

IV.—**The Glacial Deposits of Northern Pembrokeshire.** By T. J. JEHU, M.D. (Edin.),
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I. INTRODUCTION.

The area embraced in this paper consists of that part of Pembrokeshire which lies to the north and north-east of St Bride's Bay. Bounded on the west by St George's Channel and on the north by Cardigan Bay, it extends to the north-east as far as the mouth of the river Teifi, near Cardigan.

That part of the country which lies in the immediate neighbourhood of St David's has, through the laborious researches of the late Dr HICKS and others, become well-known to geologists, and may now be regarded as classic ground. The solid geology of this promontory has given rise to much discussion, and has, perhaps, attracted more attention than that of any other part of the Principality. The reason for this great interest is to be sought in the facts that the rocks of this area are of a very great antiquity, and that the sedimentary series contain the remains of some of the earliest organic forms yet found in the earth's crust, whilst the igneous rocks are also displayed in great abundance and variety, and present us, in the words of Sir ARCHIBALD GEIKIE, with "the oldest well-preserved record of volcanic action in Britain."

The geology of the district lying immediately to the north-east of the St David's promontory has not been the subject of so much attention, but the investigations carried on by DE LA BECHE and the other officers of the Geological Survey before the middle of last century have recently to some extent been revised by Mr COWPER REED, and his results are published in a paper entitled "The Geology of the Country around Fishguard," which appeared in the *Quart. Journ. Geol. Soc.* (vol. li., 1895, p. 149).

But while so much has been written concerning the ancient rocks of this country, very little attention has been paid to the more recent geological deposits. Owing to

the facts that geographically the region lies further south, and that it does not present such a great elevation of the land above sea-level, it is not to be expected that Pembrokeshire will show such marked traces of the former presence of glacial conditions as are to be met with in North Wales. Nevertheless, it has been known for a long time that this region is to a large extent covered by more or less loose and unconsolidated material, which is usually spoken of as Drift. And references are found scattered in the geological literature of the district relating to travelled boulders and other possible glacial phenomena there seen. But hitherto no attempt has been made to give a connected description of the glacial deposits with a view to the unfolding of the sequence of events which occurred during and after the Glacial epoch, and of correlating the results obtained by an examination of this area with those derived from a study of glacial deposits in North Wales and other regions. The need for further investigation will be evident to anyone who compares the map (plate i.) in Professor JAMES GEIKIE'S work on *The Great Ice-Age*, illustrating the British Isles during the Epoch of Maximum Glaciation, with the late Mr CARVILL LEWIS' "Sketch Map of England and Wales showing the Edge of Land Ice," which is reproduced in Professor BONNEY'S *Ice-Work*. In the former the southern boundary of the great ice-sheet is made to pass beyond Wales and run along the Bristol Channel; and the northern ice which overwhelmed Anglesea is marked as crossing the western end of the Llyn promontory of Carnarvonshire, and, joining the Irish Sea, it fills up St George's Channel and crosses the extreme tip of Pembrokeshire at St David's Head. In the latter the land-ice is shown as not extending over the whole of South Wales to the Bristol Channel, but with its southern edge extending no further south than is indicated by a line drawn eastwards from the St David's promontory, and the glaciation of Northern Pembrokeshire is attributed solely to local ice—the northern ice apparently extending no further south off the Welsh coast than the Llyn promontory.

The results obtained during the investigations carried on by the present writer will at any rate serve to settle the dispute with regard to the southward extension of the Northern or Irish Sea Glacier.

II. PREVIOUS LITERATURE.

References to the surface deposits and surface features of Pembrokeshire are meagre and scanty in the extreme.

Sir R. MURCHISON, in *The Silurian System* (p. 520), makes the following remarks: "The detritus which appears on the surface of most parts of Pembrokeshire is of a simple character and, as in other parts of South Wales, is of *local origin*. It consists of fragments of greenstone, porphyry, carboniferous grits, etc., all of which can be traced to the various mountains forming the crest of the country. In some parts this detritus is exceedingly coarse. . . . In other tracts, as north of Haverfordwest, we meet with finely comminuted gravel; but this is rare."

SYMONDS, in his book entitled *Records of the Rocks* (p. 53), refers to the fact that the country near St David's must in former years have been largely covered by boulders. These have now to a large extent been cleared away from the surface and used for building rough walls which serve the purposes of fences and hedges. He adds that in his opinion "these boulders are all local, and have travelled over a slope of ice and snow which once reached from the Trap Hills of Precelly down to the sea." And in another place (p. 181) he speaks of the Precelly hills in North Pembrokeshire as being "studded with ice-carried boulders, which were used for cromlechs and tumuli by a prehistoric race of men."

Messrs HOWARD and SMALL, in their "Geological Notes on Skomer Island," which appeared in the *Trans. Cardiff Naturalists' Soc.* (vol. xxviii., 1896), assert that distinct evidences of the action of ice are seen on the mainland opposite Skomer. And on Skomer Island itself blocks are found which have travelled from the St David's district and some possibly from North Wales. Flints were also seen scattered about.

Professor M'KENNY HUGHES, in his paper "On the Drifts of the Vale of Clwyd" (*Quart. Journ. Geol. Soc.*, vol. xliii., 1887), remarks that "the low-lying plateau at St David's is covered by a gravel containing flints." But he found no traces of shells there.

In a paper by Professor BONNEY "On the So-called Diorite of Little Knott (Cumberland), with further Remarks on the Occurrence of Picrite in Wales" (*Quart. Journ. Geol. Soc.*, vol. xli., 1885), some observations are found communicated by Dr HICKS relating to the glaciation of the St David's region. A boulder of picrite was found on the promontory just to the east of Porth-lisky, "resting immediately on Dimetian rock, surrounded by an uncultivated area overgrown by gorse and heather." The striæ along the coast are said to run usually from north-west to south-east. He adds: "But it is clear that very many of the boulders scattered over it must have come from the high land in the north-east of Pembrokeshire, the Precelly range. There is ample evidence of local till, and in places (at considerable elevations) of marine sand with transported boulders, fragments of flint being common among them." Dr HICKS was of opinion that "this points to the derivation of some of the materials, including possibly certain boulders, from a north-west source."

The most important communication which has appeared on this subject is a very short report read by Dr HICKS at the Cardiff meeting of the British Association in 1891, "On the Evidences of Glacial Action in Pembrokeshire, and the Direction of Ice-Flow." This report is reproduced in the *Geol. Mag.* for that year. He there refers to the presence of ice-scratched rocks and of northern erratics in the district. The direction of the glacial striæ and the probable presence of erratics from North Wales and from Ireland "would tend to the conclusion that glaciers from these areas coalesced in St George's Channel, and that the ice which overspread Pembrokeshire was derived from both these sources, as well, probably, as from a flow extending down the Channel from more northern areas." By far the majority of the boulders are said to be of local origin, but he notes a large boulder of granite and another of picrite found on Porth-

lisky farm. "The picrite boulder has been shown by Professor BONNEY to resemble masses of that rock exposed in Carnarvonshire and Anglesea, and the granite boulder, which before it was broken must have been over 7 feet in length and 3 to 4 feet in thickness, is identical with a porphyritic granite exposed in Anglesea, but not found anywhere in Pembrokeshire." He found clear evidences showing that St Bride's Bay was overspread by a great thickness of drift from the hills immediately to the north. "The intervening preglacial valleys were also filled by this drift, and the plains and rising grounds up to heights of between 300 and 400 feet still retain evidences of its former presence, and many perched blocks." Chalk flints were found at heights of over 300 feet, and have probably come from Ireland. He refers also to the crushing and bending of the strata at places, and to some well-marked examples of "crag and tail," but he does not locate these phenomena.

The late Professor PRESTWICH, in his paper on "The Raised Beaches and 'Head' or Rubble-Drift of the South of England" (*Quart. Journ. Geol. Soc.*, vol. xlviii., 1892), refers to the possible occurrence of this rubble-drift on the coast of Pembrokeshire. He thought that he had detected traces of a raised beach and 'head' near Porth Clais, and again at Whitesand Bay.

Professor BONNEY, in his *Ice-Work* (p. 161), states that "In Pembrokeshire and the adjoining districts erratics are often abundant, as may be seen near St David's. At present no systematic attempt has been made to trace them up to their sources, but they have probably come from the higher ground inland, that is to say, roughly, from the north-east." And again (p. 165) he refers to the possibility that the northern ice travelled down the bed of the Irish Sea, and perhaps ultimately overflowed St David's Head.

Dr WRIGHT, in his book on *Man and the Glacial Period*, remarks that "At St David's peninsula, Pembrokeshire, striæ occur coming in from the north-west, and, taken with the discovery of boulders of northern rocks, may point to a southward extension of a great glacier produced by confluent sheets that choked the Irish Sea" (p. 143).

Mr COWPER REED, in the paper already referred to, mentions the fact that "drift or boulder-clay causes a difficulty in tracing the boundaries or determining the characters of the underlying beds" in the Fishguard district.

III. PHYSICAL FEATURES AND GEOLOGY OF THE DISTRICT.

The county of Pembrokeshire lies in the extreme south-west corner of the Principality, and that part of it which is under consideration in this paper extends further to the westward than any other part of England and Wales, with the exception of the extremity of Cornwall. The promontory of St David's is washed on three sides by the sea which has eaten into the land so as to give rise to a variety of recesses and bays. It is the presence of hard igneous rocks that has enabled it to resist the ceaseless action

of the waves, which, owing to the direction of the prevalent winds, often beat upon the coast with great fury. The softer Lower Palæozoic slates and Carboniferous shales to the south have succumbed to the encroaching sea, and there given rise to the broad and wide bay of St Bride's. The islands lying to the west consist partly of hard igneous rocks, and no doubt were once joined to the mainland. The coast scenery is magnificent, and throughout this region the rocky cliffs rise steeply out of the sea, and sandy beaches are only found here and there, such as at Whitesand Bay, Abereiddy Bay, Abermawr, Goodwick Bay, and Newport Bay. The cliffs in places are nearly perpendicular, and everywhere exhibit excellent sections of the rocks. The outline of the coast is very jagged, reefs and stacks of rock sticking out here and there, whilst, on the other hand, the sea has penetrated in so as to form caves and coves, and small narrow *ria*-like channels, such as that seen at Porth Clais at the mouth of the Alan river, and that at the mouth of the Solva river. A silted-up estuary occurs at Abermawr to the west of Strumble Head, and a larger one on the east side at Goodwick Bay; they now form swampy ground. The only other estuaries of importance lie on the north-east side of Strumble Head, at the mouths of the rivers Gwaen, Nevern, and Teifi. That of Gwaen is also somewhat *ria*-like in character.

On the north coast Strumble Head is a prominent feature and stands out boldly to sea, and a little further to the north-east a small but well-marked headland occurs at Dinas.

The one-inch Geological Survey maps of this part of Wales were prepared before the end of the first half of last century, and no revision has yet been made. Since that time a more complete knowledge of the fossil contents of the sedimentary series has been obtained, and improved methods for the study of igneous rocks, especially with regard to their microscopic structure, have been introduced. The need for a fresh survey is generally recognised, but much new light has been thrown on the geology of St David's promontory during the last thirty years through the researches carried on by Dr HICKS, Sir A. GEIKIE, and others. And Mr COWPER REED has examined and described within recent years the geology of the area around Fishguard. But the region is a very complicated one, and much of the geology still remains obscure. The rocks of this part of Pembrokeshire are almost entirely of Lower Palæozoic age, and a remarkable variety of both the igneous and sedimentary kinds is there displayed. In the St David's region a very full development of Cambrian rocks is exhibited, and these are underlain by a series of volcanic rocks—both series often showing signs of metamorphic changes. The base of the Cambrian was taken by Dr HICKS to be marked by a conglomerate in which are enclosed pebbles of the underlying rocks. The volcanic tuffs and breccias which underlie the conglomerate were taken to be pre-Cambrian. Underneath these again comes a granitoid mass, which he regarded as still older. Later, the district was visited by Sir A. GEIKIE, who, after an examination of the ground, arrived at the conclusion that the granite is an intrusive mass, and that there is no break between the Lower Cambrian rocks and the volcanic series underlying them.

The granite covers an area lying immediately to the south of St David's, and there is another wedge-shaped mass a little to the south-west, reaching the coast on the eastern side of Porth-lisky. The St David's mass graduates into a spherulitic quartz-porphry and felsite at its northern end. The granite is surrounded on all sides but the south by rocks of the volcanic series which are marked as Andesites on the index-map. These form a ridge running E.N.E. and W.S.W., stretching from Llanhowell, past the city of St David's, to reach the coast at the southern end of Ramsay Sound. Two detached masses are marked further east, about Llanreithan.

The volcanic group consists largely of bedded tuffs; but lavas also occur, and give rise to prominent crags to the west of St David's.

Dykes and sheets of diabase traverse the other formations.

These igneous rocks are flanked on the west and south-west by the Cambrian conglomerate, and this is followed by green, purple, and gray flaggy sandstones, with intercalated red shales. Towards the base, fragments of *Olenellus* were found by Dr HICKS. In a south-east direction these are followed by the gray and black flagstones and shales of the Menevian series, and these again by gray and bluish flagstones and slates of the Lingula Flag series. Still further eastwards, a small tract of Tremadoc beds is found near Tremainbir.

Beds of the Menevian and Lingula Flag series also occur at the south of Whitesand Bay. The Lingula flags run as a continuous band from the bay inland as far as Crug-las, and on the north a band of Tremadoc flagstones and earthy slates runs parallel to a point south of Abereiddy Bay.

The north coast from St David's Head to Abereiddy is made up of slates and shales and flagstones of Arenig age. Masses of gabbro occur at St David's Head, and a little east of this, diabase masses, giving rise to rugged eminences, are seen.

North-east of Abereiddy the Llandeilo flags succeed the Arenig series, and consist of black slates and flags, sometimes calcareous, and some felspathic tuffs.

Numerous bands of "felspathic trap" are seen to occur in the tract bordering Abereiddy Bay.

Eastwards from the St David's promontory, right into mid-Wales, the sedimentary rocks are marked in one colour on the Survey maps, and are referred to as "Lower Silurian (including Upper Silurian not yet separated)." They consist of shales, slates, and gritty sandstones, with some flagstones. Mr COWPER REED found that beds of Llandeilo and Bala age form Strumble Head. Immediately around Fishguard we meet with Llandeilo and Arenig beds, and further east with Upper Llandeilo and Bala beds again. Dinas Island is composed of sandstones, slates, and conglomerates of Llandovery age.

The country around Fishguard is rich in igneous rocks. Felsites, tuffs, and agglomerates contemporaneous with the Llandeilo and Bala beds occur, and intruded into these are sills and masses of "greenstone." The latter include basalts, dolerites, diabbases, and gabbros.

Contemporaneous volcanic rocks and intrusive sheets of diabase occur in the district between Fishguard and Newport, and further south in the Precelly mountains strips of felspathic rock are indicated on the Survey maps.

East of Newport the igneous rocks die out.

Blown sands are heaped up at places on the coast, and are generally full of land shells. To the east of Whitesand Bay they rise to heights of 150 feet and are prolonged inland for nearly a mile, giving rise to the tract known as "The Burrows" or "Towyn." They are also seen at Abermawr, and cover an extensive area at Newport, and again at the mouth of the Teifi, where they form dunes known as the "Towyn Warrens."

Towards the western end the country, as seen from a height, presents the aspect of a flattened tableland or plateau, having for the greater part of its extent no great elevation above sea-level, but here and there having rocky knobs and masses jutting out, especially towards the western and north-western extremities of the promontory. The view, as seen from one of the hills on Ramsay Island, suggested to Sir ANDREW RAMSAY that in this part of Wales we have the remnant of an old plain of marine denudation, which is continued into Cardiganshire and further inland. The rugged masses of Carn Llidi and Pen Berry, which rise so boldly just east of St David's Head, and have relatively the appearance of considerable mountains, only attain heights of 595 feet and 576 feet respectively. Further east the rough eminences which stand out so prominently on Strumble Head are mostly under 600 feet in height—Garn Gelli alone exceeding that limit and attaining 625 feet. Garn Fawr, famous for the remains of ancient fortifications there found, is just short of 600 feet high.

Between Fishguard and Newport is a ridge of high land, reaching elevations of over 1000 feet at Mynydd Melyn, Mynydd Caregog, and Carn Ingle. To the south of these rise the Precelly mountains, which have a somewhat smooth outline and attain heights up to 1500 feet. From Newport to Cardigan the country is hilly, but not mountainous—the highest point being Pen Creigiau, which is 642 feet above sea-level.

The highest ground is formed of diabase and other intrusive igneous masses; the volcanic rocks occupy ground above the average level, while the low-lying ground consists of the more easily denuded slaty and shaly beds.

Passing from west to east, the land generally becomes more hilly, and the higher grounds from Newport to Cardigan are composed of hard sandstones or arenaceous slates.

The main streams of the district occupy pre-glacial valleys, and have cut their way through the drift which once filled them. The estuaries of the rivers Solva, Alan, and the Gwaen are *ria*-like in appearance, and it is probable that an arm of the sea once extended for some way up the lower course of each; for the estuaries are trench-like, with steep rocky walls on either side for a considerable distance inland, and it is hardly conceivable that these have been cut out altogether by the action of the streams.

On the northern coast there are two peninsulas of a very peculiar character, for they are separated from the mainland by trench-like valleys, which, though now never

occupied by the sea, look as if they had been so in comparatively recent times. They are both spoken of locally as islands : one lies between Abereiddy and Porth Gain, and is known as Barry Island, and the other is Dinas Island, west of Fishguard. The valley between Dinas and the mainland is particularly striking, being only a few feet above sea-level, whilst that at Barry Island is not much less noteworthy, though its bottom attains a somewhat higher level. These peculiar valleys, together with the indications shown of the former presence of the sea up the inlets at the mouths of many of the streams, and the occurrence of swampy estuaries such as those seen at Abermawr and Goodwick, seem to point to a slight rise of the coast within recent times, causing a retreat of the sea.

But at the present day the sea seems to be gaining once more on the land. At several places along the coast peat is seen at low tide, and in most of the bigger bays evidences of buried forests are sometimes seen. GIRALDUS CAMBRENSIS, who wrote in the twelfth century, says with regard to St Bride's Bay at Newgall :—"When Henry II. was in Ireland an unusually violent storm on that sandy coast blowing back the sand discovered the appearance of the land concealed for so many ages ; stumps of trees standing in the sea, with the marks of the hatchet as if done but the day before, a very black earth and wood like ebony, so that it appeared not so much like a sea-coast as a grove." * And GEORGE OWEN, in *The Description of Pembrokeshire*, written in 1603, gives an account of a very similar occurrence. He says : "About xij or xiiij yeeres past were seene on the sandes at *Newgall*, by reason as it seemeth the violence of the sea or some extreeme freshe in the winter, washed awaye the sandes (w^{ch} dayelye is and was overflowen with the tyde), soe lowe that there appeared in the sandes infinitte number of buttes and trees in the places where they had been growinge, and nowe euerye tyde overflowen : there appeared the verye strookes of the hatched at the fallinge of these tymber, the sandes being washed in the winter, the buttes remained to be seene all the sommer followinge, but the next yeere the same was covered againe with the sandes : by this it appeareth that the sea in that place hath intruded upon the lande." † Again about sixteen years ago a big storm washed away the sand and exposed roots of great trees in Whitesand Bay. Huge logs of oak trees were carried away by the neighbouring farmers, some of which are still stored, and were shown to the writer. Twigs and branches of hazel were found in abundance, although no hazel grows now near St David's. The writer is also informed that horns of deer were picked up.

Similar evidence of a buried forest has been discovered in Goodwick Bay, and all along the coast up Cardigan Bay. All this reminds one of the old Welsh tradition regarding a great inundation of a land called Cantref Gwaelod, situated in the region now covered by Cardigan Bay, which is usually attributed to the fifth century. There is also a very old tradition that St Bride's Bay was formed by an inrush of the sea.

* *Rolls*, ed. vi. 100.

† Page 247 in the *Cymmrodorion* reissue.

Referring to some of the shallow valleys and peculiar bays seen in Pembrokeshire, Sir ANDREW RAMSAY, in his essay "On the Denudation of South Wales and the adjacent Counties of England," contributed to volume i. of the *Memoirs of the Geological Survey*, says (p. 329): "In numerous instances valleys opening to the sea end in bays, and it will be found that not infrequently the headlands on either side of these bays were composed of comparatively unyielding materials. Depress the land, and these valleys become arms of the sea; raise it, and the bays become a continuation of the valleys. If Pembrokeshire were elevated but 60 or 70 feet, Milford Haven would become a shallow valley of this nature, with occasional pools or small lakes in its hollows, through which would wind the water now flowing into the haven." And similarly, if the county was depressed but 60 or 70 feet, the valleys at the lower part of their course would form sea-inlets like Milford Haven, and Barry and Dinas would be separated as islands from the mainland. It is practically certain that movements of elevation and of depression have taken place within comparatively recent times, but it is a difficult problem to ascertain the extent and duration of these movements.

The land of the St David's promontory was long ago described by GIRALDUS CAMBRENSIS as a "stony, barren, unimprovable territory, undecked with woods, undivided by rivers, unadorned with meadows, exposed only to winds and storms." Since his time the land has yielded somewhat to the continuous treatment of generations of farmers, and a great part of it is now under cultivation. But much rough uncultivated moorland still remains, which in places is overgrown with gorse, and sometimes shows a boggy nature. Such are the commons seen round about St David's, and also further east. Parts of them are occupied by shallow sheets of water, as at Trefeithan common and Dowrog common. As a rule these commons are of a clayey nature, and in places some peat formation is seen. Peat becomes more evident in the country lying to the south of Fishguard and south-west of the Precelly hills, and it is dug even right up on the Precelly hills themselves. The country from Newport to Cardigan is well cultivated for most part.

Throughout the area under consideration in this paper much of the soil is of a distinctly sandy nature. Hence the land is very dry and needs much rain. It is an old saying in this part of Pembrokeshire, that "in summer rain every day is too much, and every second day too little."

The greater part of the land is covered by a blanket of superficial material, which may all be included under the name of Drift. This is somewhat variable in character, but near the surface a sandy element seems to predominate. However, as traced laterally, the sand often passes abruptly into clay or clayey loam, and *vice versa*. This drift near its upper part is usually stuck full of boulders and rock-fragments of all kinds, and of all shapes and sizes. Good sections are seen along the coast in some of the bays, but it is very rarely that one meets with a good exposure inland. Smoothed, polished, and ice-scratched boulders can be picked out of the drift in plenty, and occur throughout the district. It is more difficult to meet with examples of striated and

smooth rock-surfaces, and this is partly owing to the fact that so much of the country is covered by the superficial accumulations; and the igneous rocks which project above the surface are so weathered and worn from exposure for such a great length of time, that any marks of glaciation which they may once have shown must have become almost entirely obliterated.

Reference has already been made to Dr HICKS' observations on the striæ seen on the rock-surfaces at places along the coast near St David's. The best example noted by the present writer is at Whitesand Bay, just at the northern corner. Here the rock, as it appears from under the cliff of drift, presents a distinctly hummocky appearance, and is smooth, polished, and well striated—the striæ having a course from north-west to south-east. It is interesting to note that out of the drift above, striated stones can be readily picked: these are generally sub-angular, with blunted angles and somewhat smooth and rounded edges. In the small valley coming down near Porth Melgan, and separating the rocks of St David's Head from Carn Llidi, a pavement of sedimentary rocks has been exposed by the removal of some turf, and this pavement shows distinct marks of glaciation. Another very good example of a glaciated rock-surface is seen quite at the other end of the district at Gwbert, on the coast to the north of Cardigan. Here, emerging from beneath the drift again, a smooth and striated rock is seen—the direction of the striæ being from a little west of north to a little east of south, showing that the ice must have come on to the land from the region of Cardigan Bay.

The igneous rocks of St David's Head and those lying further east, especially at Pen Berry, appear to be somewhat *moutonné* on their northern aspect, but no unmistakable glacial striæ were seen, and this is no doubt due to the fact that the rock-faces are so much weathered.

On the greater heights there is a general absence of perched blocks and big erratics. It is quite possible that perched blocks may have been common in former times, but they have in all probability been removed by man, for the region is full of traces of defences prepared by primitive man, and these usually take the form of great collections of boulders and stones gathered together and heaped up in the form of dykes. Splendid examples of such ancient entrenchments are seen near St David's Head, and again on Strumble Head. The few blocks seen on the high ridges are almost invariably of the same nature as the underlying and surrounding rocks.

South-west of St David's, in the Treginnis tract, some huge boulders are seen. A big one lies on the hill above the cliffs at Penmaen-melyn, but it consists of a somewhat coarse andesitic rock, which is found *in situ* at no great distance away. The boulders of granite and of picrite found near Porth-lisky farm by Dr HICKS have been already mentioned. The whole country was once strewn with boulders; and although many still remain scattered over the land, most have been cleared away and used for building dykes, etc. An examination of the stones in the dykes shows that they are almost entirely of rocks found in the locality, as might be expected. Boulders of the St David's Head gabbro are found carried in a south-eastern direction, and are plentiful in

the neighbourhood of Caerfai Bay and Caer Bwly Bay. In the country between St David's and Strumble Head boulders are also common. Blocks of "greenstone" are found around Mathry: the rock is a diabase, probably occurring at no great distance away. On Strumble Head the boulders are very plentiful, and the writer found a boulder of pierite not far from the extreme head, near the coastguard station, and another further south, near Tre-Seissyllt, together with a remarkably fresh olivine-gabbro, of a kind which is not found in the district. These will be referred to more fully in another section of the paper. East and south of Fishguard, boulders of a dark "greenstone" and of a volcanic rock which weathers white are abundant. They are found on the hill-slopes, on roadsides, and in the fields, but many have been cleared away as before. The Precelly hills are free of boulders as compared with the hills lying further north.

It may be mentioned that vestiges of antiquity abound in this part of Pembrokeshire. Hut circles, ancient entrenchments, cromlechs, British camps, etc. occur at places all the way from St David's Head to Cardigan, being particularly evident at St David's Head and Strumble Head. Some of the ancient British towns or settlements, traditions of which are to be found in the old Welsh romances, called *The Mabinogion*, are situated within this area, and one has been identified as occurring on the Garn Fawr, Strumble Head.

IV. DESCRIPTION OF THE DEPOSITS.

The glacial deposits of the district vary a great deal as traced laterally from place to place. Owing to the want of good exposures inland, it is generally impossible to mark out the limits of the different kinds of superficial detritus. One has to depend for most part on a study of the sand-pits and clay- or marl-pits which are dug in places all over the district. But it is not often that these go down to any great depth; and when occasionally a deep pit has been dug out for the purpose of obtaining clay or sand for the land or for building, it is invariably filled up again with surface-rubbish, so as not to be a danger to animals. Where a pit appeared to be of peculiar interest, the writer employed a man for digging, and in this way obtained some valuable sections. At the eastern limit near Cardigan there are brickworks, and here it is that the best sections are to be seen. The writer hopes in the near future to continue his investigations eastwards in the neighbourhood of Cardigan. The deposits which occur in the district are the following:—

3. Upper Boulder-Clay and Rubbly-Drift.
2. Sands and Gravels.
1. Lower Boulder-Clay.

1. *The Lower Boulder-Clay*.—This is a typical boulder-clay which is met with in patches throughout the district, but is best and most fully developed towards the east. It has received no attention within recent times, but a very quaint and, on the whole, a very accurate description of it is found in the works of a writer who lived in

the time of Shakespeare. In an article on Sir RODERICK MURCHISON's Silurian System in the *Edinburgh Review*, 1841 (vol. lxxiii. p. 3), it is stated that "one of the oldest inquirers connected with the geology of this ancient region is GEORGE OWEN of Henllys, in Pembrokeshire, who has been called the patriarch of English geologists." This worthy Welshman left behind him a manuscript work on the topography of his native country—a book of great value and interest. It was published in the Cambrian Register, 1793, and has recently been reproduced, under the editorship of Mr HENRY OWEN, in the Cymmrodorion Record Series. The book has been already referred to, and is entitled *The Description of Pembrokeshire*.

His observations on the boulder-clay are so good that they are well worth quoting. Writing of "the naturall helpe and amementes the soil it selfe yealdeth, for betteringe and mendinge the lande," he refers to what he calls "Claye Marle." "This kind of Marle is digged out of the Earthe, where it is found in great quantitie, and thought to be in rounde great heapes and lompes of Erthe as bigg as round hills, and is of nature fatt, toughe, and Clamye. . . . The opinion of the Countrie people where this Marle is founde is that it is the fattness of the Earthe gathered at Noes flood, when the Erthe was Covered withe the said flood a whole yeare, and the surginge and tossing of the said flood, the fattness of the Earth being clamye and slymie of nature did gather together, and by rowlinge vpon the Earthe became round in forme, and when the flood departed from the face of the earthe, the same was left drie in sondrie partes, which is nowe this Marle that is found, and how the Common people Cam to this opinion I knowe not, but it is verye like to be true, for wheresoever the same is founde, it is loppie (loose) and covered with sande, gravell, and round peblestones, such as you shall finde at the sea side verie plaine, appearing that the stones hath ben worne by the sea or some swift river."

"Also in the harte of the Marle is founde diverse sortes of shells, of fishe, as Cogle shells, Muskell shells, and such like, some altogether rotten & some yet unrotted, as also you shall therein finde peaces of tymber that ben hewen with edge tools & fire brandes, the one ende burned and diverse other thinges which hath ben before tyme vsed, & this XXth foote and more deepe in the Earth in places that never haue been digged before, and over the which great oakes are now growinge; and this seaven or eight myles from the sea, so that it is verie probable that the same came into these places at the tyme of the great and generall flood. . . ."

"This marle is of couler with vs most commonlie blwe and in some place redd." "It is verie hard to digg by reason of the toughness, much like to waxe: and the pickax or mattock beinge stroken into it, is hardlie drawne out againe, so fast is it holden: it is alsoe verie heaue as ledd." "This Marle is founde in Kemes and both Emlyns from *Dynas* vpp to *Penboy* in Carmerthen sheere, beinge about twentie myles in lengthe and about fowre myles in bredeth in most places to the sea syde, and out of this compasse I cannot heare that the same ys founde: I thinke more for want of Industrie than otherwise" (pp. 71, 73). He ends up his remarks on the Clay Marle

thus :—" And, who so list to learne more of this Marle : let him pervse a pamphlett which I have written thereof, wherein I have declared the nature of the marle, how to know yt and finde yt, and the order at Lardge of digginge and layeinge yt on the lande ; of the severall sortes thereof for what yt is good, and for what yll. And so for brevyties sake I Cesse to writte any More thereof." It is a great pity that this pamphlet has never been published, for it would be of great interest to geologists, as perhaps the earliest attempt to give a full description of the boulder-clay. It seems that the treatise was finished in 1577, and consists of twelve chapters. A footnote to the preface of Mr HENRY OWEN's edition of his *Pembrokeshire* (p. xxiv) states that a copy of the pamphlet lies in the *Vairdre Book* at Bronwydd, "written out of a copy in his own hand, by me, John Owen of Berllan, 1684."

The Kemes mentioned in the above extract is that part of Pembrokeshire lying between Dinas and Cardigan.

The present writer can bear testimony to the general accuracy of the description given by GEORGE OWEN. It is at the brickworks, Cardigan, that the best exposure is seen. There in the pit a vertical section of this boulder-clay 20 feet deep is seen. It is dark-bluish in colour, but after drying becomes more of a light bluish-gray. It is a remarkably tough and tenacious clay, and can only be dug with great difficulty, for no crevices or fissures are seen and no trace of bedding. The whole mass is strikingly homogeneous and uniform in character, and has evidently been subjected to great pressure. The bottom is not reached in the section, and so the depth attained by it at this place is not known. For most part it is very free from stones, but a little further east in the same pit these are rather more commonly met with. Some beautifully glaciated sub-angular and blunted boulders were seen, with the striæ running principally in the direction of their longer axes. Many of these boulders are of Carboniferous Limestone, and these interfere very much with the manufacture of the bricks, and are, as far as possible, picked out by the workmen. Boulders of conglomerate, grit, shaly and slaty rocks were also noted, and many of igneous rocks, which are foreign to the district. These will be dealt with again below, in another section.

One of the most characteristic features of this Lower Boulder-Clay is the presence of marine shells scattered irregularly through it. They seem to occur chiefly in its upper part, and are invariably much broken and worn, and therefore very difficult to identify. The fragments are also extremely friable. Occasionally small waterworn pebbles of quartz, etc. are seen in the clay ; but most of the stones included are ice-worn rather than waterworn in the Cardigan pit. Another striking feature is the presence of fragments of woody matter in the clay, sometimes at a depth of 15 to 18 feet.

Above the boulder-clay in the brickyard occurs 2 or 3 feet of sand and gravel and a yellowish stony clay, and towards its north end this stony clay increases in thickness to at least 7 feet, passing in places into yellow sand.

At Cardigan the height of the boulder-clay above sea-level is under 50 feet. Between Cardigan and Dinas this blue clay is seen in patches underlying small tracts of moorland, and it attains a height of nearly 600 feet a little south of Pen-Creigau, where, at a short distance below the road to Cardigan, it may be seen, though the exposures are very poor.

Just south-west of Dinas, near the roadside, clay-pits occur on Rhos-Isaf showing a depth of 6 feet. The same stiff, compact, bluish boulder-clay is here seen, full of comminuted shell-fragments. Boulders are fairly common, mostly ice-worn and scratched, but some water-worn. One example of a slaty rock showed not only fine striæ but a wide groove smoothed out by ice action. The clay gets darker as traced downwards, but the bottom is not seen. Workmen stated that it reaches a depth of at least 15 feet, and occasionally a thin seam or stratum—no more than half an inch in diameter—of fine gravel is said to occur. But no trace of bedding occurs in the clay. It is capped for 2 feet by a yellowish clay with boulders. The pits are 240 feet above sea-level. Small exposures are seen in some of the fields on Dyffryn farm, about a mile south of Goodwick. Owing to drying and weathering, it is of a light bluish-gray colour, and is here full of fragments of the local lavas and tuffs. Most of this farm is underlain by this clay. A little further south, in a field belonging to Drim farm, is a small pit of a similar character. No shell fragments were to be seen in these exposures.

Similar tough bluish boulder-clay is seen in clay-pits on Tregroes moor, at a height of over 250 feet. In fact, in all the moors lying to the south of Fishguard, with the exception of those found on mountain-slopes, this boulder-clay can be found, but it is unfortunate that there are no deep pits or good sections to be seen. But the engineers of the Great Western Railway are making borings in this neighbourhood for a tunnel, and they very kindly supplied the writer with all the information in their possession which might be of interest. A boring has been made at Trebrython farm, to the south-west of Tregroes moor, and about 150 yards from the railway. In the boring the following succession was obtained :—

- 5 feet of earthy clay.
- 5 feet of yellowish clay, with rock fragments.
- 10 feet of a somewhat tough greyish-blue clay.
- Slate rock.

The greyish-blue clay is the Lower Boulder-Clay, and it is seen that it only attains a thickness of 10 feet here. The yellowish clay may be partly the bluish clay weathered, but most probably consists for most part of the equivalent of the Upper Boulder-Clay. The boring is made at a height of nearly 300 feet above sea-level. About three-quarters of a mile down the railway towards Goodwick is a railway cutting passing through part of the superficial deposits, and a boring has been made here also. A full section of this cutting and boring is given on another page, but it may be mentioned here that typical tough blue boulder-clay is there shown which attains a depth of

18 feet, and is followed above by Sand and Upper Boulder-Clay. The Lower Boulder-Clay is partly exposed in the cutting, and is full of fragments of marine shells.

There is also a small exposure in the moor just south of Letterston.

That the boulder-clay occurs far inland is proved by an examination of a pit at Llyn, near Llangolman, not far from Maenclochog. When seen the pit was only 5 feet deep, but it is opened up by the farmers periodically to a depth of from 15 to 20 feet, and ladders have to be used to get in and out. The clay is bluish in colour and very tough, and is usually spoken of by the natives as "indiarubber clay." It occurs in boggy land at the bottom of a small valley, at a level of over 400 feet. On both sides the land rises to a higher level, and is covered by a mantle of sands and gravels.

West of Goodwick the blue clay comes to the surface just below St Nicholas Church, at Clyn Bach moor. The depth was not ascertained. Fragments of broken shells occur here, though somewhat rarely. Some boulders of igneous rocks, foreign to the district, were found, and among them an unmistakable boulder of the Ailsa Craig riebeckite micro-granite.

The bluish clay is seen at places as far as the western end of the promontory—such as in the moors around Trefain, and in the shallow pits at Henllys, below Llanrian, where very fine examples of chalk flints were seen included. In the pits of Trefeithan moor, west of St David's, this boulder-clay is exposed to a depth of 6 feet and is of the usual character. No shells were seen, but some vegetable matter occurs in the clay. The boulders were few, and those noted were all of local rocks. Somewhat similar but shallower pits may be seen on Dowrog moor, Tretio moor, and Caer-farchell moor.

It is thus evident that this Lower Boulder-Clay occurs throughout the district, but it appears to thicken as we pass from west to east, and to be best developed to the east of Strumble Head. Fragments of marine shells were found in the clay at Cardigan, at Dinas, at the railway cutting near Tregroes, and at St Nicholas, and for the determination of these and other shells mentioned in this paper the writer is indebted to Mr HENRY WOODS, M.A., St John's College, Cambridge. Owing to their fragmentary condition it has been difficult to identify with certainty the shells found in the clay. But the following species appear to be represented:—

CARDIGAN CLAY-PIT—

Pectunculus glycymeris, L.
Astarte sulcata, Da Costa.
Mytilus, sp.

DINAS CLAY-PIT—

Astarte (Nucula) compressa, Mont.
 (?) *Cyprina islandica*, L.

RAILWAY CUTTING (between Tregroes moor and Manor-owen)—

Pectunculus glycymeris, L.
Cardium islandicum? Chem.
Vulsella modiola? L.
Astarte sulcata, Da Costa.
Astarte (*Nicania*) *compressa*, Mont.
Venus (*Ventricola*) *casina*, L.
Cyprina islandica, L.

Some of the boulder-clay from the boring near Tregroes was washed and examined under the microscope. A good deal of very fine sandy material—mostly quartz—was observed, and a few foraminifera could be seen.

2. *The Sands and Gravels*.—Above the Lower Boulder-Clay comes a series of aqueous deposits, consisting of sands and gravels, which are sometimes stratified and sometimes show hardly any traces of stratification. These deposits vary very much in thickness, and are apt to die out suddenly when traced laterally. They usually occupy a higher level than that attained by the Lower Boulder-Clay, and are often seen banked on the lower slopes of the hills. In places where sections are seen passing through the different deposits, no gradual passage can be traced from the lower stiff blue clay to the sands and gravels above—and this suggests that the sands and gravels lie upon an eroded surface of the clay. The sands are as a rule yellowish and yellowish-brown in colour, and have all the appearance of being marine: they are very variable in texture, and show all gradations from very fine sand to coarse gritty sand and gravel. And the gravels are often coarse and pebbly, resembling the shingle collected on beaches. At some places the sands are charged with worn and broken fragments of marine shells: these usually occur more abundantly in the fine gravel or coarse gritty sand than in the fine sand, although minute flakes can often be detected in the latter. They seem to be collected together in the stratified beds at certain spots, and to be absent in somewhat similar beds exposed only a short distance away. For instance, shells are plentiful in the Manor-owen sand-pit, whilst not a trace of shells can be seen in the Cnuc sandy pit, which lies only about a quarter of a mile further south: and 50 yards or so beyond the Cnuc sandy pit shell-fragments are again found in sand exposed in the railway cutting. In the pits where shell-fragments are found it may often be noticed that small pieces are cemented to the surface of a rounded stone. This is doubtless due to a deposit of carbonate of lime derived from the decay of some of the shells.

Like the Lower Boulder-Clay, the deposits of sand and gravel become better developed when traced from west to east, and the best sections and pits can be seen in that part of the district lying to the east of Strumble Head. Though the St David's promontory is largely covered by a loamy sand, no sections were seen showing deposits of the well-marked marine-like sands and gravels found further east. At Ty-llwyd there are small pits reaching a depth of 5 to 6 feet, where the loamy sand is well

shown. The bottom of the deposit is not seen, but as traced downwards the material becomes very sandy. It is ferruginous, and has a reddish colour.

The sands and gravels become more evident in the neighbourhood of Mathry. A little to the east lies a rugged mass of igneous rock known as Y Graig, and on the south side of this there is a newly dug pit, exposing 8 feet of pebbly gravel and gritty sand, with streaks of fine yellow sand. The deposit gets more sandy as traced downwards, but the bottom is not seen. A tendency to a rough bedding is shown in the section. At Pont Duan, north of the roadside, a very similar gravel-pit is seen. Pen Cnue, at Castle Morris, marks the site of a mound of fine yellow sand, most of which has now been carried away.

Gravel and sand is exposed, but only to a depth of 4 feet, in a field 200 yards north of Bridge-end, and again at Heathfield, south of the house. Further north, Tre-gwynt lies on sand and gravel, and much sand is seen between Tre-gwynt and Trellys.

East of St Nicholas Church the sands and gravels cover most of the land, as may be seen in pits in many of the fields. The writer employed a man to dig here in order to ascertain if possible the depth attained by the sand and gravel. At 8 feet the bottom was not reached, but the gravel became wet, and it is probable that the blue clay lies a few feet lower down, for it crops out in the moor below St Nicholas Church. The pebbles in the gravel-pit were all well rounded, and chalk-flints were seen. Gravels and sands seem to cover much of the ground on the Strumble Head promontory, but at places a yellowish earthy clay replaces them at the surface, though they may here occur with the clay. In a boring made for a well at Llandruidion farm sand was brought to the surface, in which comminuted shells were seen. The boring reached a depth of over 20 feet, and rock was not reached.

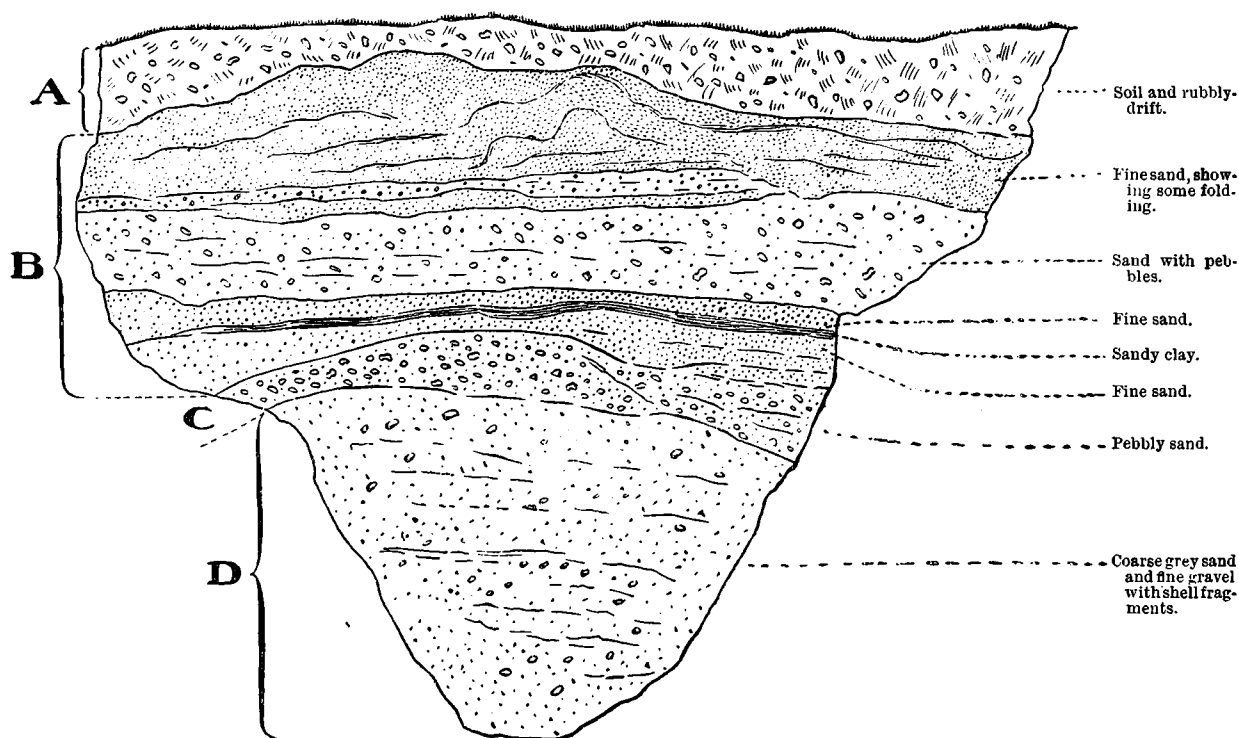
In the farmyard at Tre-howell, near the northern extremity of Strumble Head, in sinking for a well, no sand was passed through—all was earthy clay; but in a field 250 yards further north a sand-pit occurs, where 2 feet of fine yellowish sand are seen, covered by 2 or 3 feet of a loamy and somewhat stony clay. Mounds of gravel and sand occur on Caergowil, on the heights above Goodwick, and sections 7 feet deep are exposed. They are of the usual character.

South and east of Goodwick and Fishguard deposits of sand and of gravel are frequently met with. They do not occur in the form of kames or eskers, but are found lying in the slopes of the minor hills, and sometimes spreading to the top. It would be almost impossible to map them, as their occurrence is so irregular and patchy; they are apt to die out laterally in a sudden way, passing into clay or rubbly-drift. At many places they are overlain by an Upper Boulder-Clay. Perhaps the most interesting of all the sections is one seen in the Manorowen sand-pit, which lies in a small wood on the roadside, immediately south of the farm buildings, at a height of nearly 200 feet above sea-level, and two miles distant from Goodwick Bay. When visited a section of only 5 feet was seen, but means were taken to deepen it down to 12 feet. A somewhat diagrammatic view of this section is shown in fig. 1.

The materials were well stratified, and occur in the following order from above downwards :—

- A. Soil and rubbly-drift 1-3 feet.
- B. Very fine light-brown sand, with the beds somewhat contorted, passing down into thin beds of darker sand, followed by coarse sand with some pebbles. Near the bottom is a thin band of sandy clay, 3 inches $4\frac{1}{2}$ feet.
- C. Pebbly sand, variable in thickness 1 to $1\frac{1}{2}$ feet.
- D. Coarse grey sand or fine gravel, showing bedding. Some layers are more distinctly pebbly, and here and there fine sand occurs. The fine gravel is full of fragments of marine shells 6 feet.

Bottom not reached.



Greatest length 12 feet.
Depth about 12 feet.

FIG. 1.—Diagrammatic Section of the Manorowen Sand-pit.

Many of the shells have been identified, and are discussed below. Chalk-flints are common. On the opposite side of the road, below the churchyard, and at a lower level, there is a small exposure—3 to 4 feet deep—which consists entirely of a coarse gravel; but above, towards Manorowen Hill, the gravels and sand are replaced at the surface by clay.

About a quarter of a mile further south, sand is seen again at Cnuc Sandy. There is a big pit just in front of the cottage, 8 feet deep. What is seen here is for most part very fine yellow sand. Gritty and gravelly streaks and layers occur here and there, dying out as traced horizontally. No traces of shells were found here. The pit was at

one time 15 feet deep, and the bottom of the sand was not then reached. 1 to 3 feet of stony-drift cap the sandy beds at the surface.

At a distance of 50 yards further south the railway cutting has passed through 10 feet of similar very loose sand, in which fragments of marine shells occur plentifully.

The town of Fishguard is, in part at any rate, built on sandy deposits, and a good exposure is seen in a quarry on the roadside going down Fishguard Hill to Goodwick Bay. It consists of yellowish sand and fine gritty gravel of the usual kind, which near the top becomes more of a loamy, stony drift. North of the town gravel-pits are common in the fields, and at Pwll Landdu on the coast, east of Castle Point, the cliff is largely made up of gravel and a ferruginous sand, capped by a yellowish boulder-clay full of stones.

A little north of the valley of the Gwaen, at Tre-llan, near Llanllawer, fine yellow sand occurs on the lower slope of the hill of Ceunant.

It would be useless to mention every spot where the sands and gravels are to be seen. They occur in patches all the way to Cardigan, being especially well seen in Llwyn-y-Gwaer Park.

The highest level attained in this part of Pembrokeshire by the sands and gravels is at Pen Creigiau Cemmaes, just off the road leading from Nevern to Cardigan, and four miles distant from the latter place. Sand occurs at the top of the hill, at an elevation of 640 feet. Most of the hill-top is evidently of sandy material, and in a pit a section 8 feet deep is seen, showing very fine yellowish sand passing downwards into darker and more gritty material. There is only a faint trace of bedding. The bottom is not seen. This spot is nearly three miles distant from the coast. Chalk-flints and well-rounded pebbles of quartz are found. A few yards down the hill on the northern side are other small exposures, about 4 feet deep, showing more pebbly sand with rounded boulders; and on the southern side, immediately below the main road to Cardigan, is a gravel-pit, in which are seen rounded and sub-angular stones, some a foot in length. Chalk-flints and pebbles of white quartz were common, and a boulder of Millstone Grit and of a reddish granitoid rock foreign to the district were picked up. Also two pebbles of a muscovite granite. These will be referred to again below. A rough kind of stratification could be seen—layers of small gravelly pebbles separating beds of coarse shingle. The pit is 8 to 10 feet deep.

At Pant-gwyn, half a mile north of Pen Creigiau, sand is seen in a pit, and it is darker and more gritty than that on the hill-top.

Deposits of material resembling marine sands are met with even north of Cardigan, as at Banc-y-warren, but this is outside the area embraced in this paper.

Similar deposits are found far inland, even south of the Precelly hills. A few yards south of Rose-bush there is a sand-pit on the western side of the railway. A diagrammatic section of it is shown in fig. 2. The lower part is hidden by a talus slope. Above this comes 4 to 5 feet of fine yellow sand, very ferruginous in places. The sand becomes a little clayey or loamy in the eastern half of the section, and is

<i>Cyprina islandica</i> , L.	common.
<i>Tellina</i> (<i>Macoma</i>) <i>balthica</i> , L.	moderately rare.
<i>Maetra</i> (<i>Spisula</i>) <i>solida</i> , L.	rare.
<i>Venus</i> (<i>Ventricola</i>) <i>casina</i> , L.	moderately rare.
<i>Tapes</i> (<i>Amygdala</i>) <i>decussatus</i> ? L.	very rare.
<i>Cardium islandicum</i> ? Chem.	very rare.
<i>Mya truncata</i> , L.	rare.

SCAPHOPODA.

<i>Dentalium entalis</i> ? L.	rare.
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GASTEROPODA.

<i>Puncturella noachina</i> , L.	very rare.
<i>Natica clausa</i> ? Brod. and Sow.	rare.
<i>Turritella communis</i> , Lam.	common.
<i>Buccinum undatum</i> , L.	common.
<i>Tritonofusus gracilis</i> , Da Costa	very rare.
<i>Ocenebra erinacea</i> , L.	very rare.
<i>Trophon</i> (<i>Boreotrophon</i>) <i>clathratus</i> , L.	common.
" " <i>scalariformis</i> , Gould	moderately rare.
<i>Nassa</i> (<i>Hima</i>) <i>incrassata</i> , Ström.	very rare.
<i>Bela turricula</i> , Mont.	rare.
<i>Bela rufa</i> , Mont. (elongate form)	rare.

Fragments of other shells were also found, but they were too broken for identification. Some of the shell fragments found were very thick, especially pieces of *Cyprina islandica*. Many are rolled, and the majority very broken. Entire single valves of *Astarte compressa* were found; and of the univalve shells, *Ocenebra erinacea* and *Trophon clathratus* occurred in nearly perfect condition.

The fauna appears to contain a mixture of species belonging to different climates: *Astarte borealis*, *Trophon clathratus*, and *Trophon scalariformis* are Arctic and Scandinavian species, not now found living in British seas.

Astarte compressa, *Cyprina islandica*, *Buccinum undatum*, and *Puncturella noachina* belong to a northern type of British species which inhabit Arctic and Scandinavian seas in common with our own.

The shells are in very much the same condition as those which have been obtained at Moel Tryfan and at Gloppa, and most of the forms found at Manorowen occur in the other two places also. But *Nuculana*, which occurs rarely at Manorowen, is common at both of the other places.

Pectunculus glycymeris is abundant at Manorowen, but very rare at Moel Tryfan and Gloppa. *Venus casina*, though frequent at Manorowen, is also rare at the other places.

Samples of the sand from several places were examined microscopically, and they all showed a very close resemblance to marine sands. Most of the grains were of

quartz, and the smaller ones were angular, while the bigger ones tended to be more rounded.

3. *Upper Boulder-Clay and Rubbly-Drift.*—The sands and gravels are in many places covered by a yellowish-brown boulder-clay, quite different in character from the bluish boulder-clay which underlies them. This Upper Boulder-Clay is sometimes fairly tough, and is generally much more stony than Lower Boulder-Clay. It varies very much in thickness and character. Inland it often only occurs as a thin covering a few feet deep, but on the coast, where the best exposures are seen, much greater depths are attained. Sometimes it is a tumultuous unstratified till, with boulders of all shapes and sizes scattered pell-mell throughout the matrix. At other places—and it may be at no great distance away—it has more of the character of a rubble-drift, and as seen in section, has the appearance of an agglomeration of coarse and more or less angular debris, showing a rude kind of bedding. It is evident that most of it consists of material which has been re-arranged to some extent, and afterwards modified by sub-aerial agencies. It is impossible to separate the more typical unstratified boulder-clay from the rough semi-stratified clayey and sandy rubble-drift. The included boulders are derived in the main from the rocks of the district, but many far-travelled stones are also found, and these will be discussed in the next section. Ice-scratched stones are fairly common. These are usually sub-angular, with blunted angles and rounded edges. Rounded waterworn stones are also common, especially in the re-sorted rubbly-drift. No traces of marine shells are seen in the Upper Boulder-Clay and Rubbly-Drift. On the coast it is found capping the rocky cliffs at places, and in the bays fine sections, sometimes over 20 feet deep, are exposed. The foreshore is often covered with big boulders derived from the neighbouring cliffs. As the sea is now gradually gaining on the land, the cliffs of drift on the coast are being continually undermined, and the included stones and boulders are washed out and strewn over the shores. The beaches on the bays are rich in boulders and stones of rocks foreign to the district. These have undoubtedly been derived from the cliffs of drift, which are constantly undergoing a process of degradation owing to the action of the waves and of sub-aerial agencies.

By far the best exposures of these upper deposits are shown on the coast-line of the St David's promontory. Figs. 4 and 5 (Plate) represent sections seen in Whitesand Bay, and give a very good general idea of the appearance of these Upper Drift deposits. Fig. 4 shows a section of the cliff near the north end of the bay. Here the cliff is about 20 feet high and consists entirely of drift. At this spot the drift is a typical till or boulder-clay, showing no bedding, but full of stones and boulders, big and small, which are scattered confusedly through it. Most of the boulders are angular and sub-angular, and some are well glaciated. A few rounded pebbles and stones also occur. The boulders are mostly of local rocks, though some erratics are seen. Loose sandy soil occurs at the top. At the base the rock does not appear, but the shore is covered with stones derived from the cliff. A few yards further north slaty rock is seen

emerging from underneath the boulder-clay, which becomes thinner in this direction. At places the rock shows a hummocky surface, marked with glacial striae, which run from north-west to south-east. At the base of the small promontory called Trwyn Hwrddyn, on the north side, a rubble of very coarse fragments lies between the solid rock and the drift. Here the drift shows a rough sort of stratification, and has much sandy and pebbly material intermingled with boulder-clay.

Fig. 5 shows a section in Whitesand Bay seen further south. This is also about 20 feet in height, but here it consists more of a rubbly-drift. The matrix is earthy and sandy, and is choke-full of small flakes of slaty and other rocks, which have a rude kind of arrangement, especially towards the lower part. Boulders of larger size occur here and there, and consist for most part of grit and conglomerate and slaty rocks, with some blocks of the local gabbros and diabases. Pebbles of white and yellowish-white quartz are common. The top is covered by loose yellow sand, probably wind-blown, and just underneath this are traces of a pebbly bed. Though rock does not appear at the bottom just at this spot, it crops out on both sides a short distance away.

Drift of a similar kind is seen in sections, and capping the cliffs at other places on the western coast of the promontory.

Boulder-clay is seen at Porth-lisky stuck full of stones, many of which are smoothed, polished, and striated; and a boulder of the St David's Head gabbro, measuring roughly $3 \times 2 \times 2$ feet, lies on the beach below. A stony boulder-clay or a more rubbly drift is seen at various places on the south coast, the best exposures being above Caerfai Bay and at Caerbwdi Bay. At Caerbwdi the cliff is over 20 feet in height, but the base is hidden by talus: the matrix is here rather sandy, and streaks and pockets of rather fine sand are seen here and there. The included stones are often pebbly, but some are sub-angular and ice-marked. They are made up almost entirely of rocks found in the neighbourhood. Near the top flaky fragments are very plentiful, and these are derived from the local purple flagstones and slates. A big boulder of the coarse gabbro from St David's Head lies at the base of the cliff.

No good section is seen at Porth-y-Rhaw, but the drift caps the hills and cliffs to the south-east.

Very similar sections are seen on the north coast at Abereiddy and above Traeth Llyfn. At the latter place a rubble of big boulders is seen; most of these are of local igneous rock, very iron-stained and decomposed. Towards the top the section is freer of big boulders, and is full of little flakes of sedimentary and cleaved rocks.

One of the finest sections on the coast is seen at Aber-mawr, west of Strumble Head. At the northern end the rock is seen capped by 10 to 15 feet of stony-drift. As traced southwards the drift thickens to about 40 feet, then tails off rapidly. Where thickest the lower part shows some tendency to a rough kind of bedding, and is full of small flakes and little stones, more or less pebbly. This passes above into a rubbly clay, full of boulders of all sizes, most of which are angular and sub-angular, and derived from rocks of the locality. The cliffs on Strumble Head in many places are covered by a

mantle of stony till, but good sections are rare. The sections of drift exposed on the coast between Strumble Head and Cardigan are not so good as those seen west of Strumble Head, but where seen they are of the usual character.

Inland, good sections are not often met with. Much of the country in the neighbourhood of St David's is covered by drift, which consists of a sandy matrix full of boulders. But often the matrix is clayey, as may be seen in sections on the roadside near Castell, south-west of St David's, and again in a pit just off the road near Pont Clegyr, two miles east of St David's. In fact a large part of the country south-west of Strumble Head is covered by material which has been to a large extent re-arranged, and which cannot be defined accurately either as boulder-clay or as sand and gravel, though the tendency is for the sand and gravel to become more marked at a depth of a few feet from the surface. Much rubbly-drift, becoming more sandy as traced downwards, is spread out on Strumble Head, especially on the moorland above Goodwick. The sands and gravels occurring south and east of Fishguard Bay are, as already mentioned, usually overlain by a few feet of rubbly-drift or more typical stony boulder-clay. In the railway cutting between Tregroes moor and Manorowen 7 feet of stiff yellowish-brown boulder-clay is seen covering the shelly sand. This clay is spread out over much of the high land skirting the railway here on the west side. A little further south the sands and gravel die out, and the Upper Boulder-Clay seems to lie directly on the Lower Boulder-Clay, and this occurs possibly in the boring at Tre-bythton already referred to, where yellowish clay is succeeded by tough bluish clay.

It is very rarely that one has an opportunity of finding all the deposits succeeding one another in the same section, and of ascertaining the depth of each. But the engineer of the Great Western Railway at Goodwick supplied the author with particulars of the boring made in the railway cutting between Tregroes Moor and Manorowen, just about Cnuc Sandy. A complete section of the railway cutting, together with the results obtained by boring, are given on the next page. From above downwards, the deposits passed through were—

(4) Stiff yellowish-brown clay with fragments of slate-rock	.	.	.	.	.	7 feet
(3) Fine yellow sand with shell-fragments	.	.	.	.	.	10 „
(2) Stiff dark-blue boulder-clay with shell-fragments	.	.	.	.	.	18 „
(1) Gravel	.	.	.	.	.	5 „
Rock.						

This section proves very clearly the presence of an Upper and a Lower Boulder-Clay. These are separated here, as in many other places, by a deposit of sand. Most of the Lower Boulder-Clay is below the surface of the railway cutting. And a glance at the section shows that before the cutting was made, the surface of the ground was covered to a depth of 7 feet by the Upper Boulder-Clay. So it is quite possible that the Lower Boulder-Clay spreads over a much wider area than is evident at the surface, and that much of it is hidden by more superficial deposits. It is interesting to note that underneath the Lower Boulder-Clay there lies 5 feet of gravel. On comparison this was

found to be very similar to underlying grit rock when this is broken up. So it may represent material ground out of the solid rock by the movement of land-ice.

Further inland a good example of the Upper Drift is seen in a cutting on the roadside between Puncheston village and the railway station. It is a stony and rather rubbly clay. Close at hand, on Puncheston common, the Lower Boulder-Clay crops to the surface.

Further east, up to Cardigan, the Upper Boulder-Clay and Rubbly-Drift are seen in many places overlying sands and gravels or lying immediately on the blue clay.

The line of division between this Upper Boulder-Clay and the sands and gravels is not so marked as that between the sands and gravels and the Lower Boulder-Clay.

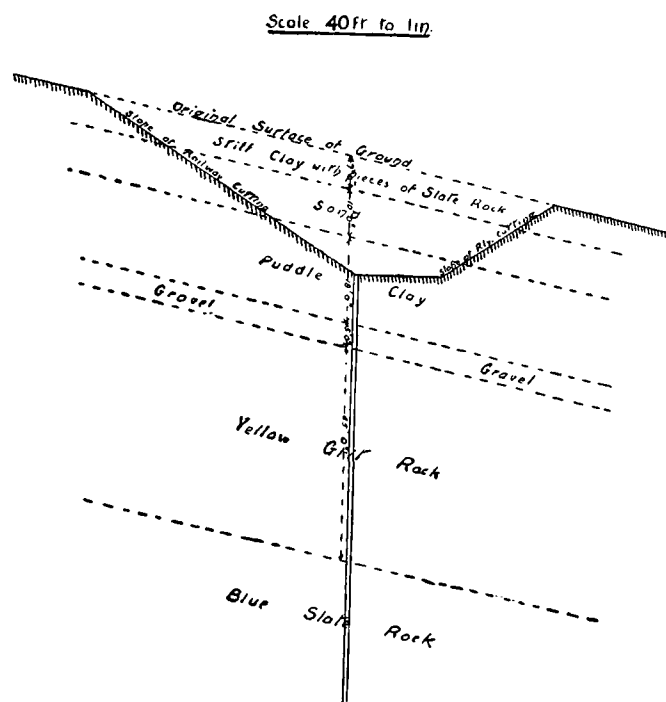


FIG. 3.—Section at Boring No. 1 on Goodwick to Letterston (existing) Railway, between Tregroes Moor and Manorowen.

V. THE BOULDERS AND ERRATICS.

The transport of boulders is of great importance as indicating the general direction of ice-movement. Throughout northern Pembrokeshire boulders may be seen scattered over the surface, and are especially common on waste or uncultivated land. Many of those found on the slopes of the hills have no doubt rolled from the parent rock above, but many, though not foreign to the district, have yet been carried for some distance by ice.

Where the land is cultivated an immense number of boulders must have been removed, but even in the fields it is common to meet with big blocks of igneous rocks, which, as a rule, have been left in the position where they were originally stranded in order that cattle may have something to rub against, or have been left on account

of their immense size, though these latter are becoming gradually destroyed by blasting operations. At many places, especially on the St David's plateau, huge standing stones, cromlechs, or other ancient remains are seen, and it is more reasonable to believe that the immense blocks used for these purposes were found as boulders near at hand than that they were quarried from the parent mass, which often lies at a considerable distance away. And this is rendered the more probable as blocks of similar size are not infrequently seen dotted over the surface. An examination of the stone dykes will show how plentifully boulders of all sizes must at one time have been studded over the ground, and what a variety of rocks is represented. Towards the western end of the area the boulders are largely found to have been dispersed from the igneous rocks on the north coast of the promontory. And everywhere the great majority are derived from parent masses found in the district. Boulders of diabase may often be seen resting on volcanic or sedimentary rocks, and *vice versa*, proving that there has been some transport. It has already been mentioned that blocks of the St David's Head gabbro are found lying to the south-east at Caerfai Bay, and Caerbwddi Bay, and on the cliffs above. This implies that there was a movement of ice from a north-westerly direction, and it agrees with the evidence shown by the glacial striæ which are seen on the coast. Erratics are met with often in the drift and on the shores, but the number which has been noted on the surface is not great. A further study of the stone dykes would doubtless bring more to light

1. *Erratics seen on the surface of the ground.*—The detection of those about to be mentioned is mostly due to the fact that they had been broken up by the farmers through blasting or other agency, so as to expose fresh surfaces. HICKS states (*Geol. Mag.*, 1891, p. 501) that he observed many northern erratics in the St David's district. The granite boulder which he discovered on Porth-lisky farm "before it was broken must have been over 7 feet in length and 3 to 4 feet in thickness, and is identical with a porphyritic granite exposed in Anglesea." He found another of picrite which he thus describes: "The boulder is somewhat rounded; its longer axis, which lies nearly south-east and north-west, measures about a yard. A transverse section is slightly triangular, the shorter sides measuring respectively about 16 inches and 22 inches. It lies on the promontory forming the east side of Porth-lisky harbour, resting immediately on Dimetian rock, surrounded by an uncultivated area overgrown by gorse and heather" (*Quart. Journ. Geol. Soc.*, vol. xli. p. 519). It was submitted to Professor BONNEY for examination, and he states that it is wonderfully like the boulders found at Pen-y-Carnisiog, Anglesea, which had been previously described by him (*Quart. Journ. Geol. Soc.*, vol. xxxvii., 1881, p. 137). In a later paper (*Quart. Journ. Geol. Soc.*, vol. xli., 1885, p. 518), Professor BONNEY remarks that "the lithological evidence rather favours the derivation of the Anglesea boulders from dykes in that island." A hornblende picrite of a somewhat similar character occurs also *in situ* at Penarfynydd, on the south-west coast of Carnarvonshire. So it is probable that the boulder found near St David's has been carried by the agency of ice from Carnarvonshire or Anglesea.

The writer discovered a big boulder of picrite on Strumble Head, on a piece of uncultivated ground a little north of Tre-sinwen farm, by the side of the pathway leading to the coastguard station at the Head. The boulder had been broken, and now lies in several pieces—the biggest piece measuring roughly $3\frac{1}{2} \times 3 \times 2$ feet—and in its original condition it must have been much bigger. Another boulder of picrite, very similar in appearance and size, and also broken, was discovered on a field lying a little to the north-west of Tre-seissyllt, between the farm and the coast north of Aberbach. A microscopic section of this rock revealed the presence of the following minerals:—brown hornblende, strongly dichroic; augite, nearly colourless; olivine, not very abundant, and always very much serpentinised and of a greenish colour; magnetite; a chloritic mineral, which is evidently an alteration product, and a little plagioclase felspar. The chloritic mineral is greenish in colour and markedly dichroic. The general appearance of the rock as seen in section was very different to that of the St David's picrite: the augite does not show such perfect forms in the former as in the latter, and there is rather more olivine in the St David's rock. The Strumble Head picrite boulder is rather more like some of the Penarfynydd specimens as seen in section, but there is not so much olivine in the former, and the poecilitic structure which often characterises the latter is not seen in the former. But it is highly probable that the Strumble Head picrites have also been borne from Lleyn or Anglesea. The two specimens found on Strumble Head lie about three miles apart, in a line whose direction is north-north-east to south-south-west. Near the Tre-seissyllt boulder of picrite lay a boulder of olivine-gabbro, also broken to pieces by blasting. The newly-exposed faces were remarkably striking, and the crystals are very fresh. The rock is quite unlike the gabbros found in Pembrokeshire. A microscopic section showed beautifully fresh olivine crystals, and the rock is undoubtedly of Tertiary age, and has probably come either from the Western Isles of Scotland or from the north-east of Ireland.

2. *Erratics in the Drift.*—As might be expected, the majority of the boulders found in the drift deposits are of local origin. They occur abundantly in the Upper Boulder-Clay and Rubbly-Drift, and in the sands and gravels, and to a less extent in the Lower Boulder-Clay. The grits, shales, and slaty rocks of Pembrokeshire are very similar in appearance to rocks of a like nature from North Wales, and the same is true of some of the igneous rocks, especially the diabases and some of the lavas. It is thus quite possible that among the boulders found imbedded in the drift many North Wales rocks may be represented, though there is no means of distinguishing them readily from the boulders of local origin. This was suggested to the writer by the discovery of boulders of a diabase rock in the boulder-clay exposed at Cardigan. To the naked eye this diabase seemed very like that found to the south-west in Pembrokeshire. But no such rock is known to occur anywhere nearer Cardigan than Newport—nine or ten miles to the south-west—and so these boulders must have come from the north. This is made all the more probable by the discovery of boulders of

what are undoubtedly northern rocks associated with these boulders of diabase at Cardigan.

Of the erratics the most important discovery in the drift was that of a small boulder of the Ailsa Craig riebeckite rock, or paisanite. This was found in the bluish boulder-clay, near the surface, at Clun-Bach moor, St Nicholas, near the south-western end of Strumble Head. The specimen was sliced, and as seen under the microscope it is identical with specimens obtained from Ailsa Craig.

Boulders of hornblende-porphyrates from the south-west of Scotland occur in the Lower Boulder-Clay as far east as Cardigan, and are found even oftener in the Upper stony Boulder-Clay. Several varieties are seen, all of which can be matched in Wigtownshire and Kirkcudbrightshire. But the erratics which are most commonly met with in the drift are reddish granophyres, quartz-porphyrates and micro-granites. Many of these are dyke-rocks, and it is very difficult to trace them to their source. Some have certainly come from Ireland, and some most probably from the south-west and west of Scotland. Lake District rocks and North Wales rocks are not so well represented.

In the clay-pits of Rhos Isaf, near Dinas, excavated in the Lower Boulder-Clay, a reddish granophyre was found, which, under the microscope, resembles very much some of the granophyres of Mull. And in the Pen Creigiau gravel-pit boulders of granophyre occur, which have come from the Carlingford district, Ireland. One was sliced, and the microscopic characters seen were identical with that of the granophyre of Barnavaine, Carlingford. These reddish granophyres are found in the drift throughout the area, but seem to be rather scarcer in the extreme west. As the writer had not much opportunity of comparing them with Irish rocks, he sent them to Prof. WATTS, of Birmingham University, who very kindly examined them. Many of the granophyres, he thinks, can be matched in the Carlingford mountains; others bear more resemblance to the Tertiary granophyres of the Inner Hebrides. The reddish quartz-porphyrates appeared to him to be like the varieties of the quartz-porphyr of Cushendale in Antrim; and among the boulders of micro-granite he noted two which are likely to have come from the mass of micro-granite at Cushendun in Antrim. He is of opinion also that the Old Red conglomerate of Cushendun might, when broken up, present examples of many of the types of boulders found in the drift of Pembrokeshire. A pebble of muscovite-granite, probably the Foxdale granite of the Isle of Man, was obtained from the gravel-pit at Pen Creigiau, over 600 feet above sea-level. Examples of Millstone Grit were obtained here also, and in the Cardigan clay-pit boulders of Carboniferous Limestone are common, often with the fossils well preserved. On the beach at Gwbert, not far from Cardigan, boulders and pebbles of Carboniferous Limestone are common. These must have come from Ireland or from carboniferous rocks which are hidden at the bottom of the Irish Sea. It is hardly likely that they have come from the small exposures bordering the Menai Straits in North Wales.

Chalk-flints occur everywhere—in both boulder-clays, in the sands and gravels, and

on the beaches. These also must be derived from the north-east of Ireland and from rocks hidden under the Irish Sea.

From the cliff of Upper Boulder-Clay at Porth-lisky a boulder of olivine-dolerite was obtained, microscopic sections of which show very fresh olivine. It is certainly a Tertiary rock, and has probably come either from the north-east of Ireland or from the western isles of Scotland.

3. *Erratics found on the shores along the coast.*—These are especially abundant at those places where cliffs of boulder-clay or drift are seen. Many of them are found lying just at the foot of the cliffs, having only recently fallen from them; and others which were picked up as pebbles on the beach have doubtless, for most part, been derived from the drift also.

Ailsa Craig, Riebeckite Rock or Paisanite found on Abermawr beach (frequent), Aberfelin beach, Porth-y-Rhaw beach.

(It is interesting to note that a boulder of this was also found in the Lower Boulder-Clay at St Nicholas, not far from Abermawr.)

Granites from the Dalbeattie area, several varieties found at Pwll Gwaelod beach (frequent), Aberbach beach (near Dinas).

Granites of Galloway type „ Whitesand Bay, Aberbach (near Dinas), Pwll Gwaelod, Gwbert (near Cardigan).

A fine specimen of a Mica-hornblende-Granite, identical with that of Auchencairn, Kirkcudbrightshire, „ Abermawr.

Mull of Galloway Granite „ Pwll Gwaelod.

Another variety from same area „ Gwbert (near Cardigan).

A Gneissose Granite from Criffel „ Pwll Gwaelod.

Granite or Quartz-Diorite from head of Loch Doon, South of Scotland, „ Pwll Gwaelod.

Biotite Granite, Loch Dee, South of Scotland „ Abermawr, Gwbert (near Cardigan).

A Diorite identical with that of a dyke near Gutchen Isle, Colvend shore, south of Dalbeattie, „ Abermawr, Whitesand Bay.

Other Diorites from the Galloway area „ Abermawr (frequent), Aberbach (near Dinas), Abereiddy.

Hornblende-porphyrte identical with one found south of Castle Douglas, Kirkcudbrightshire, „ Pwll Lan-ddu.

Other Hornblende-porphyrtes of the Galloway country „ Pwll Gwaelod, Aberbach (near Dinas), Abermawr (frequent), Whitesand Bay.

Hornblende-biotite-porphyrte, Wigtownshire. „ Pwll Gwaelod.

Silurian grits, South-West of Scotland „ Abermawr.

Muscovite-granite, Foxdale, Isle of Man „ Gwbert (near Cardigan).

Andesites, Rhyolites, and altered Tuffs of the Borrowdale series, „ Abermawr, Aberbach (near Dinas).

Reddish Quartz-porphry, probably from Cushendale, Antrim, „ Porth-y-Rhaw, Abermawr, Whitesand Bay.

Reddish granophyres and micro-granites, mostly North-East Ireland, but some possibly from West of Scotland, „ Pwll Lan-ddu, Gwbert (near Cardigan), Aberbach (near Dinas).

A gneissose Grit—locality unknown „ Porth Sele

Carboniferous Limestone „ Gwbert (near Cardigan).

Gannister „ Abermawr.

A Muscovite-granite, with microcline and some biotite—locality unknown. „ Abermawr.

The most striking fact in connection with the erratics is that so many of them can be traced to the south-west of Scotland. The Ailsa Craig paisanite has been obtained in the boulder-clay, and is frequently met with on some of the beaches, especially at Abermawr. The granites, diorites, and porphyrites of the Galloway country are also well represented, boulders being found which represent the three principal massifs, namely, (1) Dalbeattie and Criffel, (2) Cairns Muir of Fleet and New Galloway, and (3) Loch Doon and Loch Dee, and in addition some from smaller exposures, such as that of the Mull of Galloway.

The other region from which the boulders have travelled is the north-east of Ireland, and its rocks are represented in Pembrokeshire by reddish granophyres, quartz-porphyrines, and micro-granites.

A few boulders are found also which have almost certainly come ultimately from the Western Isles of Scotland.

It is a noticeable feature that the Lake District rocks are but poorly represented, and the same is apparently true of those of North Wales.

Many of the boulders and pebbles, such as those of Carboniferous Limestone and the chalk-flints, may have been torn up from the bed of the Irish Sea.

VI. GENERAL CONCLUSIONS.

The facts adduced in this paper prove conclusively that northern Pembrokeshire has been the theatre of glacial action to an extent greater than had previously been supposed. Glacial deposits cover the ground in that part much in the same way as they do further north, and present very similar characteristics. Here also we meet with a tripartite division of the deposits, namely, a Lower Boulder-Clay, Intermediate Sands and Gravels, and an Upper Boulder-Clay and Rubble-Drift, reminding us of the tripartite division found at so many places further north on both the east and west sides of England, and in North Wales. But in the present state of our knowledge it is very difficult to correlate the deposits found in one area with those found in another area; and it is not safe to assume that the Sands and Gravels always represent any definite horizon in the glacial series.

Of the deposits which have been described it is the Lower Boulder-Clay which has the widest extension; it covers much of the lower grounds inland, and is often hidden under the other accumulations. It follows the slope of the ground, and a little below Pen Creigiau Cemmaes it attains an elevation of nearly 600 feet above sea-level. The series of sands and gravels is a very variable one. Often they taper or die away suddenly into a stony or loamy drift, and at places are absent altogether. They attain their greatest elevation near the east end of the area at Pen Creigiau, where the sands reach a level of over 640 feet, and are followed immediately below by coarse shingly gravel. The Upper Boulder-Clay, where the sands and gravels are absent, is sometimes seen to rest immediately upon and coalesce with the Lower Boulder-Clay, so that

it becomes somewhat difficult to separate them. But the distribution of the Upper Drift is not so wide; it is only met with here and there, and the true Upper Boulder-Clay is often replaced laterally by Rubbly-Drift. The more sporadic occurrence of the Upper Boulder-Clay is probably due in part to the fact that it has suffered more from denudation.

The Lower Boulder-Clay is undoubtedly the product of an ice-sheet, and it has all the characteristics of a true ground-moraine. It is remarkably tough and homogeneous, and shows no traces of stratification, and it has all the appearance of having undergone great compression. The included stones are often intensely glaciated, and are sub-angular rather than rounded in form. The fact that fragments of marine shells occur in the clay proves that the ice which gave rise to it must have travelled over a sea-bottom. On the other hand, the bits of woody matter sometimes seen embedded in the tough clay to a depth of 18 or 20 feet suggest that vegetation grew on the land bordering the sea, before the advent of the ice or during an interglacial period, and that some fragments of this found their way, by means of streams or otherwise, to the sea-bottom, where they lay in the path of the ice. Or they may have been derived from the remains of a submerged forest. The included erratic stones help us to follow the direction from which the ice came, and the occurrence of boulders from the south-west of Scotland and from the north-east of Ireland in the Lower Boulder-Clay and Drift as far east as Cardigan, and the discovery of fragments of marine shells in the Lower Boulder-Clay exposed at the brickworks near that town, make it clear that the whole of northern Pembrokeshire was buried underneath an ice-sheet coming from the north. The view held by CARVILL LEWIS, that the Irish Sea glacier (as he termed it) extended no further south than the extremity of Llyn in Carnarvonshire, is shown to be inaccurate. And though Professor JAMES GEIKIE makes the *mer de glace* which overwhelmed Anglesea flow down St George's Channel, to a limit reaching beyond the south-west of Wales, he only indicates it as crossing the extreme west of Pembrokeshire at St David's Head. But the facts just mentioned show that this *mer de glace* must have passed over a great deal more of Pembrokeshire than St David's Head. It invaded northern Pembrokeshire along its whole extent, and even encroached on Cardiganshire to the east, and its trail is evident in the tough dark-blue homogeneous boulder-clay, with its northern erratics and the broken shells derived from the sea-bottom over which the ice travelled. How much further south this typical boulder-clay or ground-moraine extends is a point which must be left to future investigation.

This *mer de glace* was of course the southward extension of that ice-sheet which filled the northern basin of the Irish Sea, and which has been described by Professor JAMES GEIKIE and other workers in Glacial Geology. The latest results published are those of the investigations of Mr LAMPLUGH in the Isle of Man, and these have appeared in his Survey Memoir on the Geology of that Island. His observations on the Irish Sea Glacier are of great interest and importance, and throw light even on

what occurred to the south of his area. Speaking of the conditions which obtained in the northern part of the Irish Sea at the beginning of the Glacial period he says, "Along the shores an ice-foot probably formed in the winter and broke away in the summer into floes, which distributed their burden of rock-fragments broadcast over the sea-floor. This seems to be the explanation of the universally wide dispersal of the fragments from Ailsa Craig, which have been recognised in the drift almost all round the northern part of the Irish Sea basin, in Ireland and Wales, as well as in the Isle of Man. The sea-girt precipices of splintering rock in Ailsa would not fail to cast off a load upon an ice-foot below; and thus these fragments became strewn over the sea-floor almost as widely as the shells, and were subsequently carried by the ice-sheet into nearly every district to the southward where the shells were carried" (p. 370). This helps to explain also in a satisfactory way the occurrence of fragments from Ailsa Craig and of boulders from the north-east of Ireland, from the south-west of Scotland, and even possibly from the Inner Hebrides, in the drift, and on the beaches of northern Pembrokeshire. For the ice-sheet as it advanced would pick up any such fragments which had been previously strewn over the sea-bottom by ice-floes, and would carry them southwards on to the land as it carried the shell-fragments.

LAMPLUGH estimates that in the neighbourhood of the Isle of Man the ice-sheet, at its maximum, must have attained an elevation of not less than 2000 to 3000 feet above the present level of the sea, and the general direction of the ice-movement was from north-north-west to south-south-east. He points out that "the West-British Ice-sheet probably attained its ultimate dimensions mainly from the accretion of snowfall upon its surface, and in only a minor degree from the inflow of tributary glaciers." He calls attention to certain results which help us to understand the southward extension of the ice-sheet far enough to overwhelm Pembrokeshire. "As the British ice-sheets must always have received their increment principally from the moist Atlantic winds, it seems probable that, without any change of climate, the centre of greatest accumulation, and consequently of maximum glaciation, would tend to shift steadily westward and south-westward as the icy plateau rose higher in the path of the moisture-laden winds and compelled their earlier precipitation. This effect would, moreover, be accentuated by the obliteration of the open water in the sea-basins to the eastward. The West-British sheet might from this cause go on increasing, while its East-British and Pennine equivalents were already diminishing from lack of sufficient snowfall. . . . For the above reason, the shrinkage of the ice-sheet covering the Isle of Man is likely to have commenced while the Welsh and Ivernian sheets were still increasing." Although the ice in the southern part of the Irish Sea basin did not probably attain such a great thickness as the ice in the northern area did, nevertheless all the evidence goes to show that even as far south as Pembrokeshire it must have reached a considerable elevation. The presence of drift material at Pen Creigiau, at an altitude of over 600 feet above sea-level, indicates that the ice-sheet here was in all probability not much less than 1000 feet in thick-

ness, even if we allow that the land at that time stood at a somewhat lower level than it does at the present day. Mr LAMPLUGH gives a sketch-map of the Irish Sea (as far south as the Lleyn promontory), showing glacial striæ and probable direction of the ice-movement. The ice which streamed over the Isle of Man from the north is shown as usual to have travelled south and to have overwhelmed Anglesea, being here diverted so as to move more to the south-west on account of the opposition of the ice coming down to meet it from the mountains of Snowdonia. On the western side of the Irish Sea basin the striæ indicate that the ice moved from the land on the eastern seaboard of Ireland, and took a course from north-north-west to south-south-east, and coalesced with that which passed over Anglesea and Lleyn. Its course southwards from this limit is not shown. But in Professor GEIKIE's map the Irish ice is made to bend back to the south as a result of its meeting with that part of the ice-sheet which flowed over Anglesea, and the northern ice is shown as passing down to the west of Cardigan Bay, on account of the presence of the ice flowing west from Merionethshire and Central Wales. But the investigations carried out on the glaciation of Pembrokeshire make it clear that the Irish ice was not bent back so sharply, but, on the contrary, it continued in its original course from north-north-west to south-south-east, whilst the ice from the north was forced to invade Cardigan Bay, and must therefore have shouldered in the Welsh ice again upon the mainland. This is proved by the direction of the striæ seen along the coast, as well as by the presence of boulders of igneous rock from Ireland and the south of Scotland in the drift as far east as Cardigan. Again the presence of chalk-flint throughout the area is evidence in the same direction, for these must have come from the north-east of Ireland or from the bed of the Irish Sea; and it is possibly from this bed that the boulders of Carboniferous Limestone which are seen so abundantly at Cardigan have come. In this connection it is interesting to recall the presence of fragments of Millstone Grit in the gravels at Pen Creigiau. Our knowledge of the glaciation of Ireland is as yet very imperfect, and it is difficult to estimate what volume of ice passed seawards from its eastern border. At the present day the rainfall over Ireland is very excessive, and so it seems probable that the snowfall was likewise excessive during glacial times. This would give rise to a proportionately large ice-sheet moving outwards in all directions, and so it is quite possible that the amount of ice which found its way into the Irish Sea basin was considerably greater than has been generally supposed. And in the southern part of the basin it would to some extent oppose the passage of the western ice which overflowed Anglesea and the end of Lleyn in a south-westerly direction, and cause it to turn a little more to the south so as to travel over Cardigan Bay. The confluent sheet, forming by the junction of the Northern ice, the Irish ice, and to some extent the Welsh ice, would invade northern Pembrokeshire in the direction which is shown by the striæ along the coast near St David's, namely, from north-west to south-east, or perhaps from north-north-west to south-south-east. This would explain the transport of boulders from the St David's Head gabbro south-

eastwards to the neighbourhood of Caer-bwddi Bay. In this connection it may be mentioned that Mr J. HARRIS, in a report on erratics in South Wales, which appeared in the British Association Reports, 1898, refers to some boulders found at Pencoed, near Bridge-end, Glamorganshire. Microscopic sections of some of these were prepared and sent to petrologists for examination. The result of this is given as follows:—“One was identified with the gabbro of St David’s Head; a felsite bore some resemblance to the pre-Cambrian rocks of Pembrokeshire; two or three acid rocks, brecciated felsites, and tuffs are very like those of the Llyn promontory.” From these data it is concluded that the transport of boulders was from the west or north-west. If one of the boulders found near Bridge-end is accurately identified as belonging to the St David’s Head gabbro, it is a most remarkable fact. It is hardly safe to draw any conclusion until it has some further corroboration.

The more or less loose materials covering the bottom of the sea, which existed before the advance of the ice, would become incorporated into the lower layers of the ice-sheet. And as the ice was very thick, and moved onward slowly, it would exert a great pressure over its bed, with the result that much of the rocky floor would be torn away, and much of the material ground up and pulverised to form the typical ground moraine. The shell banks which occurred on the sea-bottom would be destroyed, and the marine detritus would be carried forward under the ice or in the ice. This accounts for the presence of shell-fragments at places in the Lower Boulder-Clay. And the most natural explanation of the shelly sands and gravels is that they represent the material of a sea-bottom, carried onwards and upwards to their present position by an ice-sheet, and re-arranged by fluvio-glacial action. That is to say, they are *remaniés* derived from the bottom-moraine of an ice-sheet which had travelled over a sea-floor. Similar sands and gravels have been found at many other places on the west side of the island, and they have given rise to much discussion—notably those found at Moel Tryfan in Carnarvonshire. The Pembrokeshire series differ from those of Moel Tryfan in that they are found overlying the well-marked stiff Lower Boulder-Clay. The most remarkable feature in connection with the Moel Tryfan beds is the great elevation at which they are found—1350 feet above sea-level. In Pembrokeshire the greatest height at which they have been met with is 642 feet at Pen Creigiau, four miles south-west of Cardigan. The mode of origin of such sands and gravels has been one of the most vexed questions in Glacial Geology. Some writers, such as MACKINTOSH, T. M. READE, and others, have argued that the sands and gravels represent marine deposits laid down in place during a great submergence. It is admitted, even by the opponents of that theory, that a partial submergence took place during Glacial times, but to what extent is not known, and there is no evidence to show that it meant a sinking of the land in Carnarvonshire to as much as 1350 feet below its present level. And the partial subsidence which is allowed is generally thought to have diminished towards the south. In Pembrokeshire no evidence can be seen along the coast which would lead us to

believe that there had been a subsidence of 640 feet below the present level, so as to account for the marine deposition of the beds found at Pen Creigiau. Further, if the advocates of a submergence point to the presence of marine shells at places in the sands and gravels as a proof, on the ground that the shells must have been altogether destroyed if carried beneath the ice in the morainic debris, one asks then how they can account for the presence of fragments of shells—some large enough to be identified—in the tough blue boulder-clay underlying the sands and gravels? No one who looks upon that clay, as exposed, for instance, at the Cardigan brickworks, can doubt for a moment that it is the product of an ice-sheet. Not a trace of stratification can be seen in it, nor is there any character which suggests even the possibility of its being the result of marine deposition. And yet marine shells are seen imbedded in the clay. This, as has been already pointed out, is due to the fact that the ice-sheet, of which this clay is the bottom-moraine, travelled over a pre-existing sea-bottom. The fact that everywhere the shells are very broken and much rolled is hardly compatible with the view that they are now found in or near the positions in which the molluscs themselves lived. And it is worthy of note that the Lamellibranch shells obtained in these sands and gravels are never found with the two valves in apposition, as one might expect to find if they lie in ordinary sea deposits. Again it has often been pointed out that it is a significant fact that deposits of this kind only occur in glaciated areas, and that wherever broken shells are found, with them there also we find far-travelled erratics present. And this is to a marked extent the case in Pembrokeshire.

Mr J. F. BLAKE (*Geol. Mag.*, vol. x., 1893, p. 267) concluded that the shelly sand at Moel Tryfan had been pushed up in front of the advancing glacier, and that, as a result of this glacier meeting that which came out of the Bettws Garmon valley, the sand got pushed into a protected corner and was left there. But in northern Pembrokeshire the sands and gravels are found scattered in patches over a wide area, and are frequently well bedded. Here they are the products of the washing and re-sorting of infra- and intra-glacial detritus. This may have gone on partly under the ice, but it would no doubt take place to a great extent at the time of the melting of the ice-sheet, when large streams would issue from the margins of the glacier and re-arrange much of the superficial deposits left on the surface of the land.

The Upper Boulder-Clay is so sporadic in its occurrence that it is difficult to draw any definite conclusions with regard to it. It may possibly represent a second advance of the ice-sheet after an interval of less severe glacial conditions. It is far more stony than the Lower Boulder-Clay, and in places passes into Rubbly-Drift. This Rubbly-Drift is very similar to that found by LAMPLUGH in the Isle of Man, and is probably “the *remanié* deposit of the ice-sheet modified by sub-aerial agencies.” At the time of the final disappearance of the ice, torrential waters must have overflowed parts of the surface, and the rubble is probably to be attributed in part to the action of these waters. Morainic material would become mixed up with rock debris, formed by ordinary weathering processes, and the whole mass would be re-arranged, and in places sifted by the waters.

Dr T. J. JEU on "The Glacial Deposits of Northern Pembrokehire."

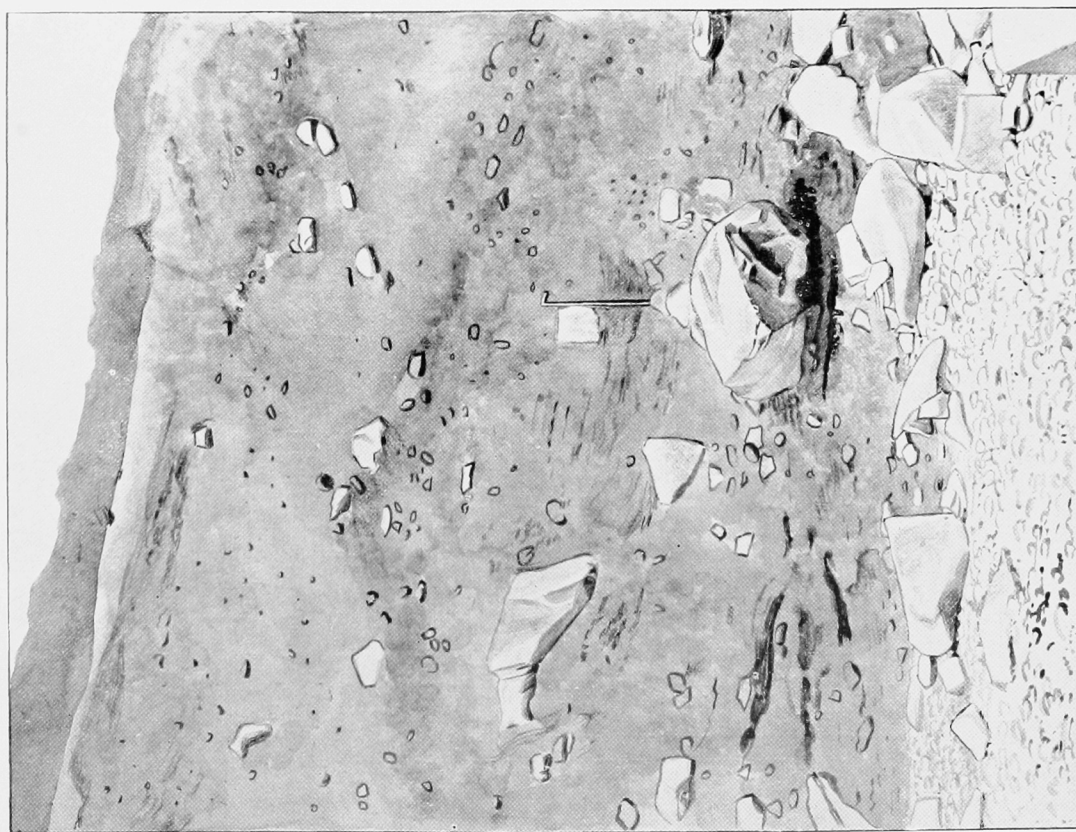


FIG. 4.—Section of Drift seen at northern end of Whitesand Bay.

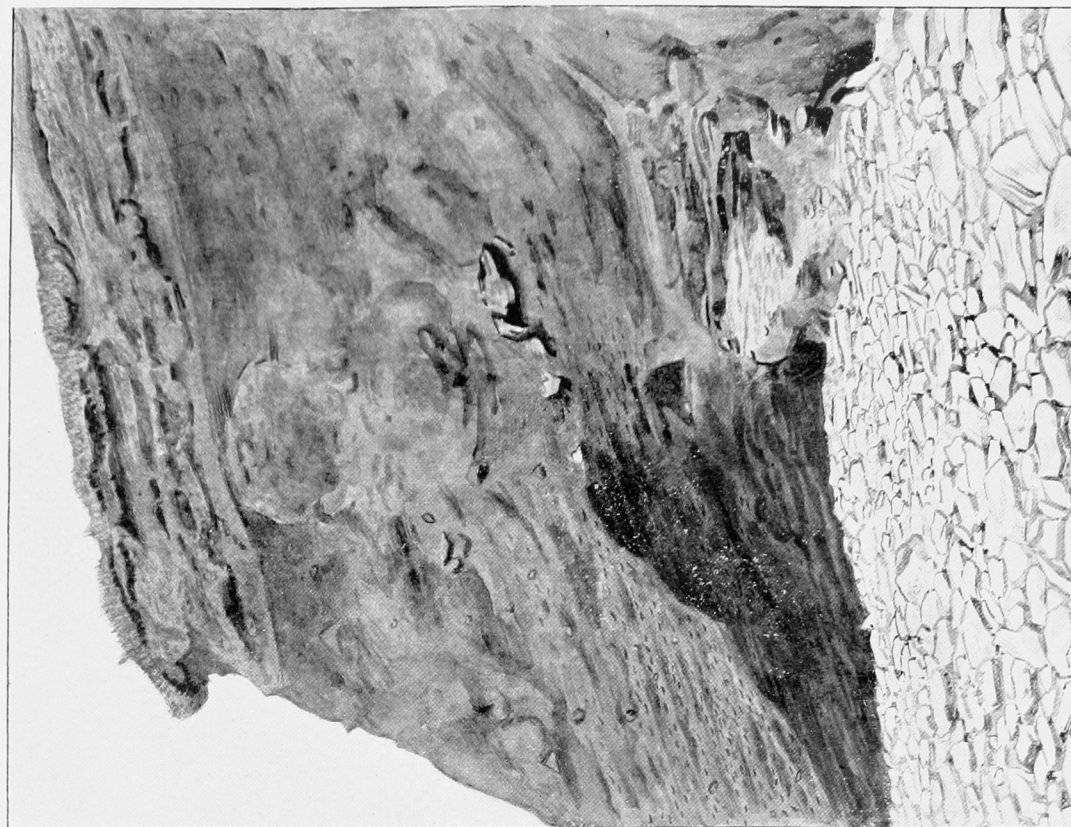


FIG. 5.—Section of Drift seen towards the southern end of Whitesand Bay.