26. *An EXPERIMENT in MOUNTAIN-BUILDING.* By the Right Hon. the LORD AVEBURY, P.C., D.C.L., LL.D., F.R.S., F.G.S. (Read May 27th, 1903.)

MANY years ago Sir James Hall illustrated the formation of folded mountains by placing layers of cloth under a weight, and then compressing two of the sides so that the cloth was thrown into folds. Since then, other and more complete experiments of the same kind have been made by Favre, Cadell, Daubrée, Willis, and Ruskin.

In these experiments the compression was from two sides. If, however, folded mountains are caused by compression due to the contraction of the earth, the compression must take place in two directions at right angles one to the other.

With the view of illustrating this I consulted Mr. Horace Darwin, and he constructed for me an apparatus consisting of four square beams of wood, resting on a floor, which by means of screws could be moved nearer to, or farther from, each other. The beams left between them a space 2 feet across and 9 inches in depth.

In the square central space I placed some pieces of carpet-baize and layers of sand, each about $1\frac{1}{2}$ inches deep. About an inch above the upper layer of sand I placed a piece of plate-glass and some weights. The machine was then set in motion, causing the beams of wood to approach one another. The sand rose in the centre, until it reached the glass, when it was flattened out.

On removing the upper layer of sand, the top-piece of cloth was as shown in fig. 1 (p. 350), which is a photographic reproduction of a cast in plaster-of-Paris. The upper surface is gently undulating in the centre, with some steep folds near the edges and one slight ridge crossing the plateau at right angles to one of the folds.

On removing the underlying layers of sand, the next layer of cloth was as shown in fig. 2 (p. 350). There are two main lines of elevation; one running from each corner, and consequently crossing at right angles. The whole surface forms a series of winding and curving ridges with intervening valleys, and gradually rises to a culminating dome a little on one side of the centre, where the two main ridges intersect. I was rather surprised at the marked difference between this and the upper layer.

Underneath this second piece of baize was another layer of sand, on the removal of which the third layer of baize was found to be thrown into folds as in fig. 3 (p. 351). This again differed greatly from, though it evidently followed the same general law as, the preceding. The ridges are narrower and more pronounced, the valleys more precipitous. There is also a marked tendency for each ridge to present a central longitudinal division.

Fig. 4 (p. 351) represents a fourth layer of baize, which was separated from the third by about $1\frac{1}{2}$ inches of sand, and from the bottom of the apparatus by a similar layer. This fourth layer of baize differs from the third in somewhat the same manner as the third differs

from the second. The ridges are narrower, shorter, more precipitous, and more broken up. This characteristic is not, however, very well brought out in the photograph. The intervening spaces form wide, flat valleys.

In another experiment sand and layers of baize were arranged as before, but the weight was placed on one side, in consequence of which the material was more easily pressed up.

In this case the ridges followed the edges, though not closely, leaving a central hollow. Here, also, in the upper layer of cloth (fig. 5, p. 352) the slopes were more gentle, the eminences more rounded, the hollows less deep. In the second layer of cloth (fig. 6, p. 352) the country is more rugged, the elevations higher, the hollows deeper. Here too several of the ridges have a tendency to become double, with in some cases a smaller ridge commencing in the depression. The elevations and hollows only follow roughly those of the upper layer. There are two main ranges, with a broad intermediate valley. One of the main ridges has secondary transverse folds.

The third layer (fig. 7, p. 353) again has only a general resemblance to the second. The folds are more numerous, narrower, and more precipitous.

The fourth or lowest layer (fig. 8, p. 353) presents a central plain, bounded by two high, one moderate, and one low, series of hills.

The models seem also to show that some hollows, which might on the earth's surface have been regarded as evidence of sinking, are in reality only relative, and due not to depression, but to the elevation of surrounding ridges.

I am proposing to make further experiments with various modifications, which at some future opportunity I hope to be permitted to lay before the Geological Society.

DISCUSSION.

The CHAIRMAN (Mr. E. T. NEWTON) said that the fact that the subject of the paper was one to which the President had given so much attention, would all the more cause the Fellows to regret his absence and the reason that gave rise to it.

Mr. HUDLESTON disclaimed any special knowledge of the subject, but wished to draw attention to a particular feature shown in the models, which, as he understood the Author, had been mentioned in his explanation. This was the more acute accentuation of the foldings in the lower part of the series. So far as his (the speaker's) experience extended, this peculiarity might be noticed in certain mountain-ranges. There is an excellent example in part of the Jhelum Valley in the Outer Himalayas, where all the beds are of one formation, namely, Middle Tertiary, and where it is easy to perceive that the lower beds, close to the river, are often vertical and extremely contorted, while higher up the angle of inclination lessens, and towards the top there is a simple anticline of moderate

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Fig. 1.

Fig. 2.

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Fig. 3.

Fig. 4.

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Fig. 5.

Fig. 6.

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Fig. 7.

Fig. 8.

dip. Generally speaking, one might say that in mountains of recent date, such as the Outer Himalayas, and even the Pyrenees, contortions are not particularly in evidence, while the higher beds are simply tilted, though sometimes at a very high angle. The case is different in regard to the older ranges, such as those of Scotland and Wales, which, being merely stumps of a mountain-chain, exhibit chiefly the lower features.

Mr. P. F. KENDALL said that these experiments were very suggestive, and he hoped that the Author would persevere with them. He would like to see the vertical scale much reduced, so that the number of folds might be increased; it would, he thought, also be desirable to make some provision for a diminution in the rigidity of the materials forming the deeper-seated layers, so as to imitate more closely the conditions prevailing in the lower portions of earth-folds. He should like to see some experiments made with contracting circles, which might perhaps throw light upon the structure of curved mountain-chains. He thought that the North-Western Highlands were far too complex in structure to constitute a suitable study of mountain-folding, and would prefer to take as an example some widespread deposit the folds of which could be traced with precision over a large area. The Chalk of the South-East of England appeared to show the phenomena of cross-folding with great clearness, and there was a major wave or fold indicated by the general dip to the south-east, and transverse ripples forming the decussating folds of the Isle of Wight, the Portsdown anticline, the great Wealden anticline, and others.

Mr. RUDLER welcomed the Author's suggestive researches, as making a great advance on the work of earlier experimentalists in the same field. By applying stresses in two directions at right angles one to the other, it seemed possible to simulate the effects resulting from the intersection of two rectangular sets of folds, such as the Caledonian and the Charnian. He foresaw a wide range of possibilities in these ingenious experiments, by varying the magnitude of the pressure and the character of the media operated on, and especially by varying the weight of the load under which the substance was subjected to strain.

Dr. JOHNSTON-LAVIS thought that some attempt to adhere to ratios such as they existed in Nature would give more value to the experiments. He would suggest that artificial loads should be replaced by thicknesses of the material compressed, proportional to the probable average thickness of the earth's crust. At the same time, the compression should be proportional to what is known to have taken place in the Alps or other mountain-chains. The compression should be slow, and some artificial denuding rain, such as water with plaster or clay, or weak hydrochloric acid with cement, should be used to represent erosion simultaneous with mountain-building. Compression should be tried, not only at right angles as in the Author's experiments, but also with the axes of compression at other angles, and moreover compression should be applied simultaneously and also consecutively. This would, to

a great extent, represent the conditions prevailing on the earth's surface at different localities and periods.

If these researches were being carried out by himself, he would use a roughened sheet of rubber attached to a ring, stretched over the top of a cylinder, and, after being charged with the materials of the experiment, allowed to contract. In fact, the arrangement would be similar to that used for stretching parchment-drumheads. He cordially thanked the Author for reviving a question that had of late been neglected, but which would be likely to afford much interesting information.

He would not terminate without warning experimenters that the lower part of the earth's crust may be far more plastic from heat than had been allowed for in earlier experiments, which would explain the great crumpling of the deeper parts of disturbed areas.

Prof. J. W. SPENCER thought that some of the models showed resemblance to structures produced in the West Indian islands by denudation, and he compared another with a Mexican plateau.

The Rev. J. F. BLAKE said that he was much interested by one of the models exhibited, which showed the production of an elevated isolated plateau or 'horst,' about the origin of which there had been much discussion abroad. In attempting to account for one in a particular instance, he had been led to the conclusion that if strata bent into a syndcline between two anticlines were afterwards bent in a direction at right angles, so that a new anticline crossed the old syndcline, such a form of ground would result, and he was glad, therefore, to see this conclusion experimentally confirmed when the conditions happened to be suitable.

Mr. WHITAKER said, in regard to the materials used in the experiments, that cloth was excellent for folding only; but, to show fracture as well, some other material would have to be used. He suggested also the application of a slight upward pressure, as well as lateral pressures. He pointed out that in one set of the casts the centre was a hill, and that in the other set it was a hollow.

Mr. H. W. MONCKTON referred to the folded rock now seen at the surface of the ground, and said that he would much like to have some idea as to the amount of strata which had been removed from above the folded rock since the folding took place. The Author's experiments threw light on this question, and seemed to suggest that although folds might be produced near the surface, the more marked folding was produced by pressure at some depth, though perhaps not at so great a depth as was at one time supposed.

Dr. J. W. EVANS suggested that the experiments might be repeated with a local load on some part of the surface, so as to imitate the effects on folding of the accumulation of sedimentary strata on the flanks of a mountain-chain.

The AUTHOR expressed his thanks for the complimentary remarks, and the valuable suggestions, which had been made.