15. *An EXPERIMENT in MOUNTAIN-BUILDING: PART II.* By the
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R.A., F.G.S. (Read March 22nd, 1905.)

IN 1903 the Society did me the honour of publishing a short paper on this subject.¹ I may, perhaps, just repeat that Sir James Hall many years ago, and others since, have 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, Ruskin, and others.

In these investigations the compression was from two sides only. If, however, folded mountains are caused by contraction due to the cooling of the earth, the compression must take place from all sides.

With the view of illustrating this, I requested the Cambridge Philosophical Instrument Company to make for me an apparatus consisting of four square beams of wood, resting upon 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 this square central space I placed layers of cloth, baize, oil-cloth, cement, etc., separated by layers of sand. The machine was then set in motion, and compressed so that the central space was reduced from 24 inches square to 22.

Since last year I have made other experiments, changing the arrangement in various ways. The results differ in details in almost every case, the initial movements being probably determined by slight differences in the texture of the substances employed.

As a typical case I may cite fig. 1 (p. 348), representing a piece of compressed baize. It will be observed that there are two main folds, which cross at a right angle; that the elevation is greatest where the two folds meet; and that, while one fold is continuous, the other and lower one is shifted somewhat to one side, for a reason to which I will presently refer. Fig. 2 (p. 348) represents another specimen also showing the cross-ridges. Fig. 3 (p. 349) exhibits similar features, but the hills and valleys are more complex, and therefore more like those in Nature. Secondary cross-folding is well shown, and there is the same lateral shifting of one arm of the cross. The elevation is shown by fig. 4 (p. 349) which gives a lateral view.

¹ Quart. Journ. Geol. Soc. vol. lix, pp. 348-55 & figs.

Figs. 5-8 (pp. 350-51) represent a series taken in January. The machine was packed as follows:—

- 4 inches of sand.
Thin oilcloth.
- 1½ inches of sand.
Cloth (medium thickness).
- 1½ inches of sand.
Thin oilcloth.
- 1½ inches of sand.
Cloth, as before.
- 2 inches of sand.

The screws were then turned 3 inches.

Fig. 5 (p. 350) represents the upper layer of cloth, thrown into sharp ridges. Fig. 6 (p. 350) represents the layer of oilcloth. The general plan is the same, but the ridges are fewer. Fig. 7 (p. 351) represents the second, lower, layer of cloth. The ridges are numerous, and have a well-marked tendency to arrange themselves in squares, as, for instance, in Kjerulf's map,¹ but are less pronounced than they would have been if they had not had the oilcloth over them. Fig. 8 (p. 351) represents the lower layer of oilcloth: the ridges are less numerous than in the softer and more flexible cloth.

For contrast, I give figs. 9-13 (pp. 352-54), which represent another series taken at the beginning of this year. The machine was packed as follows:—

- 3 inches of sand.
Cloth as before.
- 1½ inches of sand.
Linoleum.
- 1½ inches of sand.
Cloth.
- 1½ inches of sand.
Linoleum.
- 2 inches of sand.

The screws were then turned 3 inches, reducing the square from 24 inches to 22.

Fig. 9 (p. 352) represents the upper layer of cloth, which was similar to that used in the preceding series. It will be seen, however, that the folding is altogether different, owing to the influence of the underlying linoleum. This is shown in fig. 10 (p. 352). The bold sweeps are striking, and the curved valley will recall many which occur in Nature. Fig. 11 (p. 353) represents the lower cloth, which, as will be seen, shows more numerous minor folds. Fig. 12 (p. 353) represents the lower layer of linoleum. The general arrangement is the same, but the folds are sharper; in fact, the linoleum was broken along the principal ridges. Fig. 13 (p. 354) gives a lateral view.

On the other hand, the case is very different if we introduce a stiff layer of some substance such as cement. This cannot throw itself into folds, but breaks and tilts itself up, assuming the

¹ 'Geologie des südlichen & mittleren Norwegen' 1880, p. 330, figs. 279 & 280.

so-called 'writing-desk' form of Sir Leslie Stephen, so familiar to us in the Alps, and finally breaks into fragments. In some experiments these were irregular, much broken up, and in that case forced irregularly into the sandy layers in a manner that would be very puzzling to geologists; and may throw light on some difficult problems.

In others, they broke across in two rectangular fractures, as in fig. 14 (p. 354). In such a case one half (fig. 14, *a, b*) was forced over the other, *c, d*. There was also an overthrust of *a* over *b*, and of *c* over *d*. Fig. 15 (p. 354) gives a lateral view, from *c* to *d*, showing the overthrust of *c* over *d*.

The result of these fractures and overthrusts is that, instead of two cross-lines, there is a three-legged ridge consisting of a single main elevation, with a break at, or near, the centre, from one side of which a main-cross line proceeds nearly at right angles. The corresponding cross-line (fig. 1, p. 348) on the other side is lower, and is shifted to some distance, according to the amount of overthrust.

The result is, that along the lines of overthrust a boring would pass twice through the originally-single calcareous stratum, and near the central nucleus of fracture even four times.

This accounts for the shifting of the lower ridge in figs. 1 & 2 (p. 348). One is reminded of the great arch of the Alps lying at right angles to the ridge of Italy, and that of the Himalayas with India, the plain of Lombardy corresponding to that of Bengal.

In other cases, the edges of the primary fractures broke off more or less regularly. The detached pieces were then pushed up, assuming gradually a very steep angle (fig. 16, p. 355), or even becoming vertical. The main plates of plaster having now room, were able to approach one another as in fig. 17 (p. 355), without any need for more fractures or folding. Such a case is illustrated in the accompanying diagrams (figs. 16 & 17, p. 355).

It will be observed also that a layer of pliable material above the plaster would be thrown into one or a few extensive folds; while a similar layer below is prevented from doing so, the under side being comparatively flat. It accommodates itself, therefore, to the circumstances by assuming a greater number of smaller folds.

Speaking generally, it may be said, firstly, that the thicker and stiffer the materials which alternated with the sand, the bolder and fewer are the folds; secondly, that the folds are more numerous and more accentuated in the lower layers; and thirdly, that the folds tend to be at right angles one to the other.

DISCUSSION.

The PRESIDENT observed that there were some who believed that laboratory-experiments threw little light upon Nature's work, but we could approximate more and more closely to the conditions which obtained in Nature, though we could never actually imitate

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Fig. 1. (*See pp. 345, 347.*)

Fig. 2. (*See p. 345.*)

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Fig. 3. (*See p. 345.*)

Fig. 4.—*Lateral view of the above.*

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Fig. 5. (*See p. 346.*)

Fig. 6. (*See p. 346.*)

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Fig. 7. (*See p. 346.*)

Fig. 8. (*See p. 346.*)

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Fig. 9. (*See p. 346.*)

Fig. 10. (*See p. 346.*)

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Fig. 11. (*See p. 346.*)

Fig. 12. (*See p. 346.*)

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Fig. 13. — *Lateral view of the cast illustrated in fig. 12.*

Fig. 14. (See p. 347.)

Fig. 15. — *Lateral view of the above.*

$c, d = \text{plaster} ; b = \text{sand}.$

Fig. 16. (*See p. 347.*)

aa = Two halves of a layer of plaster fractured in the middle, and again a second time.

bb = Pieces broken off and forced up.

cc = Layer of flexible material above the plaster.

dd = Layer of flexible material below the plaster.

Fig. 17.—*Showing the same materials as in fig. 16, but more compressed.*

them: for instance, it was doubtful whether we could ever get sufficient pressure to imitate exactly that flow of solids of which there was evidence among the rocks.

The initial experiments of Favre were simple, but others, as Cadell and Willis, had made more elaborate experiments, and the Author had introduced further complications.

The paper which had just been read was a continuation of one previously presented to the Society by the Author, and the President hoped that Lord Avebury would continue his interesting experiments and bring further results before the Society.

Dr. BLANFORD said he thought that the Society were greatly indebted to the Author for a most interesting series of experiments. He was particularly impressed by the crossed faults produced in the layer of plaster, as this probably showed the way in which lateral pressure might act on a rigid bed intercalated among more flexible strata. The form of the surfaces produced naturally differed from that of the usual superficial features of the land, because of the absence of the erosive action of denudation.

Prof. GARWOOD asked the Author whether sections cut through the models showed the formation of cavities such as might induce the intrusion of igneous rocks in Nature, and such as seemed to have taken place in mountain-ranges like the Eastern Himalaya.

Mr. LAMPLUGH remarked on the close resemblance of the plications on the surface of the models which contained linoleum, to the corrugations sometimes shown by compressed gritty flags in the Isle of Man and at Bray Head in Ireland.

Mr. STRAHAN thought that the imitation of forms of surface produced by denudation, by the surfaces of the models as produced by folding, was apt to mislead, and suggested that a truer comparison with Nature might be obtained by planing off the surfaces of the casts to a level, and developing valleys and escarpments by erosion. The model showing two intersecting overthrusts was especially instructive. Though contemporaneous with it, one overthrust clearly broke through, and displaced the other. Moreover, the one that was broken through was overthrust from opposite directions in its two halves, in this respect resembling belts of overthrusting and compression in Nature, which, unlike normal faults, were apt to change their throw.

It would be interesting to see a reproduction of a structure that he had recently observed in Pembrokeshire. There a gentle anticline was accompanied by a multitude of small overthrusts. Without exception, the overthrusting was from the south on the south side, and from the north on the north side of the anticline. Even in the few yards of nearly-level strata in the crest, four or five little overthrusts strictly followed this rule. He joined previous speakers in hoping that these interesting experiments would be continued.

Mr. WHITAKER enquired what was the amount of pressure exerted on the top during the whole of the experiments.

The AUTHOR thanked the President, and the other Fellows of the Society who had spoken, for their kind remarks. It was said that

the casts 'too closely' resembled Nature. He observed that when the surface on which rain, etc. had to act was so irregular as in the casts exhibited, the result would mainly be to deepen the original valleys. There would be, as the models showed, at first some lakes, which would be drained by more or less deep and narrow gorges.

In reply to Mr. Whitaker, he said that there was a thickness of 3 or 4 inches of sand overlying the top layer of cloth. The actual materials used showed such hollows as those suggested by Prof. Garwood, and into these sand had been forced up, but the hollows could not, of course, be reproduced in the casts.