the structure of the Dinosaurian skeleton. In a subsequent paper we propose to give a notice of some of the more important points which M. Dollo's researches have helped to elucidate. In the meantime we cannot but recall with feelings of the warmest gratitude and admiration those earlier palæontological labourers, who, with exceedingly imperfect materials at their command, succeeded in demonstrating the existence of this great Sub-Class of Animals, which Prof. Huxley has clearly shown occupy a position between Birds and Reptiles, and help us most materially to complete the grand chain by which the Animal Kingdom is linked together.

EXPLANATION OF PLATE I.

- FIG. 1. *Iguanodon Mantelli*, Meyer; reproduction on a reduced scale of M. Dollo's beautiful plate, already referred to (Bull. Mus. Roy. d'Hist. Nat. de Belg. 1884, t. iii. pl. vii.) *i*, the ischium: *il*, the ilium: *p*, the pubis.
 „ 2. Skull of *I. Mantelli* (seen in profile) $\frac{1}{2}$ th nat. size. *p*, the præsymphyseal bone (see observations on this remarkable bone by Mr. J. W. Hulke, F.R.S. (Pres. G. Soc. 1884), in his Anniversary Address, Quart. Journ. Geol. Soc. 1884, vol. xl. pp. 47-51.)

III.—THE CAUSE OF SLATY CLEAVAGE: COMPRESSION *v.* SHEARING.

By ALFRED HARKER, B.A., F.G.S.,

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THE received theory of Slaty Cleavage has generally been held to afford a complete explanation of the observed phenomena. The proximate cause of the structure was shown by Dr. Sorby to be a superinduced arrangement of the flat and long-shaped fragments constituting the rock, in virtue of which they tend to lie in, or nearly in, the planes of cleavage; this arrangement being assisted, as Mr. D. Sharpe advocated, by a flattening of those particles themselves. These changes were ascribed to great lateral compression of the rock in the direction perpendicular to the cleavage-planes, together with some expansion along those planes in the line of their dip; and a great mass of evidence was brought forward to support this theory.

In papers recently published in the GEOLOGICAL MAGAZINE (1884, pp. 268, 396, etc.) the Rev. O. Fisher rejects this compression and would substitute *shearing*, *i.e.* a creeping motion such as would distort a cube into an oblique parallelepiped without change of volume (see Fig. 3, p. 399). He indeed admits a certain compression in addition, but it is so slight that for simplicity we may disregard it.

Mr. Fisher contends that the kind of distortion presented by the fossils of cleaved rocks is such as would be produced by a shearing motion, and he seems to imply that these appearances could not be brought about by compression and expansion. But it is easy to see that a shear of given amount is precisely equivalent, so far as distortion is concerned, to a compression of proper amount in a certain direction with a corresponding expansion in a direction perpendicular to it. For the distorting effect of any strain or system of strains can be fully represented by the 'ellipsoid of distortion,' *i.e.* the ellipsoid into which a sphere would be distorted by the

strains in question. The section of this ellipsoid by any plane will be an ellipse whose ellipticity will indicate the degree of distortion of an object situated in that plane. Further, the principal diametral plane of the ellipsoid will determine the direction of cleavage. Now the effect of a shear is to distort a sphere of radius b into an ellipsoid of semi-axes a, b, c , and it is evident that the same distortion might equally be brought about by an expansion which would increase the radius of the sphere in one direction from b to a , and a compression at right angles to it reducing the radius in another direction from b to c .

Figure to illustrate the cause of Slaty Cleavage.

It remains to inquire whether shearing can really account for the appearances observed. There being no change of volume, we should have, in the ellipsoid produced by shearing, $ac = b^2$, or in other words the three semi-axes would be in geometrical proportion: whereas in the actual ellipsoid of distortion, as calculated from observations of fossils, a and b are not very unequal, and often sensibly equal, while c is much less than either, thus giving an ellipsoid very like a flat oblate spheroid. This points not to a shear, but to a great compression and a slight expansion, giving rise to a total condensation of volume in the ratio $ac : b^2$.

Mr. Fisher certainly strikes at the weak point of the received theory, when he draws attention to the great *amount* of voluminal condensation which it requires. Thus, if slate of specific gravity 2.64 has been reduced to half its original volume by the process which impressed the cleavage-structure upon it, its former specific gravity must have been only 1.32! Still it seems impossible to escape from the fact of this compression. We have to face, for example, the evidence of the crumpling and folding of resisting gritty bands interbedded with more yielding rocks which show cleavage, as in the now historic cliff-section at Ilfracombe figured by Sorby.

On the other hand, we may notice the great *amount* of shearing demanded by Mr. Fisher's hypothesis in order to produce the degree of distortion commonly observed in the fossils of cleaved rocks. The proper measure of a shear is the relative lateral displacement of two surfaces of shearing divided by the distance between them, or in Mr. Fisher's notation, $\cot a$. It can be readily proved that—

$$\cot a = \frac{a-c}{V ac}.$$

If then $a = 2c$, we have $\cot a = .7071$ and $a = 54^\circ 44'$; or if $a = 6c$, $\cot a = 2.0412$ and $a = 26^\circ 6'$!

Mr. Fisher has applied his theory to explain the disposition of

the cleavage-planes over an extended region, but that was with the supposition, since abandoned, that the cleavage-planes were the actual surfaces of shearing: the amended theory gives much less satisfactory results. Thus, let ϕ be the angle between the cleavage and shearing planes at any given place; then it is easy to prove that

$$\tan \phi = \sqrt{\frac{c}{a}}.$$

This shows that where the shearing and consequent distortion are slight, the angle between the directions of shearing and cleavage will be nearly 45° , and although it is less for a greater amount of shearing, still, even when the shear is so great as to produce a distortion in which $a = 6c$, the angle ϕ is as much as $22^\circ.12'$. If we imagine a tract of rocks upheaved to a considerable height and partially settling down with a shearing motion, and if we believe with Mr. Fisher that such shearing is the cause of cleavage in the rocks, it appears from the foregoing formulæ that the result should be similar to that depicted diagrammatically in the figure. At the points *A, C, E*, there is no shearing and therefore no cleavage; in the neighbourhood of these points there are broad bands of rock with no sensible cleavage-structure. Passing beyond these bands, the planes of ill-developed cleavage have a hade of about 45° : the cleavage becomes gradually more marked and its hade slightly steeper towards the points *B, D*, where the shearing is greatest; and near these points the distortion of fossils is greatest and the angle the cleavage-planes make with the vertical is least.

Now I submit that all this is very different from anything recorded as occurring in nature. I have supposed the planes of shearing vertical; if they are inclined outwards as in the figure on p. 275, the discrepancy between theory and observation is still more marked, for the hade of the cleavage-planes from the vertical is then greater.

IV.—WATER SUPPLY FROM THE BAGSHOT AND OTHER STRATA. (No. 2.)

By the Rev. A. IRVING, B.Sc., B.A., F.G.S.,
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DURING the year 1883 I gave some account, in the pages of this MAGAZINE,¹ of the peculiarities of the water drawn from the Bagshot strata of the London Basin. The most important conclusion drawn in that paper from the evidence adduced was the great difference in the quality of the water according as it is obtained either (*a*) from the bright ferruginous sands of the Upper Bagshots, or (*b*) from the Middle or Lower Bagshot strata, which are all contaminated (more or less) by vegetable matter in various stages of decomposition. So far as the evidence in my possession a year ago seemed to carry me, I felt warranted in making the following generalization: "The whole of the well-water of the district which common human experience pronounces wholesome is obtained from the Upper ferruginous sands." This has been confirmed by additional facts more recently learnt.

¹ *Vide* GEOL. MAG. 1883, Dec. II. Vol. X. pp. 404-413.