*January* 21, 1875.

The Right Hon. LYON PLAYFAIR, C.B., LL.D., Vice-President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On the Origin and Mechanism of Production of the Prismatic (or Columnar) Structure of Basalt." By ROBERT MALLET, F.R.S. Received December 12, 1874.

(Abstract.)

The author having briefly traced the history of geological opinion on this subject, from before the period at which the controversy at which the igneous or aqueous origin of basalt might be viewed as settled, and having stated the views of some of the more prominent British authors on this subject of recent date, points out that, up to the present, no clear and definite theoretic views have been enunciated to account for prismatic structure in basalt, and that it is impossible to gather, with any distinctness, from systematic writers, whether prismatic structure be due to contraction by cooling alone, or whether the structure is due to preexisting concretionary or crystalline arrangement of the integral particles of the mass, or to this coacting with enormous external pressures, the origin of which is left perfectly vague, or to some play of successive and joint actions of all these various forces.

Prof. James Thomson, in a paper read some years ago, and since repeated at the late Belfast Meeting of the British Association, has proposed views, in some respects new, tracing prismatic structure to contraction by cooling only, and has expressed entire doubt as to the part supposed to be played by concretionary spheroids pressed together. Prof. Thomson's views, however, are still far from complete, and the mode assigned by him to the production of cup-shaped cross joints in the prisms fails to account for the phenomena.

The aim of the author is to point out in this paper that all the salient phenomena of the prismatic and jointed structure of basalt, as observable in nature, can be accounted for upon the admitted laws of cooling, and contraction thereby, of melted rock possessing the known properties of basalt, the essential conditions being a very general homogeneity in the mass cooling, and that the cooling shall take place slowly, principally from one or more of its surfaces.

Thus, taking the simple case of a tabular mass of molten basalt, whose top surface is level, the depth being great and the other two dimensions

indefinitely greater than that, and assuming the material at one temperature initially, homogeneous and isotropic, and that cooling takes place from the top surface only, he, on these data, proceeds to consider the phenomena that will successively result by contraction in cooling.

While the mass remains at its upper part still plastic by heat, contraction will be met by internal movements and subsidence of the top surface, and no cracking or splitting can take place until the material there has become rigid enough to break under tensile strain. He points out that this degree of rigidity, or "splitting temperature," is not reached until the top surface has fallen to between 900° and 600° Fahr.

At this temperature the cooling surface begins to separate, by fracture penetrating perpendicularly to it, into smaller surfaces. These must be similar and equal in area, and such as that their edges in contact can make up a continuous superficies. To relieve the orthogonal strains in the cooling surface, and to meet the above conditions, only three geometric figures for the separating surfaces are possible—namely, the equilateral triangle, the square, and the regular hexagon.

The author then inquires why the last of these is normally the form found in nature. He traces this to the law of least action which governs the play of all natural forces whose final result is produced by the least possible expenditure of force. He shows that, in a contracting surface splitting up into equal areas, the expenditure of work will, for the equilateral triangle, the square, and the regular hexagon, be approximately as the numbers 1·000, 0·680, and 0·519. This economy of force decides the hexagon as the form found in nature. The diameter of the hexagon, which is the upper surface of the inceptive hexagonal prism, is shown to be fixed by the relation that subsists between the coefficient of contraction of the material and that of its extension at rupture by a tensile force at the splitting temperature. This decides the diameters of the separate prisms. The splitting by contraction proceeds into the mass always in a direction perpendicular to the cooling surface; and at any instant the splitting is limited in its progress by the isothermal *couche* which is at the splitting temperature within the mass; for within that *couche* the mass is still plastic. In the case assumed, the prisms formed are straight and vertical. When the splitting has proceeded to some distance within the mass, the further cooling of each prism takes place, not only from the top, but from the sides; and the more important conditions influencing the latter in nature are pointed out.

Any one prism is coldest at its extremity, and its temperature increases along its length to the other end, where the splitting is still proceeding. The prism is hotter also, for any transverse section, as we approach its axis than about the exterior; differential strains in the longitudinal direction thus take place, by cooling and contraction, between the successive imaginary *couches*, taken from the exterior to the axis of the prism,

which tend to cause the outer portions of the prisms to tear asunder at intervals in length dependent, like the diameter of the prisms themselves, upon the relation subsisting between the coefficient of contraction and of extensibility at rupture of the material.

The prism contracts not only in its length, but in its diameter; transverse fracture at its surface, when it occurs, is therefore due to the resultant of two orthogonal forces, the one parallel to the axis of the prism, as already referred to, and the other in a plane transverse to the axis. These two forces are proportionate, the first to the length of the prism from a preceding joint or from its extremity, the second approximately to the semidiameter of the hexagon or mean radius of the *couche*; and the resultant of these two, at any point taken round the prism, is oblique to the axis and tending towards it in direction. As fracture in a homogeneous solid always takes place transverse to the line of strain, so the fracture producing a transverse joint takes place oblique to the sides of the prism—the obliquity becoming less as the fracture advances towards the axis of the prism, so that when complete it is cup-shaped, the convex surface of the fracture always pointing in the same direction as that in which the splitting of the prism itself is proceeding.

This solution, which is believed to be the first ever presented which, resting upon admitted laws, completely accounts for the production of the very remarkable cup-shaped joints, is verified and illustrated by several diagrams, showing the mode of production of these joints and the modifications of their curvature produced by varied conditions in the cooling.

It is further shown that the partial or complete detachment of certain fragments, frequently observed to be partially or wholly detached from the cusps of the concave side of these joints at and near the solid angles of the hexagon, is a consequence necessarily resulting from the mode of production of the joints themselves. The author then points out that, in the case of very slender prisms, other (and mechanical) conditions besides those of differential cooling enter into the production of the cross joints, which are at more considerable and irregular distances apart, and in planes of fracture often nearly transverse to the axis of the prism.

He also discusses the modifications produced in the prisms themselves, and in their cross joints, by heterogeneity in the mass of basalt itself—as, for example, by a more or less previously developed cleavage in the basalt in planes transverse to the axis of the prism, or by the presence of heterogeneous substances imbedded in the mass. To these latter, and to differences in conductivity or in the cooling energy at different points of the cooling surface, are chiefly to be ascribed the divergences from the normal hexagonal form of the prisms as occasionally observed, the author remarking that where such divergences occur they disappear, and the

normal hexagonal form is returned to in such a manner as to require only the minimum expenditure of work.

The conditions producing greater or less interspaces between the prisms, which may vary from point to point of the same mass, are pointed out, as also those which cause the spaces between successive joints in adjacent prisms to coincide in successive planes, transverse to their axes or the contrary.

The author then proceeds to discuss the various positions in space, and relatively to each other, which the axes of the prisms must assume, dependent on the general law, as already stated, that the axes of the prisms, however produced, are always normal to successive isothermal *couches* or planes at the splitting temperature, taken in succession within the mass.

If the mass be tabular, as already assumed, and cooling take place only from the top surface, the prisms will be straight and vertical, extending from top to bottom nearly of the tabular mass, and being separated from the bottom on which it rests by a more or less thick layer of irregular angular fragments, or of badly conducting material, tufa, scoriæ, &c., the convex surfaces of the cross joints all pointing downwards. If the mass cool both from the bottom and the top, the prisms, vertical and straight, will split upwards and downwards, and meet in an irregular intermediate stratum of angular fragments, the convex surfaces of the joints of the lower prisms pointing upwards, and the respective lengths of the upper and lower ranges depending on their relative rates of cooling. If the tabular mass cool also from one or more of its sides, as by an abutting wall of rock, prisms will be produced with their axes perpendicular to that wall, and will be separated from the vertical ranges of prisms by an inclined stratum of angular fragments. Also, if the basalt fill a crevasse producing a dyke, the prisms formed by cooling will be generally transverse to the plane of its walls, and meet somewhere towards the centre in a stratum of more or less irregular fragments, due in all cases to the irregular contractions at the extremities of the prisms breaking up their mass there into wholly irregular forms. If the upper and cooling surface have a curved convex contour, the prisms will be taper and convergent from the surface of the mass; and, on the contrary, if the cooling surface have a concave contour, or rest upon a concave bottom, the prisms will be divergent from the interior of the mass, the natural law of economy of work limiting the length or amount of taper in either case and the length of the prisms, and at a certain length of prism a new range of larger diameter partially or wholly then commencing. The convergence or divergence are simple consequences of the general law, that the splitting takes place always normal to the isothermal *couches* which are at the splitting temperature.

The author then proceeds to develop and illustrate by diagrams some of the varied and curious combinations which are observable in nature,

and due to the more or less combined play of these conditions. He then proceeds to develop, as a consequence of the general law, the production of curved prisms, or those with apparently bent axes, which are observed in almost all basaltic countries. If the cooling mass of basalt be in one of its vertical sections of such a form that successive isothermal *couches*, taken in descending order, are not parallel to the original cooling surface, as they are in all cases of straight and parallel prisms, but divergent gradually from the cooling surface and from each other, then the lines of splitting of the prisms, always normal to these *couches*, must be curved in one direction. This will be true whether the isothermal *couches* be plane surfaces divergent from a thinner to a thicker part of the mass, or whether they be curved surfaces arising from the mass reposing on a curved bottom and diverging in like manner. This explanation of the production of curved prisms, without the necessary intervention of external mechanical forces having bent into curves prisms originally formed straight, is, the author believes, here for the first time presented. He shows that great difficulties exist to the supposition that curved prisms are ever the result of the bending of prisms originally straight by extraneous mechanical effort. The author having thus shown that all the salient phenomena presented in nature by the forms, jointings, positions of the prisms, &c. of columnar basalt are accounted for as consequences of contraction in cooling, submits that this solution given by him must be the true one. He, however, proceeds to examine at some length the different views of those who have imagined that prismatic and jointed basalt has resulted from the squeezing together, by some wholly imaginary external force, of spheroidal masses more or less resembling those known as "onion stones," or so-called concretionary spheroids, such as those imagined by Mr. Gregory Watt. The author submits all points of the subject to a searching examination, and points out that, upon the only probable suppositions that can be made as to the prearrangement of such spheroids, no extraneous force of compression could produce prisms at all, but must squeeze the spheroids instead into rhombic dodecahedrons.

## II. "On the Anatomy of the Connective Tissues." By G. Thin, M.D. Communicated by Prof. Huxley, Sec. R.S. Received December 23, 1874.

(Abstract.)

Transparent animal tissues, when sealed up fresh in aqueous humour or blood-serum, by running Brunswick black round the edge of the cover-glass, undergo a series of slow changes, by which, generally within a period of 2 to 5 days, anatomical elements mostly otherwise invisible become