer and Slieve Ardagh coalfields and the downfold south of the Slieve Aughty anticline which continues south-westwards along the Shannon estuary.

The great earth-waves of the Armorican storm broke against the groyne of the Leinster Chain and, as is seen on the geological map (Fig. 6, p. 24), were made to curve to the north-west, west of the chain (north-west of Waterford) and to the north-east, east of the chain, as is depicted in the Carboniferous trough which runs north-eastwards across the south-east angle of Co. Wexford to Wexford Harbour.

The Armorican pressure left its impress upon the rocks



themselves. It cleaved the O.R.S. grits and sandstones and the softer shales, as at Malahide and Rush, and converted the Carboniferous Shale of the south into Slate. Even the limestone, e.g. about Cork and in the Killarney district, assumed a slaty cleavage whose planes strike with the folds and cut the bedding at various angles according to the parts of the fold they intersect. Nevertheless, the Carboniferous rocks contrast markedly in this respect with those of Lower Palaeozoic age; for their folding is slight and their metamorphism, in the absence of softening by heat and pressure, is generally insignificant. The close-packed isoclinal folding of Caledonian times made it impossible for the older strata to yield except in long, gentle folds or by breaking along fault planes.

The Armorican movements, in Ireland as in Wales, were unaccompanied by igneous activity: the inner zone of intense folding and granitised roots which gave England its Cornish granites lay farther south. Nevertheless, the forces generated a number of mineral lodes which run for the most part east-west and occupy fissures in the O.R.S., e.g. from Co. Waterford to Co. Kerry. The lodes of this "copper belt" were filled by solutions which flowed under pressure along the joint and fault planes. They carry rich copper ores (chalcopyrite and bornite) which have from time to time been mined in several places in Co. Cork, e.g. at Allihies (Bearhaven), and in beds at Muckross on the Lower Lake of Killarney. Large quantities of copper sulphide (copper pyrites) have been worked from lodes in the Vale of Avoca, Co. Wicklow, and in Co. Waterford, e.g. the Bonmahon group of mines.

Of this date also is the lead sulphide (galena), sometimes accompanied by silver or by zinc sulphide (zinc blende), which has been worked in many localities in the Carboniferous Limestone, e.g. at Abbeytown, Co. Sligo, at Tulla, Co. Clare, at Tassan on the marches of Armagh and Monaghan, at Caim in Co. Wexford and, less certainly, that found in the Lower Palaeozoic slates at Conlig and Newtownards in Co. Down, at Silvermines in Co. Tipperary—this was pre-eminent for its zinc, less for its lead and copper—and at Glendalough and

Glenmalur in Co. Wicklow. The latter may be of Caledonian age (see p. 52).

The compact dolomitic limestone of the Lower Carboniferous is interbedded with barium sulphate (barytes or heavy spar) in the Silvermines district. After the solutions of the sulphides of lead, zinc and iron had been introduced along the local fault and the bedding planes of the Carboniferous Limestone, barium solutions invaded the rocks and, coming into contact with the oxidation products of the sulphide ores, formed barytes by double decomposition. Barytes also accompanied the lead ores of Silvermines and Co. Wicklow.

When the Armorican pressure ceased, the reaction rent the crust in many places along fault planes which often follow the same trend. The Ballycastle coalfield, for instance, is traversed by a big fault, the "Great Gaw," which runs east-west through the coalfield (Fig. 29, p. 83)—it was penetrated by the North Star Mine—and drops down the strata on the north by at least 1200 and probably up to 2000 feet: it curls up the Carboniferous grits on the shore of Murlough Bay against the Dalradian schist and emerges in the west in the gully behind Bath Lodge, bringing the Carboniferous lavas against one of the highest horizons in the coalfield.

Many other faults of this age occur in the north and lie parallel with the Caledonian strike. One of them runs south of the Sperrin Mountains, from Omagh to Draperstown, where the Carboniferous rocks by "back faulting" slipped back along the ancient thrust plane against the Dalradian schists (see p. 49): other examples are the fault which limits the Coal Island coalfield on the north, and has a throw of about 2000 feet, and that which is followed by the G.N.R. between Pomeroy and Carrickmore in Co. Tyrone and continues south-westwards to Tempo and Lisbellaw. The central inlier of Tyrone (Fig. 2, p. 11) behaved as an upstanding mass (horst) and the beds dropped down in a series of steps on either side. Reverse movements along the original lines of compression also affected the Lisbellaw area.

By this Armorican folding and elevation, whose exact chronological value, though vast, is indeterminable, an Ireland



was created which differed fundamentally from the Carboniferous Ireland. The Carboniferous sediments themselves, as we have already seen, came out of the sea. In the destruction of strata that ensued, the first to suffer were naturally those of the uppermost division. The Coal Measures were stripped from the crowns of the upfolds throughout the country and survived only in the shelter of the downfolds: Ireland, it is important to note, lost its coal-seams almost as soon as it received them. The coalfields are now separated by wide expanses of Millstone Grit or, more commonly, of Carboniferous Limestone. This post-Carboniferous denudation was prodigious. We gain some idea of it from the fact that the Trias rests on Lower Carboniferous strata at Castle Espie, at Cultra, at Armagh, near Caledon, in the Roe valley, around Lough Foyle and at Carrickmacross (Co. Monaghan); on O.R.S. near Cushendall; on Silurian at Kingscourt (Co. Cavan) and at the head of Strangford Lough; and on Dalradian schist at Murlough Bay, Co. Antrim. The fact that the Permian rests on Carboniferous Limestone near Cookstown proves that much of this Pre-Triassic denudation was also Pre-Permian.

## Permian

The sequence of events which followed the Silurian epoch, namely, the Caledonian Movement and the succeeding continental desert conditions of the O.R.S., had an almost exact parallel in that which supervened upon the Carboniferous epoch: the Caledonian Movement had its counterpart in the Armorican Movement, the desert of the Old Red Sandstone its analogue in the desert of the Permian and Trias, often bracketed together as the New Red Sandstone. Geological history repeated itself.

The Permian rocks, which derive their name from the province of Perm in North Russia, where Sir R. I. Murchison first discovered them in 1841, are but insignificantly represented in Ireland. Their unpretentious shreds, restricted to a few isolated localities in the north-east, serve as striking monuments of the devastating effect of geological denudation. Their story will require little space.

The Permian is now found near Cultra on the south shore of Belfast Lough, and in elongated patches at Tullyconnell, near Stewartstown, in Co. Tyrone. The Tullyconnell outcrops, now largely concealed by vegetation, occur in the much-faulted area on either side of the village of Grange between the Carboniferous and Triassic strata. A small isolated patch of thin sandstone and breccias and insignificant bands of impure magnesian limestone, two and a half miles south-east of Moira on the Silurian rocks, may also belong to the Permian.

The most interesting of these fragments occurred at Cultra. Here a pale yellow or buff-coloured magnesian limestone (carbonate of lime 46 per cent., carbonate of magnesia 44 per cent.), very like the magnesian limestone east of the Pennines, crops out on the shore. It dips northwards under the lough at an angle of about 25° to 40° and rests unconformably upon Lower Carboniferous beds. This fossiliferous limestone, however, has been quarried to about sea-level for building purposes or for export to Glasgow for the manufacture of magnesium sulphate. It is, however, still visible in ancient buildings, including the old church at Holywood, and in the walls of Carrickfergus Castle where it contrasts markedly in colour with the black basalt.

From the facts just mentioned and from others gathered elsewhere in Europe it is possible to draw a few general conclusions with respect to the physical geography in Permian time. The picture we obtain is that of a desert-girt sea, in its final stage at least a land-locked basin, bounded on the north by the Caledonian mountains and severed on the south from the main ocean. This great depression, analogous in its environment to the present Aralo-Caspian basin, stretched from the Carpathians to Spitsbergen and from the Ural Mountains across Germany and the site of the North Sea into northern England. Its sea, as its fauna indicates, passed over the Solway area where the Permian rocks are well developed in the Vale of Eden, south of Carlisle, and had access to the

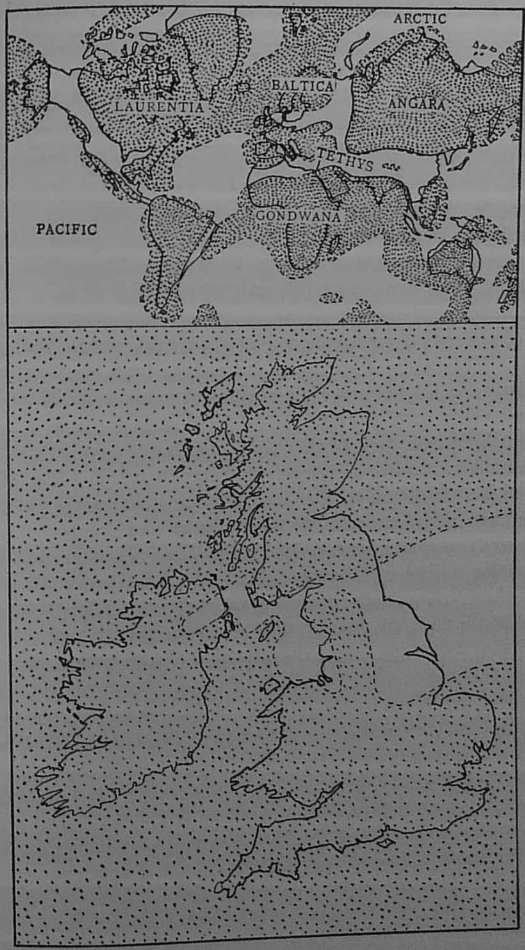



Fig. 38. Map of the Permian geography of the British Isles (inset: world geography).

Midland Valley of Scotland and of north-east Ireland by the North Channel between the Ards Peninsula and the Rhinns of Galloway (Fig. 38). The southern shore of this most westerly arm of the basin doubtless lay somewhere near the present Down coast of Belfast Lough. The Lower Palaeozoic rocks furnished material for the Permian, whose basal beds comprise angular or only slightly rounded fragments of the local grits and slates.

Permian rocks, discovered in borings in the north of the Isle of Man, prove that this part of the Irish Sea was then depressed.

The Permian environment was apparently unfavourable to life. The fauna, a decadent descendant from the Carboniferous and a relict probably imprisoned in consequence of the Armorican earth-movements, consisted of individuals which, compared with their Carboniferous forebears, were in general stunted, contorted, misshapen and impoverished. The Irish Permian fossils were the lamellibranchs *Bakewellia antiqua*, *Schizodus schlotheimi* and *Mytilus squamosus* and the brachiopod *Productus horridus*, distinguished specifically by its peculiar ornamentation with spines. While *Productus* persisted, most of the Carboniferous groups, such as the corals, cephalopods and trilobites, had disappeared. *Productus* did not long survive them; it died out before the following (Trias) period.

## Chapter VII

# THE TRIAS: A DESERT LANDSCAPE

With the opening of the Mesozoic era which witnessed the accumulation of the Triassic, Jurassic (Lias and Oolites) and Cretaceous sediments, we enter a world which differed greatly from that of the Palaeozoic era just closed. Crustal stresses had for the time being exhausted themselves so that the Mesozoic, in contrast with the Palaeozoic, was an era of almost complete crustal stability, of steady and persistent planing down of the land, and consequently of steady and persistent sedimentation. Crustal instability and igneous activity being so often intimately connected, it was also an era of complete volcanic quiescence: Ireland, like Great Britain, has not a single Mesozoic igneous rock.

This dissimilar physical world was the home of strangely different animals and plants. The Palaeozoic corals died out and were replaced by new coral groups, including the Hexacoralla, which in contrast to the Tetracoralla (see p. 79) have septa arranged in cycles of six. This group has remained dominant ever since. Sea-urchins (Echinoidea), with their free habit of life, took the place of the fixed crinoids which previously abounded. The brachiopods, chiefly the genera *Terebratula* or lamp shell (from the resemblance to the Roman lamp) and *Rhynchonella* ("beak shell") continued, but less abundantly, their places being more or less usurped by gastropods and lamellibranchs. The principal change in the invertebrate life was provided by the Ammonites and Belemnites (see p. 123) which were extremely plentiful and varied.

The reptiles, sprung from Carboniferous and Permian amphibian ancestors, possibly as a result of the "struggle for existence" occasioned by the arid conditions of the New Red Sandstone, ousted the fish as the most important group of the vertebrates. They peopled the air, e.g. the Pterodactyls ("wing finger") or flying reptiles, the land, e.g. the Dinosaurs or "terrible lizards," and the sea (see p. 126), and achieved an extraordinary diversity and often an enormous bulk, ranging in length to 100 feet and in weight to 20 tons. Birds, with reptilian affinities, and mammals now appeared but were insignificant in size and numbers—the first British mammal, the marsupial *Microlestes* ("small beast of prey"), lived in the Mendips of southern England during Rhaetic time. True birds came in during the Cretaceous. Cycads, of unknown descent, replaced the gigantic plants of the Carboniferous coal-forests and became dominant in the plant world, though they belonged to families now wholly extinct. This "Age of Ammonites," "Age of Reptiles" and "Age of Cycads" represents a new world.

The Irish Mesozoic strata, with rare exceptions, are now confined to the north-east, principally the counties of Antrim and Londonderry (Fig. 39). Belfast Lough and the Lagan valley separate two strongly contrasted topographies; to the south, the Lower Palaeozoic slates and grits of Co. Down, to the north, in Co. Antrim, the red Triassic sandstone and marls, white Cretaceous limestone and black Tertiary basalt.

Whether the rest of Ireland from the end of Carboniferous time until the present was dry land is not definitely known; for its geological record ceases abruptly at the close of the Carboniferous epoch, save for the final episode of the Glacial Period. Eight geological periods are now wholly unrepresented (see table, p. 6). Yet with marine sediments so near as west Scotland it is difficult to believe that the sea did not at least during Lias and Cretaceous times inundate the region now occupied by the Central Plain (see pp. 120, 131).

The geological Middle Ages opened with the Triassic epoch, so called because the rocks in central Germany show a Triad or threefold division (see below). In Ireland, the Trias constitutes the bottom layer of the basalt-plateau (Fig. 40). Coming out from beneath the cliffs of chalk and basalt, it forms the more gently sloping ground, as in the richly culti-

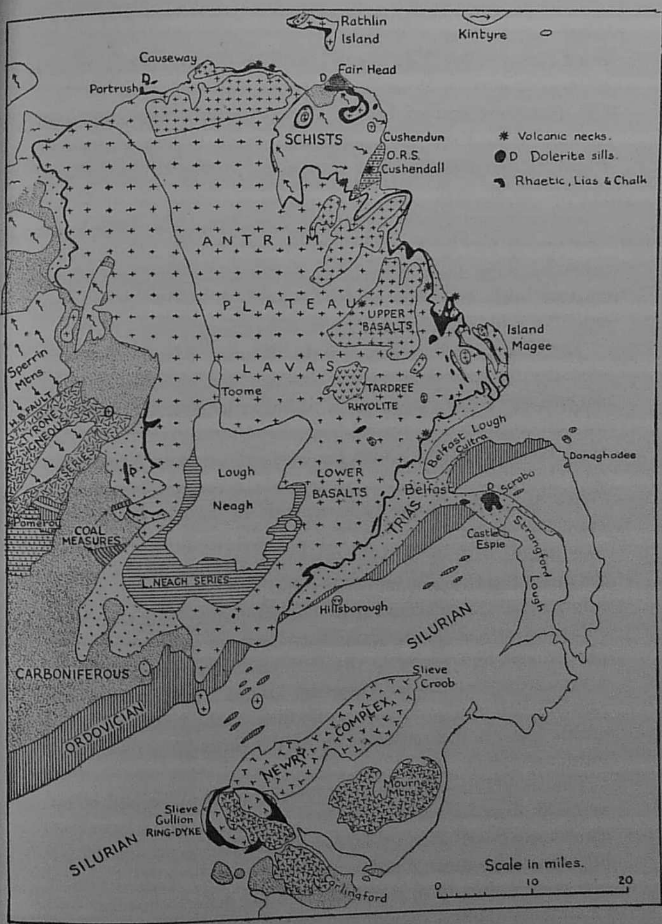



Fig. 39. Geological map of north-east Ireland (Drawn from published sources by G. L. Walker).

vated Lagan valley (Fig. 41) and north of Belfast Lough, which the sea has eroded along its soft rocks, and east of Limavady and Dungiven and of Lough Foyle, whose almost lake-like expanse arises from the Caledonian strike of the Dalradian schists on the west and the north-south strike of the basalt-plateau on the east.

Red soils near Moneymore and Cookstown also betray the presence of the Trias, while east of the plateau its red rocks account for the name of Red Bay and provide a striking colour contrast with the grey schist below and the "white limestone" above in the amphitheatre of Murlough Bay (Pl. VA).

The Trias, more especially the Keuper Marl, originally extended far beyond its present confines, and in all probability covered much of Ireland. That it did so is proved directly by an outlying patch of typical Trias sandstones, red marls and thick beds of gypsum, which has survived between Kingscourt and Carrickmacross on the borders of Cavan and Monaghan.

The Trias of the Lagan valley extends through the Dundonald Gap (Fig. 39, p. 109) where Tertiary sills cap it at Dundonald and Scrabo Hill (Fig. 41), and along Strangford Lough as far at least as Greyabbey. This valley, coincident with a post-Silurian fault, was occupied by Carboniferous beds which are still preserved at Castle Espie but elsewhere were removed in pre-Triassic and probably pre-Permian times, since Trias reposes directly on Lower Palaeozoic rocks. The valley, later partially exhumed, was apparently filled to the brim with Trias which has left the red staining of the slates as a clue to its former existence.

The Irish Trias consists in its lower part of marls and of red and pink, dune- or current-bedded sandstones. These have been extensively quarried in the face of Scrabo Hill to provide building stones, the more massive beds being easily worked and of fine grain: they have supplied stone for Belfast churches and for other buildings, including Greyabbey. The sandstones in the Lagan valley, pierced in numerous bore-holes, yield large quantities of excellent water which is used, for instance, by the various mills and by the aerated water industry.

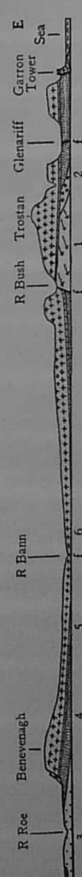



Fig. 40. Geological section through the Basalt plateau of north-east Ireland. 1. Dalradian rocks; 2. O.R.S.; 3. Carboniferous sandstone; 4. Trias sandstones and marls; 5. Chalk resting on Lias; 6. Plateau-basalts; 7. raised beach; f, fault.

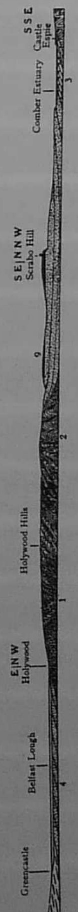



Fig. 41. Geological section from Comber, Co. Down, to Cave Hill, Belfast. 1. Ordovician; 2. Silurian; 3. Carboniferous Limestone; 4. Trias sandstone; 5. Trias (Keuper) Marls; 6. Lias clays; 7. Chalk; 8. Plateau basalts; 9. Scrabo (Tertiary) sill.

Interstratified with the massive sandstones are thinly bedded, often delicately laminated, ripple-marked and sun-cracked sandstones and sandy marls containing layers and partings of purple and green shale. Conglomerates occur at the base in certain deep borings in the Lagan valley and in places at higher horizons, as beneath the city of Armagh, on the flanks of the Dundonald valley, in the Roe valley and in Murlough Bay where Dalradian schist, quartzite and vein quartz contributed to their formation. Massive conglomerates, well exposed about Waterfoot at the mouth of Glenariff, enclose big and well-rounded blocks of quartz, quartzite, mica-schist and porphyry.

The sandstones pass upwards into a thick division of red and green mudstones traditionally termed marls. These are only slightly calcareous and consist largely of clay-minerals mixed with a high proportion of extremely fine quartz dust. At intervals they contain grey or buff sandstones which display ripple-marks, sun-cracks and casts of rock-salt crystals.

These beds are well exposed in the railway cuttings between Carrickfergus and Whitehead and explain the rich pasture lands of the Lagan valley and the hedgerows of its fields and lanes. They have been widely worked for brick-making at Kingscourt, Co. Cavan, and at Springfield, Belfast, brick being the dominant housing material in the towns and villages of the Lagan valley. The marls have sandy intercalations, greenish or grey in colour, and are interlaced in their lower and upper parts with innumerable beds or veins of white, fibrous gypsum (calcium sulphate with water). At Carrickmacross and Kingscourt the gypsum is of good quality and very thick (as has been proved by a drilling campaign in recent years) and has long been exploited both in surface and underground workings for plaster of Paris. The average output for 1943 and 1944 was 21,085 tons.

At Carrickfergus in 1850 the Marquis of Downshire in a fruitless search for coal repeated the accidental discovery of salt made in Cheshire in 1670. The marls, beneath 50 feet of glacial drift, presented the following succession in descending order:—

A. Spheroidal weathering of basalt, Giant's Causeway, Co. Antrim

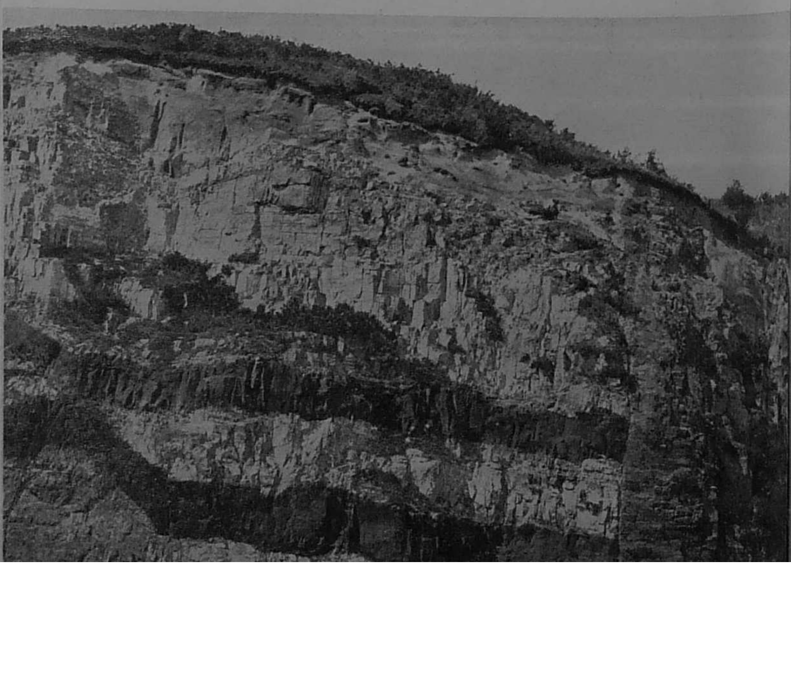
PLATE IX

B. Columnar Upper Basalt, Wishing Chair, Giant's Causeway, Co. Antrim

A. Volcanic neck, Tieveragh, Cushendall, Co. Antrim

PLATE X

B. Tertiary dyke and sills in Trias sandstone, Scrabo quarries, Co. Down





SECTION IN THE KEUPER MARLS, CARRICKFERGUS, CO. ANTRIM

| | *ft.* | *in.* |
|---|---|---|
| Red marls with thin beds of gypsum | 500 | 0 |
| Rock-salt (first bed) | 15 | 0 |
| Salt and blue band | 6 | 8 |
| Rock-salt (second bed) | 88 | 0 |
| Blue and red band | 30 | 0 |
| Rock-salt (third bed) | 39 | 0 |

Thus the Carrickfergus marls have three good beds of rock-salt, the two thicker beds as in Cheshire and Somersetshire being separated by 30 feet of marl. The salt of the middle bed was formerly mined near Carrickfergus in huge, cathedral-like caverns but is now pumped to the surface where the brine is purified and evaporated. The output of salt in 1948 amounted to 13,036 tons.

A similar bed was encountered at a depth of more than 1000 feet at Magheramorne on Larne Lough.

During the Triassic epoch a great middle sea termed Tethys girdled the earth (Fig. 42), including the present Mediterranean region: some of its detritus-free limestones are now magnificently exposed in the celebrated Dolomites of the Alps.

North of the Tethys a vast land-locked gulf covered much of Germany during the middle of the epoch; its marine limestone, the *Muschelkalk* ("mussel limestone"), separates a lower division of bright-coloured sandstones, the *Bunter* (Ger. *bunt*, variegated), from an upper division consisting mainly of marls, the *Keuper* (a German miner's term). Since the Muschelkalk sea did not reach beyond Heligoland and western Germany, the British Isles experienced throughout the whole Triassic time the continental conditions of the Bunter and the Keuper and a climate more arid than the Permian.

We visualise a vast Sahara-like desert of fairly low relief: the mountains, inherited from earlier foldings, had been by this time largely consumed and reduced to small rounded hills which continued to undergo slow attrition. Sheets of some-

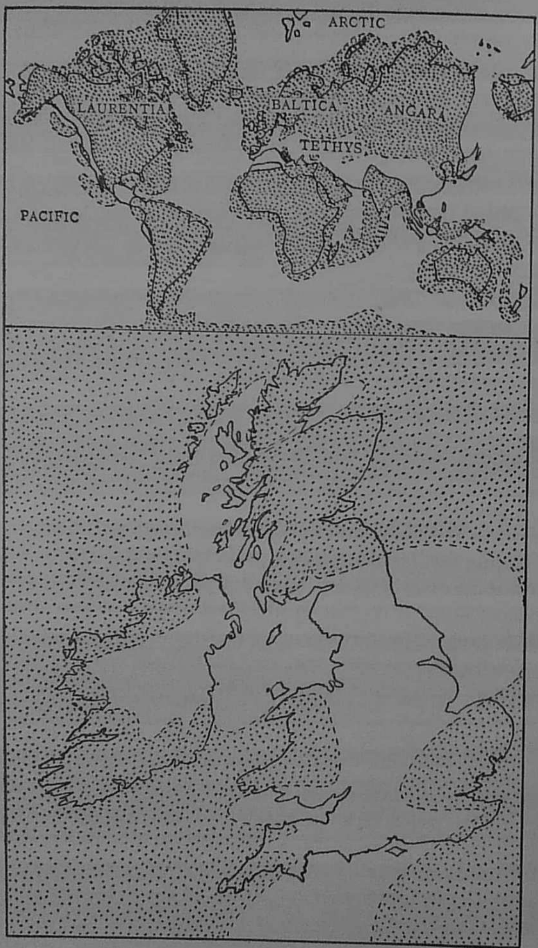



Fig. 42. Map showing the area of Trias deposition in the British Isles (inset: world geography, land dotted, and seas white).



what saline water, destitute of life, stood during the wetter periods in stagnant pools or playa lakes and arrested the clouds of red sand or dust that were blown on to them. Red was the prevalent colour of these finely laminated deposits; for under the great heat, and in the absence of vegetation which elsewhere reduces the iron, the grains of the dune-sands were coated with a thin film of red (ferric) oxide of iron.

The finer the grain, the richer the red tint, owing to ease of oxidation. Green marls which appear to indicate wetter periods occur significantly in north-east Ireland and in England at the top, of the Keuper, that is, just before the Rhaetic sea burst in and when the extreme flatness of the land allowed moist oceanic winds to induce a damp climate.

The salt-lakes, especially large in the "Midland Valley" of north-east Ireland, had salt precipitated in and around them just as it is to-day in the Salt Lake of Utah, in the Dead Sea and in the smaller and more transitory playas of America or central Asia. The waters, steaming under the grilling tropical sun, were evaporated and concentrated so that layers of salt and gypsum were left behind.

In a climate not unlike that of the present north Persia and Turkestan, with a wide daily range of temperature, hot by day and cold at night, the rocks were riven by sun and frost. Their debris, piled up against the hills, was blown across the parched plains in sand and dust storms, or was swept down during the seasons of torrential rainstorms as sands and gravels or even as masses of shingle to build delta-like fans or true deltas in the lakes. During the drier seasons, clay galls or flakes of sun-baked mud from the dried-up pans were borne by the wind or rolled by the water to be incorporated as pebbles in the accumulating strata, as seen in the quarries of Scrabo. Tracts of wet mud and silt were laid bare and were cracked irregularly by the sun to give sun-cracks or were subject to recurrent rains, whose fossilised showers or rain-pits spattered the soft sands. They were marked at Scrabo by occasional worm tracks or reptilian footprints (Pl. VI).

The sun-cracks, rain-pits, worm-casts and footprints were preserved as natural casts in the under surface of the overlying mud (marl) or sand (sandstone) which was gently wafted over and into them when the area was flooded afresh.

The hollow-faced cubes of greenish marl at Moira and Belfast (Springfield) are pseudomorphs (Gr. *pseudos*, false, *morphe*, form) after rock-salt crystals. These crystals, formed on the bottom of shallow and ephemeral bodies of water and subsequently dissolved out, left behind them casts which were later filled in and preserved as we now see them (Pl. VB).

In Keuper Marl time, when the basins had been largely filled with sediment and the hills had been worn down and levelled so that the source of the coarser detritus had been removed to a greater distance, the desert plains extended more widely over the country. Floods spread out the red laterite soils on to the plains, as they do in the west Australian deserts to-day, while in the drier seasons the dust was arrested on the damp and salt-impregnated surfaces, or was blown in clouds on to the quiet waters of the more or less permanent salt-lakes to give the reddish tint to the rock-salt and gypsum.

The beds of rock-salt may have been precipitated in a sea which gained temporary access to the Triassic basin but was subsequently cut off and converted into a "dead" sea or lake, which may have extended from north-east Ireland beneath the plain in the north of the Isle of Man to Cheshire and Somerset.

The warm, steaming waters were practically lifeless, though a few fish managed somehow to live under the unfavourable conditions. Thus the remains of *Palaeoniscus catopterus*, a small slender ganoid fish, lie crowded together and in great profusion at Rhone Hill, Dungannon. The same quarry (now abandoned and filled in) yielded a small phyllopod crustacean (*Estheria minuta*), which recalls the dry districts of South Africa where these crustacea now live through great ranges of temperature and excessive drought and occur in myriads after the rains in the wet-season pools of the sandy plains. Scorpions in the English but not the Irish Trias are a further indication of the hot climate and low rainfall of the epoch.

The causes for the desert conditions of the New Red Sandstone or of the earlier Old Red Sandstone are elusive. Though it cannot be pure coincidence that in both cases these conditions followed upon periods of mountain-building and suggest the cutting off of the moisture-laden winds by mountain barriers, the true causes are probably those which, as yet unknown, have operated in giving all parts of the world at different periods of their geological history climates strikingly different from those of the belts in which they are situated to-day.

## Chapter VIII

# THE RHAETIC AND LIAS: A TROPICAL SEA

At the end of the Trias time the oceans of the world rose once more upon the lands in a transgression rivalling that of the Lower Carboniferous. In Europe, the sea flooded a plain stretching from Scandinavia to Spain, and submerged the site of the Rhaetic Alps where its beds occur and whence they derived their name. It spread northwards from the shore of the Tethys about the Jura Mountains and initiated the epoch known in consequence as the Jurassic.

This shelf-sea, studded with islands, resembled in its shallowness the present North Sea and in its warmth the South China Sea of to-day. Since the British Isles had now been widely reduced to low-lying plains, the incoming sea flooded vast territories, at first probably temporarily and with oscillating margins. Its march was only arrested where it met obstinate rocks like the Dalradians of the west and north-west.

This earliest, Rhaetic sea was somewhat stagnant and possibly highly saline. The removal of some low barrier apparently allowed it to break into a wide region which, like the present Caspian, lay below sea-level. This explains the small and stunted forms of some of the Rhaetic molluscs, e.g. *Chlamys* (*Pecten*) *valoniensis*, and the holocaust of the "bone-bed," a thin layer of rounded fragments of fish-teeth and scales and of reptilian bones found everywhere in the British Rhaetic. Although the bone-bed may represent a periodic drying up of pools or the accumulation over a long interval when sedimentation, almost at a standstill, was unable to mask the steady accretion of organic material, it was formed more probably by a sudden marine incursion into a depressed area, so that the incoming life could not withstand the increasing salinity and the changed conditions of the waters and food supply. The shallow and land-locked sea made currents





impossible and favoured the slow accumulation on the sea-floor of a black, fetid mud, exhaling sulphuretted hydrogen, similar to that which to-day is forming at the bottom of the Black Sea.

The invading sea, which brought with it a true marine fauna that included reptiles, was the recipient of muds and sands carried down by rivers. These friable, black clays or fissile shales, with grey calcareous sandstones, comprise the lowest of the Jurassic rocks. Like the overlying Lias and Cretaceous strata, they are only preserved where the hard plateau-basalts have shielded them from later destruction. They emerge in confused slipped masses at the base of the basalt escarpment, but are otherwise too thin and too interrupted to influence the topography. They appear for a few miles north of Limavady, along Benevenagh's southern slopes, in the slips near Garron Tower, below the Coast Road just north of Larne (*in situ*), at Whitehead (railway cutting), and at Cave Hill, Belfast.

Ireland's classic exposure is in Collin Glen (4 miles south-west of Belfast), west of which the Rhaetic and the overlying Lias are both seemingly absent. In Collin Glen it includes the bone-bed (with its teeth and scales of fish) and the shales which have yielded *Pteria contorta*, *Protocardia rhaetica* and *Chlamys valoniensis*, all typical Rhaetic fossils (Fig. 44).

Besides these lamellibranchs the Irish Rhaetic has yielded gastropods, fish remains and teeth of the marine saurian *Ichthyosaurus* (see below) but no cephalopod, brachiopod, echinoderm or coral.

The marine submergence, begun in Rhaetic time, was continued during the subsequent Liassic epoch, when it probably submerged most of Ireland and even possibly the islands of the map (Fig. 43)—the word Lias, introduced into geological nomenclature by William Smith, is of uncertain derivation, having been regarded as a dialect (Somerset and Dorset) equivalent of "layers" or as derived from the Gaelic *leac*, a flat stone. Thus the Liassic sediments themselves nowhere betray the near proximity of land: the present Irish drainage, to be

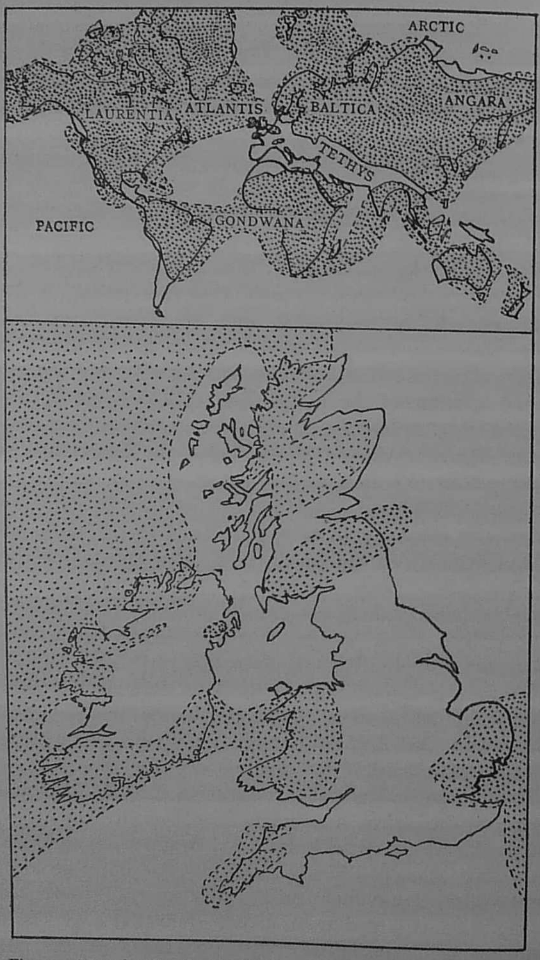



Fig. 43. Map showing the distribution of land (dotted) and sea (white) in the British Isles during Lias time (inset: world geography).



discussed in a later chapter (Ch. XI), seems to demand their presence; and earth-movements were absent between the Trias and the Rhaetic.

In Europe, the sea inundated large areas as far north as Scandinavia, north Russia and north Scotland. The invigorating inrush of the ocean, which now deeply and wholly immersed the pre-existing barriers, replaced the stagnant, unhealthy waters of the Rhaetic so that an active and abundant fauna ousted the preceding dwarfed and stunted life.

While the Lias clays of England are about 1000 feet thick and underlie some of its richest pasture lands, in Ireland their blue-black clays and more rarely compact shaly limestones are too thin and limited in extent to influence appreciably either the physical features or the agriculture. They are only visible here and there around the basalt-plateau among the landslips to which they give rise. The chief localities are Collin Glen and Cave Hill, Belfast; Whitehead, where they are largely obscured by slips; the shores of Lough Morne; Barney's Point, Island Magee; Waterloo and other places north of Larne; north of Garron Tower (includes Rhaetic with *Pteria contorta*); east side of White Park Bay in stream sections and in especially favourable circumstances peering from beneath the sandy beach; Portrush (see p. 156); and in several localities at the foot of the escarpment east of the river Roe.

The hot deserts of the Trias had now been replaced by low lands, such as the Dalradian outcrops, the O.R.S. Reeks and the Lower Palaeozoic slates of Wicklow and Down which, if they existed at all (see below), were well watered and covered with plants and discharged their muds, sands and organic debris into the sea.

This tropical sea had myriads of shells; its fossils in Ireland (Fig. 44) include the oysters *Ostrea liassica* and *Gyphaea arcuata* ("Devil's toe-nail"), the latter's massive stout shells implying local banks covered by only a few fathoms of water; the molluscs *Lima gigantea*, *Cardium ovalis* and *Hippopodium ponderosum*; and brachiopods, gastropods, crinoids, echinoderms, and an occasional coral and worm.

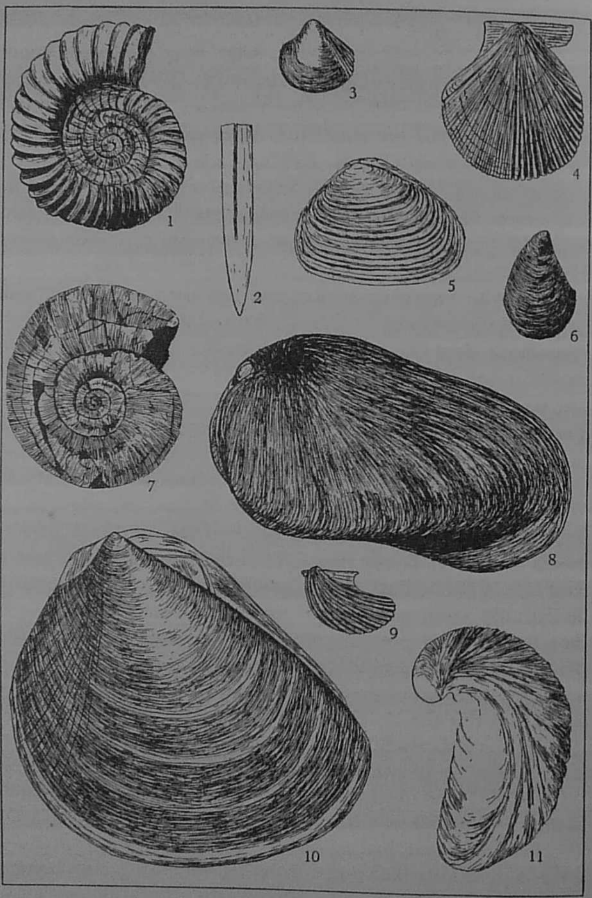



Fig. 44. Typical Rhaetic and Lias fossils of Ireland (Drawn by H. S. Black to two-thirds natural size). 1. *Scamnoceras angulatum;* 2. *Belemnites acutus;* 3. *Protocardia rhaeticum;* 4. *Chlamys (Pecten) valoniensis;* 5. *Cardinia ovalis;* 6. *Ostrea liassica;* 7. *Psiloceras planorbis;* 8. *Hippopodium ponderosum;* 9. *Avicula contorta;* 10. *Lima gigantea;* 11. *Gryphaea arcuata.*



The most important of these creatures, however, were the ammonites and belemnites of the group known as the cephalopods. The ammonite shell, named from its resemblance to the close wound horns of the Egyptian deity Ammon, was coiled in one plane like a watch-spring or like its modern relative the Nautilus. Its whorls, as the separate turns of the spiral are termed, were in cross-section elliptical, kidney-shaped, quadrate or rounded, and became rapidly bigger from the centre out-

Fig. 45. A reconstruction of an ammonite (After C. Schuchert).

wards and in some cases finally overlapped and embraced the inner whorls. Like *Orthoceras* (p. 78), it was divided by septa into numerous internal air chambers, except in part of the last or last two of these, where the body, attached by muscles to the shell, resided and had a number of arms or tentacles about its mouth (Fig. 45). The septum, no longer straight or simply curved as in the Palaeozoic *Orthoceras* or the goniatites, became increasingly intricate in its shape, probably to lend additional support to the shell. The line of junction of this plicated septum with the inner surface of the external shell is the "septal suture" or suture-line and forms a complicated pattern of curves ("saddles" and "lobes"), each of which is further frilled. The suture pattern, together with the ornamentation of the shell, such as ribs, tubercles, spines or keel, is used to diagnose the genera and species.

The thin shell with its gas-filled chambers was buoyant so that the ammonite floated readily and rose or sank in the sea with ease like the modern Nautilus, though this creature chiefly crawls along the sea-floor at varying depths. At death, the shell sank to the bottom and sediment filled its body-chamber and penetrated the septal neck into the first and probably second chamber. The remaining chambers became filled with calcium carbonate in the form of calcite or with iron sulphide (pyrites or marcasite) which was deposited from the water that obtained access to them. If the entire shell dissolved, the internal cast only remains, displaying the characteristic septal sutures which, being internal, a perfect shell cannot show.

Many ammonites, reverting to shapes their ancestors had long since abandoned, began to uncoil, the various genera entering this retrogressive phase at different times. By the Cretaceous period the uncoiling had become general, as in the case of two Irish genera, namely, the uncoiled *Baculites* (L. *baculum*, a stick) and *Scaphites* (Gr. *scaphis*, a skiff), the latter being coiled at an early stage and hooked in the adult stage. The uncoiling took place at the beginning of life, when an open spiral resulted, e.g. in *Crioceras* (Gr. *krios*, ram, *keras*, horn), at the end of life, as in *Lytoceras* (Gr. *luo*, loosen), or at the beginning and end of life, as in *Hamites* (L. *hamus*, a hook). One form, *Turrilites* (L. *turris*, a tower) from the chalk, which is coiled vertically like the gastropods, was, like them, probably a crawler and ceased to be a floater or swimmer. Since the ancestors of the ammonites had abandoned the straight shell in favour of the coiled one because this was more compact and had the supporting gas chambers directly above the animal's centre of gravity, it is not surprising to find that abrupt extinction followed the uncoiling, a fate also presaged by the great increase in size, as in the *Pachydiscus* of the Chalk, that in other groups so often preceded extinction.

The ammonites evolved from the Palaeozoic goniatites, which we have already encountered in the Carboniferous and which



had septal sutures bent into zig-zag lines. To judge by the variety of the stock, the shape of the shells and the complexity of the ornamentation, their maximum development was in the Trias.

The ammonites were extraordinarily virile when the Liassic transgression carried them into the British region for the first time—unfavourable environment probably explains their absence from the British Rhaetic sea.

Just as the trilobites and graptolites of the Lower Palaeozoic and the corals and brachiopods of the Carboniferous were used as zone-fossils, so the all-important ammonites are used for this purpose in the Lias and also, to a slight extent, in the Cretaceous rocks. The ammonites are indeed extremely delicate time-indicators; for the order showed extraordinary vitality and gave off swarm after swarm, each swarm going through a rapidly evolving cycle and dying out or inaugurating new stocks until complete extinction overtook the order at the end of the Mesozoic era. The cause of this extinction of an order which had ranged through all the seas of the world from Sachalin in east Asia to America, Europe and the Antarctic is still wrapped in mystery. This is also true of other great groups and of such forms as the *Inoceramus* which had abounded in the chalk (Fig. 48) yet died out completely in all the oceans at the end of the Cretaceous, so that not a single specimen went over into the Tertiary era.

The belemnites, the other group of Cephalopoda, consisted typically of a solid cigar-shaped guard which gave the name "belemnites" or "thunder-bolt" (Gr. *belemnon*, a dart) to the animal. A conical hollow (*alveolus*) at the blunt end received the apex of a straight shell which, with its straight sutures and a structure strikingly resembling that of *Orthoceras*, supported the body and protected its soft parts. The forward prolongation, represented among living forms by the "bone" of the cuttle-fish, is rarely preserved.

The guard which was surrounded by the mantle of the animal is made of fibrous calcite arranged radially. It is very resistant and is indeed usually the only part of the animal now remaining. It is used therefore for identification purposes according to its shape, the disposition of its superficial grooves and the depth and angle of its alveolus. Like its relative, the modern cuttle-fish or squid (*sepia*) in which the shell is reduced to a vestige (the so-called "pen"), the belemnite had a number of arms around its mouth (Fig. 46) while an ink-sac supplied ink which clouded the water so that the animal might

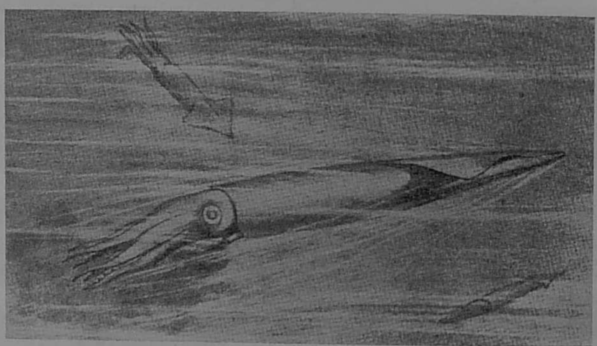


Fig. 46. A reconstruction of a belemnite (After C. Schuchert).

escape its pursuers. The ink-sac with its ink has sometimes been found fossil, though not as yet in Ireland.

The Liassic sea was also the abode of swimming reptiles. *Ichthyosaurus* (Gr. *ichthys*, fish, *sauros*, reptile), the chief of these, had a fish-like, streamlined body and paddles, made up of numerous oval or polygonal phalanges instead of normal limbs (Pl. VII). The head, furnished with spiked teeth for catching fish, was long and large with a ring of bony plates round the eye-orbits. This reptile, perfectly adapted to aquatic life, is mainly represented in the Irish Lias by detached vertebrae which are short and deeply biconcave.

*Plesiosaurus* (Gr. *plesios*, near to) resembled *Ichthyosaurus* in many ways. It had, however, short flat-ended vertebrae. Its paddle-like limbs were used like oars while those of *Ichthyosaurus* served as keels, the body being driven forward by the tail.

## Chapter IX

# THE CRETACEOUS: A DESERT SEA

The Irish Cretaceous strata emerge in a narrow ribbon of white from beneath the black lavas around the edge of the basalt-plateau (Fig. 39, p. 109). Their outcrop is appreciably wide only at Ballintoy (north Antrim), at Kilwaughter, near Larne, and at Moira, near Lisburn. Even in these localities, though covered with thin soil and short grass, the chalk does not provide open downs like those in England.

The Cretaceous rocks vary greatly in their character, thickness and fossils. Their lower part comprises the glauconitic sands, yellow sandstones and glauconitic limestone.

About the Highland Border Ridge, e.g. in Glen Ballyemon, at Murlough Bay and on Knocklayd, the chalk with its basal quartz-pebble layer or "Mulatto Stone" reposes on older rocks without the Lias and Rhaetic. At Moneymore, the Cretaceous beach contains quartzite and schist. A similar conglomerate occurs at Tamlaght, near Coagh, and on Slieve Gallion.

The most important member of the Cretaceous and the most readily recognisable of all Irish rocks is the Chalk or "white limestone" which gives its name (L. *creta*, chalk) to the formation. Distinctive and unique in the geological column, its colour and lithology contrast most forcibly with the underlying blue Lias clays and the black basalts above. It is splendidly exposed in the magnificent cliffs along the Antrim Coast Road, e.g. near Garron Point (*Gear-ran*, "white horse"), at Kenbane ("white head"), in White Park Bay and at the White Rocks, Portrush, and as a broad white band in the inland escarpments, e.g. in Lurigethan, near Cushendall. The outcrop with its dry soil and green grass is skirted by slips or talus and margined by springs of clear, limpid water, often associated with banks of moss and with porous masses of calcium carbonate termed tufa.

The chalk, usually 80 to 100 feet thick, thins to only a few feet at the head of Glenshesk and swells to 200 feet on the north coast. Even here, however, it is extremely thin compared with the 1000-1550 feet of the chalk in the Yorkshire and Lincolnshire Wolds or the Downs of south-east England.

The chalk is a hard, white limestone, much harder and denser than the chalk in the famous cliffs of Dover. Its hardness, contrary to general opinion, is seemingly unrelated to the heat from the overlying lavas, since the Yorkshire chalk which has about the same hardness lacked such metamorphism.

Its purity has caused the chalk to be quarried extensively and calcined in numerous lime-kilns and spread as top dressing over agricultural land. Large quantities are exported from Glenarm and Carnlough and are used in the manufacture of Portland cement at Magheramorne, where the chalk is mixed with Estuarine Clays (see p. 242) from the bottom of Larne Lough. The amount quarried for all purposes in the three years 1946 to 1948 averaged 237,993 tons.

The chalk is penetrated by innumerable joints, lined with yellowish calcite which occurs also in nest-like cavities and crystallised from percolating solutions after the chalk had consolidated. Numerous bands or lines of flint-nodules lie along the bedding planes or indicate the stratification where this is otherwise obscure. These black or grey flints, often with a white weathered crust, are composed of microcrystalline silica (chalcedony), many having grown in the chalk since Cretaceous time by downward percolating waters (they may be growing still). Some, however, like the Carboniferous cherts which they resemble in composition, were probably deposited contemporaneously as a gel on the sea-floor (see p. 74). Flint is the term usually reserved for the siliceous concretions of the chalk while chert is employed for those of older formations, including the Carboniferous.

At Moira, the chalk contains the curious barrel-shaped flints, with a central axial cavity and often a foot in length, which are called *paramoudras*. The word, of uncertain derivation (*peura muireach*, sea-pear?), was introduced into geological

A. Tertiary sill in indurated Liassic shales, Portrush and Skerries, Co. Antrim

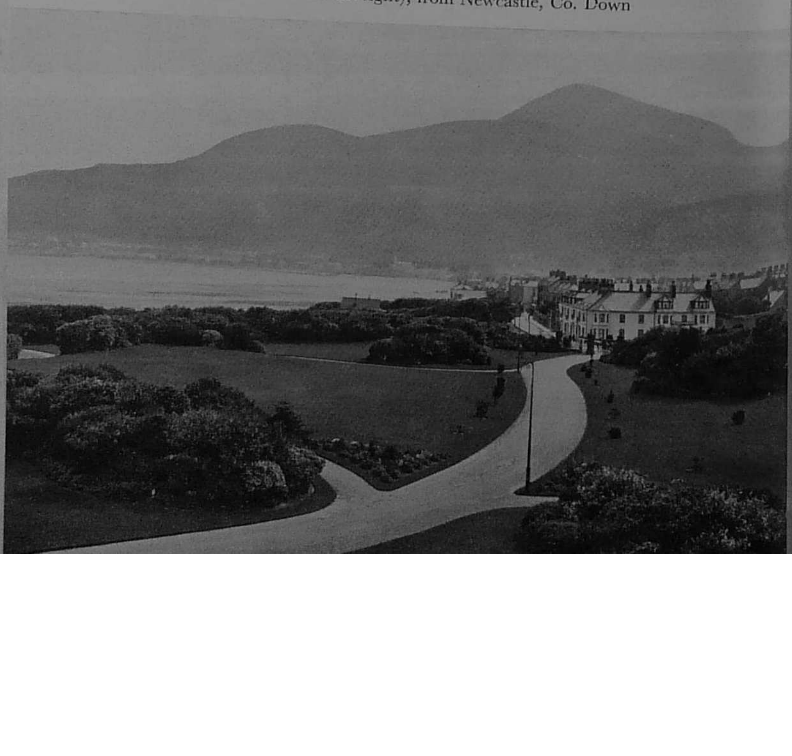
PLATE XI

B. Splitting of the Fair Head sill (D) into Carboniferous rocks (x and s) Farragandhu, Ballycastle, Co. Antrim

PLATE XII

A. North Star Dyke, Ballycastle, Co. Antrim

B. The Mourne Mountains (rounded granite hills with glacial cirque on the right), from Newcastle, Co. Down





literature over one hundred years ago by Dean Buckland, then Professor of Geology at Oxford, who was given the name by a local quarryman at Moira. They have been regarded as the Cretaceous representatives of a recent sponge (*Poterion patera*) and named *Poterion cretaceum*.

The flints have been ground for use in Staffordshire potteries and as grit for poultry-farms.

The conditions under which the Irish Cretaceous rocks were deposited must now be described. The apparently conformable passage from the Lower Lias to the Cretaceous is entirely deceptive: an enormous hiatus separates the two formations. Thousands of feet of strata present in England are missing from the Irish succession, including the Oolites which build the Cotswolds and the higher parts of the Cleveland Hills or provide the famous building-stones of Bath and Portland. Whether these beds were ever here and were later denuded or whether Ireland during this time was a land-surface, so that marine sediments of the period were not laid down, it is not yet possible to say; the widespread transgression of Jurassic times in Abyssinia, India, the Urals and other parts of Europe and the occurrence in some curtailed development of the higher horizons of the Jurassic (Oolites) in the Hebrides suggest that these seas flowed over the intervening area of north-east Ireland between west Scotland and the main region of sedimentation in England.

The higher divisions of the Lias at least were once present in Ireland; for a derived fragment of a typical Upper Lias ammonite (*Dactylioceras*) has been taken out of the Cretaceous basement conglomerate at Murlough Bay (see below), and glacial boulders, with Middle Lias fossils, have been found at Ballintoy and with Middle and Upper Lias fossils (e.g. *Hildoceras bifrons*) near Dun Laoghaire: the Pleistocene ice-sheet scraped them up from the bed of the Irish Sea and the Firth of Clyde.

During the vast interval between the Lias and the Cretaceous a shallow sea covered much of Great Britain with estuarine conditions in the north, including the coal-swamps of Brora on the east coast of Scotland, and with muddy or clear-water seas containing true coral-reefs farther south.

Towards the close of the Jurassic period subterranean movements slowly upheaved north-east Ireland and led to the removal of much rock, including in many places the Lower Lias. The Cretaceous sea in consequence deposited its sediments on a subsiding floor that cuts across the older rocks irrespective of their age or structure. They rest, for example, on Keuper Marl near Moira and Carnmoney, on Triassic conglomerate at Murlough Bay (Pl. VA) and in Glen Ballyemon and Glenariff, on Carboniferous sandstone on Slieve Gallion and in Murlough Bay, on O.R.S. in Glen Ballyemon, and on Dalradian schist in Glenaan and at Loughaveema (Fig. 53, p. 155). Present denudation is slowly exhuming this ancient peneplain.

In Cretaceous time, more particularly during the time of the Lower Chalk, a transgression, rivalling that of the Carboniferous and the Rhaetic and Lias, took place in many parts of the world. Like these transgressions, it may have been due to gentle or uniform sinkings of the land or, much more plausibly (since the transgressions are world-wide), to changes in the shape of the ocean-basins which displaced the waters over the continents. Whatever its cause, it submerged vast tracts in west and central Europe (Fig. 47) and in north Africa (east Sahara, Egypt, Cameroons, Congo), Arabia and Syria, peninsular India, Borneo, Brazil, the Atlantic and Gulf States of North America, Canada, west Greenland and Western Australia.

This clear sea of the Lower Chalk of England had a shore in north-east Ireland off which the Greensand, one of the most persistent of the Irish Cretaceous horizons, was deposited. This consists of friable sands or compact, calcareous sandstone, fine-speckled with dark-green grains of glauconite ("bluish-green"), a hydrous silicate of alumina, iron, potassium, magnesium and calcium. Similar grains are now being generated at a depth of about 100 fathoms off the shores of plutonic and metamorphic complexes where marine sedimentation is extremely slow and where dead organic matter is

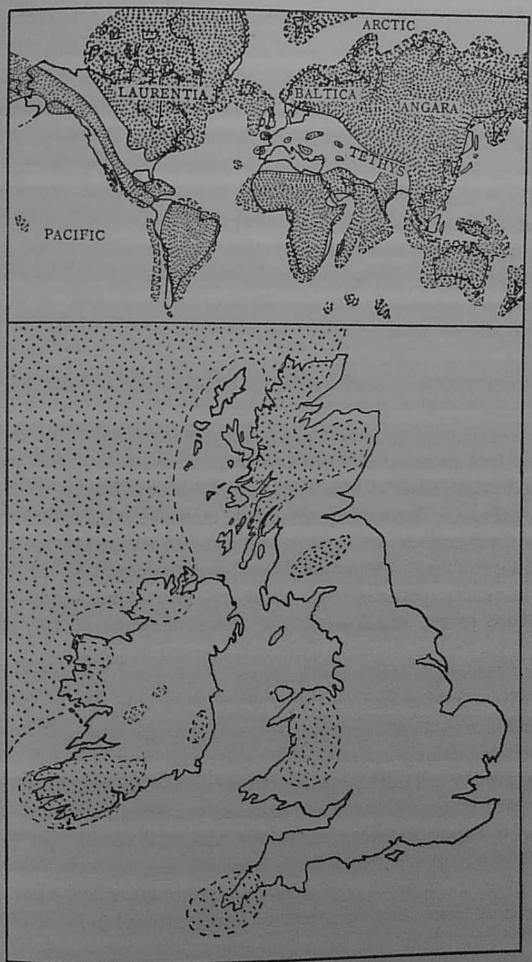



Fig. 47. The distribution of land (dotted) and sea (white) in the British Isles during Cretaceous time (inset: world geography).

acting upon the muds and converting the biotite into glauconite.

The littoral accumulations also embrace the Chloritic Sands and Chloritic Chalk which enclose some of the glauconite, erroneously identified by earlier geologists with the green mineral chlorite. In places, as at Portnakillew on the north Antrim coast, it also contains coprolites (Gr. *kopros*, dung), small, smooth-faced and brownish-black nodules about one inch in length. These consist of phosphate of lime, which was probably present in certain Cretaceous shells and at death gave rise to weak solutions of this substance which was re-deposited colloidally on the sea-floor. Their concentration on definite horizons implies either arrested sedimentation or the winnowing of the sediments by currents.

With increasing submergence and pushing-back of the shore, the shallow water or littoral sediments yielded to the pure-water conditions of the chalk which at last began to form in Ireland. The ancient sea-beach which slowly transgressed the land-surface was compacted into the conglomerate or Mulatto Stone, whose small, well-rounded pebbles of white vein-quartz, quartzite, mica-schist and Trias sandstone provide a base to the chalk when the lower divisions of the Irish Cretaceous are wanting. It is well exposed in Glen Ballyemon and Murlough Bay.

The chalk, when seen under the microscope, has no recognisable structure but consists of finely divided calcareous particles, minute spheres, *foraminifera* and fragments of other organisms (echinoids, etc.). It represents a consolidated ooze of fine calcareous mud which contained the shells of *foraminifera* (L. *foramina*, holes). These, the simplest of all the fossil protozoa, received their name from the fact that the delicate coat of the animal is pierced by numerous small openings through which tiny streamers of living protoplasm are thrust to procure food and aid locomotion. The most notable of them was *Globigerina* which, when viewed in a transparent microscope slice of the chalk, has a number of globular chambers, each chamber marking a stage in the animal's growth,



the whole clustered irregularly to resemble, as T. H. Huxley remarked, a badly grown raspberry. These extremely tiny *globigerina*, one-twentieth to one-six-hundredth of an inch in diameter, were very plentiful and were associated with shell-fragments and sponge-spicules, though the bulk of the rock is made of finely divided calcareous matter which was chemically precipitated in a sea remarkably free from land-derived material.

The purity of the chalk and the clearness of the chalk sea, together with the exaggerated importance attached to the *foraminifera*, were until recently thought to denote a deep sea and the equivalence of the chalk with the present *globigerina* ooze which occurs in depths of 1000 to 3000 fathoms. Only in this way, it was thought, could the mud-line be outstripped. But the *foraminifera* are only a small part, say one-tenth, of the chalk, and the clear-water Cretaceous organic and chemical deposits seem to have come close in-shore without an intervening mud-belt and with only the narrowest of littoral zones. The quartz and other pebbles, which are sometimes of fair size and embedded in a calcareous matrix, denote clear water up to the coast: those occasionally found in the chalk itself may have been swallowed by reptiles as an aid to digestion.

*Foraminifera*, it should be emphasised, to-day accumulate in shallow as well as in deep water, but in the former are generally masked by the sediments which the rivers carry in great bulk into the sea.

Shells in the chalk other than the *foraminifera* are largely shallow-water species, often big and thick, like those which live in disturbed seas of not more than 200 or 300 fathoms. The shape of the sea-urchins points to the same conclusion. We picture therefore a rainless desert plain of low relief fringing the northern shores of the relatively shallow chalk sea and an absence of streams which might discolour the waters or contribute mud even near the coast. Fine wind-rounded grains of quartz embedded in the chalk testify to the aridity of the surrounding land.

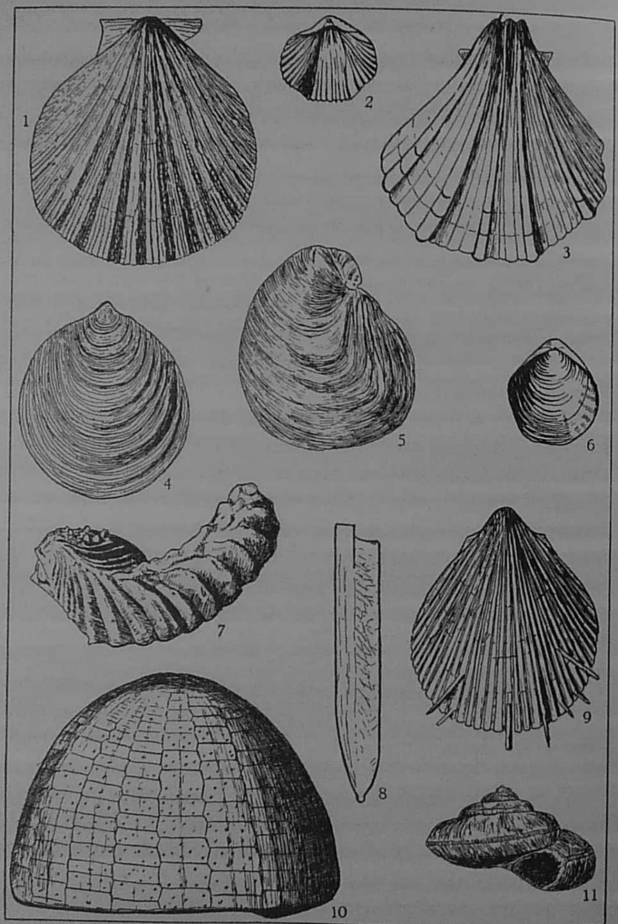


Fig. 48. Typical Irish Cretaceous fossils (Drawn by H. S. Black to two-thirds natural size). 1. *Pecten asper;* 2. *Rhynchonella octoplicata;* 3. *Pecten quinquecostatus;* 4. *Inoceramus crippsi;* 5. *Exogyra conica;* 6. *Terebratula carnea;* 7. *Alectryonia carinata;* 8. *Belemnitella mucronata;* 9. *Spondylus spinosus;* 10. *Echinocorys vulgaris;* 11. *Pleurotomaria sp.*



The fauna (Fig. 48), which in its dissimilarity to that of the Lias is a measure of the long interval between the two formations, is relatively scanty; it includes small brachiopods, e.g. *Terebratula carnea* and *Rhynchonella octoplicata*; sea-urchins, that is globular or heart-shaped bodies enclosed in "tests" composed of a number of calcareous plates fitted together at the edges, and often preserved as internal casts in flints, e.g. *Echinocorys vulgaris*; ammonites, e.g. *Pachydiscus*; and belemnites, e.g. *Belemnitella mucronata.* This most important zone-fossil, which is preserved in yellow calcite, is shaped like a pencil, with rounded apex culminating in the *mucro* or nipple-point which is rarely preserved. It has an alveolus, about one-third to one-half of the length of the guard, and a ventral slit.

Reptiles are almost unknown from the Irish chalk.

The British chalk is zoned chiefly by sea-urchins (*Holaster*, *Micraster*, *Marsupites*), brachiopods (*Terebratula*), ammonites (*Schloenbachia*) and belemnites (*Actinocamax*, *Belemnites*).

The chalk, cut off along the edge of the basalt-plateau, manifestly does not coincide in extent with the chalk sea. We can hardly doubt that this originally engulfed the greater part of Ireland as it did of Great Britain. Flints, the insoluble residue of the chalk, are found in considerable quantities in Co. Wexford and on the west coast, as in the superficial deposits of Inishbofin, Co. Galway, and of Co. Limerick, and off the coast of Co. Kerry. The sea may have been even more extensive than is represented on the map (Fig. 47) and the islands shown there may have had no existence. Drainage considerations, which will be discussed later (see p. 188), suggest that the ancestors of the modern Irish rivers, outside the north-east, began to flow on a land that appeared when the Cretaceous sediments emerged from the sea.

## CHAPTER X

# TERTIARY IGNEOUS ACTIVITY: VOLCANOES AND LAVA-PLAINS

THE Tertiary era which was ushered in at the close of the Cretaceous epoch witnessed the final fashioning of the oceans and continents, lands and seas, and mountains and plains of the world into the shapes now familiar to us. It saw, for instance, the dwindling of the Tethys and the birth and full growth of the Alps and Himalayas upon this site, and the expansion of the Atlantic Ocean to the present coasts.

At the beginning of the era, broad continental movements raised the Cretaceous sediments out of the sea and created a new land which united Ireland and Britain to the European continent. The British Isles as a whole emerged once more from beneath the waves. The Irish chalk immediately became the prey of subaerial forces and continued to be subject to them, except in the north-east where floods of lava arrested their action. This secular decay removed some of the soluble chalk and left behind the insoluble flints. These now form the layer of reddened or yellow flints, either entire or fractured, which are embedded in a stiff, dark brown or reddish clay above the eroded surface of the chalk. This clay-with-flints is usually only two feet deep but thickens to 13 feet at Magilligan and to 20 feet in pockets in the Magheramorne quarries near Larne.

Apart from some white, soapy pipe-clays and sands and lignites, of uncertain age, which fill hollows up to 200 feet wide and 100 feet deep in the Carboniferous Limestone near Caher, Co. Tipperary, and in one place north-west of Roscrea in the same county, Ireland has no representative of the Tertiary strata which play so important a role in southern Europe nor of the soft Tertiary clays, sands and limestones which, with their light soils and gravelly heaths, constitute the London





and Hampshire basins in southern England. Tertiary seas, as dredgings show, swept round the Irish coasts, but whether they submerged any part of Ireland is not known.

The Tertiary era differs markedly in its life from the Mesozoic. Cephalopods are now almost extinct, ammonites and belemnites entirely so. Brachiopods and echinoderms become much less abundant and gastropods and lamellibranchs have a familiar and modern appearance: most of the Tertiary genera still persist. The cold-blooded, egg-laying reptiles of the Mesozoic, although adapted to almost any environment and world-wide in their distribution, became wholly extinct. The removal of these fierce competitors and the increasing importance of grasses which appeared in the Eocene gave the mammals an opportunity to evolve quickly, so that the birds and mammals, the latter previously relatively few and unimportant though known as far back as the Trias, now became the dominant vertebrates: they attained their maximum size, variety and geological distribution.

Modern flowering plants in which the seeds are protected in a closed capsule or ovary (whence the name Angiosperms, "vessel seed"), though ushered in with the Lower Cretaceous or even the Jurassic in many parts of the world, e.g. southern England, Portugal, Madagascar, Greenland and North America, came in in full force in the Tertiary, together with modern insects. They ousted the cycads from first place, so that the world's vegetation assumed its present dress: the Tertiary era became the "Age of Mammals" or the "Age of Angiosperms."

The Tertiary and Quaternary, together of immense duration (cf. Table, p. 6), are, largely on the basis of the mollusca, subdivided into the following periods:—

| | |
|---|---|
| Quaternary | Holocene ("entirely recent"), Recent or Post-glacial.<br>Pleistocene ("most recent") or Ice Age. |
| Tertiary | Pliocene ("more recent").<br>Miocene ("less recent").<br>Oligocene ("few recent").<br>Eocene ("dawn of recent"). |

In Mid-Tertiary time, the world was convulsed by vast movements which raised from the geosynclinal seas the Pyrenees, Atlas, Apennines, Alps, Carpathians, Caucasus, Himalayas, the Andes, the western Cordillera of North America and the other great mountain ranges of the earth. This "Alpine storm" was unfelt in Ireland, though the "outer ripples" may have steepened the limbs and accentuated the Armorican folds and may also have upheaved Donegal, the Sperrins and Wicklows. In this way, although the structures incidental to mountain building are absent, the four successive earth-waves of cardinal importance which are traceable in the broad structure of Europe and sweep across the continent meet in Ireland in the west.

Only the earliest (or possibly two earliest) of the four Tertiary chapters interests the student of Irish geology. It chronicles the final outburst of igneous activity in the British Isles and the action of prodigious subterranean forces which in Ireland at least attained a vigour not previously experienced since Pre-Cambrian times: yielding to the O.R.S. in the rarity of its ashes and agglomerates, it far eclipsed that period in the number of its dykes and in the extent and thickness of its lavas.

The stability of the crust in the British Isles during the Mesozoic era and the complete volcanic quiescence that accompanied it find a strong contrast in the Tertiary era. Irish igneous rocks of this age include plateau-lavas, vents, dykes and sills, and plutonic masses in Barnesmore, Carlingford, Slieve Gullion and the Mournes. They complete the mountainous periphery whose volcanic records of so many periods contrast with the immunity which, for the most part, distinguished the central region throughout its geological history.

The Tertiary igneous records are exposed in deep glens, inland scarps and coastal cliffs in the north-east and may be studied with a completeness and fulness of detail that are unfortunately lacking from the earlier periods. The activity, according to its mode of expression and sequence in time, may be conveniently divided into five main episodes:



1. Outpouring of basalt-lavas.
2. Drilling of volcanic vents.
3. Injection of sills.
4. Intrusion of plutonic rocks.
5. Dyke-swarms.

### 1. Outpouring of Basalt-Lavas

The plateau-basalts of the earlier phase of the igneous cycle, though much smaller than those of the Faroes, Iceland and Greenland which occupy almost 60,000 square miles and also belong to this "Brito-Icelandic" or Thulean Province (Fig. 49), are by far the largest and most continuous in the British Isles. Extending from Pointzpass in the south to the north coast and from Belfast Lough to Lough Foyle, they cover almost 1550 square miles (Fig. 39, p. 109).

These basalt-lavas flowed out tranquilly over the chalk and devastated the country beyond the Cretaceous limits which even at this early date had probably shrunk into north-east Ireland, for the lavas now rest, as the accidents of denudation permitted, on Trias and Lower Palaeozoic rocks in the south and on Lower Carboniferous strata and Dalradian schists in the north. Where they flooded the uniformly flat country of the chalk, cumbered with its flint gravel, they baked and made porous the flints and stained them with iron-oxides leached out of the basalts by percolating waters. They also charred the trees which clothed the chalk downs and are now occasionally preserved in a scorched state, e.g. at Moira.

The magma extruded quietly and without violence since volcanic tuff and ash, the signs of explosions, are extremely rare. It gave rise to a succession of flows (Pl. VIIIA), each possibly 15 to 20 feet thick, which cooled from the initial temperature of *c.* 1100° C. to consolidate as finely crystalline basalt. This basic rock contains laths of basic plagioclase, dark augite, and sometimes green olivine; its iron-oxides, which may be 10 per cent. of the total rock, cause the basalt to weather into a rusty brown mass.

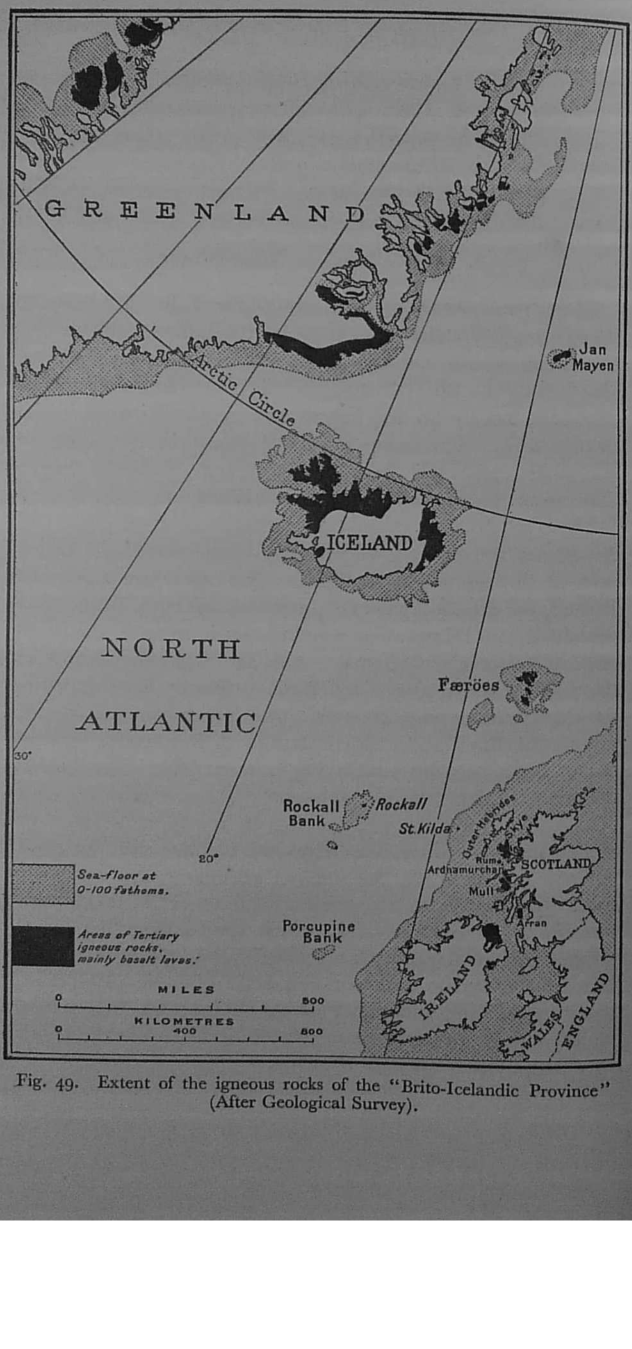



Fig. 49. Extent of the igneous rocks of the "Brito-Icelandic Province" (After Geological Survey).



The included steam, the driving force in the eruption, bubbled out of the lavas and gave them a slaggy or vesicular top like the slag from a modern iron-furnace. After the lava had crystallised but while it was still hot, volatile constituents, mainly water vapour, the latest products of the crystallising magma, forced their way into the steam-cavities, and filled or lined these with new, white or colourless minerals of calcite, quartz, or the hydrous silicates called zeolites. These almond-shaped nests of soft, silky white zeolites, for which Co. Antrim has long been famous, produce the amygdaloidal ("almond form") basalts in which the amygdales are often disposed in the direction of flow, i.e. parallel to the lower and upper surfaces of the lava (Pl. VIIIB). Sometimes the cavities are long, tapering and vertical, such "pipe-amygdales" having been generated by uprising steam, possibly when the lava flowed over wet ground or when rain fell upon its cooling surface.

The hard and compact basalt which has been extensively used for road metal and less commonly as a building stone, as in Shane's Castle and many churches and chapels on its outcrop, weathers less rapidly than the grey, amygdaloidal layers whose cellular state facilitates crumbling. This difference in the rate of weathering is responsible for the stepped outline or "trap featuring" of the basalts sometimes seen on the horizon, as north-west of Garron Tower, on Glenariff's eastern side or on Rathlin Island when viewed from the mainland. In these mural precipices, built up of successive flows, the gentle slopes of the grass-covered, slaggy layers alternate with the abrupt faces of the harder basalt. Generally speaking, however, Ulster's trap featuring is but poorly developed compared with that of Mull or Skye: rounding by the overriding ice-sheet and the thick mantle of drift and peat may explain the difference.

But even the compact lavas weather and decay. They break down along spheroidal surfaces, due probably to incipient jointing, to give the characteristic "spheroidal weathering" (Pl. IXA). The more or less hard cores of basalt are surrounded by concentric shells of various diameters which peel off in onion-like fashion or lie embedded in a brownish, gravelly or rubbly sand. If the original basalt was amygdaloidal, the sandy mass is full of zeolites which can be readily picked out as rudely shaped almonds.

The lavas were erupted not only quietly but intermittently. Their upper surfaces often had time to decompose into red soil under the tropical conditions then obtaining (see below) and before burial by the succeeding lava put a stop to such weathering. These reddened tops, which should not be mistaken for the true "interbasaltic" horizon (see below), may be seen in numerous localities, as along the path in the gorge of Glenariff or below the path which skirts the Causeway amphitheatres. They were sometimes associated with the vegetation which grew on the surface between the successive outpourings and is now preserved in pockets or thin and inconstant layers of *lignite*, e.g. above the "Organ" at the Giant's Causeway.

After the lavas had been piled up one above the other to a total thickness of many hundreds of feet, a period of volcanic quiescence intervened before the volcanicity gave rise to a second lava-pile. During this interbasaltic interval which separated Lower Basalts below from Upper Basalts above and had a long but unknown duration, the scene was transformed and the ordinary processes of attrition reasserted themselves. The lava-plains, restored to fertility under the tropical sun and seasonal rains, weathered into a bright red soil such as is forming to-day in tropical countries, for example, on the basalts in the Deccan of India and in the forests of Africa, Brazil, Mexico, Central America and the Australasian islands. The lava fields of the Lower Basalts, with their forests and poor ground drainage, rotted deeply in place. The decay was due to the decomposition of the aluminium silicates, the extensive removal of the silica, magnesia and calcium oxide, and the concentration of residues rich in ferric hydroxide and containing also aluminium hydroxide and free silica. This red laterite (L. *later*, a brick), rich in iron, shades into greenish-white



lithomarge ("stone marl") and a light coloured "bauxite" with little iron and much alumina.

A typical section of the interbasaltic zone shows:—

3. Pisolitic or "Antrim iron ore."
2. "Pavement" or lithomarge impregnated with iron oxide or ferruginous lithomarge.
1. Lithomarge.

The Antrim iron ore was formerly widely worked in Co. Antrim, as at Parkmore, Rathkenny and near Broughshane. The heaps of reddish waste on the hillsides, e.g. on either side of Glenravel, mark the line of outcrop and the sites of the old workings. The ore was exported from Belfast and from a quay, now largely destroyed, on the south shore of Red Bay, to provide a flux for the haematite ores of Cumberland and other districts in northern England. The maximum annual output was in 1880 when about 228,000 tons were mined.

The bauxite (from *Les Baux* in south France, where the mineral was first found) was formerly mined with the iron ores as at Glenarm and Straid or with lignite as at Ballintoy. The powdered bauxite was treated at Larne with caustic soda and then calcined and shipped to west Scotland, where adequate electric power was available to smelt the oxide and produce aluminium.

The laterite crops out at intervals along the junction of the Lower and Upper Basalts (Fig. 39, p. 109) and is excellently exposed in the bright-red band in the cliffs between Red Bay and Garron Tower and along the path which skirts the Causeway amphitheatres. Here the Lower Basalt has weathered spheroidally to a depth of about 20 feet. The blackish kernels, the so-called "giant's eyes," are still often intact and are interspersed in bright-red bole or a crumbling yellow mass. This is traversed by strings of red and brown iron oxide which retains clear traces of the spherical structure and of the crystals of the amygdales.

The interbasaltic zone is usually about 30 feet thick but thins where the interbasaltic drainage was good, as on Knocklayd and Benevenagh, and mounts to the exceptional thickness of 80 feet at Brown's Bay, Island Magee, and of 90 feet in the Washing Bay bore, Lough Neagh, where the interbasaltic drainage was correspondingly poor. Identical conditions of weathering, but of much shorter duration, gave the intercalations of red earth between the lavas of the Lower Basalts (see above).

The interbasaltic land nourished a vegetation which for the most part has not come down to us. Yet leaves and twigs, washed into pools or into the quiet reaches or backwashes of streams or rivers and subsequently sealed and compressed by the weight of the Upper Basalts, are still preserved in places as leaf-beds or layers of vegetable matter from which the gaseous elements, oxygen and hydrogen, have escaped. This brownish lignite (L. *lignum*, wood), with its recognisable leaf impressions and fragments of bark, is naturally associated with the iron ore and has occasionally caught fire in the iron-ore mines, sometimes smouldering for several years. It occurs in inconstant layers or pockets as at Straid, Ballypalady (in the railway cutting, one mile west of Templepatrick), Dunloy, Ballintoy (2 to 5 ft. thick), Glenarm, Rathkenny and at Craigahulliar (east of Portrush). Here a valley was eroded into the surface of the Lower Basalts and the vegetation lining the surface was washed down into the hollow—the lignite, resting on the bauxitic soil, is only a foot or so thick on the edges of the hollow but is 20 or more feet thick at the bottom (Fig. 50). Coaly plant remains may also be seen below the columns at the large landslide east of Port na Spaniagh and near the old mine in the cliffs below Portmoon House. The compressed vegetation is also fairly common as leaf-beds or as carbonised tree-trunks without true lignite.

The plants, which include eucalyptus, sequoia, pine, oak, alder and plane tree, together with a few ferns, grasses and reed-like plants, grew in a climate similar to that of southern Europe or North Africa to-day. Their state of preservation is unfortunately so unsatisfactory that their age, which is probably Eocene or Oligocene but may be later, is still uncertain.



A resumption of volcanic activity closed this period of weathering and plant growth. New lavas, now the Upper Basalts, flowed over the plant-beds but failed materially to alter their constitution, possibly because of the rapidity with which a hard crust, of low conducting power, consolidated on the underside of the lava stream.

The flows of the Upper Basalts are very fine-textured and usually much thicker than those of the lower series and less completely parted by weathered tops. They are also pronouncedly columnar, especially on the north Antrim coast, and nowhere better than in the majestic cliffs at the Giant's

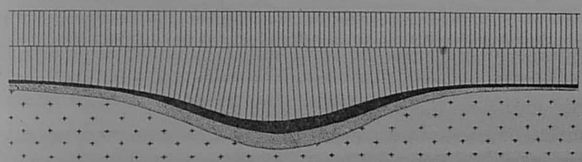


Fig. 50. Diagrammatic section through the Craigahulliar Quarry, Portrush, showing Lower Basalt (crosses) overlain by bauxite (dotted) and lignite (black) and by two lavas of the Upper Basalt.

Causeway. Here the thin flows of the Lower Basalts, up to 10 or 12 in number, each capped by its red or grey, contemporaneously weathered top, contrast with the thick, columnar lavas which tower above the red interbasaltic horizon in the successive tiers that are famous the world over (see Frontispiece). The remarkable regularity of the columns has naturally given rise to the legends of Finn ma Coul and other giants.

The Upper Basalts of the Causeway amphitheatres, in their fullest development, consist of three lavas, the first two each about 120 feet thick, the third and highest much thinner and not always preserved. Each lava has its regular, six-sided prismatic columns (well seen in the tessellated pavement of the Grand Causeway, in the "Organ," and less regularly in the "Irish Harp") and an upper series of thinner, starch-like columns overlain by a grey, slaggy and less resistant layer whose gentler slope is often masked by grass.

The regular columns, which when isolated by weathering stand out as pillars, e.g. the "Chimneys," are by no means so geometrically hexagonal as theory demands: a sixth side has often been suppressed to give the pentagonal column; four-, seven- or eight-sided columns are occasionally found—the top stone of the Wishing Chair has eight sides—and there are imperfect instances of nine- or ten-sided blocks. Cross-fracturing, in the form of ball and socket joints, convex or concave upwards, has segmented the columns into cheese-like pieces, so well seen on the Grand Causeway (Pl. IXB) or in the Organ.

We may now briefly consider how this double-tier system of columns originated. The lava cooled by slow conduction into the basalts below, by rapid radiation into the air above and began to crystallise. In the bottom layer of the lava-stream which cooled and crystallised very gradually and uniformly, the uniform contraction led to uniformly spaced centres in the contact plane and to planes of contraction which arranged themselves as hexagons. As cooling and crystallisation progressed into the warmer mass the planes extended upwards, and vertical hexagonal columns came into existence.

Meantime, the layer beneath the thin slaggy crust was exposed to variable winds and rains: it cooled less regularly and crystallised more rapidly. Its centres of crystallisation, affected by pressures and escaping gases, were less widely spaced and less regularly disposed. These wavy, starch-like columns, fractured across at short intervals, met the regular columns along a plane which, as is seen in innumerable sections, is remarkably even and sharp. The cross-jointing in the regular columns was later than the columnar fissuring and originated as a result of the rapid cooling of the outside of the columns, which caused compression here and tension in the interior.

The columnar structure is arranged at right angles to the cooling surface: in a horizontal lava therefore the columns are vertical. If, however, as at the Grand Causeway and still



more noticeably in the Craigahulliar Quarry (Fig. 50, p. 145), the lava was poured into a river-valley, the columns lean inwards.

Columns are the rule in the Upper Basalts between Ballycastle and Portrush on the north coast, but elsewhere are rare in both Upper and Lower Basalts, though they occur in the lower horizon, for instance, near Lisburn (Belshaw's quarry), at Whitehead and Retreat Castle, and on the north side of Glen Ballyemon.

The plateau-basalts preserved to us are only a fraction of those which originally existed. If we stand on the heights of Benevenagh, which frowns grimly upon the plain about Lough Foyle, or look over Down and the Lagan valley from the dominating height of Cave Hill, Belfast, it requires little imagination to appreciate that the lavas, which originally flowed with great fluidity almost like a thin oil and are now cut off abruptly in escarpments, at one time deluged much of the country beyond, including the schist-country of Inishowen and the slate-country of Down. The massive dome-shaped outlier of Knocklayd (1695) (Fig. 63, p. 176) bears eloquent testimony to the former extent of the basalts in north-east Antrim; for around it the volcanic pile has been entirely removed together with the Cretaceous platform from which it rose.

Proof that the lavas did once extend beyond their present limits is given by the outlying patches at Market Hill and Pointzpass, and at 1500 feet O.D. on the flanks of Slieve Gallion; by those that rest on the southern, lower slopes of Slieve Naglogh in the Carlingford area—these are amygdaloidal lavas, somewhat altered by the adjoining granophyre; and by those which occur near Forkhill in the Slieve Gullion area. Here the lavas, dropped down and preserved in volcanic vents, consist not only of basalt but, as is characteristic of such plutonic centres, of more acid lavas, such as andesites and trachytes. The plug of olivine-dolerite on the north slope of Camlough Mountain (west of Newry), the amygdaloidal basalt-lavas and the olivine-dolerite sill intruded into the Carboniferous and Triassic rocks at Kingscourt, Co. Cavan, and the dyke-swarms (see p. 172) point to the same conclusion. Dredgings from the floor of the Atlantic off the west of Ireland suggest that detached areas of Tertiary igneous activity occurred even in these remote regions, namely, off the coast of Kerry (basalts and altered Chalk) and on the Porcupine Bank (olivine-gabbro).

Denudation after the emission of the lavas has therefore been immense. The volcanoes have been stripped to their roots; the lava-plateau has shrunk to a mere remnant; and the tiers of lavas have been sectioned in bold, dark cliffs or mountain spurs, as in Lurigethan (*Lurrig*, the end), near Cushendall, and in the hills north of the Lagan valley which fall gradually in height towards Lough Neagh. The upper basalts have been worked back to mere caps on the highest summit, e.g. Knocklayd (1695), Divis (1567) and on Trostan (1817), the highest point in Co. Antrim and in the basalt country (Fig. 39, p. 109).

Slice after slice of lava has throughout untold ages been detached from the basalt edge by the slow processes of weathering. On the south, the recession of the long escarpment off Down has provided the contrast in geology and scenery between Down and Antrim. On the north, subsidence into the sea and the attacks of Atlantic breakers have severed the connection with Staffa, the northern end of the legendary causeway of Finn ma Coul.

The present plateau is therefore only a small relic of the vast mass of lava which formerly covered north-east Ireland. The lavas have been reduced both laterally and vertically; the surface of the country has been lowered, to judge by the Mourne granites, by possibly as much as a mile since the close of the igneous episode. We may therefore never know whether the granites had volcanoes above them which emitted surface lavas or what the initial extent of the basalts may have been.

No definite idea of the original thickness of the lavas can now be formed. The Lower Basalts are thickest at Benevenagh



(850 feet), Downhill (950 feet) and Templepatrick (720 feet) and in a bore just west of Washing Bay, Lough Neagh (991 feet). The Upper Basalts are also incomplete, and in the Washing Bay bore are 444 feet thick. There are reasons for believing that a third series of lavas at one time covered the Upper Basalts.

The interbasaltic period of lateric weathering and plant growth was not altogether one of volcanic quiescence, for acid volcanoes were then active. Their lavas, of the same composition as the granite of the Mournes that cooled underground, lie at intervals along a line running north-north-west south-south-east (e.g. Eslerstown, Kirkinriola, Cloughwater and Templepatrick) and suggest that the acid magma rose along a fissure aligned with the dyke-swarms.

Compared with the basic flows, their area is very limited (a little over 12 square miles). They form a series of rounded eminences, such as Tardree Hill (793), Carnearny Hill (1043), Browndod (868) and Scalboa Hill (764). In their appearance, as seen, for example, in Shane's Castle and in the Gateway, High Street, Antrim, and in their chemical and mineralogical composition the acid lavas present a striking contrast to the basalts. There are two main types. The first or "Tardree" variety is a pale yellow or grey porphyritic rock which at Tardree is columnar, with porphyritic crystals of clear orthoclase and blobs of transparent or smoky quartz. The second and less conspicuous type is a dark, glassy obsidian which decomposes rapidly into sand, as at Sandy Braes, east of Tardree. Fluidal rhyolite, with ribboned flow structure, and spherulitic obsidian (this is an obsidian with radiating fibres of felspar) occur south-west of Carnearny.

That these acid lavas are of interbasaltic age is proved directly by the decomposed fluidal rhyolites, eight feet thick, which were passed through on this horizon in the bore at Washing Bay and by the finding of an underlying and an apparently overlying basalt about Browndod. Indirect proof is supplied by the rhyolite pebbles in the interbasaltic detrital beds at Glenarm, at Ballypalady and a quarter of a mile south-east of Scawt Hill, and by the bipyramidal crystals of quartz derived from that rock in the bauxites.

An isolated outlier similar to the Tardree rhyolite occurs on the Ordovician slates about four miles west of Hillsborough, Co. Down.

## 2. Drilling of Volcanic Vents

Pipes drilled through the crust by the volcanic gases served as feeders for the rising basic magma. These orifices of the volcanoes which helped to build up the pile of coalescing lavas are now generally concealed beneath later lavas and with almost the sole exception of Slemish are only visible around the margin of the plateau: denudation, which reveals while it destroys, has uncovered them.

The original cones and craters have long since disappeared: the cylindrical pipes alone remain. These, with the exception of Carrick-a-rede and much less conspicuously of Carnmoney Hill, Tieveragh and the Forkhill vents, were filled with magma that has consolidated very slowly into a hard coarsely crystalline dolerite. They have therefore withstood the erosive forces and now project above the surrounding country as conical eminences or "necks."

Slemish (1437) provides the finest of these cores. Its huge fortress-like plug, oval in plan and about one mile in diameter, rises above the smooth curves of the basalt-plateau some six miles east of Ballymena.

The oval plug of Carnmoney Hill, near Glengormley, Belfast, has a volcanic agglomerate, no longer visible, on its northern side. It cuts through the Keuper Marl, Lower Lias, Chalk and Basalt (Fig. 51), the rude, massive columns, disposed as usual at right angles to the cooling surface (in this case a vertical cylinder), being arranged horizontally and radially.

The vent of Scawt Hill (1249) in the escarpment face four miles south of Glenarm (Fig. 39, p. 109) enriched the contact chalk with silica, magnesia, iron-oxides and alumina from its hot solutions and gave birth to a number of rare minerals



(larnite, scawtite). Contamination of the magma itself by the chalk produced in the outer part of the neck a hybrid zone of other minerals.

Additional necks occur at Ballygally Head, with columnar structure and metamorphism of the adjacent chalk into a crystalline marble; at Tieveragh, a cone-shaped hill in the O.R.S. above Cushendall which is strikingly prominent when viewed from the coast around Red Bay or from the surrounding country (Pl. Xa); at Tievebulliagh, seen at a distance from Cushendall; at Black Rock, north of Straidkilly Point, rudely jointed and with radiating columnar structure;

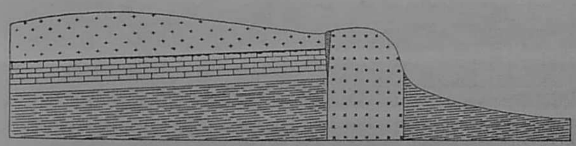


Fig. 51. Diagrammatic section through the volcanic neck of Carnmoney, Belfast (After Geological Survey), showing the neck piercing the Trias Marls (dashes), Lias clay (white), Chalk (bricks) and Plateau-basalts (crosses). The neck has ashes (dotted) on its north side.

at Bendoo, beneath the coastguard station at Ballintoy, its large radial and horizontal columns conspicuous on the north-west—it pierces the chalk; in the neighbourhood of Moira; at Scalboa and Greenisland; and very remote from the main field of lava, the plug of fresh olivine-dolerite in Dalradian hornblende-gneiss at Bunowen, south-west of Clifden, Co. Galway.

The basalt on which the ruin of Dunluce Castle is perched is probably not a volcanic neck but a solution pipe in the underlying chalk into which the basalt lavas, long consolidated, have slumped or collapsed and become broken up or brecciated. A corresponding feature is laid open in the big Ballymagarry quarry in the chalk by the roadside two miles east of Portrush.

Carrick-a-rede, on the north Antrim coast, is the best known explosive volcano in north-east Ireland (Fig. 52). Its vent, finely dissected by the sea, is choked with a coarse agglomerate of large and small blocks of black basalt, embedded in a light-coloured tuff. It emitted a bed of ash, the grey of which contrasts strikingly with the black of the basalt. This bed, about 100 feet thick near Carrick-a-rede, thins rapidly eastwards in the cliffs to disappear at Doon Point three miles away.

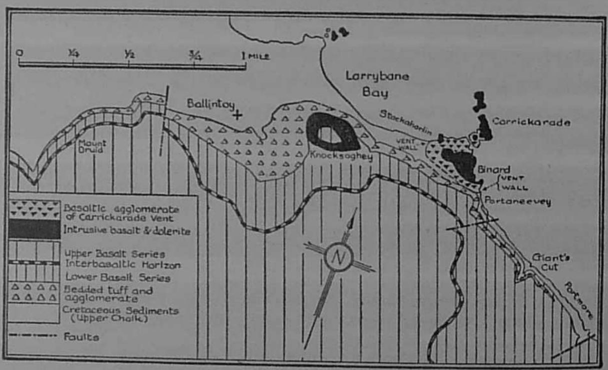



Fig. 52. Geological map of the area about Carrick-a-rede, Co. Antrim (After S. I. Tomkeieff).

The pieces of chalk, chalk-flint and wisps of Lias clay which were disgorged by the volcano and embedded in the ash prove that the explosive forces in opening the pipe drilled through Lias and Cretaceous, though neither of these is now visible above sea-level at this place.

### 3. Injection of Sills

Intrusive sills occur among other places at Kingscourt, Co. Cavan, at Scrabo Hill, Co. Down, at Ardtrea, Co. Tyrone, and in Co. Antrim at Carrickfergus (it underlies the castle), the Maidens, Fair Head, Sheep Island, Knocksoghey and Portrush. Since all these sills are situated outside the margin of the lava-



plateau, the exact place in the igneous sequence is not determinable by field evidence; we can, however, say that they preceded the dykes which traverse them.

Sir A. Geikie, who did so much to elucidate the problems connected with the Tertiary igneous history of Britain, was of the opinion that the sills were referable to the declining phase of this protracted period when the volcanic energy was largely spent. The molten rock, no longer able to penetrate the ever-thickening pile of lavas and appear at the surface, flowed underground, being guided by the bedding and other planes of least resistance in the sedimentary formations. Like the acid bosses, to be noticed presently, the sills represent some of the more deeply seated phenomena of the period. They possess the chemical and mineralogical composition of the lavas that reached the surface—the Portrush sill resembles chemically the Lower Basalts—but in their coarser texture and in other ways they betray the conditions under which they originated and solidified.

At Scrabo Hill (540) the Trias sandstone is protected by a hard dolerite cap which covers its summit and favours the growth of whins. Along its edge, as in the quarries on its eastern face, the dolerite weathers into large "nigger-heads" or spheroidal masses and breaks down into a sandy mass in which sand-martins build their nests. Several thin sills of basalt also lie along the stratification planes in the underlying Trias (Pl. XB). The magma insinuated itself under great pressure, indurated and bleached the sandstone in immediate contact, broke across the beds to higher horizons and sent off thin veins to the south. Since the "transgression" to higher horizons and the occasional tapering out of the sills are in the same direction, the source lay to the north, i.e. in the direction of the Antrim basalts.

A second sill forms the Maidens, a group of reefs about six miles off the entrance to Larne Lough. Their coarse and massive dolerite, without roof or visible base, is traversed by a well-marked sheet-jointing and by pronounced vertical joints which control the vertical sides of the islands and their direction.

A third sill, 200-250 feet thick at the face, underlies Fair Head (636), as the map shows (Fig. 29, p. 83). It breaks off to the north in a superb precipice, gashed by deep clefts coincident with joint planes or small shatter belts such as the fault plane of Grey Man's Path. Cyclopean columns, up to 50 feet in girth, run from the top to the bottom of the sill along its whole face.

The sill is an olivine dolerite or even gabbro—its crystals of augite and plagioclase range up to two inches in length—but has a basalt base at its contact with the indurated Carboniferous shale below. That the rock is intrusive and not a thick lava-flow is proved by its stepwise transgression across the Carboniferous rocks: this is admirably seen in the repeated "scarps" on its surface and along its truncated edge in Murlough Bay, and diagrammatically shown in section, Fig. 53. It is confirmed by the splitting of the sill in the cliff at Farragandoo (Pl. XIB) on the Ballycastle side of the head, where finger-like projections, about twelve in number, dovetail into the Carboniferous shales and sandstones in a remarkable way. Further proof is provided by the little patch of Carboniferous rock at the north-east corner of Lough Dhu that still adheres to the roof of the sill and has been converted by its heat into a hard, splintery or impure porcelain styled porcellanite. The contact with and baking of the chalk at the head of Murlough Bay establishes the post-Cretaceous age of the sill and throws its age forward into the Tertiary igneous cycle.

The "Lower Columnar Range," about 30 to 50 feet thick, penetrates the Carboniferous strata below the main sill and between Murlough Bay and Grey Man's Path.

The last of the sills to be considered is at Portrush and the Skerries, a chain of islands about one mile from the coast (Fig. 54). This "Portrush rock" played an important part in the controversy, the echoes of which have long since died away, that raged in the eighteenth century between the "Neptunists" and the "Vulcanists" or "Plutonists." The first, largely inspired by Werner of the School of Mines at Freiberg in Saxony, believed that basalts were laid down as

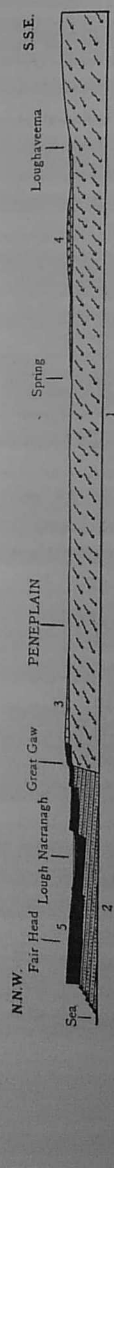



Fig. 53. Geological section showing the transgression (diagrammatic) of the Fair Head Sill, the peneplain of north-east Antrim, the geological succession about Loughaveema and the Great Gaw Fault. 1. Dalradian schist; 2. Carboniferous, with scree (black triangles) on the seaward face; 3. Chalk; 4. Plateau-basalts; 5. Fair Head Sill.

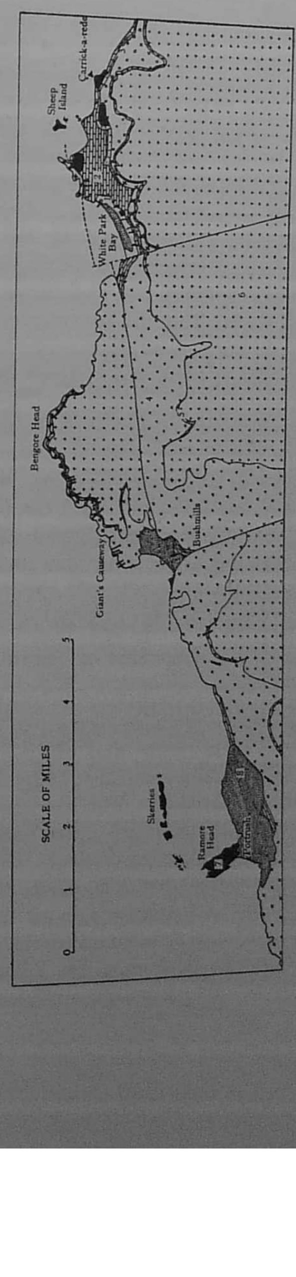



Fig. 54. Geological map of the Portrush and Giant's Causeway area (Based on Geological Survey). 1. Lias; 2. Chalk; 3. Volcanic ash bed; 4. Lower Basalts; 5. Interbasaltic Bed; 6. Upper Basalts; 7. Intrusive rocks; 8. Sand-dunes.

sediments in water; but when challenged by the vulcanists, who maintained that basalts were ancient lavas or volcanic rocks, to instance a basalt containing fossils, had to confess that such had yet to be found. It was in these circumstances that towards the end of the eighteenth century Kirwan described a "basalt" that contained ammonites (e.g. *Schlotheimia angulatum*). For a time this occurrence served as a most convincing argument against the Plutonists. Nevertheless, John Playfair of Edinburgh, a champion of the Plutonist school in Britain, differentiated from specimens forwarded to him between true basalt (or dolerite) and the fossiliferous but intensely indurated aqueous shale. Thus the Portrush rock consists of two rocks, namely, a thick sill of olivine-dolerite which becomes fine-grained along its roof and has been intruded into Lias shale. This blue porcellanite, on account of the baking it has suffered, breaks with a pronounced shell-like fracture and is so brittle that it is virtually impossible to extract the ammonites.

Because of their great hardness, both beds resist the onslaught of the waves and stand out into the sea, as Ramore Head, and strike east-west through the Skerries, where they dip southwards at about 14° and present a bold north front to the Atlantic.

## 4. Intrusion of Plutonic Rocks

Scotland had a pronounced development of local centres of eruption which probably represented the basal wrecks of big volcanoes. They were situated in Skye (Cuillins and Red Hills), Rhum, Ardnamurchan, Mull, Arran (two centres) and, possibly, in Ailsa Craig. The Irish centres were Slieve Gullion, Carlingford, Mournes (two centres) and probably Barnesmore.

The plutonic centres of Slieve Gullion, Carlingford and Mournes are separated from one another by tracts of Silurian strata so that their relative ages are not directly determinable from actual junctions or contacts (Fig. 55). There is, however, some reason for thinking, as Dr. Richey has conjectured, that the centres, while generally co-eval, worked independently and

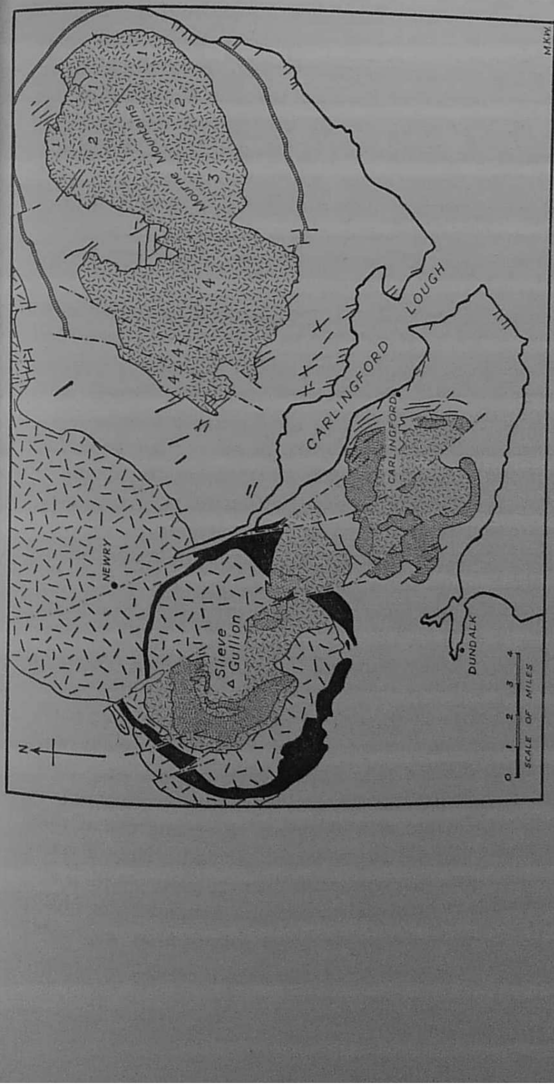



Fig. 55. Map of the igneous complexes of the Mourne and Carlingford Mountains and of Slieve Gullion (After E. H. Hatch and A. K. Wells). Newry granite, large dashes; Mourne granite, small dashes; Tertiary gabbros, stippled; granophyres, dot-dash ornament; acid ring-dyke of Slieve Gullion, black.

at somewhat different times. This may be surmised, for instance, from the individual peculiarities of the composition of the complexes; for in areas so close to one another the rock-types would be expected to be identical if the intrusions had their origins in a common magma reservoir. From the evidence of the local sequences of intrusion we may suspect that the order in which the various centres came into action may have been, first, Slieve Gullion, next Carlingford and, lastly, the Mournes. The Slieve Gullion Ring-complex was associated with volcanic phenomena and was earlier, in part at least, than a north-westerly ring-belt of intrusions that extended from the Carlingford district. The paucity of dykes of post-granite age in the Mournes may point to the late date of this granite.

The dome of Slieve Gullion (1893), situated about five miles south-west of Newry, is encircled by a ring of curving ridges and hills seven miles in diameter, which is broken across by subsequent faults, including that at Camlough (Fig. 56), and continues on the south-east into the Carlingford mountains. This magnificent ring which soars to more than 1000 feet belongs to the class of ring-dykes and is unusually simple in character. Composed of Tertiary igneous rocks, it surrounds a broad curving hollow floored by Newry granite.

Explosive gases, most probably rising from an intruding acid magma down below, drilled orifices now filled with agglomerate blocks of Newry granite, Silurian slate, and basalt lava, etc., along the south-western part of the great circular fissure sloping slightly outwards (at 70°). Later, the acid magma itself welled up the fissure to solidify as a ring-dyke of porphyritic felsite and granophyre which, in virtue of its hardness, stands out most conspicuously as a great circular wall around Slieve Gullion (Pl. XIII). The magma may have reached the surface of that day and fed a ring of volcanoes.

The Slieve Gullion area therefore represents the deeply denuded relics of a Tertiary volcano. It had a ring of vents fed by acid magma that now forms the ring-dyke. Within the ring there existed a large caldera occupied by a lake into which lavas were erupted, the lavas being followed by explosion

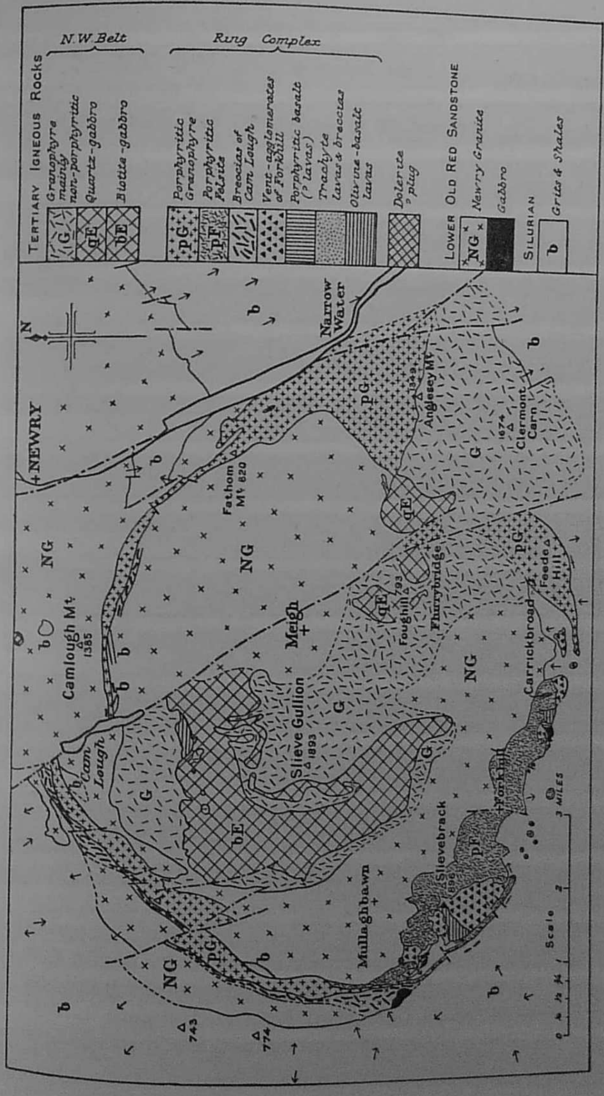



Fig. 56. Geological map of Slieve Gullion and its ring-complex (After J. E. Richey).

breccias composed of the Newry granite. The whole pile of lavas and breccias was subsequently injected by many thick dolerite sills. Relics of the lavas, breccias and sills now build Slieve Gullion itself.

A second igneous complex, of oval plan and great lithological variety, forms the higher portions of the Carlingford promontory between the bays of Carlingford and Dundalk

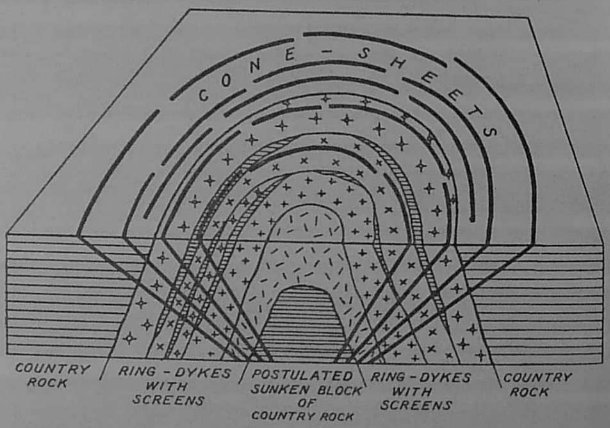



Fig. 57. Diagram to illustrate the origin of cone-sheets and ring-dykes (After J. E. Richey).

(Fig. 55). The ground rises from the Carboniferous plain to the south, and more steeply from the western shore of Carlingford Lough. The complex consists mainly of gabbro and granite which invaded Silurian grits and slates and Carboniferous Limestone, the granite generally building the base of the mountain, the gabbro the summits culminating in Slieve Foye (1933). The mountain, when viewed from a distance, appears rugged and serrated, with precipitous and craggy heights that contrast most vividly with the smooth curves of the granite on the Mourne side of Carlingford Lough. The dark lustrous gabbro, possibly of about the same age as that of the Cuillins of

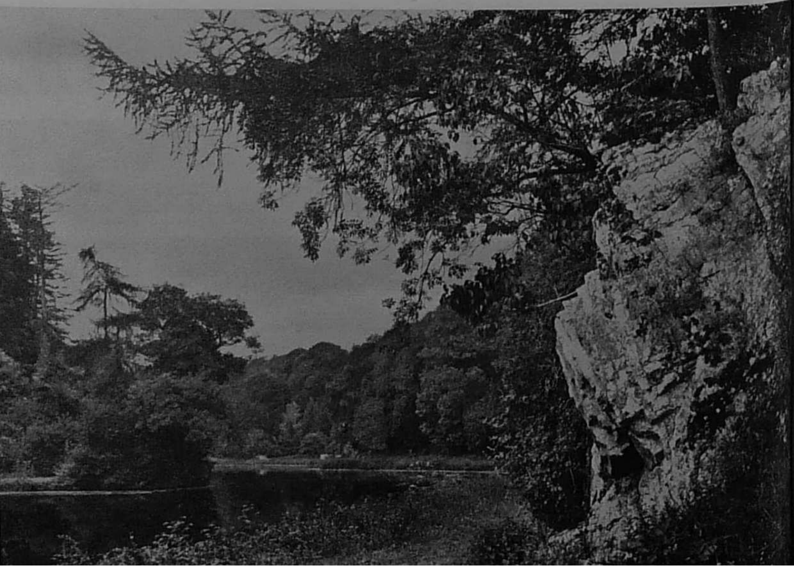


Relief model of north-east Ireland

A. The Central Plain at Ballinasloe, Co. Galway

PLATE XIV

B. Rejuvenated gorge of the R. Boyne, at Beau Parc





Skye, forms an almost continuous peripheral ring, five miles in diameter, and rises with steep or vertical sides, enclosing the low ground occupied by the grey granite and granophyre.

The gabbro in the centre of the granophyre may be a subsided portion of a roof-sheet which originally spread over the ring-complex, as in the Mournes (see below).

In contrast to Slieve Gullion, where cone-sheets are sparsely distributed, Carlingford had a large number of very fine cone-sheets of quartz-dolerite averaging 10 feet in thickness but ranging from mere veins to sheets 40 feet thick. These sheets encircle the complex, especially on the flanks of Slieve Foye and north-west of Carlingford on the east, i.e., very significantly, where their course was parallel with the general tension denoted by the dyke-swarms (see p. 169). They were injected into the earlier plutonic masses and the underlying Silurian slates and Carboniferous Limestone at approximately 40° from the horizontal, and issued from a common focus situated a few miles below the centre of the intrusive complex.

Cone-sheets and ring-dykes are the infillings of fissures due to stresses of different kinds set up in the roof of a restricted magma-reservoir of regular dome-shape. This arose as a cupola on the main magma-basin in a zone of crustal weakness. The ring-dykes, such as those of Slieve Gullion and of Carlingford, probably mark fairly closely the position and lateral extent of this local reservoir (Fig. 57).

Intense pressure at the top of this tapering magmatic column, which worked its way upwards, induced strains in the relatively thin crustal cover. They found relief by opening one or more cone-fractures so that cone-sheets, usually fine-grained, ensued. When the column subsided and the pressure was reduced, the roof tended to collapse along outwardly inclined fractures, and ring-dykes of coarse grain were intruded. Cone-sheets on a small scale have been produced experimentally by pressing a steel ball on to a piece of glass. Their regularity in all kinds of structure and country rock and their independence of pre-existing planes of weakness suggest that the fractures and injections happened suddenly or abruptly.

Cone-sheets may have originated a very few at a time as a result of subterranean explosion: like the dykes to be mentioned presently, their intrusion may have been intermittent. Their cumulative effect was obviously to cause central upheaval.

The Mourne granite which is intruded into Silurian slate (Fig. 58) attains in its 55 square miles the largest outcrop of any Tertiary granite in the British Isles. Because of its massiveness, it gives rise to a knot of high, bold and rounded domes which sweep down from a height of 2796 feet in Slieve Donard to the sea at Rostrevor and Newcastle (Pl. XXIb).

The western mass extends on all sides beneath a cover of Silurian slate that dips outwards and caps the granite in a few isolated places, e.g. on Finlieve (1888), Slievemoughanmore (1837) and Cock Mountain. These caps enable us to reconstruct the rest of the slightly dome-shaped roof over this part of the granite (Fig. 59).

The slates of the foot-hills have on all sides been baked and altered by heat from the granite magma and veined by the magma itself. Such contact metamorphism, which becomes less and less recognisable as we go from the actual junction, is by no means so severe as in the rocks of the same age and kind within the contact-aureole of the Newry granite (see p. 55). This contrast points to a difference in the temperature of the magmas or in their content of volatile gases.

The Mourne granite, prevalently grey or white, is coarsely grained so that we can detect with ease its dark quartz, its opaque, porcellanic plagioclase (albite) and its shining flakes of black biotite. The margins have numerous drusy cavities, i.e. cavities which were originally vapour or shrinkage hollows that allowed crystals to grow readily in them. The druses are now lined with perfect crystals of smoky quartz, showing the characteristic hexagonal prisms and terminal pyramids, of rectangular white albite and tiny "books" of black biotite, less commonly of topaz, fluorspar, stilbite and green beryl. Owing partly to these drusy cavities, well seen, for example, at the Diamond Rocks near Hare's Gap, the granite is used for

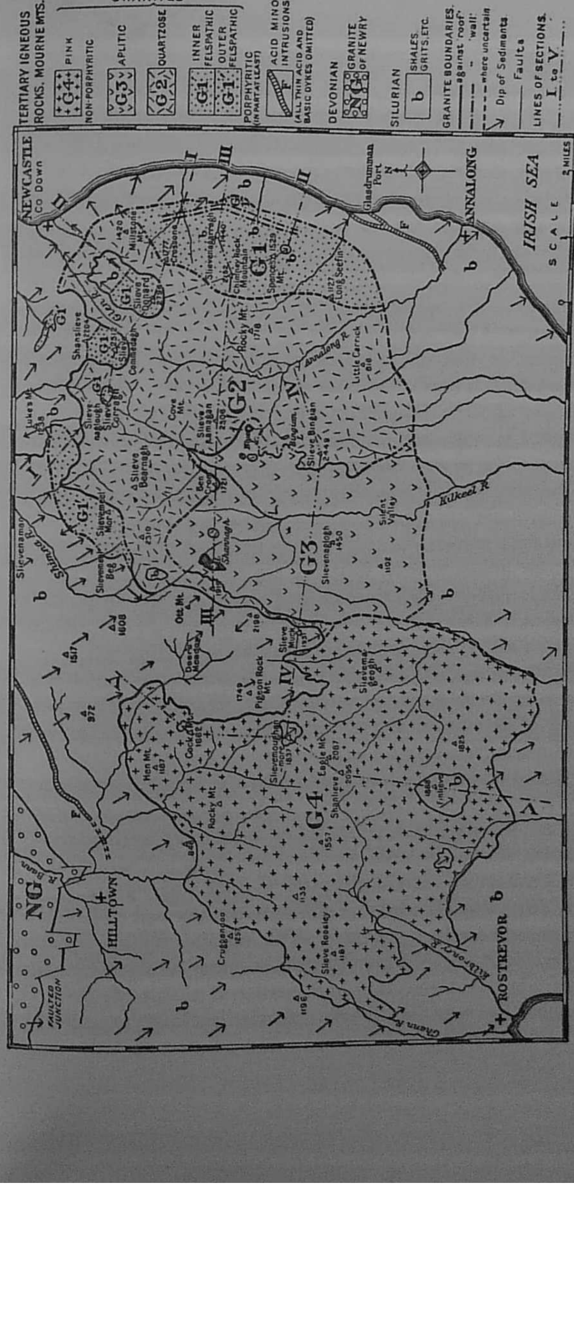



Fig. 58. Map showing the distribution of the various granites in the Mourne Mountains (After J. E. Richey).

economic purposes on a more limited scale than the older Newry granite.

Dr. Richey, to whom we are indebted for much of our knowledge of the Tertiary plutonic rocks of north-east Ireland, has shown that the Mournes consist of four varieties of granite, all bearing a strong family resemblance and possessing the same minerals in closely similar proportions yet differing slightly in their appearance and mineral composition. The western Mournes are composed of pink granite, the eastern Mournes (which are in contact with the western Mournes over a distance of two miles) of three varieties arranged one within the other in the order of their intrusion and with a marked eccentricity towards the south-west (Fig. 59). The three varieties are (*a*) a felspathic variety (G1 and G1′) which was intruded to a greater altitude than the granite of the western Mournes, (*b*) a quartzose variety (G2), distinguished by very abundant quartz, much of it so dark as to give the rock itself a characteristic appearance, and (*c*) an aplitic variety (G3) of much finer texture.

These granites were intruded separately and have well-marked, fine-grained contacts and drusy cavities near their margins. They did not apparently displace or disturb the Silurian slates, for, as indicated on the map (Fig. 58), these everywhere maintain the dip and strike directions found elsewhere in Down right up to the granite margin. Only to the south of Newcastle did the invading magma push the beds outwards or upwards by its pressure.

The granites came into position by the foundering *en masse* into a magma reservoir of a steep-sided Silurian block, shaped like an inverted flower-pot. The outwardly inclined ring-fracture, such as we have already encountered in Slieve Gullion and Carlingford, extended upwards at an angle of about 70° to a dome-shaped cross-fracture over the top and well below the ground-level of the time. This opening became greater as the block, more dense than the magma, subsided into the underlying acid reservoir and continued to subside until it reached the lower and therefore heavier layers of the reservoir.

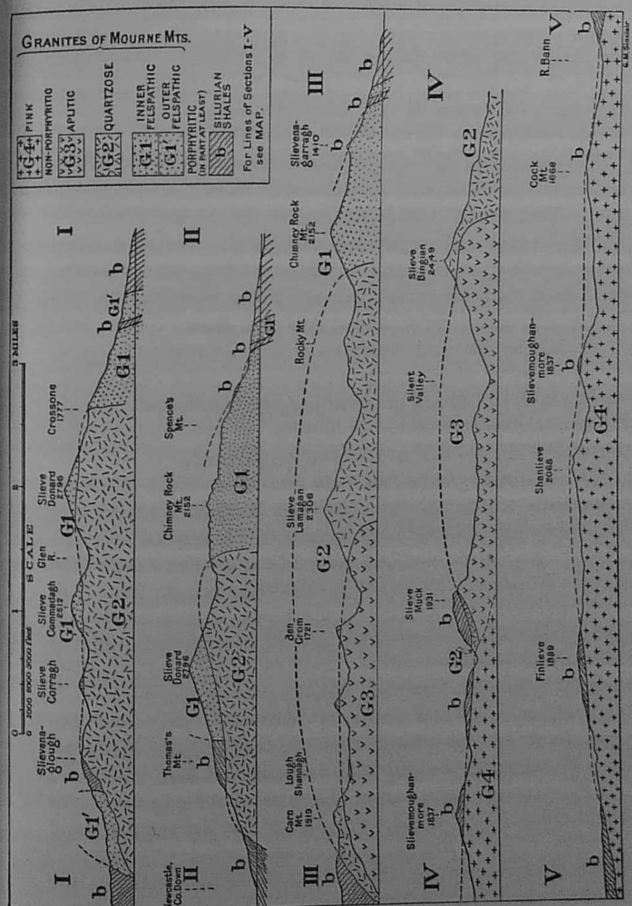


Fig. 59. Geological sections through the Mourne Mountains showing the flat roofs of the intrusions (After J. E. Richey).

While the block was sinking, the magma was being injected with great pressure into the ever-widening ring-cavity and into the still wider space below the roof. Further subsidence, following the consolidation of the felspathic granite (G1 and G1′), provided room for the later injections, each injection being encompassed by the preceding one (Fig. 59).

The granites of the eastern Mournes were therefore of the nature of ring-dykes with flat, sheet-like extensions below the roof. They cooled and crystallised in the depths beneath a slightly domed roof of Silurian slate in the case of the first granite, and of older granite in the case of the later granites. An interval between each intrusion allowed each mass to cool and solidify before the next intrusion took place.

Denudation has removed the outermost and earliest injection to its roots but has just exposed the roof of the central and latest injection. It has nowhere proceeded sufficiently deeply to uncover the floor of the granite, so the fate of the sinking block of Silurian strata can only be conjectured.

The Mourne granite has only one cone-sheet. This was apparently fed directly from the main magma reservoir and independently of the Mourne granite. This very broad cone-sheet of granophyre can be followed at intervals all round the eastern Mournes closely parallel with their margin from Hilltown to Newcastle and by Glasdrumman Port to north-west of Kilkeel. It dips everywhere inwards towards the granite at an angle of about 30° and to a focus about three miles underground. At Glasdrumman Port (north of Annalong) it is composite, i.e. its acid centre of quartz-felspar-porphyry has been intruded into a basic sheet of hornblende-olivine-basalt now found at the margins and in undigested dark patches in the light-coloured acid centre. The basic rock has incorporated and hardened part of the country slates and has acquired acid xenoliths which it brought up from below.

Granites similar to those of the Mournes occur in the Slieve Gullion and Carlingford areas.

The question of relationship in time of these plutonic intrusions to the plateau-basalts does not admit a decisive answer by direct evidence owing to the great distance which separates them. Fortunately, however, the age is ascertainable by indirect means. The Mourne granites, for example, are of the type that occurs in the demonstrably Tertiary areas of Mull, Skye and especially Arran. Basalts identical with the Antrim lavas are associated with the Slieve Gullion rocks and form part of the roof of the Carlingford granophyre. The plutonic bodies, moreover, acted as foci to the Tertiary dyke-swarms (see p. 170). In the case of the Mournes, the granite is intersected by a later set of dykes and itself cuts off abruptly at its margin an earlier set of dykes. It is inferred, therefore, on the fissure-eruption theory, that the Irish granites are not only Tertiary but of interbasaltic date and co-eval with the acid phase of activity in Co. Antrim represented by the Tardree rhyolite.



Still more detached is the isolated porphyritic granite of Barnesmore, situated astride the Barnesmore Gap in Co. Donegal (Fig. 3, p. 13). It is a red or flesh-coloured granite whose magma was rich in fluxes (water, etc.) which permitted the growth of large crystals. That it was intruded after Carboniferous times is suggested by the fact that it has furnished no pebbles to the basal Carboniferous beaches to the south-west. Its Tertiary age seems to be confirmed by its relationship to a dyke-swarm.

With the dolerite boss at Bunowen, Co. Galway, already encountered (see p. 151), the Barnesmore granite links the Tertiary igneous rocks of north-east Ireland with those of the Porcupine Bank (150 miles west of Galway), where dredgings in 500 feet of water reveal an association of gabbro and granite similar to that at Carlingford.

## 5. Dyke-Swarms

The most widespread of the Tertiary rocks in Ireland, as in Scotland, are the basic dykes. These are thickly distributed in the north and north-east and occur sporadically over Mayo, e.g. west of Killala Bay and about Castlebar, over the Curlew

Mountains and over Meath and Louth. They may be readily seen in coastal sections, e.g. in Down, at the Giant's Causeway, and as low walls running out to sea near Ballycastle and on the shores of Belfast Lough. Inland, they are largely obscured by peat and glacial drift but are visible in many quarries, including those of Scrabo Hill (Pl. XB) and Cave Hill, Belfast, and are encountered in borings for water in the Triassic sandstones of the Lagan valley. The width of the dykes is fairly uniform though less than the 10-foot average of the Scottish dykes: they vary from thin, black ribbons to dykes tens of feet thick. Forced up rapidly and along the thousands of vertical fissures by the gigantic expansive force of the volcanic gases imprisoned in the vast reservoir below, the highly mobile magma solidified between the walls of the fissures to form the dyke-system.

The dykes, which pierce rocks of most varied character, occasionally have a columnar structure at right angles to the walls or cooling surfaces, e.g. in the Camel Rock at the Giant's Causeway, but more commonly, as in the Scrabo quarries, have a platy structure parallel with the sides.

Their great resistance to atmospheric forces has usually caused them to stand out as wall-like "dykes," e.g. at the Camel Rock at the Causeway (in basalt lavas), and in the North Star Dyke, Ballycastle (in Carboniferous shales; Pl. XIIA). In Down, they frequently make slight ridges covered with whins, whence the name "whin-stone," used so often in the country for basalt. In Co. Antrim, they are sometimes the cause of waterfalls and of sudden windings of streams.

Where, as rarely happened, the country rock was the more resistant, the dyke has weathered into a ditch. The best example is furnished by Maggie's Leap, a trench about 1½ miles south-west of Newcastle which the sea has eroded along a dyke intruded into the baked slate of the contact-aureole of the Mourne granite. Other examples are the yawning chasms in the sea-cliffs of Co. Mayo and the clefts in the cliffs of the Donegal granite in Poisoned Glen, Co. Donegal, and the ditches on the granite moorland above.



While the lavas, despite their high temperatures, have baked but feebly the rocks beneath them, the hot magma which passed along the dyke fissures—probably for a very long time—has metamorphosed considerably the country rock immediately adjacent. It has converted the chalk into a white crystalline limestone or marble, as in the Cave Hill quarry, Belfast; indurated and bleached the red Triassic sandstone, as in the Scrabo quarries; baked the Carboniferous shales in the Ballycastle coalfield, as along the edge of the North Star Dyke and more remarkably in the sea-stacks of the Carrickmore Dyke; and reduced to cinders, in places as far as nine feet from the dyke, some of the coals in the old mine workings at Ballycastle.

The dykes run with remarkable persistence, e.g. for some 15 miles east of Upper Lough Erne and south-east of Enniskillen. They range as far as Skye in west Scotland to Cleveland in north-east England and to north Wales (Fig. 60). They also trend extremely regularly and uniformly between north-west and north-north-west (the North Star Dyke trends N. 15° W.) and disregard the lithology and structure of the country rock.

This independence of the nature and age of the rocks implies that the rents the magma ascended were opened by new forces which, doubtless accompanied by earthquakes, stretched the crust over wide regions. The parallelism suggests a uniformity of stress akin to tension. What these powerful forces were it is impossible to say with any certainty. They have been associated with the creation of the North Atlantic Ocean by vertical subsidence or a horizontal drift of North America away from Europe in accord with Wegener's displacement theory (see p. 47); with a "crustal creep" of Europe into the "deep" which stretches away from the Bay of Biscay; with tension in a crust weakened by a sheet-like magma lying at a depth of about 20 miles and extending possibly to Iceland and Greenland; or with pressure from the south-east which induced tension at right angles to this direction.

The swarm may have been formed by one tension. Alternatively, the dykes may have occurred successively: each time the stress, with the co-operation of the magmatic pressure, reached breaking intensity, a dyke-fissure was developed and concurrently injected; repetition of the process produced the dyke-swarm.

The fissures presumably penetrated the entire thickness of the reservoir's roof which, being in a state of tension, allowed the magma to flow both vertically and horizontally. The total width of the parallel dykes furnishes a measure of the crustal extension across their trend. Calculations in Scotland suggest that the Mull swarm implies a stretching of one mile in 26 miles or 3·8 per cent. and the Arran swarm one mile in 14·4 miles or 7 per cent. The expansion due to the Hillsborough swarm was 0·77 per cent., that of the Mourne swarm 2·51 per cent.

The concentration of this multitude of dykes into broad swarms passing through the plutonic centres (Fig. 60) manifests a genetic connection between them. The centres were places of exceptional crustal weakness occasioned by the large bodies of fluid magma, under pressure, beneath them and the locally thinned crust: this opened like a sheet of stamps being torn at the perforations.

In Scotland, the swarms pass through the plutonic centres of Skye, Mull and Arran. In Ireland, the granites of the Mournes, Carlingford, Slieve Gullion, Barnesmore and others still beneath the surface (see below) played a similar role.

The dykes of the Mourne swarm, associated with the eastern Mournes only and well seen south of Newcastle, are crowded into a belt which measures seven miles across the trend—the dykes become sparse near Newcastle and about one mile south of Annalong. The 130 dykes on the shore between these places vary in width from a few inches to 55 feet—the average may be about seven feet. Many are andesitic, so that they differ in composition from the other dyke-swarms of Tertiary age. Most are earlier than the granite and are cut off sharply at its junction. Others are later, and in traversing the granite have incorporated crystals of its quartz and felspar. The andesitic dykes, of intermediate composition, seemingly arose locally from the contamination of the (basic) basalt

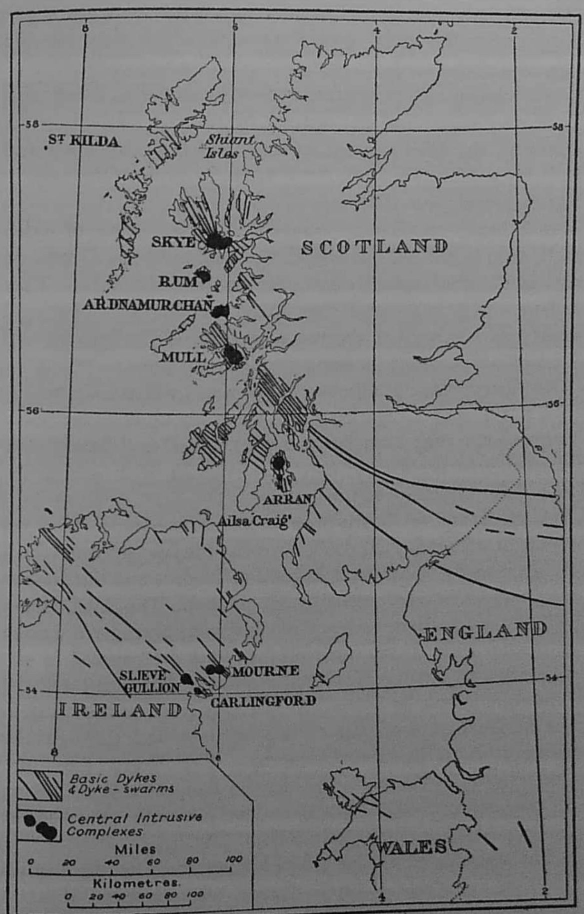



Fig. 60. Map of the Tertiary dyke-swarms and central intrusive complexes of the British Isles (After Geological Survey).

magma with the (acid) granite through which they passed: they indeed enclose large pieces of semi-digested granite.

The Mourne swarm, continuing north-westwards, is met with in Slieve Gullion and the Sperrin Mountains. In the other direction, the Irish swarms are represented in Anglesey and Carnarvonshire (Fig. 60), near Wem in Shropshire and in Lundy Island, west of Devon.

It is hardly possible to exaggerate the profusion of dykes to be seen in the old quarries in the Carboniferous Limestone and in the Silurian slates and grits about Carlingford. They belong to a great mingled swarm that stretches to the Donegal coast and is related to the two complexes of Carlingford and Slieve Gullion which lie along the dyke direction.

The Barnesmore granite too has a swarm which includes the dykes of Upper Lough Erne and those about Poisoned Glen (see above): their abundance in the Donegal and Barnesmore granites may be because they here coincide with one of the main joint directions of the granite.

A third and a fourth swarm, which converge upon no visible granite-mass, are probably related to two granites which lie respectively below the acid lavas of Tardree and the quartz-porphyry of Hillsborough (Fig. 39, p. 109). The third crosses Belfast Lough about its head and intersects Strangford Lough at Scrabo Hill, where three of the dykes are exposed in the quarries. It cuts the north coast between Fair Head and the Causeway where its dykes conspicuously traverse the lavas in the various amphitheatres; two of them cut through the columns of the Grand Causeway. The North Star and Carrickmore dykes and others in the Ballycastle area belong to this swarm. The fourth swarm cuts the Down coast between Ardglass and St. John's Point (Fig. 61).

The abundance of the dykes led naturally to the fissure-eruption hypothesis of Sir A. Geikie, who suggested that, as in present day Hawaii and Iceland, the magma in the dykes fed the lava-flows. Later investigations have raised doubts as to the correctness of this view. In the first place, dykes are nowhere in Ireland and rarely elsewhere seen to feed a

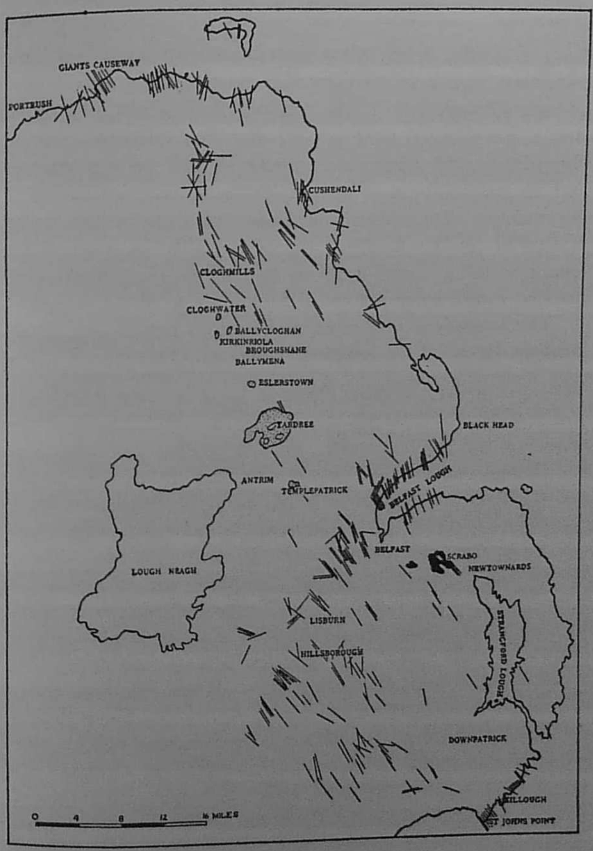



Fig. 61. Map of the Tardree and Hillsborough dyke-swarms with the aligned acid rocks between Templepatrick and Cloghwater (After J. K. Charlesworth and J. J. Hartley).

flow; secondly, dykes, when associated with lavas, are later than these, and, as in the Cave Hill quarry, Belfast, invariably go right through them to the surface; and thirdly, the dyke-swarms are focussed upon pre-existing local plutonic centres. Nevertheless, the negligible amount of tuff or agglomerate and the insignificance of any explosive activity may warrant the retention of the fissures as feeders of some of the lavas. Numerous small volcanoes, aligned possibly in rows along fissures running north-west south-east, supplemented their activity, especially probably in the later part of the period.

This tremendous vulcanism and igneous action had repercussions which will be outlined in the next chapter.

## Chapter XI

# TERTIARY DENUDATION: RIVER SCULPTURE

### 1. Earth-Movements

The Cainozoic era in north-east Ireland, after the outpouring of the lavas and the close of the igneous cycle about forty or fifty million years ago, was one of earth-movement and denudation.

The uprise of the gigantic masses of magma which built up the basalt-plateau in its original horizontal dimensions and vertical depth left the crust above the reservoir inadequately supported so that it fell in. The collapse was probably augmented by the magma's diminished pressure upon its roof and its solidification within its basin, since crystallisation involves a reduction of volume. It was aided by a general cooling resulting from the loss of heat brought up by the lavas and by the increased density of the crust due to the basic intrusions and extrusions.

The crustal adjustment assumed the form of block-faulting and gentle folding and warping. The basalt and the underlying chalk are seen all round the margin of the basalt-plateau, e.g. at Cave Hill on the south, along the Coast Road on the east, at the Causeway on the north and in the Roe valley on the west, to be gently tilted towards a centre about Lough Neagh (Fig. 40, p. 111). The steep scarps face outwards, the long dip slopes incline inwards. This sagging was accompanied by abrupt and numerous dislocations. The friction in their planes, often immense, is now recognisable in the grooving or polishing of the rocks termed slickenside, in the smashing of the rocks into angular fragments or fault-breccia, magnificently displayed in the chalk quarries at Ballintoy Harbour, and in the curling down of the rocks into the fault on the upthrow side and their curling up on the downthrow side.

Thus the chalk south of Ballintoy Harbour is roughly horizontal, but is tilted at an increasing angle towards the north until it is almost vertical. The basalt on the north or down-throw side is similarly dragged up towards the fault so that the columnar lavas between the harbour and White Park Bay are canted over to the north in the conical raised-beach sea-stacks (Fig. 62).

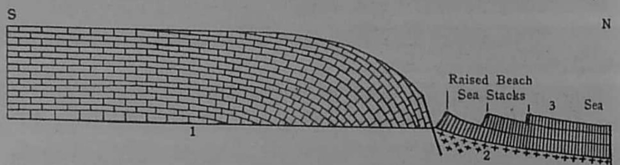



Fig. 62. Diagrammatic section showing fault-drag, Ballintoy Harbour, Co. Antrim. 1. Chalk; 2. Lower Basalts; 3. Upper Basalts.

The rocks along the north Antrim coast break off along east-west faults, for example, between the Bush estuary and Ballintoy Harbour (Fig. 54, p. 155). Rathlin Island, composed of black basalt resting on white chalk, is but a piece of the basalt-plateau isolated between downfaulted strips to the north and south.

Many north-south faults traverse the rocks on the north coast, as on Rathlin Island, the black basalts being thrown

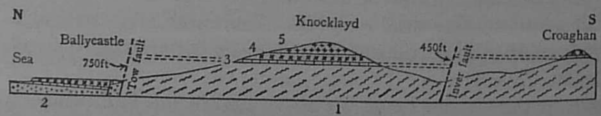
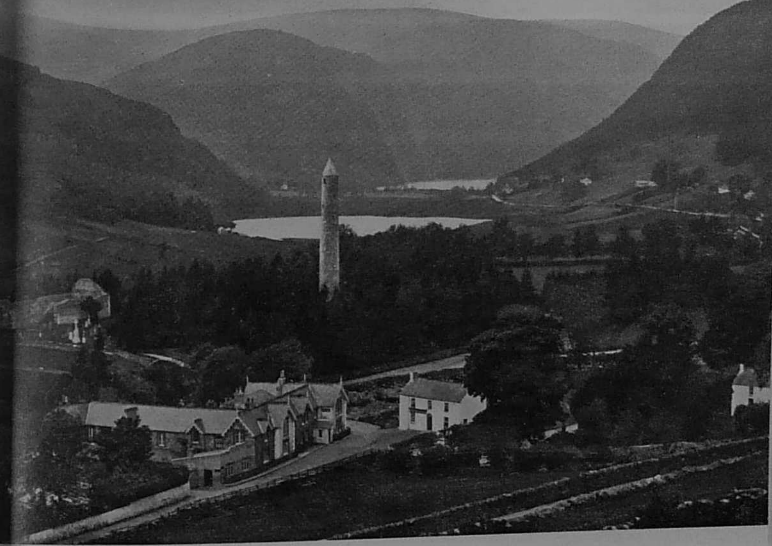



Fig. 63. Geological section through Ballycastle, Knocklayd and Croaghan showing Tow and Inver faults. 1. Dalradian schist; 2. Carboniferous sandstone; 3. Chalk; 4. Lower Basalts; 5. Upper Basalt (with Inter-basaltic bed, not marked, at base).

down in several places against the white chalk as seen from the mainland. Similar faults occur east and west of Kenbane and at Portbraddan, White Park Bay (Fig. 54). The basalt is faulted down against the schist east of Dungiven and also west of Knocklayd by the Tow Fault (throw about 700 feet), which has shattered the chalk in the quarry just south of Ballycastle (Fig. 63).

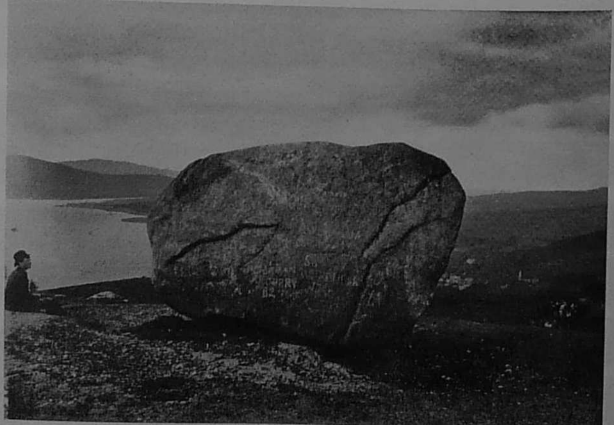


A. Glendalough, Co. Wicklow, a typical U-valley

PLATE XV

B. View into cirque in which lies Lough Avoonane, Brandon, Co. Kerry
(Photo, A. W. Stelfox)

A. Drumlin scenery, near Lisbellaw, Co. Fermanagh
(Photo, J. C. Harper)



B. Cloughmore, an erratic of (pink) Mourne granite on Silurian rocks, above Rostrevor, Co. Down



The basalt has also been lowered into the North Channel along a series of strike faults (i.e. faults which run parallel with the strike of the beds) which, sloping or *hading* against the dip, cause the outcrops to be repeated several times (Fig. 64). They bring up the soft Triassic strata along a strip which the sea has eroded into Larne Lough. Faults likewise throw down the beds along the lower Bann valley (Fig. 40, p. 111) and about Lough Neagh (Fig. 30, p. 90).

A suite of east-north-east faults traverses north-east Ireland along the ancient Caledonian strike lines. One of them runs along the valleys of the Larne Water and Six Mile Water and brings up the chalk by about 500 feet in the heart of the basalt country at Templepatrick—its continuation west of Lough Neagh may be the fault which runs along the north side of the Coal Island coalfield (p. 90).

In the Lower Palaeozoic terrain of Down, Armagh and Louth, as in the Midland Valley of Scotland, the Tertiary faults often trend with the dyke-swarms. The Newry fault, for instance, which runs along the valley of the Newry River with a large downthrow to the west, continues northwards by the steep face at Goraghwood station under Lough Neagh and along the lower Bann, while a branch fault wrenches the boundaries of the Carlingford igneous mass (Pl. XIII). A parallel fault has shifted the Slieve Gullion Ring-dyke by one mile about Camlough (Fig. 56, p. 159)

Dislocations of this age bound the tongues of Carboniferous strata in the Owenkillew basin (about Gortin) and in the upper Roe valley. They also fractured the rocks in Co. Donegal and displaced the boundaries of the Barnesmore granite: the wild Barnesmore Gap is a notable example of a fault valley. Farther south, they contributed to the final break-up of the ancient land-mass (St. George's Land) that embraced the Welsh and Wicklow Mountains.

These movements broke up the basalt-plateau extending northwards to Iceland, and by admitting the North Atlantic into the region cut Ireland off on the north and along the North Channel. They also dictate the course of many rivers

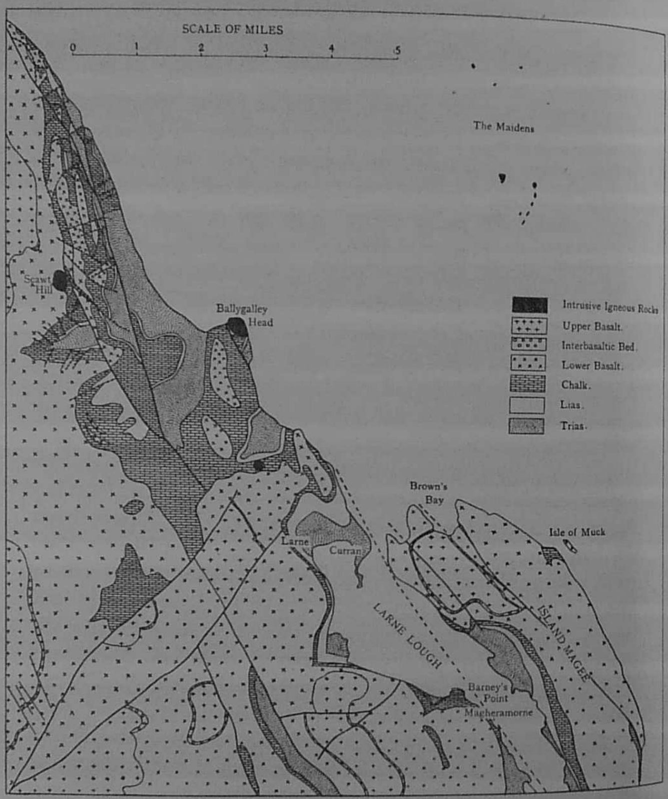



Fig. 64. Strike faults dropping the Antrim plateau into the North Channel (Based on Geological Survey).



in north-east Ireland, such as the Six Mile Water and Larne Water, the upper Bush and the lower part of the Newry River. They also help to explain the depression of Lough Foyle to the north of the uplifted Sperrin Mountains. Some idea of the influence of this youthful block-faulting upon the scenery in the north-east may be obtained by carefully inspecting Plate XIII.

Tertiary movements also led to the formation of Lough Neagh. This broad expanse of fresh-water in the midst of the basalts, the biggest lake in the British Isles (153 sq. miles), is surrounded by extensive boggy flats and low shelving shores which accord with the shallowness of the lough—the depth averages less than 40 feet as the submerged contours or isobaths show (Fig. 65). This lake basin was produced by a sagging, which dropped the chalk from 1500 feet above sea-level on the eastern shoulder of Slieve Gullion to probably about 2200 feet below sea-level in the Washing Bay bore (Fig. 30, p. 90). The sagging and faulting began almost immediately after the outpouring of the basalts, even indeed during the interbasaltic interval, and continuing interruptedly until fairly recent times, have led to the drowning of the stream-channels on its floor.

The initial sinking is recorded in the Lough Neagh clays which, buried beneath thick drift, alluvium or peat, are exposed chiefly in workings for tiles and pottery. They mount gently from the southern half of the lough (Fig. 39, p. 109) into the low land around to 150 feet above sea-level, and underlie about 180 square miles of country. Blue-grey or white in colour, they consist chiefly of kaolin or china clay with intercalated sands and lignites. The latter, up to 25 feet thick at Sandy Bay, is concentrated locally and on various horizons, and may represent "pine rafts" which floated out into the lake and finally became water-logged and sank to the bottom among the ironstone nodules ("petrified potatoes") with which they now occur.

The clays were laid down in a lake probably twice the size of the present Lough Neagh. Its shells (*Paludina*, *Unio*) suggest an Eocene age, though the plants indicate rather the

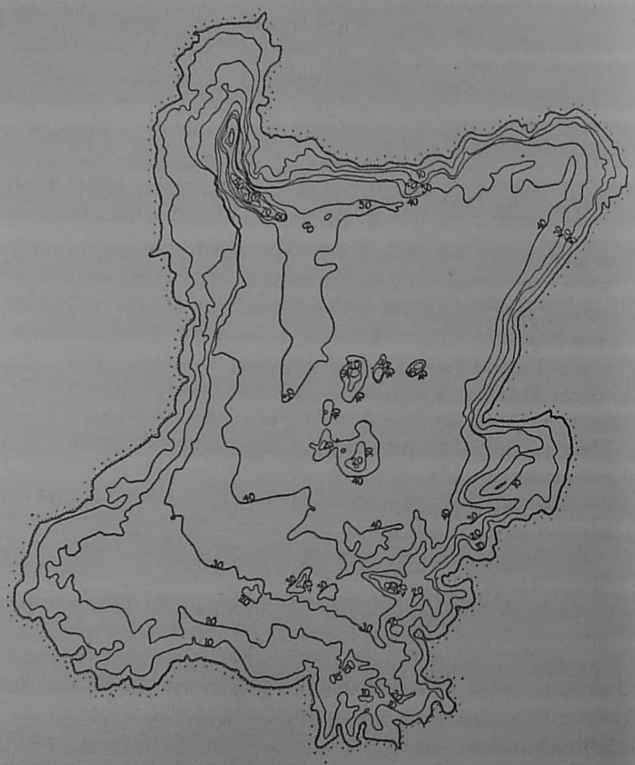


Fig. 65. Isobaths of Lough Neagh (Based upon the Admiralty Chart). The isobaths (at ten-foot intervals) show the general flatness of the floor of the lake and the position of the narrow channel which descends to 102 feet below the surface of the lake.



Upper Oligocene. The occurrence of the clays immediately upon a bed of lithomarge 71 feet thick, which rests in turn upon the Upper Basalt, places them directly after the basalt flows; their richness in kaolin proves their derivation from the "post-basaltic" lithomarge.

The maximum thickness of the clays is not known, but in the Washing Bay bore they were 1148 feet thick (Fig. 30, p. 90). The basalt-plateau during the time of their deposition was already being warped: the lithomarge was being stripped off the uplands and being dumped down by streams on the slowly sinking lake-bottom.

The silicified wood, popularly supposed to be petrified by the waters of the present lough, is embedded in the Lough Neagh clays and in the overlying drift the ice made from them. Hot solutions, similar to the geysers of present-day Iceland, followed the volcanic eruptions and converted the wood into its present state, replacing the original tissue particle by particle so that the structure is still well preserved. The wood is chiefly coniferous, belonging to the genus *Sequoia*, of which the well-known *Wellingtonia* or Redwood is a living example.

## 2. Planation and Rejuvenation

The geological forces had by the opening of the Tertiary era roughed out the block from which the sea, rivers and atmospheric weathering later and with extreme slowness fashioned the present Irish topography: this sculpture is essentially a Tertiary event.

In their ceaseless attack, rivers ultimately attain a concave graded curve, the "profile of equilibrium," which rises imperceptibly in the lower reaches and slightly more steeply towards the source. In extreme old age the rivers are graded from source to mouth and meander sluggishly, their geological work almost or wholly accomplished.

Collectively, with the aid of rain and the weathering processes, they lower their watersheds and produce an almost featureless plain, the "peneplain" or "peneplane" ("almost plain"). This surface of subaerial wasting rises from the ancient shores in accord with the river curves, its few residual hills or mountains, termed monadnocks, serving to gauge to some extent past denudation.

Complete planation depends upon a constant sea-level which provides the base-level below which rivers cannot erode. But sea-level, as we have seen, is not immutable over long periods: it is affected by a wide continental uplift or a lowering of the sea. Either of these gives the rivers a new lease of life ("rejuvenation") so that erosion is once more active.

Throughout Ireland's Tertiary history periods of rest and planation have alternated with periods of movement and rejuvenation. At least four peneplains, in various stages of development, are traceable throughout the country. Each planation was terminated by bodily uplift of the land or by world-wide lowering of sea-level which gave the rivers renewed vigour by steepening their gradients and allowing them partially to dissect the peneplains: this is brought out by the longitudinal profiles of Irish rivers. Such rejuvenated rivers have all the signs of youth, namely gorges, waterfalls and narrow V-shaped cross-sections.

The ages of the several planations and rejuvenations, the elements in this multicycle, are not directly ascertainable in Ireland, since Tertiary sediments with which they could be linked are virtually unknown. That they are later than the Cretaceous has already been shown, while their post-basaltic age in the region of Tertiary igneous activity is obvious. It is proved by the dykes in the sides of the Glens of Antrim and in Poisoned Glen, Co. Donegal, which could only have been injected before the glens were eroded; for otherwise they would have filled the glens instead of maintaining a straight course across them.

Since Ireland, in contrast to England and Wales and still more to Scotland, has few wide uplands above 1000 feet, the highest (and therefore the oldest) of the peneplains still preserved to us above 2000 feet has been largely destroyed by destructive forces working at lower levels. Relicts of the plain



which have survived later dissection and demolition are, however, traceable above the cirques or *cums* of Co. Kerry and the Wicklow Mountains: their age may be late Miocene.

The middle peneplains are well preserved in every upland; they rise from a height of about 600 (to 800) and above 1000 feet. In the Wicklow Mountains, they form the Vartry plateau on the east and the valley of the upper Liffey on the west, and elsewhere occur where the granite has been worn down to a mature plateau. The 600-800 plain is well developed south of a line from Cahore Point, Co. Wicklow, to Skibbereen and south of the Comeraghs and Knockmealdowns. In the Mournes, the plains are preserved in the Deer's Meadow below the source of the River Bann, and at the head of the Silent Valley, as seen, for example, from the dam of the reservoir. In the basalt-plateau, they are well displayed at the head of Glenshesk and Glenarm—Slemish and Agnews Hill are monadnocks—and in north-east Antrim where they have uncovered the "fossil" pre-Cretaceous peneplain (see p. 130). The lower one forms the plain of the Six Towns between Omagh and Draperstown and that south of Slieve Gullion between Goraghwood and Dundalk. With its higher associate, it is seen at Slieve Beagh, Co. Monaghan, and is traceable with ease through the west and south of Ireland. Some of these plains and rejuvenations are readily recognisable in the photograph (Pl. XIII) of the relief model of north-east Ireland (scale—one inch to the mile) which is in the Geological Department, Queen's University, Belfast.

A 400-feet peneplain is widely distributed throughout southern Ireland inland from the south coast, and is seen elsewhere in many places, e.g. in the Clogher valley, the plain north of Fintona, the recess east of Newtown Stewart, Co. Tyrone, and the plain between Newry and Dundalk, from which the railway descends with a gradient of *c.* 1 in 100. From evidence gleaned in Great Britain, its age is probably early Pliocene.

The lowest platform in this "chronological staircase" which takes us back step by step through Tertiary time constitutes the Central Plain. Occupying roughly one-quarter of the country, this plain confers on Ireland its most peculiar physical character. It stretches westwards to where Lough Corrib, Lough Mask and Lough Conn form almost a continuous moat between it and the mountains; to the Ox Mountains and the treeless plain of north-west Mayo; and to Sligo and Clare where the Carboniferous plateaus break off in terraced scarps. Its scenery reflects the underlying geological monotony (Pl. XIVA), since for the most part it truncates Lower Carboniferous strata. Relief is found only where the more ancient Silurian or O.R.S. protrudes in isolated, heather-clad inliers or where the later Coal Measures build terraced tablelands.

Nowhere, except perhaps on an occasional gravel mound, does the plain lie above 300 feet. The river Boyne rises at 289 feet and Lough Allen, near the source of the river Shannon, is at only 160 feet. The Royal Canal reaches 324 feet at Mullingar in the heart of the plain, and the Grand Canal mounts to its highest point of 279 feet, 26 miles west of Dublin. To this extreme flatness we must ascribe the countless artificial ditches on the plain; the sluggishness of the rivers and their habit of flooding wide tracts during the wet seasons; and the imperceptible merging of the river-basins into one another so that it is apparently a matter of chance whether a small stream starting on the plain discharges its waters into the Irish Sea or into the Atlantic Ocean. The river Shannon, which drains by far the largest part and about one-sixth of the country, winds in an unbounded and aimless fashion and broadens at intervals into big lake-like expanses with sinuous shores and numerous islets. The river Erne above Belleek is but a series of lakes.

This low peneplain also extends into the undulating coastal plain of Wicklow and Wexford, where it truncates the Carnsore granite and the cleaved slates and massive grits of the Cambrian. In the north-east, it is seen in the Ards Peninsula and the low lands of Down and Armagh (Pl. XIII). It sends an offshoot along the river Erne to Ballyshannon, cuts across the



Carboniferous and Dalradian rocks about Donegal Bay, and truncates the granite in The Rosses.

A rejuvenation, working back from the plain, caused a dissection of the higher surfaces and a carving out of the Glens of Antrim, e.g. Glenariff, in which the stream is busily cutting a gorge in the hard basalts (Pl. XIII); the gorge of the river Bann in the granite above Hilltown; the valleys of the White Water and other rivers above Draperstown; the innumerable winding ravines that intersect the O.R.S. Fintona Beds; the deep Devil's Glen cut into Cambrian slates; the waterfall where the Dargle leaps into the Deerpark at Powerscourt, Co. Wicklow; and the lower valleys of the Sperrins (Pl. XIII) and the mountains of the west.

The big valleys which notch the Wicklow Hills on the east, e.g. Glendalough and Glenmalure, are deeply incised, and in their shortness contrast with the great length of those which flow westwards from the divide. A like contrast is presented by the youthful, deep, steep-sided Glens of Antrim that fall directly into the North Channel and the broader and shallower valleys of the west which discharge into Lough Neagh and enter the sea at Coleraine after a circuitous route (Pl. XIII).

The Central Plain was in turn uplifted so that its rivers were revived and sank gorges into it. The river Shannon falls 97 feet in 18 miles below Killaloe and provides the rapids of Doonass and Castleconnell and the fall used by the Shannon Hydro-electric Works. The river Boyne is encased in a gorge (Pl. XIVB) and the rails of the G.N.R. on the bridge at Drogheda are 109 feet above the Boyne below; and the main railway line from Cork to Mallow and Dublin (which found the natural valley covered over with buildings) climbs out of the valley of the Lee so steeply that it tunnels through the rocks for three-quarters of a mile and rises by a gradient of 1 in 60. The Clady is entrenched in The Rosses, the Eask in the plain about Lough Eask, and the steep-sided valley of the Newry River is well seen as the railway climbs out of it south of Goraghwood, and affords an extensive view of the peneplain rising towards the Mournes.


Fig. 66. Contoured map showing the buried valley of the River Liffey (After A. Farrington).



The rock-floors of these rejuvenated valleys, now concealed by glacial drift, grade with a sea-level more than 100 feet lower than now. The valleys are steep and gorge-like as the buried valley of the Liffey illustrates (Figs. 66, 67), though the tributaries are little affected. Before the Glacial Period, instead of the present gentle slope from Phoenix Park to the sea, the limestone plain ended in a steep scarp which ran north-eastwards past Glasnevin towards Santry. The river, not the Liffey (see p. 234) but the Rye, a local stream, flowed in a deep valley that left the present course at Kingsbridge and

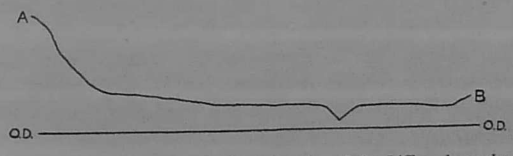



Fig. 67. Section across the buried valley of the Liffey along the line A—B of Fig. 66 (After A. Farrington). (Vertical scale, 6 times the horizontal.)

swung to the north to intersect the line of the modern coast near Annesley Bridge at least 120 feet below present sea-level.

The Lagan valley, as proved by bores for water, descended to more than 100 feet below sea-level beneath Belfast. The river Bann may have excavated a gorge extending backwards into the Lough Neagh area, a narrow and steep-sided gorge, still open, being detectable in the floor of the lough which descends 102 feet below the water-surface (Fig. 65).

This sketch of the successive planations and rejuvenations shows that the Irish rivers were initiated on a surface now wholly lost to us, which may have lain hundreds or even thousands of feet above the present surface. The older cycles of Tertiary age were earlier than any features now present, even in the most rudimentary form.

While rivers, like the upper Erne, occasionally coincide with anticlines and others lie in downfolds—the lower Bann flows in a faulted syncline in the plateau-basalts, the Main in a slight syncline tilted to the south (hence the curious southerly flow of this river into Lough Neagh), and the lower Boyne and the estuary of the Shannon in synclines in Carboniferous strata—the majority of Irish rivers are not so related. Many on even a casual inspection of the geological map (Fig. 68) are seen to be out of harmony with the structures beneath their present floors and to flow through gorges across ridges of hard rock. The Shannon, the longest river in the British Isles (214 miles) and the natural boundary between Connaught on the west and Meath on the east, rises on the wet, sombre moorlands of Co. Cavan and winds sluggishly through bog and meadow and between marshy and reedy shores, falling only 51 feet in 130 miles. It escapes from Lough Derg between Slieve Bearnagh (1746) and Slieve Arra (1517) to saw its way through the hard Silurian barrier at Killaloe.

The Barrow, Nore and Suir all rise on the long Slieve Bloom-Keeper Hill anticline and enter the broad estuary of Waterford Haven after pursuing separate ways and crossing barriers far above the plains they have just forsaken. The Barrow dissects the Leinster granite core at Craiguenamanagh, between Brandon Hill and Blackstairs Mountain; the Nore traverses O.R.S. below Thomastown; and the Suir crosses the same rocks at Newcastle. The Slaney flows through the heart of the granite country; the Owenmore trenches the Dalradian quartzites on its way to Blacksod Bay, Co. Mayo; the Ballysadare River breaches the Ox Mountains at Collooney, a few miles south of Sligo town; and the Moy River and its tributaries cross the granite and schist of these mountains in their northerly passage to Killala Bay.

These and other instances of anomalous drainage are explicable only if we assume that the rivers originated upon a "superimposed" surface which differed from the present, and that the barriers did not exist when the river courses were first laid out. The Irish rivers, except in the north-east, began at a higher level upon a plain of Cretaceous rocks, recently emerged from the sea and resting possibly upon the Oolites, Lias, Trias

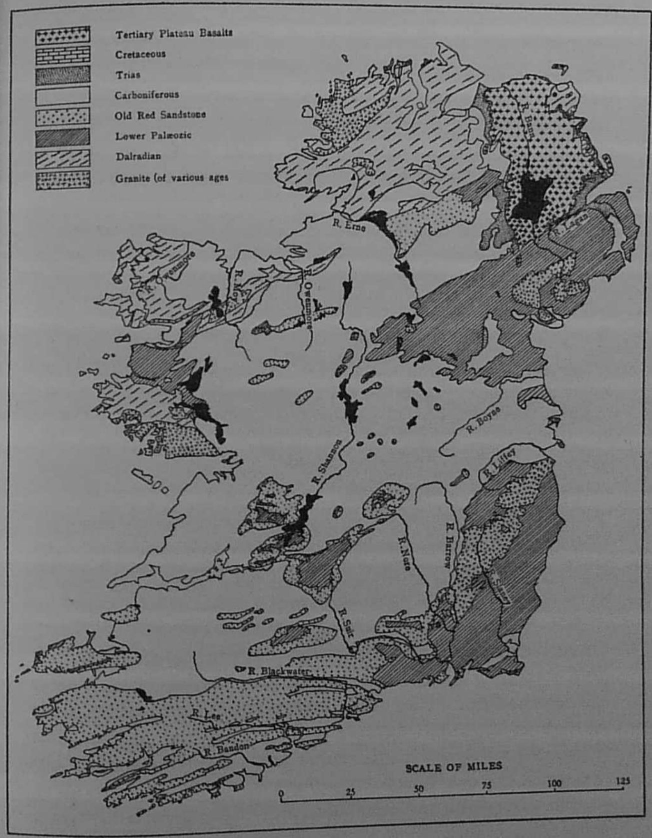



Fig. 68. Geological map showing the relationship of some Irish rivers to the rock-distribution.

and Carboniferous strata (Fig. 69). The rivers flowed above even the highest of existing mountains. Their courses were necessarily quite independent of the ancient geological structures impressed by the Caledonian and Armorican Movements, and generally had a southerly trend which is still traceable in the courses of the Shannon, Suir, Nore, Barrow and Slaney. During their evolution, they gradually removed the soft Mesozoic strata and lowered their beds into the complex

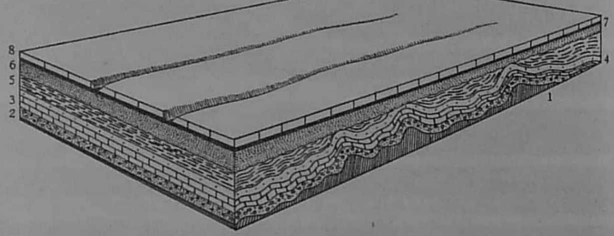



Fig. 69. Block diagram showing the origin of the Irish rivers on a "superimposed" surface. 1. Silurian; 2. O.R.S.; 3. Carboniferous Limestone; 4. Millstone Grit; 5. Coal Measures; 6. Trias; 7. Lias and Oolites; 8. Cretaceous.

foundation, retaining their course irrespective of the nature and structures of this or of the outer rim to which they bear no relationship. They were, however, unable to widen their valleys in the more durable rocks as they did in the softer Carboniferous strata. In some cases the denudation has exhumed the pre-Triassic topography.

The rivers of north-west Donegal display a radial arrangement, resembling that of the English Lake District; they probably arose on a mantle of Cretaceous strata that has since been removed. The Sperrin Mountains also provided a major divide, north of which the drainage flowed along north-west lines.

This remarkable feature of cutting across ridges of hard rock is nowhere better exhibited than by the rivers of Co. Cork,



made classic by Professor J. B. Jukes in 1862. The Blackwater, Lee and Bandon flow for considerable stretches along broad, longitudinal valleys, with alluvial flats and marshes, which conform to the Armorican synclines. Each river in turn suddenly abandons its course to pass through a narrow transverse gorge that runs roughly north-south across the O.R.S. (Fig. 68). The river Blackwater, for instance, flows 57 miles along its broad Carboniferous trough, but instead of pursuing this straight out to sea at Dungarvan, 12 miles away, deserts it near Cappoquin and turns abruptly to the south through a picturesque glen, 300-400 feet deep cut through the Mangerton axis, one of the dominant physical features in south Ireland. Similarly, the Lee, instead of following the valley to Youghal, turns south through the complicated drowned inlets of Cork Harbour, traversing two high ridges to reach the outer sea at Crosshaven. The Bandon likewise changes its course at Inishannon. The inlets of Lough Hyne, Castle Haven, Glandore and Rosscarbery, though now fed by insignificant streams, cut through the most southerly range of Co. Cork in other steep-sided gorges, as fine as those just mentioned.

South and west of Cork and Mallow, owing to a change in facies in the Carboniferous rocks (Ch. V), the contrast in resistance to erosion between Carboniferous and O.R.S. is less pronounced and the characteristic drainage pattern undergoes a change.

Professor Jukes supplied an explanation which, with the modifications our greater knowledge enables us to make, accounts satisfactorily for this behaviour. The rivers, as already explained, originally flowed at much higher levels and probably over Cretaceous rocks, though these have long since disappeared: of the ancient surface no relic now persists. These north-south "consequent" rivers cut down through the Cretaceous strata and any Jurassic rocks that may have underlain them into the latent zones of weakness beneath. They continued to saw their way through the Armorican anticlines and received as tributaries the "subsequents" which coursed west-east along the ever-deepening and broadening longitudinal valleys. The strong tributaries, thrusting back their heads more and more to the west along the softer strata of the long synclines, gradually became the dominant members of the drainage system and intercepted or "captured" the upper reaches of the transverse streams. Since the strike-rivers were never able to excavate below the lower reaches of the transverse rivers, they adopted these as channels by which to reach the sea.

The Brinny, north of Inishannon, marks the position of the main stream to which the Bandon was originally tributary. Similarly, the Finisk River had its headwaters drawn into the Blackwater, and the Glashaboy and Owenacurra which meet in Cork Harbour were the consequents of the Lee system—the "passages" of this harbour represent old north-south valleys subsequently drowned by the sea. One continuous stream, to judge by the existing abandoned valleys ("wind-gaps") across the ridges, probably flowed from Buttevant by Mallow, Blarney and Ballinhassig to Kinsale.

Hence a slow and progressive adjustment of drainage to structure has nearly transformed a north-south system of consequents into an easterly drainage pattern conforming with the pitching folds. The longitudinal rivers, however, do not flow strictly along the axis of the synclines on the Carboniferous Limestone but along the outcrops of the softer Lower Limestone Shales (about 100 ft. thick) at the margins, e.g. on the north side of the wide valleys in the case of the Lee, near Cork, and the Curraheen and Tramore valleys, and on the south side in the case of the Owenbeg tributary in the Blackwater syncline and the river Suir between Clonmel and Carrick. Only where the synclinal trough is narrowed down and the Carboniferous almost removed, as in the Bride valley west of Cork, does a single river occupy the middle of the valley.

Since it would be mere "accident" that the longitudinal rivers should lie just over the synclines in the Carboniferous strata on the exposure of the basement rocks, it is necessary to



assume that they have been subsequently adjusted to the old structures by shifting laterally down the dip of the O.R.S., i.e. down the flanks of the anticlines.

Consequent streams drained to the north-west and the south-east from the Wicklow Hills. Thus the Liffey flowed through Brittas col and the King's River through the col north-west of Blessington. The present course of the Liffey is due to glacial diversion (see p 234) and to "capture" of the King's River by a pirate stream that cut back from Ballymore Eustace, and to capture of the Liffey by a tributary of the King's River working northwards along the strike of the slates from about Blessington. These changes (Fig. 70) are, we may be sure, only a few of those countless others that arose from the fierce competition as the rivers of the country gradually adjusted themselves to the exigencies of the gradually emerging structures.

While the Tertiary rivers were sculpturing the land to leave behind them only the "skeleton of a departed country," the newly born Atlantic was beating upon the shores and eroding the ragged ends of the Caledonian and Armorican folds into a highly irregular coast. Where it met the relatively soft and soluble Carboniferous Limestone it produced spacious indentations with shallow floors backed by low cliffs or coastal strips. In Donegal Bay, its action has proceeded less far than in the rectangular inlet of Clew Bay, where only a narrow fringe of limestone is now preserved. Galway Bay, greatly indented against the Carboniferous Limestone but cut off sharply and in a straight line against the faulted granite; the semicircular bays of Tralee and Brandon; Sligo Bay, divided into Drumcliff and Sligo Bay proper, by the promontory which contains the metamorphic rocks of Rosse's Point; all these, with Killala Bay, bear witness to the weakness of the Carboniferous Limestone in face of the Atlantic waves. In like manner, the bays and estuaries of Wexford lie in the soft Carboniferous rocks which intersect the more ancient slates and schists in the south-east.

The rias of Co. Kerry (Roaring Water Bay, Dunmanus Bay,

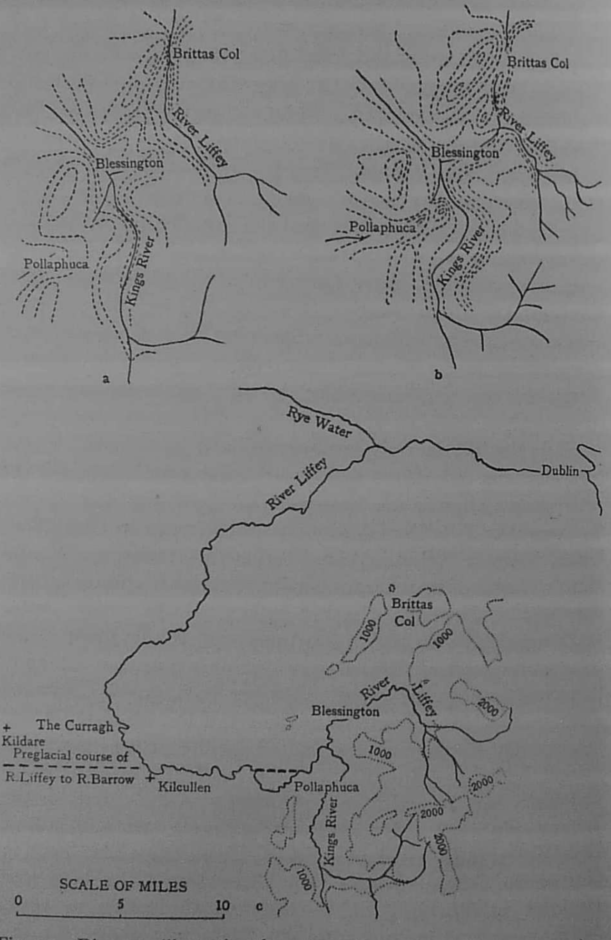



Fig. 70. Diagrams illustrating three stages in the geological history of the River Liffey (Redrawn from A. Farrington).



Bantry Bay, Kenmare River and Dingle Bay), whose floors steadily widen and deepen seawards with the pitch of the folds (Fig. 71), lie in longitudinal valleys eroded in the soft and partially submerged Carboniferous rocks. Their picturesque bays which, like the rias of north-west Spain, are wide-mouthed and represent the drowned headwaters of a river-system that has all but disappeared, have comparatively low, often marshy and sandy shores. These contrast forcibly with the rocky headlands and rocky inlets and shoals, the peaks of partially submerged ridges, which rise precipitately from the sea where the rugged O.R.S. forms the prongs of the fork-like promontories.

The Central Plain may be in part a plain of marine denudation, the ultimate product of the attack of the sea. No

Fig. 71. Section along Kenmare River, a typical Kerry ria.

relics, however, of Tertiary marine sediments have been found associated with it.

The ceaseless attack of the geological agents throughout the Tertiary era finally produced an island which did not differ essentially from the Ireland we know. The land was carved into mountain and glen, hill and plain. The sea entered the basin of the Irish Sea, parted Ireland from Great Britain, and drowned the coastal valleys to give Ireland her numerous natural harbours, as in the East and West Passage of Cork and the flooded, complex valley system of Cork Harbour and the rias of Kerry. Its shore-line with well-defined rock-platform and cliff, still well preserved (Fig. 72), forms the pre-glacial raised beach which encircles Ireland just above the modern shore and emerges from beneath the glacial drift along the whole south coast from Carnsore Point to Cape Clear, including East and West Passage and Cork Harbour, as well as up the east coast of Wexford, Wicklow, Meath and Dublin and the west coast of Clare, Galway and Sligo (Rosse's Point). Marine

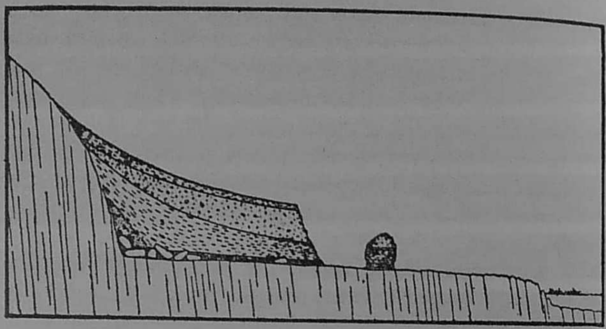


Fig. 72. Diagram of the pre-glacial raised beach and overlying deposits, Courtmacsherry Bay, Co. Cork (After W. B. Wright).

shingle and wind-blown sand often lie in the angle at the bottom of the cliff-face.

The stage was now set for the last great drama of Ireland's geological history, the Great Ice Age.

## Chapter XII

# THE GREAT ICE AGE

### 1. The Glaciers and Ice-Sheets

During most of her geological history, Ireland has been favoured by warm climates: the warm seas of the Lower Palaeozoic; the deserts of the O.R.S.; the coral seas and steaming swamps of the Carboniferous; the grilling deserts of the New Red Sandstone; and the tropical seas of the Mesozoic.

The Tertiary era in Europe had a climate that gradually worsened: this is recorded in its land vegetation and marine shells. The tropical climate of the Eocene, when molluscs, resembling those of the present-day Indian Ocean, and cinnamon, fig, palms, magnolias, sequoias, crocodiles and turtles lived in the Thames valley, yielded to more temperate conditions in the Miocene, when traces of frost appear for the first time on fossil leaves, and to a much colder climate at the end of Pliocene. The seas became cooler and the winters sharper and longer.

This steady deterioration culminated for reasons which are but imperfectly known in the Glacial Period or Great Ice Age. This age of snow and ice, of glaciers and ice-sheets, which was universal in its occurrence (Fig. 73) and began perhaps about one million years ago, has profoundly influenced the country, its soils and agriculture, and its animals and plants.

With the lowering of the summer and annual temperatures and the oncoming of arctic conditions, the aspect of Ireland, as of the rest of the British Isles, underwent a drastic change. Frost acted upon the cliffs around the coasts and produced the "head" which overlies the pre-glacial raised beach. Floating ice rafted a few far-travelled boulders, such as Antrim flints, to the pre-glacial beach of Co. Cork and, with the help of the later ice-sheet, scattered pebbles of the Ailsa Craig microgranite, speckled with its blue crystals of the mineral riebeckite, over the floor of the Irish Sea.

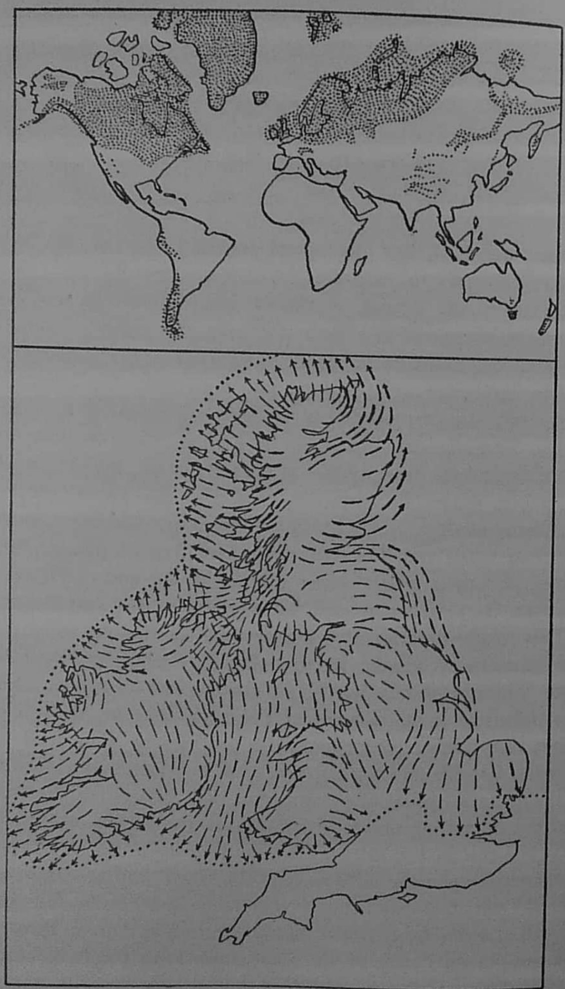


Fig. 73. Extent and lines of flow of the ice in the British Isles during the Ice Age (inset: world distribution).



The higher mountains acted as gathering grounds for the accumulating snows. Small glaciers, fed by snows in the innermost recesses of the mountains of Donegal, Leitrim, Mayo, Galway and Kerry, grew longer and longer with each successive year and crept slowly down the valleys. Finally, they coalesced

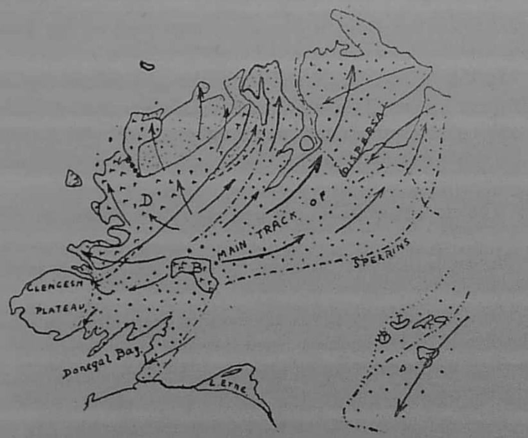



Fig. 74. Fans of the granite boulders in north-west Ireland (After J. K. Charlesworth). B, outcrop of Barnesmore granite; D, outcrop of Donegal granite; T, outcrop of Tyrone granites; dotted areas, country covered by granite boulders; dash-line, limits of dispersal of the Donegal granite boulders; dot and dash line, limits of dispersal of Barnesmore granite boulders; dotted line, limits of dispersal of Tyrone granite boulders; dash and two dot line, western limit of the Scottish Ice; arrows, direction of ice-flow. Scale, 25 miles to one inch.

upon the plains, shrouded the whole country and issued from between the mountain clusters around the coasts. In the north-west, for example, the ice streamed radially outwards from a centre in the Derryveagh Mountains and Barnesmore Hills on the main watershed of Co. Donegal. Thus countless boulders of Barnesmore granite are distributed over two fan-shaped areas which together cover more than 1200 square miles (Fig. 74). The ice flowed outwards down the Foyle and

Finn and over Inishowen; swept into Donegal Bay on the south-west; passed eastwards along the corridor between Omagh and Draperstown; and proceeded westwards over The Rosses, which it dotted with boulders from the Donegal granite, the largest of them, about the size of a cottage, occurring near Crolly railway station. Linking up with that on the Leitrim Hills, it formed a huge pool of ice over the intervening depression which Lough Erne now occupies.

Farther south, the ice radiating from the mountains of Co. Galway fashioned the innumerable naked and rounded rock-bosses of Connemara and the drumlin mounds which rise from the plain between loughs Conn and Mask and Clew Bay (Fig. 75).

The ice streamed southwards along the Shannon estuary and south-eastwards into Co. Cork by way of Limerick and Charleville. Finally, it passed freely off the Atlantic sea-board between Donegal on the north and Kerry on the south to calve fleets of bergs where the rapidly deepening sea was able to float it. The melting bergs dropped their freight of stony debris to the sea bottom whence it has been dredged up in recent times.

The ice surged northwards against and over the Ox Mountains and through the gap west of them leading to the coast north of Ballina: it carried boulders of the Ox Mountain granite to about Sligo and Rosse's Point, including the big "Easky boulder."

Flowing over the Central Plain with remarkable regularity from the great ice-centres in the west and north-west, the ice carried the "Limestone gravels" on to the granite and slate of Co. Wicklow to a height of about 1000 feet, and on to the northern flanks of the Galty and Knockmealdown Mountains and the western slopes of the Comeraghs and Slieve Bloom. Boulders of the easily distinguishable granite of Galway were transported east of Slieve Bloom to Roscrea, over the limestone country of Galway and Clare to the north-western extremity of Galtymore (with the Carboniferous volcanic rocks of Co. Limerick), and to Mallow, 100 miles from their source

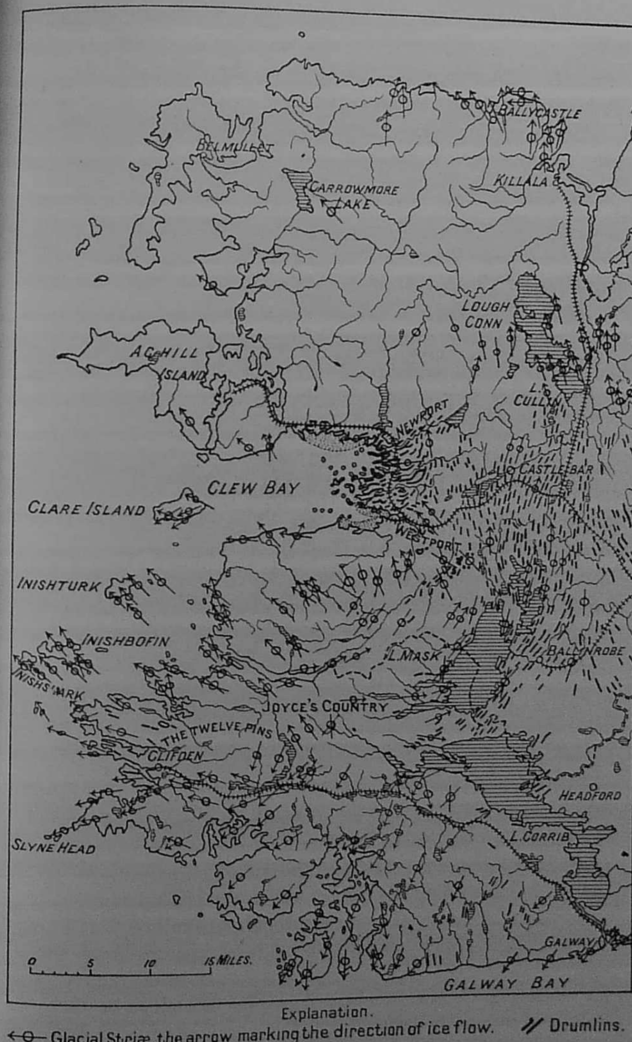



Fig. 75. Map showing the direction of ice-flow and the orientation of the drumlins in west Connaught (After T. Hallissy).

(Fig. 76). They were also swept on to the limestone of the Aran Islands outside Galway Bay.

The ice, moving from the north-west upon the Leinster Hills, split on their western and north-western flanks, the influence being felt as far away as Maynooth. The eastern branch

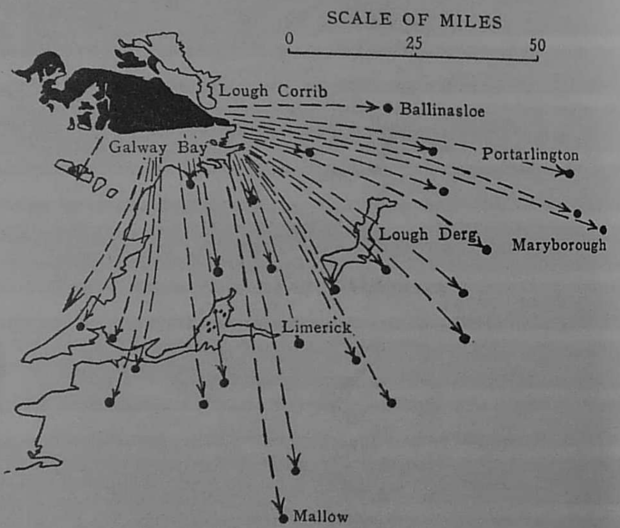



Fig. 76. Fan of the boulders dispersed by ice from the Galway granite.

passed into the Irish Sea and flowed parallel with the coast. The western branch, pushing along the western shoulders of the range into Waterford and Wexford, deployed off the south coast and overbore the feeble indigenous glaciers on the Wicklow Hills, compelling them to merge in the general flood and to scatter their material to the south-east (see below).

An O.R.S. drift, transported by local glaciers from the south-west, extends over about 3000 square miles of country as far as eastern Co. Cork, where it overlies the older northern drift, and to a northern limit running from Cloyne to Tralee.



The evidence for all these movements is extremely clear. The ice, shod with sand, mud and boulders held firmly in its sole, rasped the solid rock over which it passed and in doing so engraved the ice-scratches or striae which point in the direction of the ice-flow. It also polished the quartzite, quartz and other hard rocks with its rock-flour, though subsequent weathering has usually effaced both polish and striations on highly crystalline rocks like granite and gabbro. The rocks have been dressed and moulded into characteristic shapes termed *roches moutonnées*, which have rounded and abraded impact sides and craggy and rugged lee sides where the ice quarried or "plucked" the rocks away along joint or other structural planes.

The material gathered in this way was deposited as glacial "drift," which consists very often of a till which floors the valleys and plains and wraps round the hills. This boulder-clay is typically stiff, tenacious and unstratified and contains boulders of all sizes, often scored and scratched and stuck in the clay without any arrangement. The boulders and matrix are alike composed very largely of materials derived from the underlying rocks; on the granites of Donegal, Galway, Leinster and the Mournes they are chiefly granitic, on the plateau-basalts of the north-east mainly basaltic, on the slates of Down, etc., predominantly slate, in the Lagan valley disintegrated Trias and therefore red, and over the Central Plain grey and of Carboniferous Limestone.

The ice left a trail of pebbles or boulders either on the surface or in the drifts. These "erratics," moving with the ice, became smaller and smaller as the distance from the parent rock increased. From time immemorial the larger ones, especially those of granite, have been used in monuments, as in megaliths, while more recently they have served for stone-basins, for fonts or for crushing corn or apples.

Ice from the south-west Highlands of Scotland and Firth of Clyde invaded north-east Ireland and proceeded south-westwards over the counties of Antrim and Londonderry and southwards to the Mournes and Carlingford Mountains. Pressed from behind, the ice deepened in front of these barriers

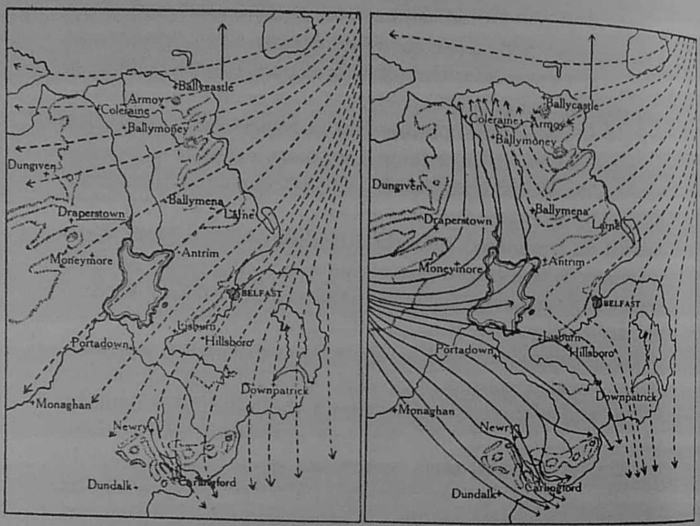



Fig. 77. Diagrams showing the lines of ice-flow over north-east Ireland, (A) during the earlier phase of the Scottish glaciation, (B) at the subsequent stage of confluence of the Scottish and Irish ice-sheets (After A. R. Dwerryhouse).

until it was able to surmount them, but was deflected to the east towards Dundrum Bay and southwards towards Carlingford Lough, the point of divergence being situated near Hilltown (Fig. 77).

The Scottish Ice which rounded the basalt hills and the domes of the Mournes and scored the rocks in numerous places, as along the sides of Lough Dhu on Fair Head (W. 35° S.), passed to a line which coincided with the western limit of dispersal of erratics from eastern sources, e.g. Antrim chalk and flint, basalt and Scottish rocks. This line ran approximately along Lough Swilly, by Fahan and Londonderry to the northern foot of the Sperrins and from Draperstown, south-east of Pomeroy, across the Clogher valley to the eastern flank of Slieve Beagh and the vicinity of Monaghan.



The Scottish Ice brought slate from Girvan (Ayrshire) to Belfast Lough and Antrim, Goatfell granite and pitchstone from Arran to Down, and the Ailsa Craig microgranite to all the coastal areas in the north-east as far west as Moville and Malin Head and to such inland localities as Limavady, Dungiven, Kilrea, Armagh, Monaghan, Dromore, Ballynahinch and Newry. It scattered the Dalradian schists (from north-east Antrim and Kintyre) over the north-east in a fan opening to the south and west and conveyed the Fair Head dolerite to Ballycastle, Armoy and beyond—columns are plentiful on the shore of Ballycastle Bay. Carboniferous sandstone was transported from Ballycastle to Portrush, Cushendun microgranite to Belfast, Cushendall porphyry to Ballymena, Glenarm, Island Magee and Downpatrick, Slemish dolerite to Templepatrick (big boulder seen from the railway), Tardree rhyolite to Cookstown Junction, Lisburn, Newry and the western shores of Strangford Lough, and Castle Espie Limestone to the islands of this lough and to Killough and Newcastle.

Erratics of chalk-flint and basalt were widely distributed. Silurian material was carried on to the Newry granite outcrop, and erratics of this granite were scattered over the Silurian country to the south and within the margins of the Mourne granite. Carboniferous Limestone from the Armagh area was incorporated in the drifts about Slieve Gullion, and that from the north part of Strangford Lough is sufficiently plentiful south and south-east of Downpatrick to enable a number of lime-loving plants to grow there.

Monuments of the great transporting power of the ice include Cloghmore, the block of Mourne granite, $12\frac{1}{2}$ feet long and 9 feet high, which rests on the Silurian slate at 957 feet above Rostrevor (Pl. XVIB); the Butterlump and Wren's Eggs, blocks of Scrabo dolerite on the shores of Strangford Lough; and the covering stone of the cromlech of Proleek, Co. Louth, a basic rock from Slieve Gullion.

South of the Mournes, the Scottish Ice, the western component of the Irish Sea Ice, invaded a narrow strip of land of varying width, and beyond Dublin pressed the local glaciers in upon the flanks of the Wicklows and advanced across the coastal plain to Wexford. It brought with it Mourne granite (as far as Wexford and Cork) and deposited about Dublin a mixture of the local Carboniferous strata, Old Red Sandstone, and Lambay porphyry, with such northern material as chalk and chalk-flint, Trias sandstone, Silurian grit, Mourne granite and Ailsa Craig microgranite. In Co. Wexford, its till is so highly calcareous that like the overlying "manure gravels" it has been used to ameliorate the clay lands.

Sometimes the drifts, as about Belfast, south of Lough Foyle and about Dublin and Killiney, contain marine shells. Since these are traceable up to about 1300 feet on Three Rock Mountain, Dublin, they were early interpreted as evidence of a glacial submergence of this amount. They are now believed to have been scooped up from the bottom of the Irish Sea and dragged up upon the land by the ice-sheet which completely filled the basin. Significantly, they are usually broken and sometimes striated, and are found only where the ice came in from the sea.

For meteorological reasons only imperfectly understood, the glaciers issuing from the Irish mountains now grew more powerful and the Scottish Ice less so. Adjustments in the flow took place, particularly in the north-east. The opposing ice-sheets met about Lough Neagh and deflected one another to north and south (Fig. 77B). The ice from north-west Ireland streamed over Slieve Gallion and down the Bann and south-eastwards over Slieve Gullion and fanwise over Lough Neagh, carrying with it boulders of the igneous and metamorphic rocks of Tyrone to Moira, Toome, Randalstown and other places.

While the earlier flow (Fig. 77A) is now only detectable by striae and certain features in the erratic distribution, the later flow (Fig. 77B) is related to many scenic features, including the drumlins of the Main and lower Bann (see below) and the numerous "crags and tails" in Down, ice-moulded to the south and craggy to the north, e.g. the tail stretching to the south-south-east from Scrabo Hill and the tail, one of the finest in the British Isles, which extends in the same direction from Slieve



Gullion to beyond the village of Drummintee two miles away (Pl. XVIIA).

At some time during the Ice Age, the climate ameliorated and the ice melted from the face of the country. Towards the end of this milder period, when the level of the sea was possibly fifty fathoms lower because sea-water was abstracted to build the ice-sheets, the mammoth (*Elephas primigenius*) entered Britain over dry land from the continent and roamed freely as far west as Galway: a humerus bone has been dredged from the bottom of Galway Bay. It also wandered into the north; a young tooth, the first to be found in the British Isles (1715), was obtained at Maghery, Belturbet, Co. Cavan, and other teeth have been later discovered in coastal Antrim (Larne, Kilwaughter, Ballyrudder, Carncastle and the head of Glenariff) where the ice incorporated them in its drifts during a subsequent re-advance.

This re-advance carried the ice to an edge which ran from Co. Wexford round the northern flanks of the Wicklow Hills and by Baltinglass, Cahir, Tipperary, Charleville and Newcastle West to the mouth of the Shannon and the west coast (Fig. 78). This line is now recognisable from the enormous moraines of sand and gravel which the ice and its streams laid down along the decaying ice-edge. South of this "Southern End-moraine," the country was a habitable fringe, a tundra of arctic plants except where glaciers occupied the glens in the Wicklows, Comeraghs, Knockmealdowns and Macgillycuddy's Reeks and other mountains of Kerry. These glaciers were greatest at a slightly later stage, since in the Wicklow Hills the local glaciers drained freely, as off the Vartry plateau, and laid down their moraines upon the limestone-bearing boulder-clay of the earlier ice, e.g. in Glencree and the valley of the King's River.

South of the End-moraine, the drift is older than that to the north; its topography is more mature and lacks the sharp features of the later or Newer Drift as seen, for example, north of the river Slaney in Co. Wexford and north of Hacketstown in Co. Carlow. It is sometimes associated, particularly in


Fig. 78. Map showing the distribution of the Irish eskers (osar, outwash and kame-moraines), the South Irish End-moraine and the extent of the local glaciations in the south at a later stage (After J. K. Charlesworth).

the valleys, with accumulations of sand and gravel, as in the Blackpool valley north of Cork City, which though widespread has no conspicuous features.

## 2. The Retreat

The glaciers of the southern clusters, whose striated surfaces and other glacial features are plentiful and strikingly clear, withdrew step by step into the savage cirques or *cums* (Welsh, *cwm*) in the heart of the mountains. A great piedmont glacier was spread over the plain about Killarney and along the



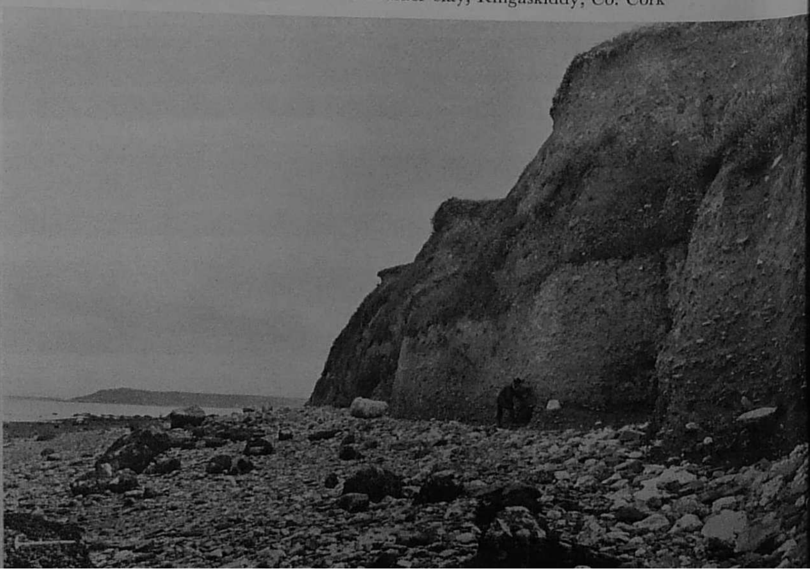
A. "Tail" stretching from the southern end of Slieve Gullion (Photo, J. S. Loughridge)

B. Nunatak of Slieve Bernagh, Mourne Mountains

A. Terminal moraine, Barnes Old Bridge, Barnesmore Gap, Co. Donegal

PLATE XVIII

B. Section in boulder-clay, Ringaskiddy, Co. Cork





whole northern foot of the mountains from Headford Junction to the head of Dingle Bay. It shrank back into the Reeks, depositing its load along its front, as in the rudely concentric mounds which encircle the mouth of the Gap of Dunloe and extend about one mile from the entrance. The ice in the Flesk valley withdrew southwards and in its later stages dammed up a "Lake Kenmare" which overflowed at its head into the Flesk drainage: the terraces margining "Lake Kenmare" are well seen north-east of Kenmare (Fig. 79). Glaciers rooted in the cums flung their moraines as lunate barriers across the valleys, as in the Reeks and in the Sheen valley south of Kenmare, imprisoning the drainage in wild mountain tarns (Fig. 80).

The Wicklows had at the same time a swollen valley glaciation which was nourished on the uplands stretching from the head of Glenmacnass to north-east of Sally Gap and from Wicklow Gap to Lugnaquillia. On the western side, the glaciers were usually small—they included the upper Slaney, Ballydonnell and King's River glaciers—but on the east were larger. The chief of these was the Avonmore Glacier, which was formed by the confluence of the glaciers passing along Glenmalure, Glendalough, Glendasan and the other glens of north-east Wicklow. It thrust a lobe to beyond Aughrim and its snout to near Arklow and, escaping from the valley about Lough Dan, spilled eastwards as a piedmont glacier on to the Vartry plateau. The Avonmore Glacier had to the south-west the Ow Glacier and to the north the small Glencree Glacier.

These glaciers (Fig. 81) strewed the surface of the Palaeozoic country east of the Wicklow Hills with numerous blocks of the Leinster granite, many of them weighing several tons. The best known is the Motta Stone, a grey granite boulder, 15 feet by $9\frac{1}{2}$ feet and 9 feet high and roughly 200 tons in weight, which lies at 816 feet on the summit of Conary Hill near Castle Howard: it was carried about 12 to 15 miles from Glenmalure.

On their retreat, the Wicklow glaciers left behind them the

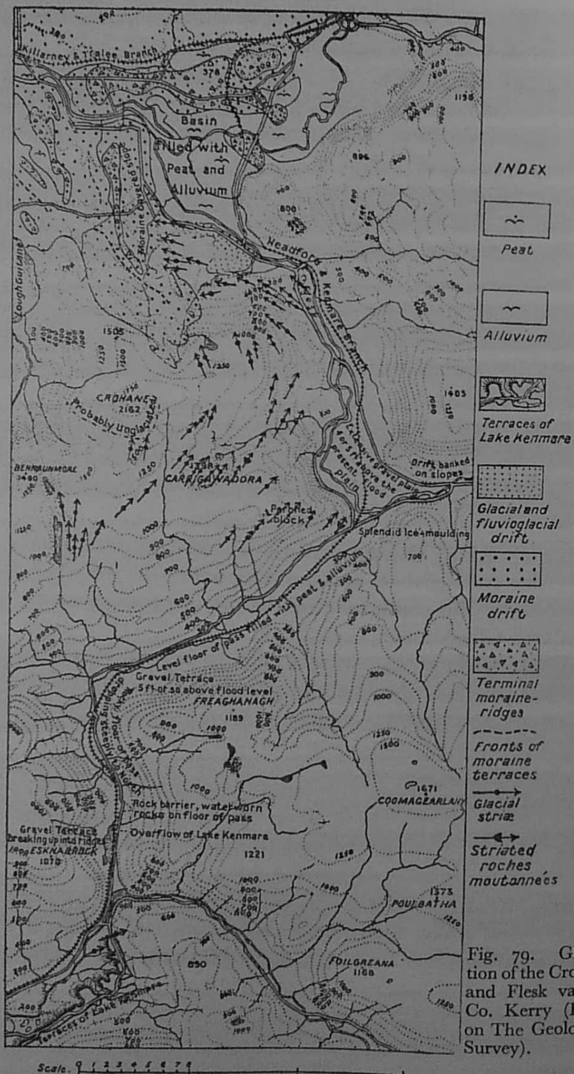



Fig. 79. Glaciation of the Crohane and Flesk valleys, Co. Kerry (Based on The Geological Survey).



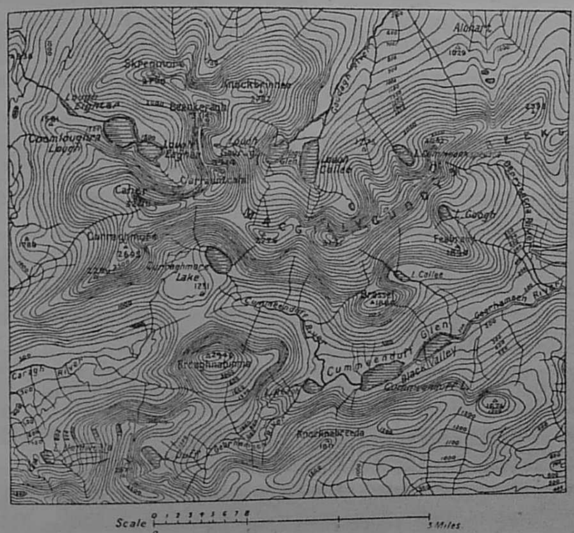



Fig. 80. Contoured map of the Carrauntoohil and Macgillycuddy's Reeks, showing the profound modification by cirque formation (Based upon the Ordnance Survey).

moraines which now span, for example, Glendasan and the valleys of Avonmore and Avonbeg, and are well seen around Annamoe and south of Rathdrum. Among the last to be laid down were the magnificent block-moraines which enclose the mouths of the cirques, e.g. Upper and Lower Loughs Bray, Co. Wicklow, and those which cross the rather inaccessible valleys of Lugnaquillia.

The main ice which, as we have seen, flanked the Wicklow Hills on both east and west, closed the mouths of the valleys and ponded their water in an intricate series of glacier-lakes (Fig. 81). These lakes, held up by ice-dams, received the hill drainage and the copious meltwaters from miles of ice-face. Their capacious "spillways" were excavated by the overflow

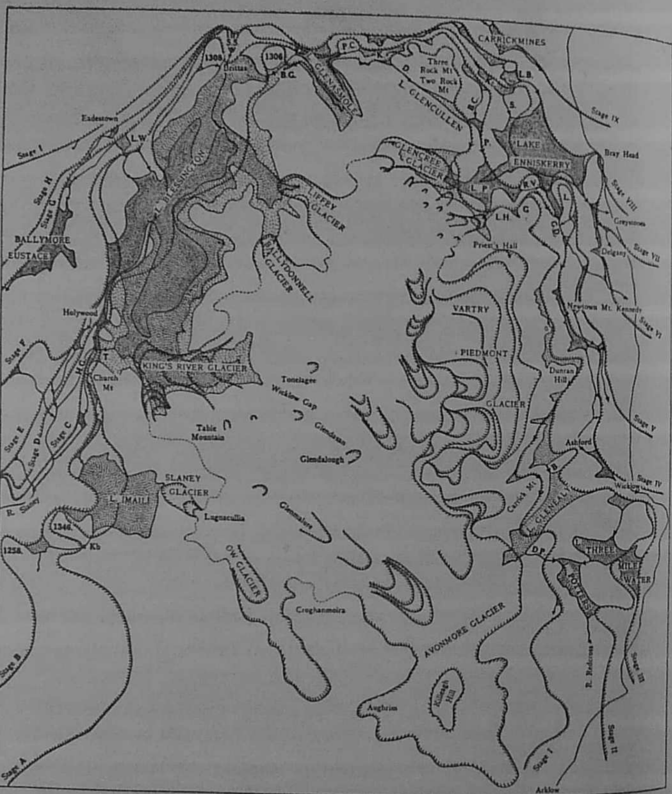



Fig. 81. Map showing the distribution of the local glaciers and glacier-lakes in the Wicklow Mountains (After J. K. Charlesworth).



waters across the main watershed or projecting spurs or along the hillsides. Often steep-sided, deep and broad-floored, these "overflow valleys" resemble railway cuttings. When the ice receded and the natural drainage resumed its course to the sea, the spillways were left abandoned as "dry valleys," either completely dry or carrying only insignificant streams. Examples of such overflow valleys are Hollywood Glen on the west, a valley three miles long and 150 deep, and on the east, the wooded Dingle, the immense gorge of the Scalp and the even larger Glen of the Downs.

The most extensive of these glacier-lakes was "Lake Blessington": dammed up to the west in the valleys of the Liffey and King's River, it had a surface of ten square miles at its top level of 930 feet. By aligning its overflows, and those of the other lakes, it is readily seen that while the ice maintained its pressure against the Dublin Hills it withdrew steadily to the east and west of the hills in great curves moulded upon the relief (Fig. 81).

The ice-sheet, with the improving climate, retired from the Southern End-moraine and laid down, along its decaying, immobile margin or at the mouths or in the tunnels of the streams that coursed beneath it, the eskers which form wide expanses of rolling, billowy country or narrow, steep-sided ridges. By progressive thinning, the ice uncovered the higher hills, e.g. the Castlecomer plateau, Slieve Bloom, Keeper Hills, Slieve Aughty, Slieve Arra and the hills between Shannon estuary and Galway Bay. Separate lobes protruded southwards down the broad intervening valleys of the Barrow, Nore, Suir and Shannon. Their stepwise shrinkage is depicted by the magnificent moraines (Fig. 78) which festoon the valleys and are looped back over the hills. Where the moraines skirt rocky slopes, as on Slieve Aughty and the hills of north Mayo and Clare, they are very stony and assume irregular shapes because of their coarseness.

In disappearing from the Central Plain the ice became inert along its margin and disintegrated apparently into three partially confluent lobes, centred respectively upon the mountains of Donegal, Leitrim and Galway. Their stages of dissolution are portrayed by the countless eskers, composed of well-stratified, assorted and frequently current-bedded sand and gravel, which thickly bestrew the plain and were deposited in the re-entrant angles or embayments of the ice-edge or between masses of dead ice detached from the main front.

North of the plain, the Ox Mountains emerged above the gradually shrinking ice as this fell away from their flanks. Two lobes were formed, the one withdrawing eastwards along Sligo Bay and through Collooney Gap, the other receding west of the Ox Mountains and southwards towards Lough Conn (Fig. 78).

In the north, the ice thinned and some of the higher peaks of the Mournes, including Slieve Bernagh and Slieve Bignian, emerged as nunataks: they are recognised by their angular outlines (Pl. XVIIB). Simultaneously, the Scottish Ice retired northwards along the Irish Sea basin and across Down and left virtually no trace of the manner of its withdrawal. A well-marked ice-front, however, is given by the "Carlingford Moraine." This great accumulation of sand, gravel and boulders, which was laid down after a period of temporary retreat and re-advance, skirts the hills north-east of Dundalk and delineates a big Carlingford Glacier which filled Carlingford Lough and fanned out over the low land on either side (Fig. 82). East of the lough, the ice flanked the northern Mournes and thrust tongues through Windy Gap, over Dear's Meadow into the White Water valley, and through Hare's Gap into the Kilkeel or Silent valley. This valley was occupied at this stage by a big glacier which deposited at its snout the moraines which span the valley just below the reservoir: it was nourished by ice which flowed through Hare's Gap and by local glaciers on the adjacent summits. The Annalong valley also had a local glacier at this stage.

East of the Mournes, the ice-edge is marked by a large moraine which skirts their sides south of Newcastle to beyond Bloody Bridge, where its bouldery accumulations are magnificently displayed.


Fig. 82. Map showing the distribution of the drumlins, glacial sands and gravels and glacier-lakes in north-east Ireland (After J. K. Charlesworth).

The ice shrinking southwards along the Main and lower Bann ponded the land-drainage and its own meltwaters in a series of glacier-lakes along the hillsides west of the Bann and east of the Main. It held up a lake in the upper Main which discharged by the valley, now almost dry and followed by the railway between Dunloy station and Ballymoney. The load deposited along its stagnant margin and in its sub-glacial tunnels built up the sand and gravel mounds and ridges which are well displayed about Ballymena and Kilrea and along the railway about Killagan and Glarryford.

The wide valleys of the Sperrin area were the sites of large glacier-lakes which, drained by overflow valleys, cut across spurs and cols, and which were successively thrown out of action by the retreat of the ice to the west: Barnes Gap and Gortin Gap are among the finest of these (Fig. 83). During the withdrawal from the highest peaks the main watershed emerged and small glacier-lakes were formed which extended over the cols. More rapid recession on the north caused a drainage northwards across the cols from the lakes impounded in the deep recesses on the south. The waters from both sides of the mountains were carried into a lake, held up by the ice standing against Benbradagh and Benevenagh (Stage 1). Further retreat produced a series of lower lakes: those on the south, e.g. "Lake Glenelly," discharged by large outlets into the Moyola River, those on the north into the river Roe, the two systems of drainage at this stage being quite distinct (Stage 2).

With continued retreat the lakes on the south, e.g. "Lake Gortin" and "Lake Glenelly," drained by a large transverse valley—the "Inver" valley—into similar lakes on the north, e.g. "Lake Claudy" and "Lake Burntollet" (Stage 3). This Inver channel continued in action until further retreat allowed the drainage to escape west of the Sperrins by the series of lakes and connecting overflows, the latter including the Strabane Glen, just east of the town of Strabane.

South of the Sperrins, the ice receded along the Omagh-Draperstown corridor, depositing as it did so the marginal accumulations which swing across the plains of Co. Tyrone,



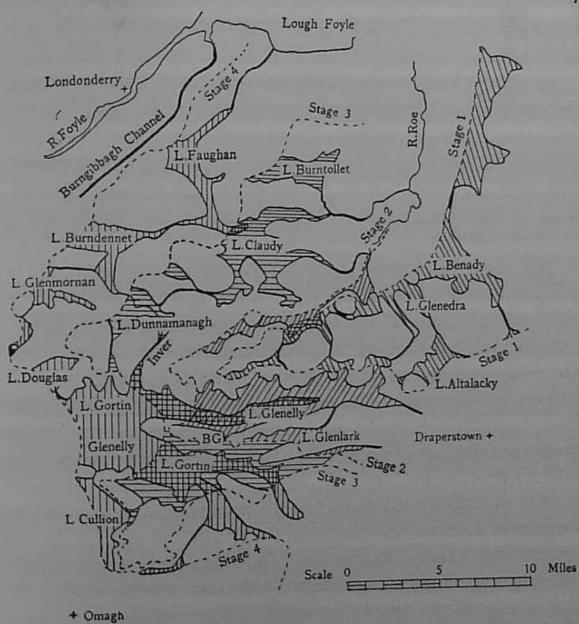



Fig. 83. Map of the glacier-lakes of the Sperrin Mountains (After J. K. Charlesworth).

e.g. about Lough Fea. On the north, the ice shrank into a big glacier which fell back south-westwards along Lough Foyle, the counterpart of that which was simultaneously retreating southwards along Lough Swilly.

Crescent-shaped moraines enable us to trace the stepwise recession of the glaciers of Donegal back to their sources. Among the last to be deposited were the mounds which block the northern end of Barnesmore Gap (Pl. XVIIIA).

Local glaciers persisted for some time in the cums of the Curraun Peninsula and in those that scar the northern flanks of Slievemore and Craughaun on Achill Island, the eastern face of

Corslieve and Nephin Beg, and the northern and eastern face of Nephin.

In Galway, the ice was finally centred about four mountain groups, viz. the Twelve Bens, Joyce's Country and the Maumturk and Partry Mountains. It occurred too in the Mweelrea Mountains north of Killary Harbour. Lateral and terminal moraines, e.g. south-east of Maam Cross, about Lough Inagh, west of Kylemore, south of Leenane and in the Erriff valley, mark the recession into the cums.

The Mournes also had a number of small glaciers in the local cirques at a late stage (Fig. 84). They scarred the east face of Finlieve (1888), Eagle Mountain (2084) and Slieve Muck (2198) and occupied the sites of Lough Shannagh and Blue Lough. Others were fed on Meelmore (2237) and Commedagh (2512) or overlooked the Annalong valley. They faced the east or north, where the snow tended to linger on the shady and wind-shadow slopes and faced south only where high ridges afforded protection as at the head of the Annalong valley.

The Scottish Ice during a late phase advanced once more on to coastal Antrim. In the north, the re-advance carried the ice to the line Armoy, Ballymoney, Coleraine and Articlave, the ice-edge crossing the river Bann south-west of Ballymoney. In the south, the ice proceeded up the Lagan valley to just west of Lisburn.

The northern region was overridden at this stage from the north-east in marked contrast with the south-north direction of the previous movement (Fig. 77B, p. 204); its marginal moraine, well seen east of Ballymoney, about Armoy and south of Ballycastle, is charged with Scottish and other north-eastern material.

This body of ice, standing across the mouth of the Bann, ponded the drainage in a vast glacial-lake (altitude about 60 feet) which flooded the lower Bann and the low land about Lough Neagh (Fig. 82). The lake overflowed at the lowest point of its rim, namely, by the well-marked valley which is now followed by the main road and railway from Portadown by Scarva and Pointzpass to Newry.

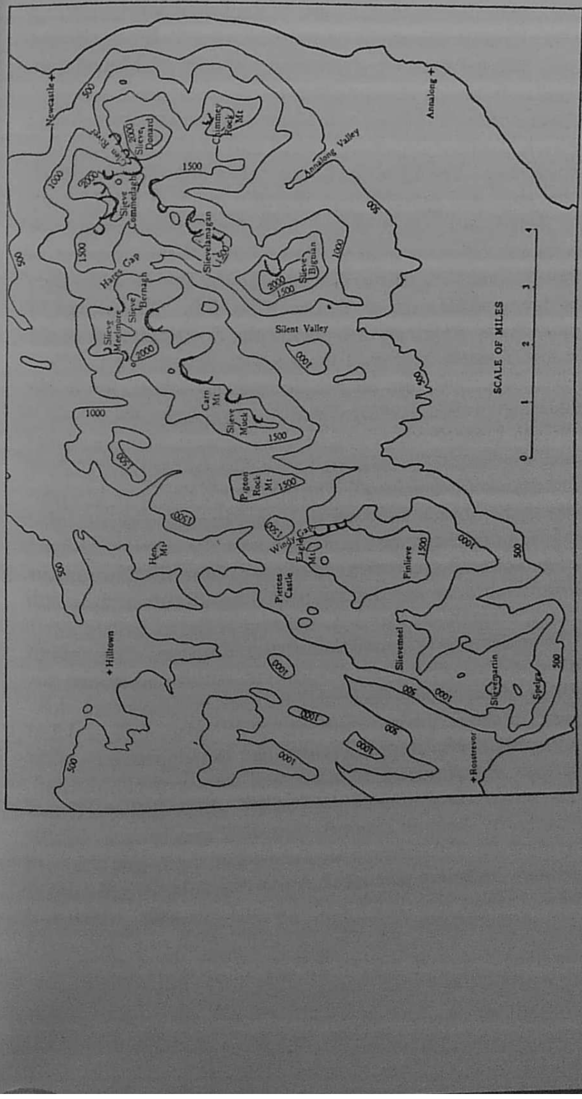



Fig. 84. Late-glacial cirques, Mourne Mountains (After J. K. Charlesworth).

A contemporary glacier-lake (altitude *c.* 140 feet) was held up in the Lagan valley by the Scottish Ice standing at Lisburn. Its well-defined spillway, the valley of the Broad Water, carried the surplus waters from the outlet (well seen at Boyles Bridge on the Belfast-Portadown main road just east of Moira) into glacial Lake Neagh, about Aghalee.

The closure of the Bann and Lagan valleys was short-lived: the ice in this forward position passed into an inactive state and melted away. The ice in the Lagan valley deposited its debris as the sands and gravels which underlie much of the Lisburn and Belfast area. As it melted, it opened a lower escape for the impounded water so that "Lake Belfast," the successor of "Lake Lagan," was able to discharge by the Dundonald valley into Strangford Lough at Comber (Fig. 82). The warps or finely banded clays, which represent the finest material of the glacier-streams issuing from the ice, now floor the bed of the ancient lake: they are used in Stranmillis, Belfast, for brick-making.

"Lake Belfast" lay to the south of a suite of glacier-lakes which the Scottish Ice held up in the Glens of Antrim. These lakes drained at first into the Lough Neagh drainage by over-flows at their heads, and later by lateral streams which carried the surplus discharge and the waters from the melting ice-front along the basalt escarpment southwards from Glendun in the direction of Larne and northwards and westwards to the north Antrim coast (Fig. 82).

These features are nowhere better displayed than about Ballycastle, where the main road from Cushendall follows the spillway from "Lake Glendun." This "Loughaveema over-flow" (intake on the main road at 840 feet) deposited its deltas south of Ballyvoy at 510, 430 and 340 feet respectively, their flat tops and steep fronts being well displayed (Pl. XIXB). They were formed in a "Lake Carey," which discharged successively by several deep, rock-walled gorges into "Lake Glenshesk." This in turn was controlled by a succession of spillways, including that which runs westwards along the Inver valley south of Knocklayd and that at Capecastle, which was



the outlet of a big lake formed by the merging of "Lake Carey" and "Lake Glenshesk."

These glacier-lakes and their connecting spillways enable us to trace step by step the final withdrawal of the Scottish Ice from the Irish coast: several stages may be recognised (Fig 82). Scotland was at that time almost wholly covered with ice; the story of its recession into the Scottish corries only begins after the Irish story has closed.

### 3. Influence of the Ice upon the Scenery

The Ice Age carved its memorials on mountain and plain. In many ways it profoundly influenced the scenery of the country. Its ice scored the rocks, left innumerable *roches moutonnées* in the mountainous districts, and scattered a multitude of erratics and erratic blocks over the land, including many of the so-called "rocking stones" which were poised insecurely. Like a stream, it often deposited its materials in the shelter of a crag to give rise to the "crag and tail." The crude asperities of even the most durable rock yielded to its action. The flowing outlines of the hills that almost everywhere meet the eye in a distant view result directly from its passage. Even the gabbro of the Carlingford Mountains, which has a serrated outline when seen from afar, is beautifully rounded when inspected close at hand. On the uplands, the ice cleared away the surface debris of previous ages and left behind but scanty deposits of its own. It beneficially modified the soils of such areas as the Silurian and granite tracts of Armagh and Down by intermingling the various kinds of rock. The soils of southern Ireland were drastically transformed. Thus the limestone valley of the Blackwater in Co. Cork is so laden with non-calcareous glacial drift from the O.R.S. ridges that scarcely one of the lime-loving plants of the Carboniferous Limestone is to be discerned within it.

The Golden Vale of Limerick on the confines of Cork, Limerick and Tipperary owes its proverbial fertility to the fact that the ice has gathered and mixed together

Old Red Sandstone, Silurian grits and slates, igneous rocks and the local Carboniferous Limestone.

The typical youthful river-valleys, with their V-shaped cross-section, overlapping spurs and steep sides, were modified into U-valleys by the glaciers which passed through them. The "toes" of the spurs were severed to give the triangular facets or gable-ends, so well seen in Glendalough (Pl. XVA); the sides were plucked and over-steepened and the floors were widened. Such U-valleys occur on the eastern side of the Leinster Chain, e.g. Glendalough, Glendasan and Glenmacnass, in Poisoned Glen and Glen Veagh, Co. Donegal, and in the Silent Valley and Glen Valley, Mourne Mountains. The Glens of Antrim, on the other hand, which lay athwart or sloped towards the ice-flow and had probably much less active ice, have been but little altered, except in their upper parts.

The ice lowered the cols it passed through, as in the Gap of Dunloe, Killarney, and in the Hare's Gap in the Mournes. The heads of valleys were widened by frost, abrasion and plucking into cirques or cums (cooms or coums), immense amphitheatres or bowl-shaped recesses where frowning cliffs look down upon dark tarns ensconced in rock-basins and rimmed by block-moraines. The broad flat floors are especially noticeable in the *lugs* of Mweelrea, Co. Mayo. The cums lie on either side of the knife-like ridge of Brandon (3127), Co. Kerry, and occur in other parts of this area (Pl. XVB); form the Devil's Punch Bowl and the three tarns on successive steps on the ascent of the Horse's Glen in the Killarney area; scar the high table-topped mountains of the Comeraghs (2597)—Coomshingaun, the most notable, has a sheer cliff over 1000 feet high above the lake which rests upon its floor; scallop the Twelve Bens of Connemara (Fig. 85); and harbour the loughs Bray (depth, 95 ft.) in Co. Wicklow.

Rock-basins also proclaim the resistless force and intense severity of ice-erosion. These depressions, surrounded by rock and deeper than their outlets, are sprinkled in their hundreds throughout Ireland and range from small solitary loughs, such



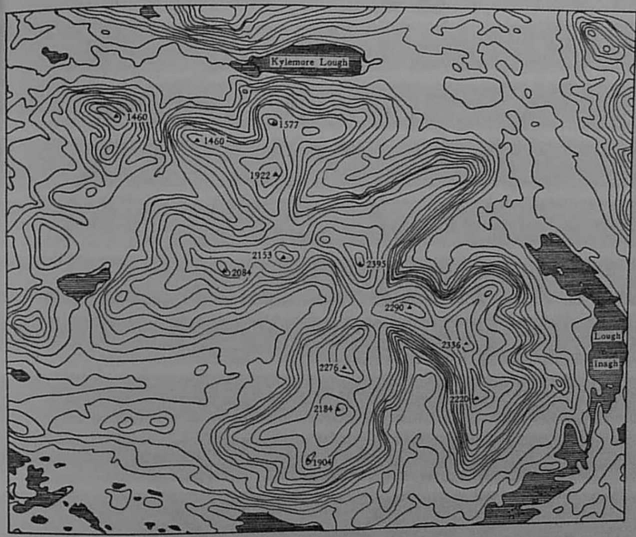
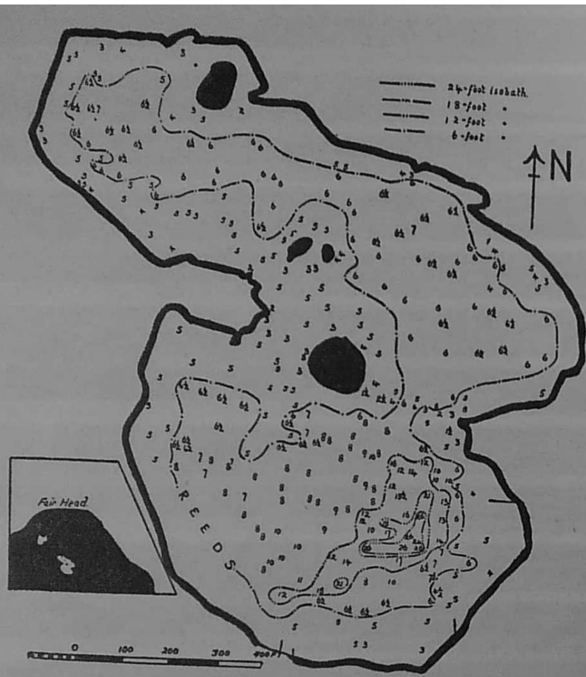



Fig. 85. Map showing the Twelve Bens and their glacial cirques (Based on Ordnance Survey). Bengooria or Diamond Hill (1460); Knockbrack (1460); Benbaun (1577); Benbrack (1922); Muckanaght (2153); Benbaun (2395); Bencollaghduff (2290); Benbeola (2336); Derryclare (2220); Benbreen (2276); Bengower (2184); Benlettery (1904).

as Lough Dhu and Lough na Cranagh on Fair Head, Co. Antrim (Fig. 86), and Lough Augher in the Gap of Dunloe (Killarney), to dark cirque-lakes like those which nestle in the northern face of the Dingle Peninsula and at the head of Glengeigh near Caherciveen, or those of various sizes which are dotted over the mountainous promontories of Kerry where the beetling crags of the cums surmount them. Some of their desolate islands have the remains of churches and dwellings of the early religious settlers who sought solitude upon them.

To the category of rock-basins belong Lough Dan in the schist of the Wicklows and those of the lake-strewn Rosses



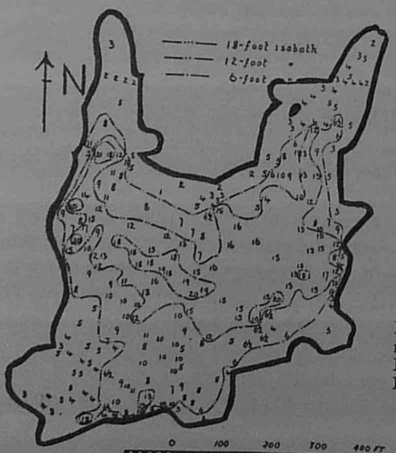
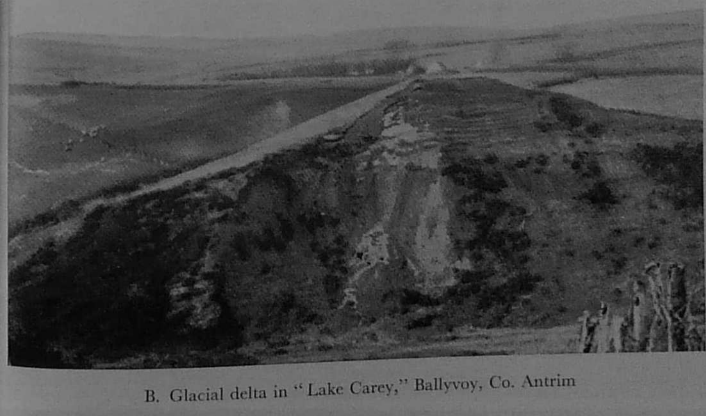




Fig. 86. Bathymetrical map of Lough Dhu and Lough na Cranagh, Fair Head, Co. Antrim (After J. K. Charlesworth).



A. Partially submerged drumlins, Strangford Lough, near Killinchy, Co. Down



B. Glacial delta in "Lake Carey," Ballyvoy, Co. Antrim

A. Weathered granite, Castles of Commedagh, Mourne Mountains

PLATE XX

B. Diatomite (Kieselguhr), Toome



which the ice gouged out along joint planes in the Donegal granite, and those in the labyrinth of land and water in the Pre-Cambrian of Connemara, where the proportion of water to land reaches its maximum for the country of not less than one to thirty-three (Fig. 87).

The valley lakes of west Ireland, e.g. Lough Veagh, Lough Glen, Lough Gartan, Lough Salt and Lough Eask in Donegal, are also rock-basins, though Lough Melvin and the lakes embosomed in the cliff-walled valleys of Glencar and Glenade in Sligo appear to have morainic dams.

Lough Leane and Muckross Lake, two of the far-famed lakes of Killarney, with their indented, shelving shores and numerous low islets of Carboniferous Limestone, lie in a downfold in the rocks, the landward continuation of Dingle Bay. Their origin is complex. Solution has hollowed out the limestone caves with their graceful forms and delicately and fantastically carved patterns. Ice-erosion has supplemented this action and has played an important role in the Upper Lake of Killarney, while big crescent-shaped moraines have helped to pond Lough Leane and Lough Coragh.

Although they are most abundant in the west, from Donegal to Kerry, the biggest lakes are on the Central Plain. Some are but the broad expanses of the sluggish rivers that flow through them. Others owe their origin to an uneven heaping up of the eskers or other glacial deposits. The mushroom-like shapes which are found in the limestone and margin the lakes in places, as on the edge of Lough Ree and of Lough Corrib, north-west of Galway town, point to the solvent action of waters charged with carbonic and humus acids. Yet the lakes as a whole are not due to solution. Some, like Lough Ramor and Lough Gowna which occur in Silurian strata, lie in hollows in non-calcareous rocks.

Lough Derg, which is broad and shallow, and has an irregular coast where it rests upon Carboniferous rocks and widens out into the bay-like expansions of Youghal and Scarriff just north of the junction with the Silurian slates, contracts from 9 miles to 1 mile and deepens to 112 feet in the

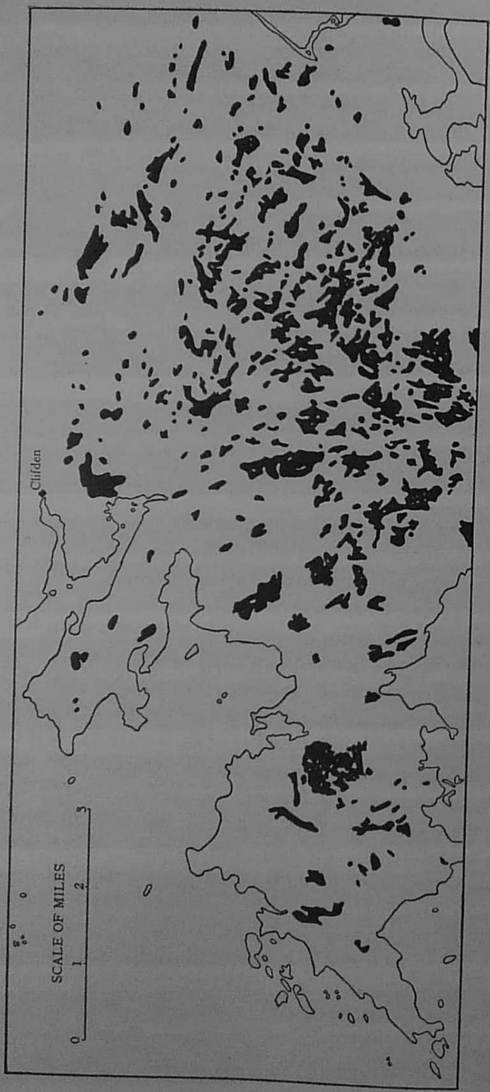



Fig. 87. Map showing part of the lake-area of Connemara (Based on Ordnance Survey).



channel-like section through the slates north of Killaloe. This part at least is due to erosion by ice.

Similarly, while Lough Mask's shallow eastern limestone shore, highly indented and bestrewn with islets covered with grass and bushy vegetation, may have been modified by solution, the straight western shore, with its bare metamorphic rocks rising steeply out of the water, must be credited to ice-erosion.

Ice also fashioned some of the coastal inlets into fjords. Carlingford Lough shallows from 16 fathoms opposite Killowen Point, about half-way up the lough, to a characteristic threshold at the entrance which is only 4 feet deep and even rises into Carboniferous Limestone islands. Mulroy Bay is likewise a fjord; its intricate entrance channel of "the Narrows" is only 2 fathoms deep, though inland (where the fjord widens into a lake-like expanse) the floor falls to 14 fathoms.

The Admiralty chart of Lough Swilly (No. 2697) reveals two deeper, isolated basins separated by shallow bars from one another and from the sea outside. The pools lie in constrictions where the hard quartzite ridges strike obliquely across the lough, namely, between the quartzite of Rathmullan and Inch Island and east of Knockalla (Fig. 88), i.e. just where the ice velocity would be highest and the erosion most severe.

The drumlin is yet another result of glaciation, and like the terms *cnoc*, *slieve* and *ben* has its own peculiar meaning.[1] In a drumlin country the glacial drift, usually boulder-clay, forms mounds which exhibit smooth, graceful outlines and average perhaps one-third of a mile in length (Pl. XVIA). In plan, they are elliptical or egg-shaped, aligned in the direction of ice-flow: a blunt, steep and higher end lies upstream and a narrower and lower one points downstream. They are built up and moulded by the ice so that in their shape they resemble fish, torpedoes or racing cars which are also streamlined to offer least resistance to the flow. Thus the drumlins of Down,

[1] *Cnoc* (anglicised Knock) signifies a hill, *Slieve* a mountain, and *Ben* a steep or pointed mountain.

where the ice was moving from the north (Fig. 77B, p. 204), are steep and blunt to the north, while those of Co. Antrim, where the ice passed from the south, are steep and blunt to the south.

Drumlins are usually associated in groups (Fig. 82, p. 215).

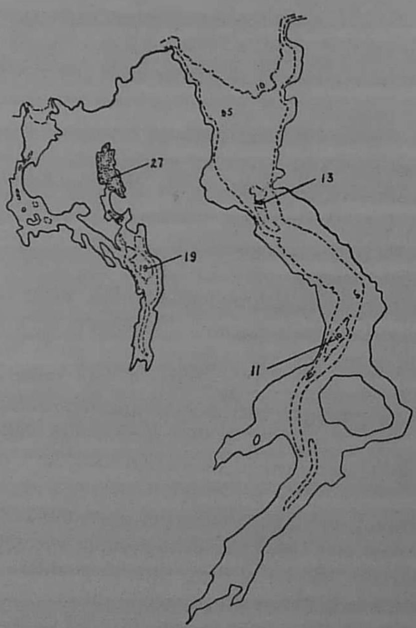



Fig. 88. Postition of the fjord-basins in Lough Swilly and Mulroy Bay (Based on Admiralty Chart).

In Down, for example, they are so abundant that they give rise to the peculiar "basket of egg" scenery (Fig. 82; Pls. XIII, XIXB), a type, however, by no means restricted to Down, for it is seen equally well in Armagh, Monaghan and Cavan, around Donegal Bay between Ballyshannon and Killybegs, about



Lough Erne, and Bantry Bay and around Clew Bay where Maxwell Close described the drumlins and introduced the name into international literature.

Drumlins are interlaced with lakes, water-logged hollows, peat flats, alluvial soils or pastures and with winding streams. Innumerable lanes and roads, lined with hedgerows, zig-zag among them when going with their length, e.g. north and east of Donegal Bay and from Belfast to Downpatrick or Newcastle, and cross them in switchback fashion when traversing their stream, e.g. the east-west lanes and roads of Down and Armagh.

When partially submerged, the drumlin country gives rise to an even more fascinating type of scenery. Strangford Lough, which is but a submerged part of the plain of Down, has innumerable drumlins which connect with the mainland as promontories (Pl. XIXA). As the floor of the lough falls into deeper water the peninsulas pass insensibly into an archipelago and finally, where waves have almost completed their destructive work, into low, bouldery shoals or "pladdies" (from the Scottish *fladdaly* or Norse *flat-ey*, "flat island"). A similar "drowned" drumlin landscape forms the catchment area of the river Erne in north-west Cavan, while Upper Lough Erne is a network of channels between a myriad of green islands and is bordered by extensive flats presenting an intricate maze of bog and alluvium broken only by drumlin mounds (Fig. 89). Lough Gowna is a similarly partially submerged drumlin country in Co. Longford.

Clew Bay is a veritable archipelago of cliffed drumlin-islets that is fringed in deeper water by shoals and reefs of boulders, the remnants of consumed drumlins, and in shallower water by promontories where the drumlins are still largely preserved (Fig. 90).

Among the most typical scenic features dating from the Glacial Period are the eskers. These sands and gravels are distributed widely either as tangles of billowy mounds, with rolling and knobby surface, or as ramparts, steep-sided, narrow-crested and up to 60 feet high, which wind serpent-like across the plains

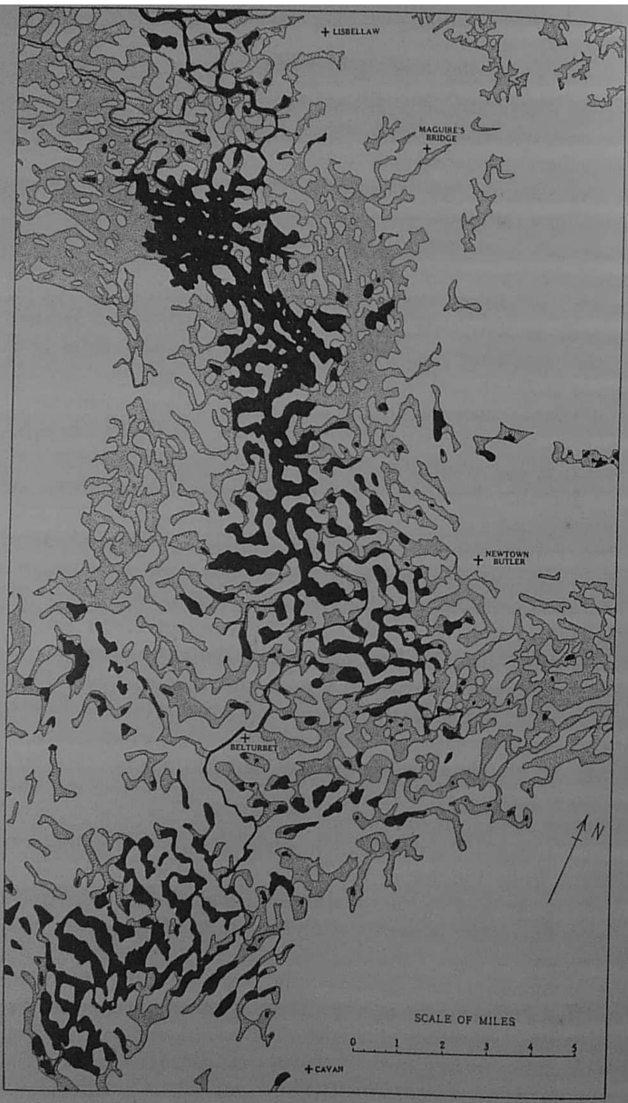
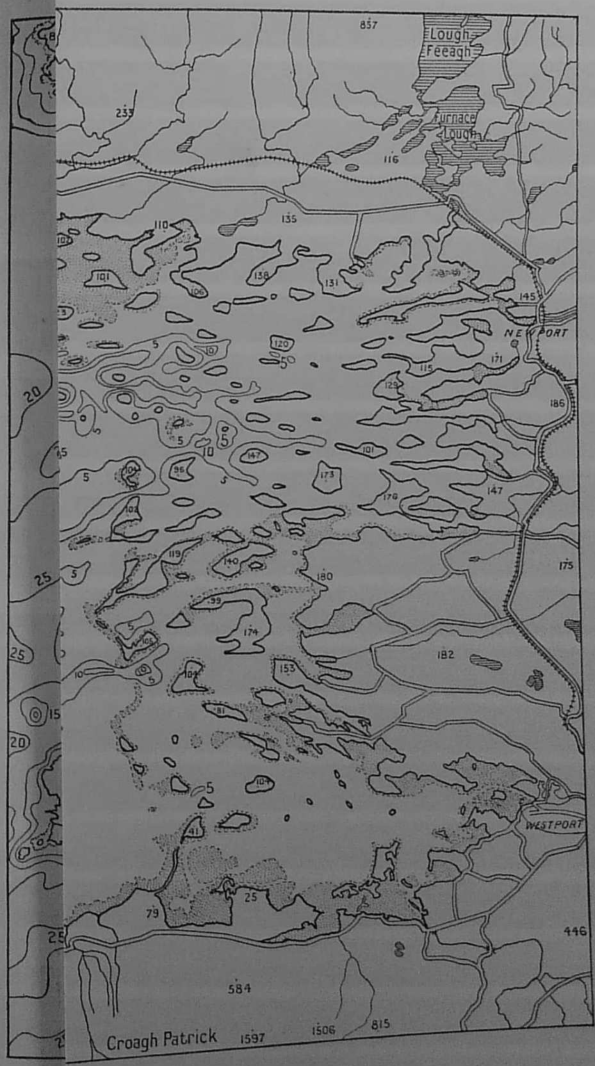



Fig. 89. Map showing the distribution of land (white), of water (black) and of peat and alluvium (dotted) about Upper Lough Erne (Based on Geological Survey).



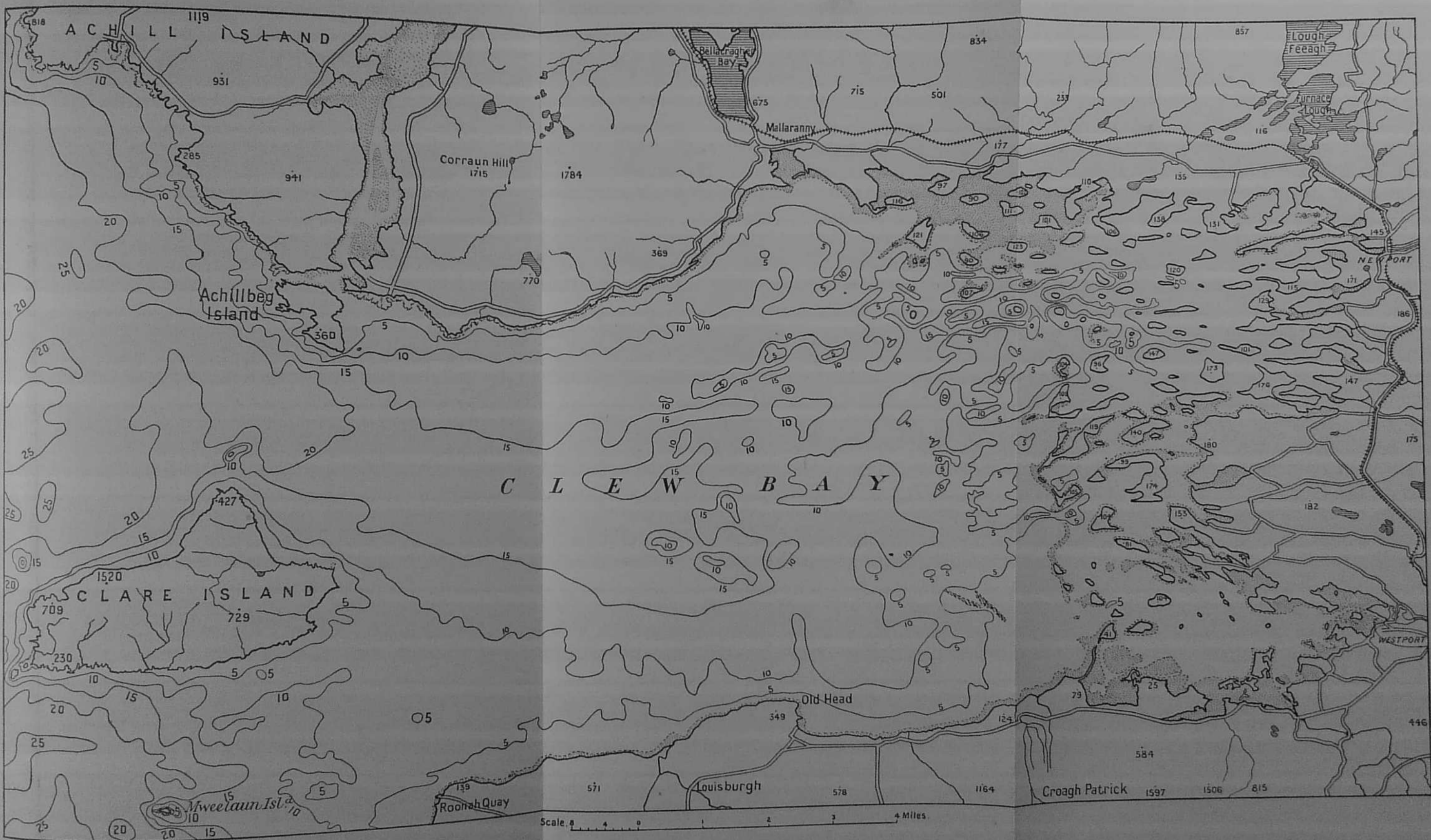



Fig. 90. The drumlin archipelago of Clew Bay (Based on The Ordnance Survey).

(Fig. 91). Their abundance may be gauged from the map (Fig. 78, p. 208) or from the fact that *eiscir* or the anglicised form esker is the name of some fifty townlands and is combined in the names of many other places, especially in the Central Plain. Perhaps the most celebrated is the *Eiscir Riada*, which extends with slight interruptions from Dublin to Galway, and in modern times has controlled lines of canal and railway and in ancient times was at least theoretically the boundary between the Kingdom of Tara in the north and of Cashel in the south. This ridge which is breached by the Shannon at Athlone, where the gap was guarded in ancient times, was used as the

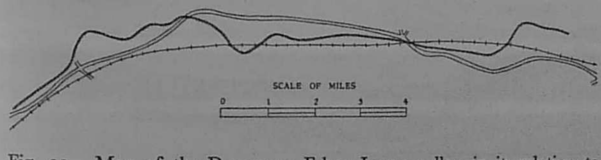
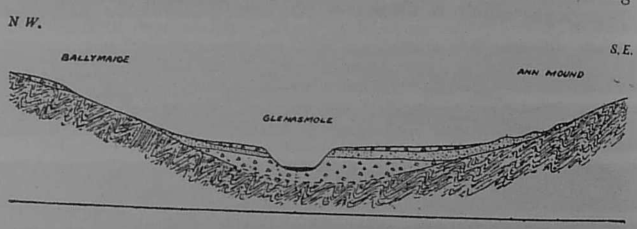



Fig. 91. Map of the Dunmurry Esker, Lagan valley, in its relation to the road and railway between Dunmurry to the north-east (right) and Lisburn to the south-west (left).

post road from Dublin to Galway, over a distance of thirty miles. In this respect it was typical of many other eskers whose efficient drainage and elevated narrow backs make them natural causeways. Roads, for instance, run upon eskers between Philipstown and Edenderry, in the neighbourhood of Banagher, Athlone, Birr, Maryborough, Shannonbridge, Ballinasloe and Monivea, along part of the Greenhills Esker near Dublin, and on the "Lisburn esker" in the Lagan valley.

The eskers are distinguishable from the sombre bogs through which they run by their green surfaces, whence the alternative name "green hills"; for their well-drained slopes are carpeted with grass and are the home of the few gravel-loving plants which haunt the Central Plain. Many of the eskers in Mayo, Roscommon and Leitrim are called *cluain* (*clon* or *cloon*) as in Cloonfannon and Cloonmore, since they often form isolated patches of dry fertile land in the midst of bog and undrained land. They also give rise to extensive heaths, e.g. the Great Heath of Maryborough situated a few miles north-east of this town.

Their perfect drainage is also connected with the numerous demesnes, parklands and fertile meadows which lie upon them; with the soft, springy turf of the big army training ground of The Curragh, Co. Kildare; and with the rearing and training of Irish hunters in Tipperary, Kildare and Meath. The mixture of debris from different sources explains the fattening




Silurian rock. Boulder clay. Sand and gravel.

Fig. 92. Geological section across Glenasmole near Dublin (Based on The Geological Survey).

lands of Meath and north Kildare, "the richest soil" which Wakefield "ever saw turned up with a plough." Their suitability for pasture and ease of working account for their frequent association with old raths or circular ramparts.

Many gorges and waterfalls throughout the country also indirectly proclaim the action of the ice-sheet. The rivers, resuming their flow on the retreat of the ice, found the surface covered with drift of various kinds. The vast majority had no difficulty in finding their old valleys. Though lined with thick drift, these still persisted as hollows at the surface so that the rivers now run, like the Lagan above Belfast or the river in Glenasmole in the Wicklow Hills, between banks of drift within their old valleys (Fig. 92). The Kilkeel River in the Silent Valley flowed over sands, gravels, fine silts and granite boulders (up to 15 feet long) which were penetrated to a depth



of 172 feet in making the trench for the dam of the reservoir (Fig. 93).

In numerous cases, however, the old valley was completely choked with drift and the river lost its way over shorter or longer distances and cut down into hard rock. Ireland has many such "glacial diversions." The river Roe, for example, lost its way near Limavady and flows through the "Gorge of the Roe" west of its old valley. The Lower Bann has similarly lost its way; it has wandered out of its course at "The Cuts," just south of Coleraine—the old valley is to the east—and at Portna, where the buried valley runs beneath Kilrea. In this way there arose the rapids in a river whose rock-floor is below sea-level (see p. 187).

The river Corrib flows placidly for five miles out of Lough Corrib and then saws its way into the Pre-Cambrian rocks in Galway City to reach the sea, abandoning its old course which passed just east of the town and under the big railway bridge.

The river Erne in like

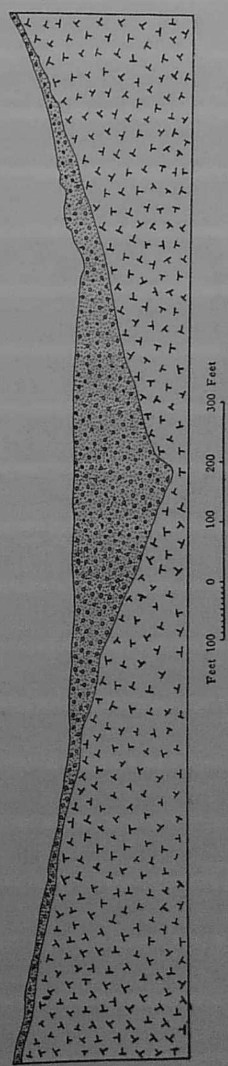



Fig. 93. Section across the Silent Valley on the line of the dam of the reservoir (After G. McIldowie).

manner missed its old channel, which ran directly westwards from Belleek, and turns abruptly northwards at this place to flow for six miles through a gorge with falls and rapids, e.g. at Belleek, a source of electric power, and at the well-known Falls of Ballyshannon.

The Ballyemon River has been similarly diverted to Cushen-

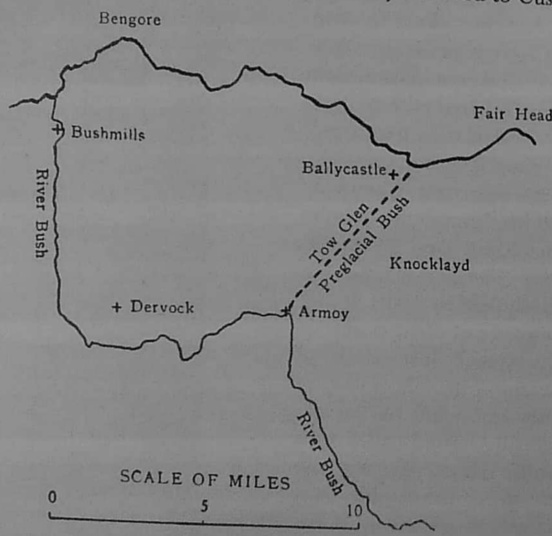



Fig. 94. Glacial diversion of the River Bush, Co. Antrim (After J. K. Charlesworth).

dall from its ancient northerly course into Glendun. A like fate overtook the river Bush, which instead of reaching the sea at Ballycastle by the Tow valley, west of Knocklayd, has been turned through a right angle at Armoy by the big moraine which it skirts, and ultimately breaches, to flow northwards to Bushmills (Fig. 94).

The river Liffey, as we now know it, did not exist before the Ice Age, for it then flowed past Blessington and Kilcullen into the river Barrow. It was diverted by the vast morainic



accumulations or eskers of The Curragh, where a bore proved the drift was 234 feet thick and the "solid" rock was at 127 feet O.D. South of Blessington it also missed its valley, which is now concealed by more than 130 feet of drift so that the river cuts a gorge into a spur of the Ordovician slate at Pollaphuca ("pool of the fairy") and as far as Ballymore Eustace, beyond which it once again flows in drift within its ancient valley (Fig. 70, p. 194).

## Chapter XIII

# THE RECENT PERIOD: THE RECOVERY

### 1. The Attack of Weathering Agents

The ice-sheets finally relinquished their grip on Ireland. The glaciers passed away as recently, perhaps, as 20,000 years ago: the topographic features are still remarkably fresh; the drumlins have retained their curves; and the rivers are busily seeking the floors of their drift-filled valleys.

The ice left behind it a land strewn with wreckage and disharmonic features which the normal erosive forces, once more released, have done their best to efface. These forces were especially vigorous in late-glacial time when snows still lay thickly on the hills in winter, the ground was frozen, the run-off of the streams was greater, and the rivers were swollen, notably at the melting in spring. The turbid rivers rasped their channels rapidly and wind and water acted freely upon a land which was swathed in drift and bare of vegetation.

The newly born rivers have endeavoured to restore their pristine shapes and to readjust the valleys to their own needs. Valleys have reverted to less bold and more stable forms, and the U has tended to give place to the V in cross-section by the wasting of the over-steepened sides by slips and screes. The walls of the cums have also been stripped by slips, cumbered with scree and ravined by streams, and aggraded waste has partially concealed the floors. The rivers have sawn through steps and barriers, as below many lake-basins now completely drained, or have cut through moraines in boulder-strewn gorges below the wild mountain tarns in the west. They have sometimes accomplished an impressive clearance of drift.

Inland and coastal slopes which were over-steepened and sapped by the glaciers have been especially prone to landslips. Examples are found beneath Tomies Rock in the Gap of Dunloe and particularly where water percolated through the





Carboniferous Limestone of Leitrim and Sligo, e.g. in Glencar and Glenade, or through the chalk above the lubricated and slippery Lias clays and Keuper Marls around the basalt-plateau. Under the enormous weight of the superincumbent masses, the limestones have slipped out leaving "slip gullies" behind them, such as the Swiss valley above Glencar, Co. Sligo. They have given rise to disorderly hummocks and pinnacled masses, like those skirting the lofty escarpment of Magho, south of Lough Erne, or the slices that have broken away at Cave Hill and Bellevue, Belfast, at the Gobbins, at Straidkilly (the "slipping village"), at Garron Tower (Fig. 95),

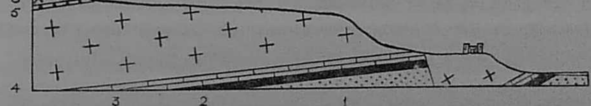



Fig. 95. Section through the landslip, Garron Tower, Co. Antrim. 1. Trias; 2. Lias; 3. Chalk; 4. Lower Basalts; 5. Interbasaltic Bed; 6. Upper Basalts (Drawn by P. Padget).

and in the face of Benevenagh east of Lough Foyle. In Co. Sligo, where the massive limestones rest on the shales of the Calp, the vertical joints cause the escarpments still to present bold precipitous faces.

Screes too have taken their toll. Below the vertical face of the sill of Fair Head, Co. Antrim, frost has broken off the rude columns to build the magnificent but dangerous block-scree in which the blocks may weigh 2000 tons.

Lakes, such as those between the drumlins or in the kettle-holes of the sands and gravels on the Central Plain and in Co. Antrim or Co. Londonderry, have vanished in enormous numbers. Streams and rains have carried in their muds, and vegetation has grown up from the floor and sides to oust the waters by marsh and bog or replace them by alluvial and cultivated flats. The disappearance of lakes may be seen in all stages in such typical drumlin country as Down.

Millennia of atmospheric disintegration have everywhere decomposed the surface rocks into soils, including the heavy, rich, brown soils of the basalt of the north-east. Acids in the peats have leached out the iron, which, as Nature's colouring agent, is present in most rocks, and have bleached the rocks white. The iron held in soluble combination as the hydrated oxide (limonite) has flowed to the lowest levels of the bogs to form the reddish-brown bog-iron ore, or to the bottom of shallow lakes to form lake-iron ore. Since this porous mass, with its mixture of sand and clay, takes up sulphur in its finely divided state, it has been gathered in great quantities (e.g. in Donegal, Galway, Clare) for purifying gas.

The ravages of time have given us the characteristic scenery of the granite, as at the Diamond Rocks or Castles of Commedagh in the Mourne Mountains (Pl. XXA), the granite crumbling along its mural joints into coarse gravel and sand, stained brown with iron.

The solubility of the Carboniferous Limestone in waters containing carbonic acid, a notable solvent of limestone, has allowed the streams, especially in pure and thickly bedded limestone, to plunge down shallow holes or *Sluggas* and to burrow under ground into "caverns measureless to man." The sluggas are round, bowl-shaped hollows, sometimes open to subterranean streams but generally floored with stones and loose clay. The waters flowing under the *cong* or neck between Lough Mask and Lough Corrib may be observed in the vicinity of Cong in gloomy caverns below—the canal four miles long, constructed between the two lakes during the Great Famine, is of course as empty as the day it was completed. A subterranean channel, about one and a half miles long, communicates between Lough Garvagh, the true source, and Shannon Pot or Lugnashinna, the legendary "Source of the Shannon," a deep round hole in the Carboniferous Limestone up which the water bubbles and overflows at 350 feet.

Caves have been hollowed out of the limestone in Benbulben and other mountains of Co. Sligo, near Lough Allen and Lough Arrow, in the Marble Arch (12 miles south-west of Enniskillen), and at the Toomeens, a series of natural arches



through which the river Ardsolla flows in Clare. Their dripstones or stalactites suspended from the roof and their stalagmites grown upwards from the floor beautify numerous caves, including the Mitchelstown Caves in the side of the Galty Mountains, Co. Tipperary.

The Fergus emerges as a full-grown river from the limestone near Ennis, and much of the drainage of Clare and Galway is underground and reappears in intertidal or submarine springs. Numerous grassy depressions in Connaught and elsewhere fill by underground waters in wet weather to form blind lakes or *turloughs* (*Tur*, "dry"). They drain by the same channels to form green pastures in dry summers.

Towards the wet and windy west, where the soil-cover becomes thin, the horizontal limestone emerges in a country thickly sown with angular blocks and crossed by high walls of grey limestone. Its grey pavements are intersected by countless criss-cross furrows, hollowed out along the rectangular joints by rain and percolating waters. Many rare plants spring from the insoluble residue at the bottom of the grooves. These bare pavements, watered by no stream but honeycombed with innumerable underground channels, floor the country about Lough Mask and Lough Corrib, about the head of Galway Bay, and in the Aran Islands, which stand across the mouth of the bay, and with their reefs and shelves of limestone, form an outlier of the mainland. Their chief exposure, the home of arctic-alpine and Mediterranean plants (see p. 243), rises in terraced slopes to Slieve Elva (1134) in the desolate plateau of the Burren ("great rock"), south of Galway Bay. Of its bare pavements Cromwell's captains said "there was not enough water to drown a man, nor wood to hang a man, nor ground to bury a man." (Pl. IIIB.)

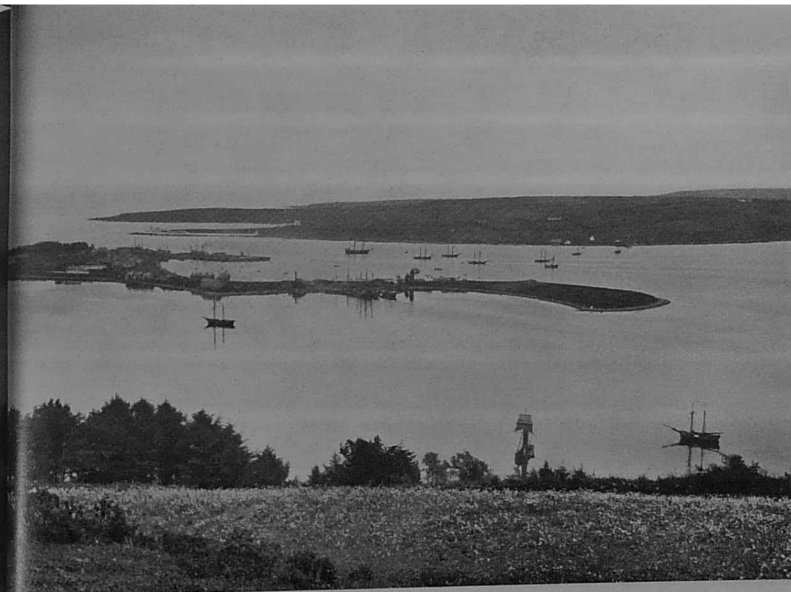
The chalk has few of these limestone features, though waters flowing off the basalt sink into the chalk, for example south of White Park Bay and about Kilwaughter (south-west of Larne). They deposit their calcium carbonate as tufa in springs or as stalactites in the roofs of sea-caves, e.g. at the foot of Larrybane cliff, near Ballintoy. Loughaveema, the "vanishing lake" situated by the roadside between Cushendall and Ballycastle, rises and falls with the rainfall and vanishes entirely after a long spell of dry weather. At this time its underground drain, which runs above the junction of the chalk with the underlying impervious schist (Fig. 53, p. 155), takes the entire flow from the bottom of the lake to a spring on the moors.

The sea has also attacked the coasts, particularly where they are made of drift. It has scarped the ends of the drumlins, as is well seen along the shores of Donegal Bay and Clew Bay and along the road skirting Strangford Lough between Newtownards and Portaferry. Vast quantities of drift have been removed in the process. The resistant boulders have built up pavements along the shore and the muds have accumulated in sheltered localities, as in the sloblands. These have been reclaimed in "intakes" by erecting artificial banks, e.g. south of Lough Foyle, about the head of Belfast and Strangford loughs and in Dublin Bay and Wexford Harbour. The shingle has been heaped up into bars like those that festoon the bays between the rocky headlands of Co. Wicklow and Co. Wexford, e.g. the Murrough between Greystones and Wicklow, which are backed by salt marsh or lagoons. Wexford Harbour is almost closed by a narrow spit of sand, three miles in length.

Violent Atlantic storms, the artillery of the oceans, have torn huge blocks from the beds of the west coast, e.g. in Co. Sligo, and tossed them beyond the reach of ordinary tides. Onshore winds have blown the sands from the more shelving shores into dunes which festoon the heads of bays all around the country, as in Dundrum Bay and White Park Bay, at Portrush and Portstewart, and especially in Co. Donegal and the west, e.g. west of the Mullet Peninsula, Co. Mayo. The natural sand blast, with the aid of solution, has smoothed and fluted the boulders of chalk on the east shore of White Park Bay.

### 2. The Isostatic Response of the Crust

The ice-sheet by its weight depressed the crust beneath it. When the ice melted and the load was removed, the crust rose.



A. The Curran, Larne, Co. Antrim, a spit in the raised-beach sea

PLATE XXI

B. The "submerged forest", Bray, Co. Wicklow. E.C.=Estuarine clay; P.=peat; S.=sand

The full response was not immediate, the uplift being delayed until most of the ice had disappeared.

The recovery in the British Isles was naturally greatest where the ice had been thickest, namely in Scotland. In Ireland it was mostly felt in the north-east where the invading Scottish Ice first reached the Irish coast. The earlier (late-glacial) beaches, so widespread in Scotland, are rare in Ireland; the 100-foot beach may occur at Malin Head, Inishowen (storm beach?), and is represented by the 50-foot beach in the north-east, at Waterfoot (with caves), north of Cushendun Bay, at Ballycastle and at Church Bay, Rathlin Island. The Littorina or "25-foot raised beach" of Scotland is more widespread: it is at about 20 feet in north-east Antrim and falls steadily to present sea-level about Arklow Head, Co. Wicklow, in the south and about Rosse's Point, Co. Sligo, in the west.

The isostatic response has brought the land out of the sea and exposed the ancient shore-line as a raised beach, now well out of reach of even the highest tides. On exposed stretches, it forms a raised rock platform, e.g. the Grand Causeway and the notches at the headlands between the amphitheatres of the Giant's Causeway. The Antrim Coast Road, built between the cliffs and the sea as a relief work during the famine of 1848, is a further example. The shelf is furnished with sea-stacks, e.g. the "Tether Stack" near Downhill, the Steucans at the Giant's Causeway, Granny's Rock, Ballycastle, and the conical stacks near Ballintoy Harbour (see p. 176), and is backed by a cliff with caves which are well seen at Waterfoot, Cushendun (Pl. IIIA), Ballintoy Harbour, Giant's Causeway and the White Rocks, Portrush.

On more sheltered coasts, the uplift has brought up true shingle beaches with marine shells, e.g. south and east of Lough Foyle, including the triangular spit of Magilligan which because of its remarkable flatness and extent—it occupies about a dozen square miles—was admirably suited to provide a base (length 7·89 miles) for the Ordnance Survey primary triangulation of the British Isles in 1827. The beach is also seen at

Ballycastle, at Cushendun and at the mouth of Glenariff—these are deltas in the raised-beach sea—and in the sickle-shaped Curran of Larne (*corran*, a reaping hook), a spit deposited at the entrance to Larne Lough by the tidal current of the raised-beach sea (Pl. XXIA). It also underlies numerous coastal villages and towns, such as Cushendun, Kilroot, Ballyholme, Dundrum, Newry, Warrenpoint, Greenore and Dundalk, and the isthmus connecting the Hill of Howth with the mainland (Fig. 15, p. 41); and occurs at intervals along the coast of Donegal and its islands, e.g. Inishtrahull ("island of the big strand").

At the heads of bays the uplift has brought up the littoral muds of the quieter waters. These tough "Estuarine Clays" lie beneath Larne Lough and the southern shores of Lough Foyle and under Strangford Lough about Newtownards and Downpatrick. They surround the head of Belfast Lough from Holywood to Whitehouse and underlie lower Belfast, including the City Hall, Municipal College of Technology, Law Courts, B.B.C. Building and the slipways of the shipbuilding yards, all of which were erected upon innumerable wooden or concrete piles, 20 to 40 feet long, driven into the clays. The older buildings have suffered considerably from the decay of the tops of the timber piles which have been repaired at much expense by constructing concrete rafts above the piles. The Customs House, Post Office, Bank of Ireland, Trinity College and other buildings in the centre of Dublin are similarly situated.

At the time of the raised-beach sea, Horn Head and Rosguil Peninsulas, Co. Donegal, Ramore Head, Portrush, and the Hill of Howth were islands. Inishowen (*Innis Eoghain*) was divided into Malin, Doagh Island and Inch Island, and was largely separated from the rest of Donegal by a narrow strait which the road and railway now follow between Londonderry City and Fahan on Lough Swilly. A narrow firth likewise extended up the Foyle to Strabane and Murlog ("sea-cave"), near Lifford; several islets studded its surface; jutting creeks ran in among its thickly wooded shores; and an arm reached westwards as far as Castlefinn.



Although the sea flooded the lower Bann there is no evidence that it ever entered the Lough Neagh basin after the ice melted. It is true that the shrimp, *Mysis relicta*, and the pollan, *Coregonus pollan*, both related to marine species, occur in the lake and that a group of plants, usually of maritime habitat in Ireland, e.g. *Scirpus maritimus*, *Spergularia rupicola*, *Viola curtisii* and *Trifolium arvense*, live on its sandy shores. These distributions have led to the hypothesis of a recent marine invasion of the lake. But the pollan also inhabits Lough Erne and Lough Derg and the upper Shannon, into which sea-water has certainly not penetrated; *Plantago maritime* abounds along the shores of Loughs Mask, Conn and Derg, and the maritime plants *Silene maritima* and *Asplenium marium* grow by the lakes of Killarney at some 70 feet where a submergence is out of the question. It is concluded therefore that these plants live around Lough Neagh because of its sandy shores and open conditions, and that the shrimp and pollan wandered into the lough from the direction of Newry or Coleraine when the raised-beach sea submerged the lower reaches of the rivers and curtailed the water courses.

### 3. The Return of the Plants and Animals

Ireland's fauna and flora have a recent geological history which is by no means clear. Two of their minor groups, the so-called Lusitanian and American elements, have been focal points of much controversy. The first consists of several species which to-day are mainly found in the Iberian Peninsula (Lusitania, Roman name for Portugal) and include, among the plants, *Saxifraga spathularis*, *S. hirsuta*, *Euphorbia hiberna* (Irish spurge), *Arbutus unedo* (strawberry tree) and the Pyrenean heaths *Erica mackiana*, *E. mediterranea* and *Dabeocia polifolia*, *Pinguicula grandiflora*, *Simethis planifolia* and the orchid *Neotinia intacta* and, among the animals, such forms as the Kerry spotted slug, *Geomalacus maculosus*, the millepede *Polydesmus gallicus*, the woodlice *Platyarthrus hoffmannseggi*, *Trichoniscus vividus* and *Metaponorthus cingendus*, the earth-worms *Allolobo-*

*phora vineta* and *A. georgii*, the dragon fly *Tinodes maculicornis* and a number of molluscs. Most of these species live to-day in Kerry and Cork, though some range as far north as Donegal and as far east as Wicklow.

The American element, separated by the broad Atlantic from its main area of distribution in the middle latitudes of North America, is composed of a few species only, including the water-weed *Naias flexilis*, the pipe-wort *Eriocaulon septangulare*, two closely allied orchids *Spiranthes gemmipara* and *S. stricta*, the fresh-water sponge *Heteromeyenia ryderi*, and a few wingless insects.

Irish Naturalists, in general, believe that these two elements are broken-up remnants of past invasions and among the oldest in the country: they withstood the rigours of the Glacial Period in some asylum in the west or south. Others, however, contend that the severe glaciation from which Ireland suffered at the height of the Ice Age destroyed all its life. Had any mountain top projected above the ice as a nunatak, it could have harboured only a few arctic or alpine plants. When the ice receded from the south and warmer conditions prevailed, the plants and animals returned, the latter leaving their bones in a few caves in the south (see table below).

### Table of Pleistocene Cave Animals

| | Mammoth | Cave Hyæna | Bear | Arctic Lemming | Scandinavian Lemming | Irish Deer | Reindeer | Arctic Fox | Lynx |
|---|---|---|---|---|---|---|---|---|---|
| Ballinamintra (Cappagh) | – | – | + | – | – | + | + | + | – |
| Castletownroche (Co. Cork) | + | – | + | – | + | + | + | – | – |
| Doneraile (Co. Cork) . | + | + | + | + | + | + | + | + | – |
| Edenvale (Co. Clare) . | – | – | – | + | – | – | – | – | – |
| Keshcorrin (Co. Sligo) . | – | – | + | + | – | – | + | – | – |
| Kilgreany (Co. Waterford) | – | – | + | + | – | + | + | + | + |
| Lough Gur (Co. Limerick) | – | – | + | + | – | + | – | – | – |
| Shandon Cave (Dungarvan) | + | – | + | – | – | + | + | – | – |



The position of these caves, except Castletownroche, is given in the map (Fig. 96) as follows: Ballinamintra (G): Doneraile (J): Edenvale (K): Keshcorrin (H) (Y): Kilgreany (R): Lough Gur (A) (W): Shandon (J).

The recurrence of the glacial conditions that carried the ice-front to the line of the Southern End-moraine (Fig. 78, p. 208) forced the plant and animal life to withdraw once more: the mammoth failed to survive this last glaciation in Ireland. The early reappearance of the giant deer and reindeer suggest that they had not receded far and quickly followed the retreating ice-front. Their remains lie side by side in a number of late glacial or early post-glacial deposits.

Among the plants, the arctic and alpine species almost certainly survived this glaciation. The Lusitanian species probably did not do so, though judged by their vertical range in the west to-day, they are not sharply distinguished from the alpines in their powers of endurance.

With the returning warmth, the Glacial Period finally passed away in ways we have considered, and the arctic plants and animals followed in the wake of the ice. Lemmings, now found only in arctic regions, spread into Co. Waterford (Kilgreany), Co. Limerick (Lough Gur), Co. Sligo (Keshcorrin) and Co. Clare (Edenvale); the reindeer (*Rangifer tarandus*) wandered into Cork, Limerick, Waterford, Wicklow, Dublin, Clare, Sligo, Roscommon, Tyrone, Longford, Meath and Westmeath (Fig. 96); and the Irish Deer (*Cervus giganteus*) roamed the country in great numbers—the Ballybetagh Bog, Co. Dublin, has yielded over 100 heads as well as several skeletons. (Fig. 97.)

Arctic conditions were apparently general throughout the country, since the cold *Salix herbacea* flora, including one or more of the following—*Salix herbacea, Saxifraga hypnoides, Oxyria digyna, Arenaria ciliata, Thalictrum alpinum*—has been found in places as far apart as Frenchpark, Co. Roscommon, Ralaghan, Co. Cavan, Ballybetagh, Co. Dublin, Dunshauglin and Ratoath, Co. Meath, and Roundstone, Co. Galway. Indications of it have been found at Sloggan Bog, Randalstown, Co. Antrim.

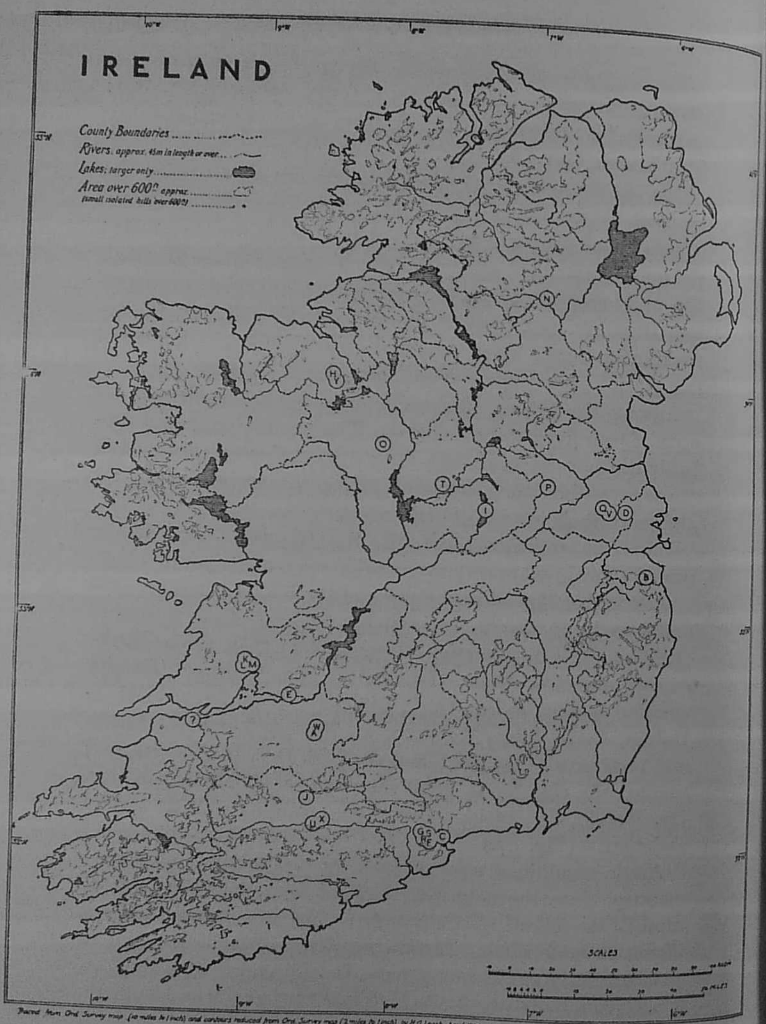



Fig. 96. Map showing the distribution of reindeer in Ireland (After G. F. Mitchell).

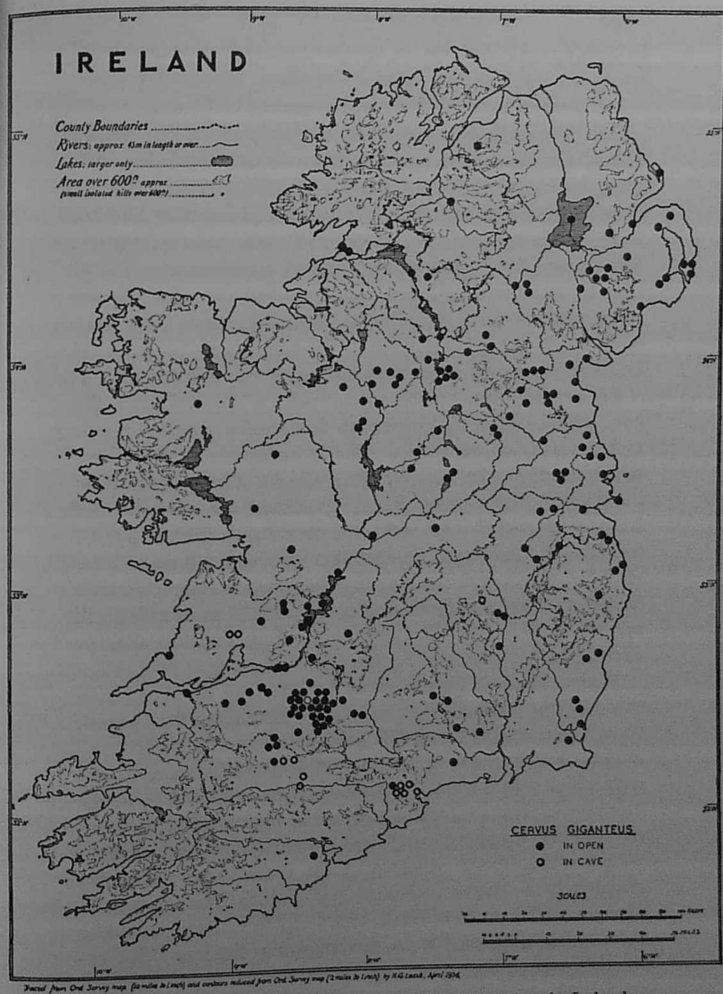



Fig. 97. Map showing the distribution of the Irish deer in Ireland (After G. F. Mitchell).

In keeping with this climate are the stunted fresh-water shells, reminiscent of those now found in Greenland and north Europe, which lived in the White Bog at Killough, Co. Down.

Soil flow or "solifluction," which in the form of "head" (see p. 197) had been active at the onset of glaciation, was again operative; its effects have been seen, for example, at Ballybetagh. Evidence here and at other places near Dublin, as well as in counties as far apart as Cavan, Galway, Meath, Monaghan, Roscommon and Wexford, suggests a period of climatic improvement before the arctic bed and after the ice retreated from the Central Plain. During this time, there were open woods or scrub birch with willow and some juniper, and an extensive growth of grasses and herbaceous plants.

The rapidly ameliorating conditions which followed the *Salix herbacea* or Ballybetagh period allowed temperate plants and animals to immigrate. The innumerable shallow lakes which studded the country after the ice disappeared were inhabited. The Central Plain was almost one vast sheet of fresh-water dotted over with countless islands formed by the summits of the eskers. In the lakes there were deposited the stratified marls, white or blue in colour, which abound in such fresh-water shells as *Bythinia*, *Planorbis* and *Limnaea*, which still survive, and by alga-like plants including the stonewort or *Chara*, which is the main feature of the marls.

Miring in these Chara or shell-marls may have been the cause of the extinction of the Great Irish Deer in Ireland, though the extinction of this graceful and well-proportioned animal has been attributed to epidemic distemper, to the wolf which was formerly prevalent, or, more probably, to the increase of forests which served as the asylum of its foes and reduced the feeding grounds by preventing the deer, with its wide antlers, from entering. Like the reindeer, it failed apparently to survive the cold of the Ballybetagh period when a rich growth of little arctic-alpine willows, including *Salix herbacea*, covered even the low-lying districts. The extinction was earlier than many of the marls and much earlier than the bogs.



The returning fauna and flora entered Ireland over land-bridges, principally in the southern part of the Irish Sea and between Donegal and the Scottish Isles. At that time the Irish Sea was at least 100 feet lower than now and was largely replaced by land with lake-like expanses drained by an "Irish Channel River" (see below). Wolf and red deer were abundant and widespread, the red deer being found in the shell-marls and in and under the peats. The brown bear probably lived into this period in the Central Plain and farther south.

Of the animal assemblage of late-glacial or early post-glacial times that comprised lemmings, arctic hare, bear and wolf, the arctic hare has alone survived into historic time. It has, however, developed racial peculiarities, as it did in Scotland, and forms a distinct species or a sub-species (*Lepus timidus hibernica*). Remains of the wolf (*Canis lupus*) have been found in Iron Age sites.

Willow, birch, hazel and Scotch pine, as shown by pollen grains and macroscopic remains in the peats, were the first to enter the country and become dominant. They were followed by the warmth-loving oak, elm, alder and, lastly, by beech, which was probably a human introduction.

Eight vegetation horizons have now been recognised. Zones I and III are arctic layers, with the *Salix herbacea* flora, reindeer and Irish Deer: thick ice formed on the countless lakes and solifluction or soil flow occurred round their margins. A short period of warmer climate in zone II separated them, e.g. at Ballybetagh and Ralaghan. Zone VI is Neolithic, zone VII Bronze Age and zone VIII Early Christian (see table on pp. 250, 251).

A rise of sea-level, owing to general world causes which may have included the melting of ice-masses in polar latitudes, produced the thin film of water known as the Irish Sea. It drowned the long parallel inlets of the rias of Kerry; flooded the low-lying fens and forests of the coastal plains; and gave rise to the "submerged forests" found between tide marks, as in Dublin Bay (Pl. XXIB), and at a depth of about 30 feet at the head of Belfast Lough and Strangford Lough. It separated

# LATE- AND POST-GLACIAL DEVELOPMENT IN IRELAND

| Baltic Chronology (Figures approximately) | | Zones | | Periods | Flora and Vegetation: First record of trees and other plants / Changes in frequency of trees | | Flora and Vegetation: Development of Vegetation | Deposits (non marine) | Climate | Changes in Levels | Archaeological Levels | Zoning in England (Godwin) | Zoning in SW-Norway (Fægri) | Zoning in Denmark (Jessen) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 B.C. | Post-Glacial: Sub-Atlantic | VIII | c, RS A, b, RS B, a, RS G | Alder-Birch-Oak Period | Rise of Betula | Ceratophyllum Submersum; Spergula arvensis a.o. weeds; Hulled & Naked Barley, Flax | General Deforestation | Ombrogenous peat generally Slightly decayed | Oscillating; Markedly oceanic Summer-tp. falling | Transgression | HISTORIC TIME; LATE BRONZE AGE; Shield of Hallstatt-type 'Cloonlara | VIII; RS- | XI | RS I-; IX; RS II- |
| | | | | | | | | | | | | RS | RS (BLYTT) | RS III |
| 3000 | Post-Glacial: Sub-Boreal | VII | b | Alder-Oak Period | Pinus disappears; Quercus-maximum; Maximum of Hedera and Ilex; Sambucus nigra; Further Rise of Alnus, Decline of Ulmus | Small Spelt, Emmer, Naked Barley, Plantago lanceol.; Myrica | Woods in Wicklow Mountains at ca. 600 m. Local deforestation in W-Ireland | Pine-stumps common; Wood peat and well decayed; Ombrogenous peat prevailing | Rather dry, Maximum of Summer-temperature | Regression in NE-Ireland; Maximum of Transgression in NE-Ireland. High water Level at Cushendun abt. 6,5 m. above modern h. w. l. | NEOLITHIC: Bann culture, Newferry; Raheelin; Derrytagh North; BRONZE AGE: MIDDLE, EARLY; Site at Cushendun (Horiz. 4) | VII VIII; ----RS-; b; VII; U-decline | X; U-decline | VIII; U-decline |
| 5000 | Post-Glacial: Atlantic | VII | a | Alder-Oak-Pine Period | Oftenmost Corylus-minimum; RB of Alnus | Eriocaulon septangulare; Raised bog and Blanked bog species | The lowlands and the lower mountains covered with woods (Atlantic to Boreal V) | Ombrogenous peat, well decayed, Wood-peat and Swamp-peat common; First records of Raised- and Blanket-bog peat | Rather warm and oceanic (Atlantic to Boreal V) | Transgression continued | MESOLITHIC: Island Magee; Flint industry at Portrush; Late Larnian at Cushendun Horizon 3 | a; RB of Alnus (W-England) | IX; RB of Alnus | VII |
| | Post-Glacial: Boreal | VI | c, b, a | Hazel-Pine Period | Pinus-max., NE. Ilex; Alnus pollen sporadic; Pinus-max. SW.; Ulmus-max.; Corylus-maximum; RB of C-M | Erica Mackaii; Cornus sanguinea, Hedera Helix, Taxus, Viburnum | | Peat below Bann diatom.; Wood-peat common, Swamp- and Fen-peat; Peat below the Warren at Cushendun; Submerged peat in Bann estuary | | Transgression in NE-Ireland continued; Transgress. of level now -0,8 m. Cushendun; Transgress. of level now -5,8 m. Bann; Transgress. of level now -8 m. Belfast | MESOLITHIC: Island Magee; Early Larnian at Cushendun (Horizon 1 & 2); Toome Bay culture | VI; RB of Alnus (E-England) | VIII | VI; RB of Alnus |
| | Post-Glacial: Boreal | V | | Hazel Birch Period | Max. of Betula pubesc. Pinus silv., Betula alba; RB of Corylus | Cladium, Erica ciner. & tetral.; Najas flex. & marina | | Limnic deposits prevailing. Wood peat | | (Submerged peat on Dogger & Leman & Ower banks North-sea) (Boreal V and Pre-Boreal IV) | (Fish-spear. Leman & Ower Banks) | V; RB of Co. | RB of Co. | V; RB of Co. |
| 8000 | Post-Glacial: Finiglacial, Pre-Boreal | IV | | Post Glacial Birch Period | Populus tremula; Salix caprea & cinerea | Calluna, Ceratophyll. dem.; (Salix herbacea in the Lowland) | Birch woods still some Empetrum-heaths | Limnic deposits prevailing. Swamp-, Fen- and Wood-peat | Temperature rising | | | IV | VII | IV |
| | Late-Glacial: Gotiglacial, Younger Dryas | III | | Younger Salix Herbacea Period | In the lowland Salix herbacea, Betula nana, Dryas octopetala, Oxyria digyna, Arenaria ciliata | | Scattered Betula pub. Empetrum heaths and Tundra | Solifluction-earth, Clay and Clay-mud | Sub-arctic oceanic | | | | VI | III |
| | Late-Glacial: Gotiglacial, Allerød Period | II | | Late Glacial Birch Period | Betula pubescens; Juniperus communis | Betula nana, Eleocharis multicaul., Litorella, Ranunculus Ling., Salix cf. phylicif. | Park Tundra and Empetrum heaths | Various kinds of Mud | Mild sub-arctic oceanic | Late-glacial sea with "100 ft" Terraces in Scotland | | | V | II |
| | Late-Glacial: Daniglacial, Older Dryas Period | I | | Older Salix Herbacea Period | Salix herbacea, Empetrum nigrum. Isoetes lacustris, Myriophyllum alterniflorum | | Tundra | Solifluction-earth and Clay | Presumably Arctic | | | | I-IV | I |

the Isle of Man from England and broke down the land-bridges, thereby preventing further ingress of plants and animals, except by accidental dispersion by winds, birds and sea-currents. Hence Ireland lacks certain species, for example, mole, vole, common toad, common hare (the Irish hare is the arctic hare, *Lepus timidus hibernica*), viper, crested and palmated newts, snakes, certain fresh-water fish (barbel, chub and dace) Unios and Viviparas, blindworms and a number of plants, e.g. the needle-furze (*Genista anglica*), sweet milk-vetch (*Astragalus glycophyllos*) and the lily of the valley (*Convallaris majalis*), all of which are found on the other side of the Irish Sea; they did not arrive at the bridge-heads in time to cross. The submergence also permanently separated human sites of north-east Ireland, e.g. Cushendun, from those of south-west Scotland, e.g. Campbeltown in Kintyre, which previously had been one cultural region. On the south coast, it continued until a later date, since the Ardmore Cranog, Co. Waterford, and the Rostellan dolmen, Co. Cork, are partially submerged.

During the period of the Estuarine Clays and of the growth of the trees, now found as stumps below the bogs, the temperature of the air rose to about 2·5° C. (4·5° F.) above that of the present. During this "post-glacial warm period," which affected the whole of the North Atlantic area and may have been felt over most of the globe, warmer shells lived in the Irish Sea, e.g. at Larne and Cushendun, and pine and birch spread to about 1000 feet above their present limits and flourished in the west, where the strong winds and exposure make such growth impossible to-day. Greater dryness during part of this time caused many small lakes, as in Donegal, to dry up, and even lowered the level of Lough Neagh, since forest peat is found submerged on its southern shores.

A pastoral population now took possession of the country. They brought with them their domestic animals, namely, the ox, goat, horse, pig and dog.

When the climate deteriorated about two and a half thousand years ago (*c.* 500 B.C.), the tree-limit was brought down the hillsides and trees ceased to grow on the wind-swept plains of



west Donegal, Mayo and Galway and on the outer islands. A few molluscs withdrew from the coasts of Antrim and Belfast Lough to the west and south.

This climatic worsening which set in fairly rapidly and was accompanied by increased moisture, caused the trees to be replaced by an extensive growth of peat such as to-day mantles the country, with certain noteworthy exceptions (Fig. 98). The great red bogs of the Central Plain began to grow and mountain bog clothed the hills and even the mountain tops. The woodlands were largely overwhelmed, as the buried remains of pine, oak, yew and hazel everywhere testify, and only survived where the drainage was unusually good. The spreading peat even mantled the cairns and other monuments raised by the people of the Bronze Age.

The peat, which to-day covers about three million acres or one-seventh of Ireland to an average depth in the mountain bog of perhaps five feet and in the Central Plain of about eighteen feet, is found chiefly in the wetter west where excessive moisture and warm winds encouraged its growth. It blankets the Comeraghs, Galtees, Knockmealdowns, Wicklows, Sperrins and other high mountains and often floors the low plains, including the Central Plain where it lies among the eskers, especially in the Bog of Allen and the flats south of Athlone, and those of west Mayo north of Clew Bay, the Silurian country south of Clew Bay, the lake-strewn Connemara and the flats south of Lough Neagh and in north Antrim. While impervious rocks like the Carboniferous shales of Clare and the Coal Measures of Munster aid its growth, other rocks which favour drainage are peat-free, e.g. the Carboniferous Limestone south of Lough Mask, the Burren about the head of Galway Bay and the uplands of Co. Roscommon. Even the limestone country south of Galway Bay, that rises into the rain-bearing winds from the Atlantic to almost 1000 feet, is practically destitute of peat. To this category belong also the glacial sands and gravels, inclusive of the eskers of the Central Plain, e.g. in Meath and Kildare, those east and west of the Wicklow Mountains and in the Golden Vale of Limerick, the valleys of the

Fig. 98. Map showing the distribution of the Irish peats.



Barrow and Nore, the Bann and Main, and in the Clogher valley and plain of Fintona.

Drumlins, though composed chiefly of boulder-clay, facilitate drainage by the steepness of their flanks, so that peat in the drumlin belts is confined to the inter-drumlin hollows or to small tracts bare of drift. Hence, the rarity of peat in the area extending from the Ards Peninsula into Co. Cavan, in the country margining Donegal Bay on the north and east, and in the valley of the Erne and the drumlin districts of Clew Bay and Bantry Bay.

With the incoming plants and animals, there also entered prehistoric peoples. Although Palaeolithic or "Old Stone Age" Man, a hunter and fisher, was probably a contemporary of the mammoth and other "glacial" animals in Ireland, there is no trustworthy evidence that this was so. Skeletal remains of this age have not yet been found, though a Neolithic skeleton at Kilgreany, Co. Waterford, has been erroneously referred to this date. Crude and very heavily rolled implements, reminiscent of Lower Palaeolithic types but apparently Mesolithic ("Middle Stone") in age, are found in the 25-foot beach, especially at Larne and in a few river valleys. A succession of related but distinctive littoral cultures emanating from some eastern focus reached the shores of north-east Ireland in Mesolithic times. The chalk cliffs of Co. Antrim, with their inexhaustible supplies of flint, exercised a magnetic attraction upon peoples on the opposite shores and far beyond it. Fishing, fowling, hunting and collecting formed the basis of subsistence. Outside this focus of settlement we know nothing of Mesolithic Ireland.

The flint implements of these Mesolithic people are found in astonishing numbers at Cushendun at the base of the raised beach or in the lowest (late-boreal) peat; at Larne, redistributed and worn, within the raised-beach spit of the Curran; and at Glenarm, resting on the raised beach. The raised-beach cultural sequence culminated in the evolved industry of Strangford Lough where the Mesolithic settlements and hearths occur directly on the raised-beach gravels, and in the basal gravels. In the Lower Estuarine clay at Island Magee they belong to the first wave of pre-Campignian immigrants to reach the Antrim sea-board.

The peoples of the Neolithic or New Stone Age lived on the north-east coast after the time of the raised beach sea. Their flint implements (Fig. 99) are found in the deposits of this age in numerous localities, including Dundrum, Rathlin Island, Portstewart and Castle Rock.

The "kitchen-middens" of the early peoples of the following Bronze and Iron Ages are found in many coastal sandhills, including Donegal, Cork Harbour, White Park Bay and on both banks of the Bann at its mouth. These refuse heaps consist chiefly of oysters, limpets, mussels and pectens, with fragmentary bones of domestic animals (horse, ox, sheep, goat, pig) and red deer, fish and birds, including the Great Auk (*Alca impennis*) which is now extinct. Worked flints, pot shards and charcoal show that the shores were then inhabited. The sand dunes, which rest upon the raised beach and are therefore of later date, were built up during the Bronze and Iron Ages. Explorations in the raised beach caves of White Park Bay have brought to light nothing earlier than the Early Iron Age.

That prehistoric man also lived inland is proved by the scrapers, perforators, blades, gravers and small hammerstones, all of Early Mesolithic age, in the diatomaceous earth. This "Bann clay," dull bluish-grey tinged with brown, seals a layer of peat, two or three feet thick, which contains pollen of oak and alder (late Atlantic or early Subboreal age). It extends beneath the broad flat floor of the river Bann between Portglenone and Toome Bridge, i.e. between Lough Neagh and Lough Beg, as a thin layer averaging three to four feet in depth. It was laid in shallow fresh-water, for it is composed of the siliceous "tests" of countless millions of microscopic, single-celled, fresh-water plants called diatoms. The diatomite was deposited primarily during the winter floods, that is at the cool season when diatom floras are best developed. During the summers, the site was dry and was used by the peoples who probably came from Denmark and whose main occupation was

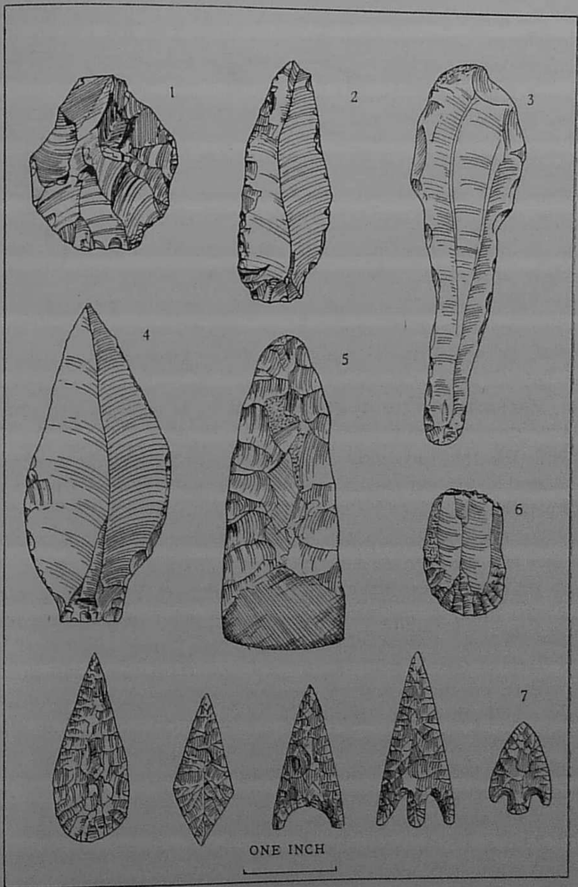



Fig. 99, Mesolithic Neolithic and Bronze Age artefacts (Drawn by E. E. Evans, to two-thirds natural size).
1, Island Magee; 2, Cushendun; 3, Larne; 4, River Bann; 5, Axe with polished edge; 6, Scraper; 7, Arrow heads.

fishing. Their flat Bann flakes of flint, chestnut-brown in colour, were hafted to shafts and used as fishing spears. The less common artefacts of polished basalt are found at various horizons in the diatomite. The basal layers have charcoal of willow, alder and oak and a pottery of Neolithic (Windmill Hill) type. The deposit was forming during late-Atlantic and Subboreal times, i.e. about the beginning of the second millennium B.C. (see pp. 251, 252).

The diatomite, which has a silica percentage of 73·01, has been worked extensively at Toome (Pl. XXB) as a heat-insulating material, as an absorbent of nitro-glycerine in the manufacture of explosives, or, mixed with clay, in the making of bricks. The output for the three years 1946 to 1948 averaged 7515 tons.

The table (pp. 250, 251) may help to make more understandable the ages and relationships of these various events. It relates the tree succession, the human cultures and the marine stages to the chronology and climatic periods established in Scandinavia.

We have now completed our description of the kaleidoscopic events and the pageant of life to the point where the pre-historian and historian take up the tale.

Ireland's geological history, immeasurably venerable and written on the face of the country, tells of a titanic conflict in which the ceaseless fretting of the rocks, under varying conditions of climate, has sought to counter the effects of repeated earth-movements. The island, bounded by a coast-line of modern date, received the indelible impress of its main physical features as far back as the Palaeozoic era.

The girdle of mountain clusters, with its richly varied relief and attractive contrasts, its rugged peaks, bare summits, bleak and desolate moors, picturesque gorges and embosomed lakes, is the weft of geological forces and finds its satisfying explanation in the complicated pattern of the geological map.

The smooth outlines of the granite hills of Donegal, clothed



in heather and moss, contrast with the white, serrated ridges and cones of the Dalradian quartzite which flank them on either side and surpass them in height and grandeur. The bareness and stark sterility of these quartzites yield to sombre wastes of bog and heather in the Sperrins and the similar schist country of Donegal, with its flowing curves and expanses of peat, heather and grass that cloak the drift. The schists of Mayo and Galway underlie the plains studded with lakes, peat-bogs and alluvial flats that rise into the quartzite of the Twelve Bens and spread westwards to a coast of rugged and spectacular cliffs and numerous indentations.

The diversity of the rocks in Leinster and the degree and manner to which they have succumbed to the denuding forces afford a scenery attractive in its beauty and grandeur. Granite, massive in its proportions, impressive glens with cascading streams cutting back into lonely cums, sylvan vales, meandering rivers and fine coastal cliffs, all combine to produce a scenery which is not excelled.

The barren, heathy moorlands and continuous watersheds of the longitudinal ribs of the O.R.S. of the southern anticlines alternate with the soft pastoral synclines, fertile and wooded, of the Carboniferous Limestone. Contrasting with the grassy Lower Palaeozoic hills of the south-east, they rise westwards into the tangle of wild mountains that tower upwards into the superb cones of the Reeks and some of the wildest rock-scenery.

The Tertiary igneous episode left its memorials in the north-east. Its lavas are sculptured into table-topped or ice-moulded hills and plateaus, draped in peat and heather: they break off in steep or precipitous coastal scarps or in deep romantic glens in which the grim, black lavas contrast with the thin band of the underlying white limestone, the blue of the Lias clays, and the red and more gentle slopes of the Triassic sand-stones and marls. Its gabbros give rise to the serrated sil-houette of the Carlingford Hills and its granites to the smooth domes of the Mournes, with their grass, heather or fine moss or their bare crags weathered along mural jointing.

The Carboniferous Limestone, with its lime-loving plants, builds the hills of Clare, terraced with alternate precipices, grass or scree-covered slopes and flat and curiously weathered platforms. It also forms the massive and imposing table-lands of Co. Sligo whose level and flat tops betray the general horizontality of the strata and whose steep and rugged faces, faintly stepped, are reached by deep and picturesque glens, lined with scree and slip and scarred by cascading streams.

The limestone also floors the wide Central Plain where the hills that shut in the valleys have vanished and the "features of the cramped, southern synclines have spread out over half of Ireland." This soft and pleasing landscape, with its grass-lands and peat and tints of green and brown, is broken by the "green hills" which rise in mounds and ridges above the peaty wastes and by the O.R.S. inliers which for the most part have gentle slopes and rounded backs clothed with heathery moor. It merges into the limestone uplands of Roscommon, with their numerous sheep, grey stone walls and a scenery reminiscent of the Pennines of England on a miniature scale. On the north-east, it is penetrated by the broad wedge of rough and irregular country of the Lower Palaeozoic strata that, with its abundant farm houses, winding roads and inconsiderable hills and innumerable drumlins, sweeps south-westwards from Down to part the watery lowlands of Upper Lough Erne from the grazing lands of the eskers of Meath and Westmeath.

The Carboniferous Limestone carries its slightly undulating country and pastures along the off-shoots from the plain and along the southern valleys of the Barrow, Nore and Suir, which guide the roads and railways, and by Enniskillen and Lough Erne to Donegal Bay, where the richly wooded country stops abruptly against the wild and rugged hills of the Barnesmore granite.

The peats have seemingly passed their optimum and are in a process of decay. They are cracking and crumbling and



wasting, especially on the cols and on the tops and flanks of hills. Even on the plains their increase has slackened or ceased. Their mantle is being dissected by a labyrinth of channels and left as rugged "hags." Ireland's geological history is unfinished; the face of the country is still changing and Nature's chisels are still at work remodelling the design.

# SELECTED BIBLIOGRAPHY

The following contractions have been used in compiling this short bibliography:—

*G.M.*=Geological Magazine.
*I.N.J.*=Irish Naturalists' Journal.
*Q.J.G.S.*=Quart. Journ. Geol. Soc., London.
*P.G.A.*=Proc. Geol. Assoc.
*P.R.I.A.*=Proc. Roy. Irish Acad.
*S.P.R.D.S.*=Sci. Proc. Roy. Dublin Soc.
*S.T.R.D.S.*=Sci. Trans. Roy. Dublin Soc.
*T.R.I.A.*=Trans. Roy. Irish Acad.
*T.R.S.E.*=Trans. Roy. Soc. Edin.


CHAPTER I: PRE-CAMBRIAN

Anderson, J. G. C., 1948, The Occurrence of Moinian Rocks in Ireland, *Q.J.G.S.*, 103, 171-90.
Bailey, E. B. and W. J. McCallien, 1934, The Metamorphic Rocks of North-East Antrim, *T.R.S.E.*, 58, 163-77.
Hartley, J. J., 1938, The Dalradian Rocks of the Sperrin Mountains, etc., *P.R.I.A.*, 44B, 141-71.
McCallien, W. J., 1930, The Gneiss of Inishtrahull, *G.M.*, 57, 542-9.
1935, The Metamorphic Rocks of Inishtrahull, etc., *P.R.I.A.*, 42B, 407-42.
1938, The Geology of the Rathmullan District, etc., *ibid.*, 44B, 45-59.
Wager, L. R. and G. Andrew, The Age of the Connemara Schists and of their Metamorphism, *G.M.*, 67, 271-5.

CHAPTER II: THE LOWER PALAEOZOIC

Cole, G. A. J., 1921, The Problem of the Bray Series, *P.R.I.A.*, 36B, 1-10.
Gardiner, C. I. and S. H. Reynolds, 1896, The Kildare Inlier, *Q.J.G.S.*, 52, 587-605.
1897, An Account of the Portraine Inlier (Co. Dublin), *ibid.*, 53, 520-39.
1898, The Bala Beds and Associated Igneous Rocks of Lambay Island, Co. Dublin, *ibid.*, 54, 135-48.







CHAPTER II: THE LOWER PALAEOZOIC—*continued*

Gardiner, 1909, On the Igneous and Associated Rocks of the Tourmakeady District (Co. Mayo), *ibid.*, 65, 104-52.
1910, The Igneous and Associated Sedimentary Rocks of the Glensaul District (Co. Galway), *ibid.*, 66, 253-78.
1912, The Ordovician and Silurian of the Kilbride Peninsula, Mayo, *ibid.*, 68, 75-102.
1914, The Ordovician and Silurian Rocks of the Lough Nafooey Area, Co. Galway, *ibid.*, 70, 104-18.
Harper, J. C., 1948, The Ordovician and Silurian Rocks of Ireland, *Proc. Lpool. G.S.*, 20, 48-67.
Hartley, J. J., 1933, The Geology of North-Eastern Tyrone, *P.R.I.A.*, 41B, 184-285.
Kilroe, J. R., The Silurian and Metamorphic Rocks of Mayo and North Galway, *ibid.*, 26B, 129-60.
Reed, F. R. C., 1899, The Lower Palaeozoic Bedded Rocks of County Waterford, *Q.J.G.S.*, 55, 718-72.
1900, The Igneous Rocks of the Coast of County Waterford, *ibid.*, 56, 657-93.

CHAPTER III: CALEDONIAN MOVEMENT

Reynolds, D. L., 1931, The Dykes of the Ards Peninsula, *G.M.*, 68, 97-111.

CHAPTER IV: OLD RED SANDSTONE

Shackleton, R. M., 1940, The Succession of Rocks in the Dingle Peninsula, *P.R.I.A.*, 46B, 1-12.

CHAPTER V: CARBONIFEROUS

Adamson, J. H. and G. F. Wilson, 1933, The Petrography of the Lower Carboniferous Rocks of North-East Ireland, *ibid.*, 41B, 179-90.
Dail Commission, 1921, Memoir on the Coalfields of Ireland, Dublin.
Wright, W. B., 1924, Geology of the Ballycastle Coalfield, *Mem. Geol. Surv. Ire.*

CHAPTER VII: TRIAS

Reynolds, D. L., 1928, The Petrography of the Triassic Sandstone of North-East Ireland, *G.M.*, 448-73.

CHAPTER IX: CRETACEOUS

Hume, W. F., 1897, The Cretaceous Strata of County Antrim, *Q.J.G.S.*, 53, 540-606.

CHAPTER X: TERTIARY IGNEOUS ACTIVITY

Charlesworth, J. K., 1937, The Olivine-Dolerite Sill of the Maidens, Co. Antrim, *I.N.J.*, 6, 248-50.
—Hartley, J. J., 1935, The "Tardree" and "Hillsborough" Dyke Swarms, *ibid.*, 5, 193-6.
Cole, G. A. J., 1896, The Rhyolites of the County of Antrim, etc., *S.T.R.D.S.*, 6, 77-114; *et al.*, 1912, The Interbasaltic Rocks (and Ores and Bauxites) of North-East Ireland, *Mem. Geol. Surv. Ire.*
Harris, N., 1937, A. Petrological Study of the Portrush Sill and its Veins, *P.R.I.A.*, 43B, 95-134.
Holmes, A., 1936, A Record of New Analyses of Tertiary Igneous Rocks, etc., *ibid.*, 89-94.
Rao, T. V., 1928, A Study of Bauxite, *Min. Mag.*, 21, 407-30.
Reynolds, D. L., 1937, Contact Phenomena indicating a Tertiary Age for the Gabbros of the Slieve Gullion District, *P.G.A.*, 48, 247-75.
Richey, J. E., 1927, The Structural Relations of the Mourne Granites, *Q.J.G.S.*, 83, 655-88.
1932, The Tertiary Ring Complex of Slieve Gullion, *ibid.*, 88, 776-849.
1932, Tertiary Ring Structures in Britain, *Trans. Geol. Soc. Glasg.*, 19, 42-140.
Tomkeieff, S. I., 1935, The Dolerite Plugs of Tieveragh and Tievebulliagh near Cushendun, etc., *G.M.*, 77, 54-64.
1940, The Basalt Lavas of the Giant's Causeway district of Northern Ireland, *Bull. Vulcanologique*, Ser. 2, 6, 89-143.
—Marshall, C. E., 1935, The Mourne Dyke Swarm, *Q.J.G.S.*, 91, 252-92.
1940, The Killough-Ardglass Dyke Swarm, *ibid.*, 96, 321-38.

CHAPTER XI: TERTIARY DENUDATION

Farrington, A., 1927, The Topographical Features of the Granite-Schist Junction in the Leinster Chain, *P.R.I.A.*, 37B, 181-92.
Jukes, J. B., 1862, On the Mode of Formation of some of the River-Valleys in the South of Ireland, *Q.J.G.S.*, 18, 378-403.
Miller, A. A., 1939, River Development in Southern Ireland, *P.R.I.A.*, 45B, 321-54.



CHAPTER XII: GREAT ICE AGE

Charlesworth, J. K. 1924, The Glacial Geology of the North-West of Ireland, *ibid.*, 36B, 174-314.
1928, The Glacial Retreat from Central and Southern Ireland, *Q.J.G.S.*, 84, 293-342.
1928, The Glacial Geology of North Mayo and West Sligo, *P.R.I.A.*, 38B, 100-15.
1929, The Glacial Retreat in Iar-Connacht, *ibid.*, 39B, 95-106.
1931, The Eskers of Ireland, etc., Geography, 16, 21-7.
1938, A Map of the Glacier-Lakes and the local Glaciers of the Wicklow Hills, *P.R.I.A.*, 44B, 29-36.
1939, Some Observations on the Glaciation of North-East Ireland, *ibid.*, 45B, 255-95.
Dwerryhouse, A. R., 1923, The Glaciation of North-Eastern Ireland, *Q.J.G.S.*, 79, 352-421.
Farrington, A., 1934, Glaciation of the Wicklow Mountains, *P.R.I.A.*, 42B, 173-209.
1936, The Glaciation of the Bantry Bay District, *S.P.R.D.S.*, 21, 345-61.
1944, The Glacial Drifts of the District around Enniskerry, Co. Wicklow, *P.R.I.A.*, 50B, 133-57.
Flint, R. F., 1930, Origin of the Irish Eskers, *Geog. Rev.*, 20, 615-30.
Wright, W. B. and H. B. Muff, 1904, The Pre-Glacial Raised Beach of the South Coast of Ireland, *S.P.R.D.S.*, 10, 250-324.

CHAPTER XIII: RECENT PERIOD

Charlesworth, J. K., 1930, Some Observations on the Origin of the Irish Fauna and Flora, *P.R.I.A.*, 39B, 358-90.
1932, The Distribution of the Irish Peats, *I.N.J.*, 4, 37-9.
—Macalister, R. A. S., 1930, The Alleged Palaeolithic Implements of Sligo: A Summary, *P.R.I.A.*, 39C, 18-32.
Forrest, H. E., 1926, Prehistoric Mammals of Ireland, *I.N.J.*, 1, 112-14, 152-3, 215-19, 234-36, 259-62, 284.
Jessen, K., 1949, Studies in Late-Quaternary Deposits and Flora-History of Ireland, *P.R.I.A.*, 52B, 85-290.
Martin, C. P., 1930, The Raised Beaches of the East Coast of Ireland, *S.P.R.D.S.*, 19, 491-510.
1936, Prehistoric Man in Ireland. Lond.
Mitchell, G. F., 1940, The Reindeer in Ireland, *P.R.I.A.*, 46B, 183-8.
Movius, H. L., 1939, The Irish Stone Age. Camb.

The reader may also consult the *Handbook of Geology of Ireland*, by G. A. J. Cole and T. Hallissy, 1924 (Murby); the Memoirs and Maps of the Irish Geological Survey, details of which are to be found in the *List of Memoirs, Maps and Sections, etc. published by the Geological Survey* (Dept. of Industry and Commerce, Dublin; *The Geology of North-east Ireland*, by J. K. Charlesworth *et al.* (Proc. Geol. Assoc., vol. 46, 1935, pp. 441-486); *The Geology of South-east Ireland, together with parts of Limerick, Clare and Galway*, by L. B. Smyth *et al.* (Proc. Geol. Assoc., vol. 50, 1939, pp. 287-351); *The Geology of Eastern Ireland*, by D. W. Bishopp, *et al.* (Intern. Geol. Congr., 18th Session), London, 1948; and the author's two summaries, with complete bibliographies, entitled *Recent Progress in Irish Geology*, 1924-37 (Irish Naturalists' Journal, vol. 6, 1937, pp. 265-273), and 1937-50 (ibid., vol. 10, 1950, pp. 61-71).

The following works of a general nature may also be usefully consulted:—

Davies, A. M., *Introduction to Palaeontology* (Murby). 2nd ed. 1947.
Geikie, A., *Ancient Volcanoes of Great Britain and Ireland* (Macmillan). 2 vols. 1897.
Harker, A., *Metamorphism* (Methuen). 1932.
Holmes, A., *Principles of Physical Geology* (Nelson). 1944.
Jukes-Browne, A. J., *Building of the British Isles* (Stanford). 3rd ed. 1911.
Kilroe, J. R., *Soil Geology of Ireland*. Dublin, 1907.
Marr, J. E., *Scientific Study of Scenery* (Methuen). 4th ed. 1912.
Neaverson, E., *Stratigraphical Palaeontology* (Macmillan). 1928.
Read, H. H., *Geology* (Home University Library). 1949.
Swinnerton, H. H., *Outlines of Palaeontology* (Arnold). 1923.
Tyrrell, G. W., *Principles of Petrology* (Methuen). 2nd ed. 1930.
Tyrrell, G. W., *Volcanoes* (Home University Library). 1931.
Wills, L. J., *Physiographical Evolution of Great Britain* (Arnold). 1929.
Wright, W. B., *Quaternary Ice Age* (Macmillan). New ed. 1937.

# INDEX