On the Nature and Occurrence of the Plant-bearing Rocks at Pettycur, Fife. By W. T. GORDON, M.A., B.Sc., Falconer Fellow of Edinburgh University, and Advanced Student Exhibitioner of Emmanuel College, Cambridge.

(Read 17th March 1909.)

THE plant petrifactions obtained at various times from the rocks of Calciferous Sandstone age at Pettycur, on the north shore of the Firth of Forth, have proved exceedingly interesting to the palæobotanist, but hitherto very little attention has been given to the manner of their occurrence from a geological standpoint. When carrying out a special study of plant remains from this locality I became interested in the nature and distribution of the rock-masses containing them. During a visit to the locality in company with Mr Robert Campbell, M.A., B.Sc., we were fortunate in discovering a large mass of the material in the cliff above the shore on the west side of Pettycur Bay; since then I have discovered detached pieces of petrified vegetable remains and also small blocks of calcareous material containing similar plants embedded in the rocks to the east of Pettycur Harbour.

The occurrence of fossil plants at Pettycur has been known since 1871. In that year Mr G. J. Grieve of Burntisland noticed that several blocks of limestone, lying loose on the shore, contained recognisable plant remains in a petrified state. The earliest reference to these plants with which I am acquainted was published in the Transactions of the Botanical Society of Edinburgh [1] on the 11th May 1871. It is there recorded that "Professor [J. H.] Balfour exhibited a specimen of a fossil lately discovered by Mr Grieve near Pettycur."

The next reference is in the Report of the British Association Meeting at Edinburgh,[2] also in the same year, recording a paper by Mr G. J. Grieve, "On the Position of Organic Remains near Burntisland," of which, however, no abstract is given. This paper does not appear to have been subsequently published elsewhere, but, in a general account of the meetings of the Geological Section of the British Association at Edinburgh some mention of it is made. I am indebted to Mr Hopkinson, the author of the digest in question, for bringing it to my notice. It is there [3] stated that "Mr Grieve's attention was first directed to the specimens by observing on the shore large masses of

[1] *Trans. Bot. Soc. Edin.*, vol. ix. p. 168, 1871.
[2] *Sectional Report, Brit. Ass. Edin.* (1871), No. 41, p. 98, 1872.
[3] *Proc. Geol. Ass.* (1871), vol. ii. pp. 309-320, 1872.

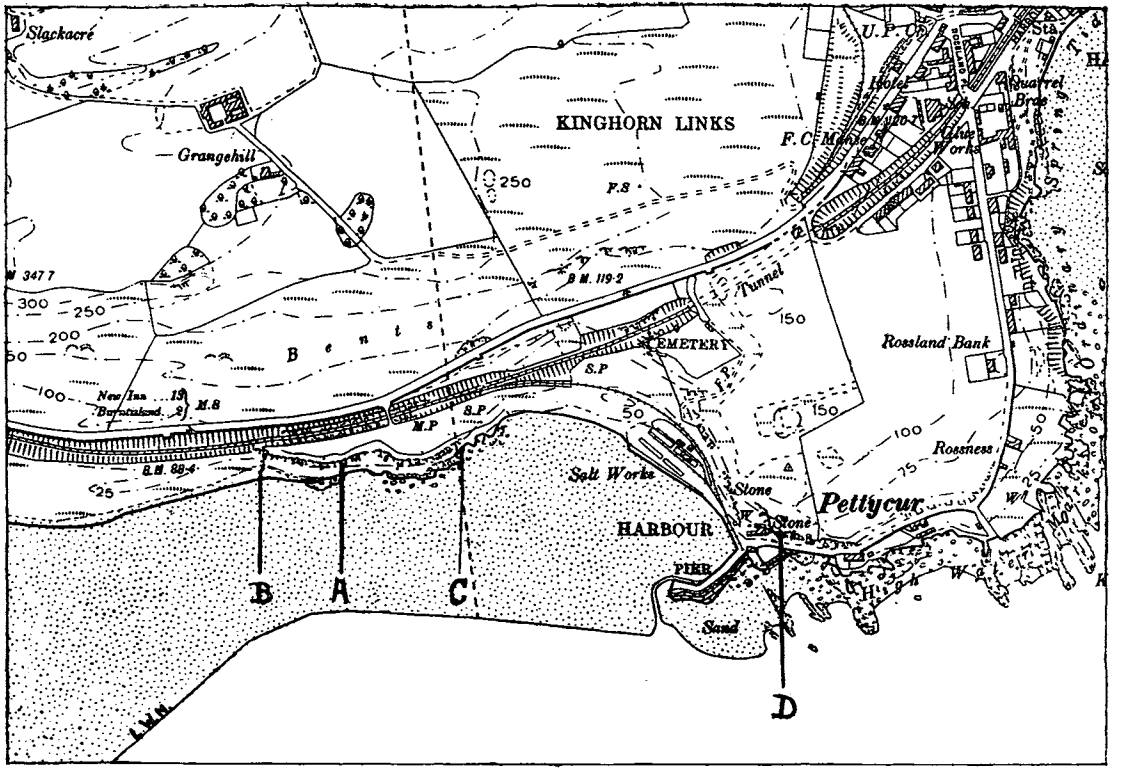
limestone which had been polished by drifting sand. These were found to be filled with coal-plants, and the limestone was traced to the cliff above, where it appeared to be intercalated in a mass of volcanic products. Mr Carruthers, in a paper by himself on the vegetable contents of these masses of limestone, said that he considered that the plant remains had been enclosed in a peaty condition from the surface bed on which they were growing when the volcanic ash was ejected, the lime abounding in the bed having subsequently calcified them, preserving all the details of their structure."

The plant remains discovered by Mr Grieve were sent to Professor W. C. Williamson for examination, and at this same meeting of the British Association, the latter read a paper in which he referred to Heterangium (Dictyoxylon) Grievii,[1] one of the Pettycur plants. This plant was subsequently more fully described and figured in the Philosophical Transactions of the Royal Society.[2] In none of his memoirs, however, does Professor Williamson give any account of the lithological character of these plant-bearing blocks.

There is another reference, in the Transactions of the Botanical Society of Edinburgh,[3] to fossil plants from Pettycur. On the 10th April 1873 Mr C. W. Peach exhibited thin sections of fossil plants "from the ash-beds" at Pettycur. These sections are now, I think, in the General Collection of Fossil Plants at the Natural History Museum, London.[4]

As quoted above, Mr Grieve stated that the blocks could be traced to the cliffs, "where they appear to be intercalated in a mass of volcanic products." Mr Peach records that his specimens were obtained from the trap-tuffs. Mr Hopkinson has informed me that he was present at a Geological Excursion to Burntisland after the British Association Meeting in 1871, and he was shown loose blocks on the shore but no pieces *in situ* in the cliff. For the next twenty-nine years no reference was made to these blocks, but in 1900 we get the last record in the Geological Survey Memoir on Central and West Fife, where it states that the blocks "may have fallen out of these basalts," which are seen exposed in the cliff. None of these references gives any very definite information as to the exact position of the masses in the cliff, and the indefiniteness of the early records accounts for the qualification of the statement as expressed in the Geological Survey Memoir. Since 1873 those who have visited Pettycur

[1] "On the Structure of the Dictyoxylons of the Coal Measures." *Sectional Report, Brit. Ass. Edin.* (1871), No. 41, p. 111, 1872.
[2] *Phil. Trans. Roy. Soc. London,* p. 277, 1873.
[3] *Trans. Bot. Soc. Edin.,* vol. ix. p. 505, 1873.
[4] They are numbered V. 8890 and V. 8893.



Map of Pettycur and District, showing positions from which the limestone is obtained. Scale 6 in. to 1 mile.

to obtain specimens of fossil plants have collected them from the loose material on the shore. At one time a large accumulation of this limestone lay on the foreshore, and it was thought that the masses might have been excavated from the railway tunnel to the west of Kinghorn Station. This is probably only partially correct, as in all likelihood some of the material came from the railway cutting about 400 yards west of the tunnel.

The rock is generally referred to as the "Burntisland Limestone," and sometimes even as the "Burntisland Coal," but both names are misleading. The blocks occur much nearer Kinghorn than Burntisland, indeed Pettycur, the exact locality, is a part of Kinghorn. That the rock is not always a limestone, the analyses published below clearly demonstrate. The limestone band known locally as the Burntisland Limestone belongs to a lower horizon and outcrops on the Golf Course at Dodhead Quarry.

On the other hand there are two calcareous rocks found at Pettycur, one a hard and fairly continuous band seen on the wall of the cliff just before entering the west end of the railway tunnel previously referred to, and the other occurring as detached blocks in the igneous tuffs and agglomerates. The hard band of limestone overlies thick tuff beds and lava flows, and is succeeded by other volcanic beds. These volcanic tuffs and even some of the lavas contain pieces of limestone, and one bed yields the blocks with petrified plants. The distribution of these blocks is very local, and their occurrence has never been recorded beyond the limits of a stretch of shore about half a mile in extent.

As the majority of the blocks contain 80 per cent. to 90 per cent. of calcium carbonate the name "limestone" may be retained, and I think it will save confusion if it is called the *Pettycur Limestone*. From the analyses given below it will be seen that this rock sometimes consists of almost pure silica, so that the word "limestone" is used as conveniently characterising the majority of the masses of this material, rather than as a strict geological designation.

As already mentioned, Mr Campbell and myself obtained a piece of the material *in situ* in the cliff. This cliff consists of a volcanic tuff containing large masses of igneous rocks imbedded in the finer ash. The limestone block was about 10 feet above the path which skirts the base of the cliff and some 60 yards from the western extremity of the cliff. The position is marked A on the map (text figure), and also in Pl. XXXI. Fig. 1. This particular specimen was partially removed by Dr Kidston, Mr Gwynne-Vaughan, and myself, and it contained the typical Pettycur plants. Pl. XXXI. Fig. 2 shows a near view of this block before its removal.

Since this specimen was discovered I have been able to obtain

Photo by A. G. Stenhouse, F.G.S.

FIG. 1.

Photo by A. G. Stenhouse, F.G.S.

FIG. 2.

other pieces from a position about half-a-mile east of this place. It is on the east side of the hill marked D in Pl. XXXI. Fig. 1, and the exact position is shown at D (text figure). The occurrence is at Pettycur House, where a tuff is exposed by the side of the road. Overlying the tuff are lenticular patches of black shale which are very much contorted. Above the shale there is a mass of basalt, but it is from the tuff below the shale that the plant petrifactions are obtained. This bed is referred to in the Survey Memoir on Central and West Fife as a basalt, and a Lepidodendron is noted as having been obtained from it. Dr Kidston has identified this Lepidodendron with his Lepidodendron Pettycurense.

The peculiarity of the specimens from this place is that they occur sometimes without any matrix, petioles of Diplolabis Römeri—a genus new to Britain, which I hope to describe shortly—and stems of Lepidodendron lying quite bare in the tuff. At the same time masses of calcareous material containing plants are also found, and as the plants are petrified in both cases, any explanation of their occurrence must account for the presence of the matrix in one case and its absence in the other.

I have obtained the following plants from this locality :—

Diplolabis Römeri, *Zygopteris Duplex*,
Heterangium Grievii, *Lepidodendron Brevifolium*,
Lepidodendron Pettycurense.

The loose material which I have almost entirely removed from the shore for examination occurred in quantity near both ends of the railway cutting (these positions are marked B and C in text figure), while the specimens at Pettycur Harbour (position D) are on the same horizon as the beds pierced by the tunnel. It is thus probable that the plant remains have been excavated both from the cutting and from the tunnel. The rock from which the limestone masses are derived lies above the lower basalts of King Alexander's Crag, and is a volcanic tuff of coarse texture containing large blocks of igneous rocks both rounded and angular. The presence of such large masses indicates close proximity to the centre of eruption. The tuff at Pettycur House does not contain so many blocks, and they are all much smaller.

The chemical nature of the plant-bearing blocks is exceedingly varied, and its composition as given by Stopes and Watson [1] cannot be taken as typical. I have made analyses of three specimens (they were parts of the blocks I had been examining for petrifactions), which in tabular form are as follows :—

[1] *Phil. Trans. Roy. Soc.*, B, vol. cc., p. 167, 1908 ; also Scott, "Studies in Fossil Botany," 2nd Edit., p. 11, 1908.

	Specimen 1	Specimen 2	Specimen 3
SiO_2	17·71 %	1·7 %	94·09 %
Fe_2O_3, Al_2O_3	·97 %	1·4 %	·56 %
$CaCO_3$	72·2 %	90·1 %	traces
$MgCO_2$	6·64 %	3·56 %	1·17 %
Carbon and water	Undetermined.	Undetermined.	Undetermined.

The analyses were made to determine the chief constituents, so that the water and carbon were not estimated.

With regard to the origin of these petrifactions, we find that Mr Carruthers' opinion as quoted above appears to imply that the plant tissues were not petrified until after their enclosure in the tuff. The Geological Survey Memoir conveys the same idea and also suggests that the whole mass was really a land surface over which a lava flowed. Thus there should be one or more large sheets of plant-bearing rock. None of the specimens collected is in the least lenticular but on the contrary they are irregularly cuboidal, and this applies also to the mass *in situ* in the cliff. In my opinion it is much more probable that the plant remains were petrified before being enclosed in the tuff. Pieces of petrified wood are quite common in the tuffs of Fifeshire, but these are in general very much charred and by no means well preserved; other specimens from North Berwick in similar rocks are in the same charred condition, and so also are the specimens from Laggan Bay, Arran. The presence of masses of brecciated limestone containing small angular pieces with plant petrifactions enclosed in them still further strengthens the idea that these fossils were petrified before enclosure in the tuff. In many cases the brecciation is well marked and the fragments have been recemented either by calcite or silica, the latter in the form of amethystine quartz (Pl. XXXII. Fig. 1).

Taking into consideration the varied chemical constitution of the blocks, it seems highly improbable that they can be classed as comparable with the coal-balls of the coal measures. The amount of silica present is very considerable in some cases, and in others constitutes the main mass of the rock, while the amount of magnesium carbonate does not bear any relation to that of calcium carbonate. The only explanation which can satisfy all the observations must, to my mind, be one involving the action of thermal springs containing dissolved mineral matter, and the whole condition of this part of the Carboniferous Series undoubtedly favoured the occurrence of such springs. To enumerate the observations, we find that the specimens are

(*a*) Composed of material varying from nearly 95 per cent. silica to 95 per cent. carbonates.

Trans. Geol. Soc. Edin., Vol. IX., pp. 358 *and* 360, *Plate XXXII.*

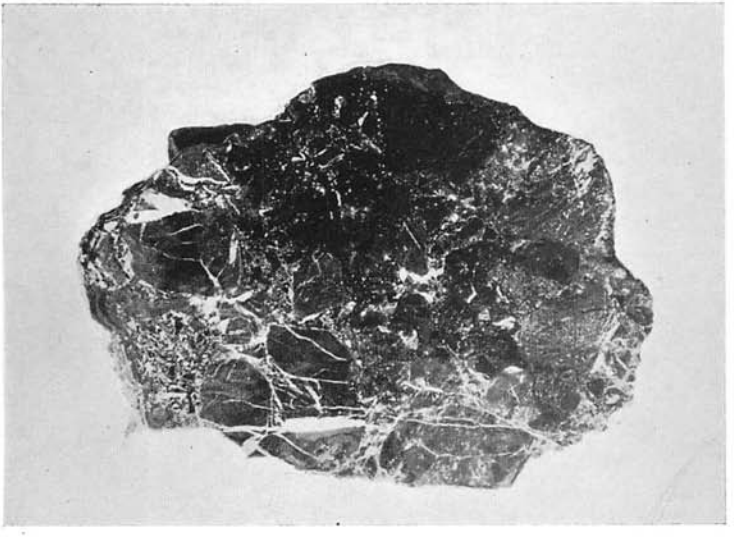


FIG. 1.

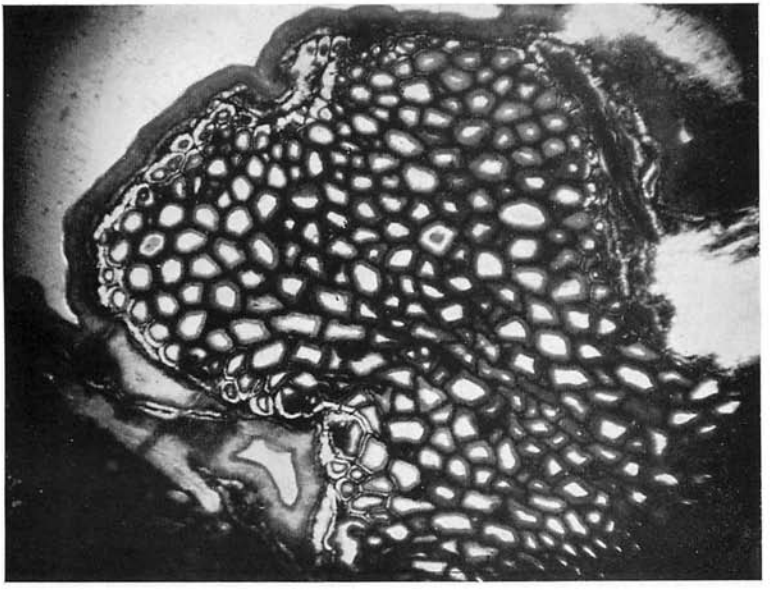


FIG. 2.

(β) Sometimes made up of portions containing no plant remains, suddenly alternating with portions mainly composed of petrified plant tissues.

(γ) Devoid of marine or freshwater organisms.

(δ) Often brecciated, and never occur as nodules but either as large cuboidal blocks, rough angular fragments, or isolated pieces of petrified plant débris.

The explanation I offer is that in the vicinity of the volcanic crater, of the presence of which there is abundant evidence, there were probably small pools fed by thermal waters from underlying volcanic sources. (The extraordinary volcanic activity is indeed the most striking feature of this region.) Into these pools plant débris would be from time to time drifted, and the water, highly charged with mineral matter in solution, would gradually water-log these plants. As the water percolated upwards through limestones it usually contained much lime in solution, but in some cases the material has been silica. The accumulation of the deposits from these springs would form small lenticles of calcarous or siliceous material, parts of which would contain plants while other parts would be composed of purely mineral matter. The next volcanic outburst would destroy these deposits, tearing them into pieces, and depositing the fragments among the other volcanic ejectamenta in tuffs and agglomerates. There would thus be both large masses and small pieces scattered here and there through the tuff. Where a few pieces were associated together they were sometimes recemented into a breccia by either silica or calcite.

At the same time many pieces of plant tissue lying near the area of deposition of the tufa would be petrified but not enclosed in any of the tufaceous matrix. Such pieces would naturally be included in the volcanic agglomerate without any matrix surrounding them, so that their occurrence does not in any way invalidate the theory of thermal springs.

It may be objected that the siliceous masses may have been originally calcareous and subsequently replaced by silica, but preparations show that the silica was obviously first laid down round the cell walls and then grew into the cell lumen. Indeed the silica has been laid down in two distinct forms—the first of the nature of chalcedony and the internal space with crystalline quartz. Had there been subsequent silicification the centres of replacement would have been scattered and would not have coincided with the original centres which started from the cell walls. In other words secondary replacement would have given a concentric spherical replacement irrespective of the position of the cellular structure, whereas in this case the centres of deposition are ranged along the cell walls. This is shown ex-

ceedingly well in Pl. XXXII. Fig. 2—a few cells from the stele of a petiole of Zygopteris Duplex. The thermal spring theory satisfactorily explains all the phenomena while none of the other theories so far given does so.

Since this paper was read an additional observation of great interest has been made. I have discovered a large mass of calc tufa with the normal coralloidal structure, enclosed in the volcanic tuff at Pettycur House. It is in this same tuff that the specimens of plants were found (text figure, D). This proves the presence of springs depositing calcareous material during Carboniferous times, and indicates the possibility of plants becoming petrified in the manner I have indicated above.

I am indebted to the Carnegie Trustees for a grant to defray the expenses of the illustrations in this paper.

EXPLANATION OF PLATES (PHOTOGRAPHS FROM UNTOUCHED NEGATIVES).

PLATE XXXI.

FIG. 1. General view, locality at Pettycur. Positions A and D indicate where blocks were got *in situ*.

FIG. 2. Nearer view of block at A.

PLATE XXXII.

FIG. 1. Mass of brecciated limestone, the fragments re-cemented partly by calcite and partly by silica. × $\frac{1}{3}$.

FIG. 2. Petiole trace of Zygopteris Duplex, showing double deposition of silica. × 30.