extremity to the bottom of the ventral valve, and by the other end to the extremity of the quadrilateral cardinal process of the dorsal valve. M. Duthiers states that one can thus establish the mechanism of the opening and occlusion of the shell; that when the animal wishes to open his shell, the power P is represented by the muscle (c), its point of application being at the extremity of the cardinal process of the ventral valve: the resistance R is the weight of this valve which has to be raised; the point of support is found in A ; we have, therefore, a lever of the first kind. If it were required to close the shell, the same analysis would be applied to the lateral muscles, by reversing, however, the power and the resistance, the point of support being always in the articulation A .

10. *T. Mediterraneum*, after Duthiers, twice the size of life, with its valves open.
11. *T. affine*, Bosquet. Interior of the dorsal valve enlarged, from the Upper Cretaceous formation of Limbourg.

III. ON SOME SPECIAL INDICATIONS OF VOLCANIC ACTION IN THE CARBONIFEROUS PERIOD AT BURNTISLAND, FIRTH OF FORTH.

By ARCHIBALD GEIKIE, F.R.S.E., F.G.S.

ON the northern margin of the Firth of Forth, opposite Edinburgh, a line of steep craggy slope sweeps round from behind the village of Burntisland to the shore about half a mile eastward. The highest and most precipitous portion rises to a height of 631 feet; and the space between its base and the shore is so short that when seen from a short distance, the hill seems to shoot almost directly out of the sea. Hence these heights form conspicuous landmarks all over the Lothians. Their scarred fronts and verdurous slopes bear all the characteristic features of the minor hills in the lowlands of Scotland—a union of brown mouldering crag, often steep and bold, with soft green hollows, and with shelving sides that are either cumbered with ruins from the cliff overhead, or dotted with bushes of golden gorse. Such scenery is to a geological eye eminently ‘trappean;’ it at once suggests beds of greenstone, basalt, and ash, with the other concomitants of ancient volcanic eruptions. And truly amid all the rich development of volcanic phenomena in these Lowlands, the rocks of the Burntisland shore deserve to stand up as conspicuous landmarks. They have been laid bare by rains and frosts and the waves of the Firth along some miles of the coast-line, where they can be studied, bed after bed, in the minutest detail. I know of no such section in any other part of the kingdom.

Just beyond the eastern outskirts of Burntisland the high grounds curve round to the shore, which they reach in a line of cliff known as the King’s Craig,—one that has a melancholy

interest in Scottish history, for it was over its mist-covered edge that Alexander III. lost his life. This cliff consists of various greenstones, basalts, ashes, shales, sandstones, and thin coal-seams; the whole, as proved by fossil contents and geological position, belonging to a low part of the carboniferous system. Viewed from the westward or from the sea, the stratification of these crags can be distinctly followed with the eye, since the hard lava-beds vary in colour and in their mode of weathering, while the softer sedimentary strata that lie between them are marked in the distance by grassy slopes. Brown and greenish ledges of rock, rising in parallel bars to a height of 300 feet above the beach, form the upper part of the crag, the lower portions sinking beneath blown sand, coarse bent-grass, and gorse. That single crag, therefore, furnishes us with the record of a long series of submarine volcanic eruptions, each separated from those that preceded it by a longer or shorter interval, during which sandy or muddy sediment was deposited over the hardening lava or ash. One little episode in this history is worthy of notice, partly because interesting in itself, and partly because, as a sample of geological evidence, it tells its own story with singular clearness. In descending order the beds which form the upper part of the west end of the King's Craig are as follow:—

12. BASALT, *about 15 feet thick.*

11. Green shales, *with Cyprid cases* and fragments of Plants; 4 feet.*
 10. Blue shales, *with thin limestone-seams made up of Cyprid cases* and fragments of Plants; 1½ foot.*
 9. Green ashy shale and thin ash-seams, *with similar fossils; about 14 inches.*
 8. Green ashy sandstone, *with similar fossils; 6 inches.*
 7. Green ashy shale and ash, *the same fossils very abundant in some layers; about 3½ feet.*
 6. Dark greenish and black fissile shale, *with Plants, &c.; about 6 inches, passing down into*
 5. Green crumbling fireclay; *1 foot.*
 4. Coal; *5 or 6 inches.*
 3. Brown shaly fireclay, *with rootlets; about 5 inches.*
 2. Black carbonaceous shale; *an irregular layer.*
1. GREENSTONE; *about 15 feet.*

The greenstone marked No. 1 in this table is one of the most remarkable beds in the cliff. Its light-green colour makes it visible a long way off, and chiefly aids in giving the cliff the conspicuous stratified appearance it has when seen from a

* Probably the co-called *Cypris* (*Leperditia*?) *Scotoburdigalensis*.

distance. Along the upper surface of the bed the vesicular and scoriaceous character of a lava-flow is well shewn, while the texture throughout is exceedingly irregular, varying from a loose slag to a firm compact lava. The basalt (12) must at one time have been a rough, porous slaggy lava. Even now the disappearance of the mineral matter which subsequently filled up the cavities has gone far to restore the original aspect of the mass. No one who looks at these two beds can doubt that they must have been poured out, probably over the bottom of a shallow sheet of water, as streams of molten rock. Between the eruption, however, of the greenstone and that of the basalt, it is evident that a considerable interval must have elapsed, in order to admit of the gradual deposition of the ten intervening groups of strata, which have a united thickness of from ten to fifteen feet. This interval was chiefly passed in the transport and deposition of fine muddy sediment over the greenstone. Yet it was marked too by the growth of a mass of peaty vegetation (now the coal-seam, No. 4) which must have flourished on the spot, for its rootlets can be seen branching out into the clay below. It would appear either that the water had been so shallow that the fifteen feet of greenstone nearly sufficed to reach its surface, or that some upheaving movement, connected with the volcanic phenomena of the district, had at this place raised the bottom to the level of the upper surface of the water. In either case the water was almost dispossessed, for the thick peaty accumulation which supplanted it, and which is now represented by the coal-layer, in all likelihood had at least its larger plants waving green in the air. Nevertheless a slow subsidence was the predominant movement during these ages. Hence after a time the peat-bed, carried beneath the water, was covered with new muddy deposits mingled with small crustacean valves and drifted fragments of plants. It is in the clay lying immediately over the coal that the incident occurs which is the occasion of this paper.

In the summer of 1862, when making a detailed investigation of the Burntisland district for the Geological Survey, I found the following section near the top of the west end of the King's Craig. The lowest bed (3) is the same brown shaly fireclay marked 3 in the table; No. 4 is the coal-seam; No. 5 the green crumbling fireclay by which the coal is overlain. It will be noticed

Section of King's Craig, showing the position of the Volcanic Stone in the ancient mud-bed.

that in the upper fireclay a large angular stone is stuck in a vertical portion. With this single exception there were no stones of any kind observed in the bed, which continued throughout a fine-grained fireclay. The intruded block was of a pale felspathic greenstone, different from any of the beds of the cliff, and weighed perhaps six or eight pounds. It rested on the surface of the coal-seam, or at least was separated from it by an extremely thin layer of the clay. The part of the coal-seam immediately below it was considerably compressed, but did not appear to be otherwise altered in texture. Moreover the laminae of the fire-clay, for perhaps a couple of inches from the bottom, were bent sharply downward along the sides of the stone, in the manner shewn in the figure, while a little higher in the bed, instead of being turned down, they rose slightly upward, and seemed to be heaped up around and over the stone. The layers above the stone shewed no trace of disturbance. Now it is plain that this greenstone block is something abnormal and extraneous in the fireclay, and not a part of the ordinary sediment of that deposit. It is clear also that the block must have been introduced into the clay when the latter was soft and yielding, and even before the underlying coal-seam had hardened into stone. Indeed the time of its introduction is exactly fixed by the evidence from the stratification of the fireclay. The block must have come into its present position after the deposition of that portion of the fireclay which it squeezes down, and before the accumulation of the part which is heaped up over it; in other words, just when the bed of fireclay was about half-formed. It is further evident that as no other stones are visible, and no change takes place in the nature of the sediment composing the fireclay bed, the introduction of this greenstone block cannot have been brought about by the agency of currents of water. On the contrary, from the vertical position of the stone, the compression of the coal-seam, and the sharp depression of the layers of fireclay, we cannot but infer that the stone must have dropt upon the muddy bottom, and from some considerable height, to enable it to squeeze its way so markedly down through the clay upon the underlying coal. Had such a solitary block occurred in the heart of a deposit like the Carboniferous Limestone of Ireland, or the Chalk of Surrey,* its introduction might have

* See Jukes' *Manual of Geology*, 2nd edit. p. 146, for an account of blocks of granite, schist, and other rocks, in the Carboniferous Limestone of Dublin; also a paper by R. Godwin-Austen, F.R.S., F.G.S., 'On a Granite Boulder found in the White Chalk near Croydon,' in *Journ. Geol. Soc.*, vol. xiv. p. 252.

been attributed to its having dropt in mid-ocean either from the roots of some floating tree, or from a raft of earth-laden ice. But in the present instance, the water was in all likelihood very shallow, and there is therefore not much probability that either drifting wood or ice had anything to do with the transport of the greenstone boulder. There is only one supposition which will satisfactorily account for all the phenomena, viz., that the stone is a true volcanic bomb, which was ejected from some neighbouring crater, and fell with force through the shallow marshy water, burying itself deep in the half-formed fireclay bed. Nor is this the only evidence of the continued activity of the volcanic forces in the Burntisland district during the interval between the outpouring of the greenstone (No. 1), and the basalt (No. 12). Many of the intervening strata are charged with fine green ash, shewing that showers of ash continued to be thrown out intermittently during the whole of the interval between the emission of the two lava-streams. And yet during that time, notwithstanding the igneous agencies—indeed, perhaps as a consequence of their activity—the conditions for the development of life seem to have been eminently favourable. Plant-remains are abundant, and the cases of the little Entomostracous Crustaceans occur in such multitudes as actually to form of themselves layers of stone.

When I saw the stone in 1862 it was ready to fall out of the fireclay matrix; but to preserve it as far as might be for the inspection of geologists, my colleague, Dr. Young, and myself built it round with loose stones. Perhaps it is still intact, but I have not seen it since, and the frosts of every winter help to alter the face of the cliff.

The whole of the district from which this illustration is taken affords admirable studies in trappean geology. The student will learn more of the details of palæozoic volcanic phenomena from an attentive examination of that coast-line in the course of a single day, than he will be likely to gain from books alone during a week of hard reading. I am tempted to quote one or two additional sections from my note-book, but as these will shortly appear in greater detail in the 'Memoirs of the Geological Survey' I refrain. The illustration given in this short paper is a fair sample of the kind of evidence which the Fife Coast affords of the abundant though local display of volcanic action during the earlier portions of the long Carboniferous period.