Apparatus for Instruction in Geography and Structural Geology.

By Professor WILLIAM H. HOBBS, University of Michigan.

With Illustrations.

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(*With Illustrations.*)

1. *Map Contours.*

UNTIL the student has become familiar with the idea and use of surface contours as employed on hypsometric maps, a very large part of the field of physiography remains closed to him. He is in the position of the student of music who is unfamiliar with musical notation. Thus in a

strict sense he is debarred from making use of the great reference libraries of physiography—the topographic atlas sheets—until he has acquired the language in which they are printed. Some students, and those especially who possess what the Germans term *Vorstellungsgabe* and we *visualising power*, move rapidly toward an intelligent use of the map. Others will require every aid which can be afforded them before the grammar even of the subject is acquired. For many it will only be necessary to read with care the excellent and remarkably clear statements concerning the manner in which contours express elevation which appear upon the inside of the covers of the United States Geologic Folios. Obviously it is not for such students that the aids hereafter to be described were especially designed, though it is thought that even for them individual laboratory study with the apparatus will be of distinct advantage.

A topographic contour map being always an approximation only to a correct representation of the configuration of the country, it may be described in terms (1) of the measure in which it assumes to approach a correct delineation, and (2) the measure of warrant for the degree of correctness assumed. These contrasted ideas are embodied in the terms precision and accuracy. The measure of precision is afforded by the map in its scale and in its contour interval. A map printed on the scale of two inches to the mile, and with a contour interval of ten feet, makes larger assumptions than one printed on the scale of two miles to the inch and with a contour interval of one hundred feet. Though more precise the former may, however, be no more accurate than the latter. Assuming, however, that the map was intelligently, skilfully, and conscientiously made, its accuracy will depend chiefly on how many points there are upon the map whose position and elevation have been determined, since these are the basis upon which the contours have been sketched.

In the case of the most accurate of contour maps, the engineer by means of his transit locates and fixes the altitude of a very large number of points. He then notes at each of these, or at such points as seem necessary for his purpose the direction and the angle of the slope. Contour lines, representing as they do points on the same level, are horizontal and therefore at right angles to the directions of slope. The map maker's task is therefore completed by drawing his contour lines perpendicular to the lines of the steepest slope, and at such distances from the points located as the altitudes and angles of slope at each of the latter require. The simple model and exercise which are to be described aim to put the student in the position of the engineer who makes the map, and, when the work has been completed, to apply a simple test of its accuracy from the use of which the actual map-maker is debarred.

The apparatus for the purpose consists of a box of galvanised iron one foot square upon the bottom and five inches in depth (see Fig. 1) with a $\frac{3}{4}$-inch flange or rim at the top. On each of two opposite sides this rim is provided with a row of stout iron pegs one-eighth of an inch in diameter and three-eighths of an inch in height, and these are set one

inch apart with the terminal pegs in each row half an inch from the side walls of the box. The box is further provided with a small brass faucet set at one corner and low enough to empty it of water to within half an inch of the bottom. Four inches above the bottom, a narrow stripe is painted on all four sides so as to allow of bringing the box to a level position when largely filled with water. There is, further, on one side a series of narrow stripes at half-inch intervals extending downward to the bottom. This gauge is to permit of withdrawing the water from the uppermost level in successive half-inch layers.

An attachment to the box is a stiffened brass strip one inch in

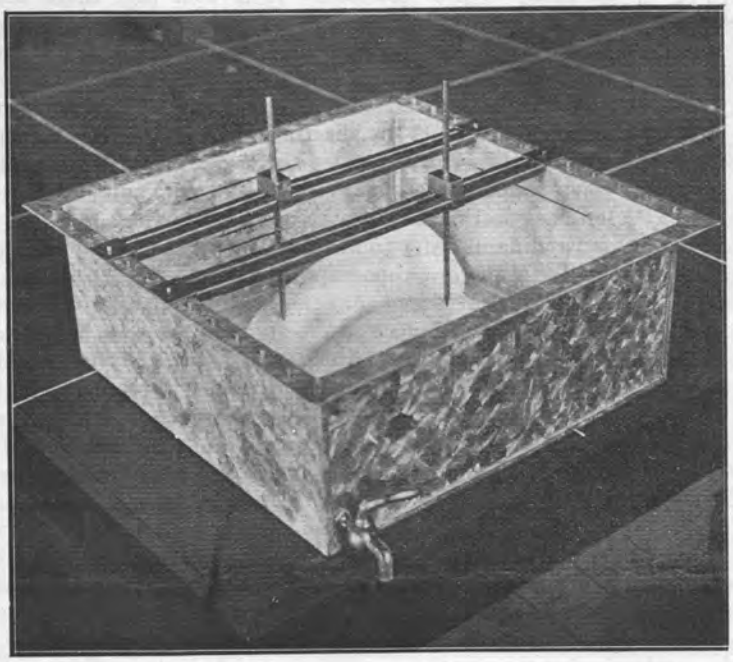

FIG. 1.—An Apparatus for Instruction in the use of Map Contours.

width perforated at each end, and of just such length as to stretch across the top of the box from the peg on one rim to the corresponding one upon the other. This strip, except at the ends where it overlies the flange of the box, is divided lengthwise by a slot. It is further graduated into half-inch intervals and provided with a sliding carriage supporting loosely a vertical rod pointed below and, like the strip itself, graduated into half-inch intervals (see Fig. 2). The sliding of the carriage along the strip, and the movement of the rod upward or downward through its carriage, together permit of bringing the point of the rod to any point in the middle vertical plane of the strip. The transfer of the strip successively from one pair of pegs to each of the others further permits of reaching all points in a series of near-lying, parallel, vertical planes,

and thus, so far as is necessary for our purpose, we may locate the position and fix the altitude of any point within the box. The vertical rod is so graduated that when the point rests upon the bottom of the box, the reading is zero. This is the datum plane corresponding to sea level or any other assumed datum. The figures corresponding to successive half-inch elevations of the rod from the floor of the box are in order 1, 2, 3, 4, etc.

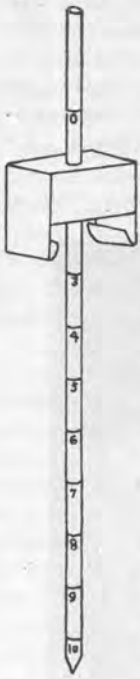

FIG. 2.—The Sliding Carriage and the Vertical Measuring Rod.

Models, constructed of plaster of Paris to represent a portion of the earth's surface, are made of such size as to fit easily within the box. It is well that these be of quite simple character; such, for example, as a volcanic cone, a pair of drumlins, or a simple area of mature erosional topography. To prepare these models a form is first made in artist's modelling clay. This is covered with strips of cotton sheeting, and plaster of Paris put on in a thin coat in order to form a mould, from which, when hard, models may be cast in the numbers needed for class work. The casts are smooth and coated with oil or vaseline in order to keep out the water.

To prepare a topographic map of any desired model, the latter is placed on the floor of the box, and the measuring attachment to the apparatus is fixed in position upon a pair of pegs which will allow the point of the measuring rod to describe a section across one of the margins of the model. Measurements are now made successively at half-inch intervals along this first section, and the readings recorded at corresponding intervals on cross section paper. The direction of slope and its amount may be taken with a small clinometer compass at each observing point or as often as is deemed necessary, the direction being either taken accurately with the compass or estimated with the eye in reference to the sides of the tank. For this purpose it is necessary that the apparatus be oriented so that its sides correspond to the cardinal directions. One section completed, the attachment is moved to the next succeeding row of pegs where a similar process is carried out, and so on successively until all sections have been covered.

With the model still before him the student now begins drawing the contours (see Fig. 3). After such corrections as the instructor can suggest have been made, the box is filled with water to the level of the uppermost stripe. This water is now drawn off in successive half-inch layers, and each contour of the map in turn compared with the temporary shore-line of the model to which it should correspond.

The association of a definite form of model with each map which the student prepares, tends to supply the form element to the map in a way not possible where no similar comprehensive view of surface form is obtained. The section paper used in the exercises, is better chosen with a unit other than one inch, so that the idea of map scale may be gained at the outset through a comparison of this unit with the inch standard

of the apparatus. If alternate contours be first drawn, the comparison of this map with the completed one will show how the shorter contour interval adds detail to the map. Each apparatus may, if desired, be provided with two measuring attachments, and so made available for use at one time by a group of four students, two of whom record the measurements while the others observe. Thus provided with two

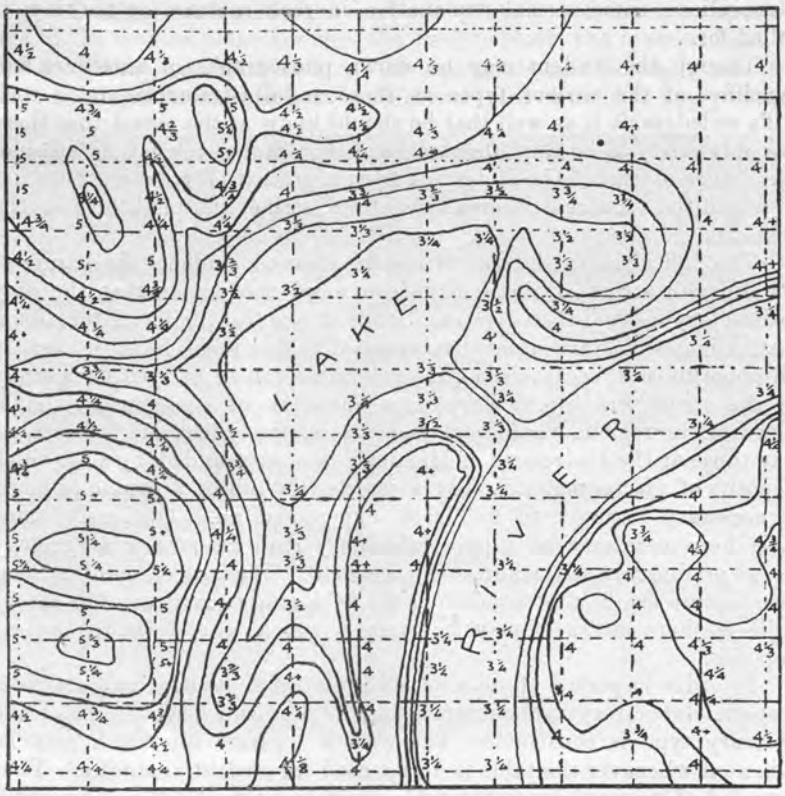

FIG. 3.—A Student's Map on section paper of a simple model of Low Relief.

attachments and exclusive of the plaster models, the apparatus may be constructed in lots of six at a cost of three dollars each.

2. *Mountain Structures.*[1]

Practical structural geology is essentially an exercise in synthesis,

[1] This second part of Professor Hobbs' paper has been included here because, although unlike the first, it does not deal directly with geography, yet the subject is one which the geographer must grasp thoroughly if the problems of earth structure are to be understood. Such a piece of apparatus as is here described may therefore well form an adjunct to a geographical laboratory.—ED. *S.G.M.*

but one which must often be carried out with many of the needed elements missing. In order intelligently to set forth from the incomplete data the actual dispositions and attitudes of the rock layers, a consideration of the types of warped surfaces into which rock layers are thrown in the process of folding, is first of all essential. Where abrupt variations are noted from the curve demanded by the greater number of observations, some special explanation in rock rupture, or faulting, is called for.

Though the student may be shown photographs of anticlines and synclines of the various types as these are illustrated in single rock cliffs or ledges, it is as well that he should know at the outset that these are only rarely to be thus observed, and that much of what we know of the nature of rock folds is derived from a process of patching together in which the scattered observations of dip, strike, and pitch furnish the elements

The difficulties in the way of making clear to students the nature of the dip and strike of rocks, have convinced the writer that the only satisfactory method is to give each student practical drill. Educational institutions which are situated in areas of folded rocks have the best of all opportunities, because the class excursions can be utilised for a study of the strike and dip. Very large numbers of students are found, however, in regions where rock beds lie relatively flat, and still others, like those at the University of Michigan, are surrounded by such thick deposits of glacial material that a journey by rail of a couple of hours is necessary in order to find rock exposed at all. Obviously, then, it is here necessary to supply laboratory drill in structural geology as a preliminary to studies in the field. We are of opinion that even where the best of conditions for field study exist, the laboratory drill as here outlined may be made a valuable adjunct to the excursions.

In order to permit of suitable studies of rock position and attitude, a special laboratory table must be used. For this purpose one of the ordinary type is constructed, but with a separate top which may be taken off whenever the table is to be used for structural studies. Thus denuded of its usual cover, the table presents a top of soft wood painted like a blackboard and divided by narrow white stripes into square sections which can be numbered with chalk on the township plan. In Fig. 4 such tables are shown in use with the tops removed. One of them appears in the foreground with its usual cover, and the removed covers are seen standing against the wall of the laboratory near the entrance door. These covers are strongly braced with cleats and have a flange which fits over the edge of the inseparable top of the table so as to be maintained in position. It is well to place the tables, at least when they are in use for structural studies, so that the section lines correspond to the cardinal directions.

To represent the rock outcrops in the laboratory studies, a simple device which we may call an "outcrop block" has been constructed. This block, which is shown in Fig. 5, is made by sawing out from $\frac{7}{8}$ inch board a rectangle four inches by six, and then sawing from the middle

of one of its narrower edges a rectangular piece one and a half inches deep and two inches broad. This piece is slipped down from its former position within the larger block so that it projects by one-fourth of an inch. A $\frac{1}{4}$ inch hole is then bored through both pieces, keeping to one side of the median plane of the board, and a bolt provided with a washer and wing-nut passed through and fastened. A similar but shorter bolt is passed in a direction at right angles to the first and toward the other side of the median plane through the smaller block, the rounded head of the bolt being accommodated in the free space left between the two blocks. The outcrop block as thus constructed is fixed in any position

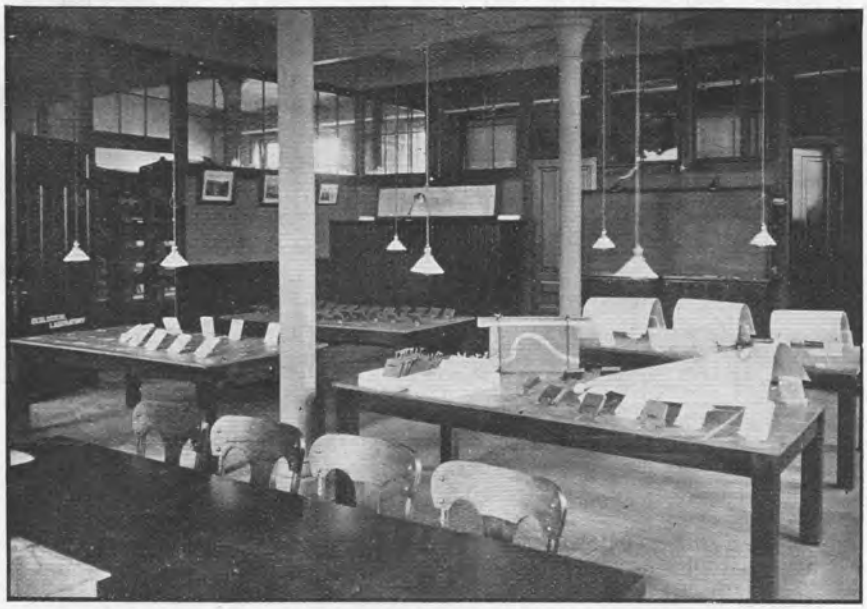

FIG. 4.—Laboratory tables in use for studies of mountain structures. The nearer table to the right is arranged to illustrate the relation of varying strike and dip to pitch. The nearer table to the left shows a series of outcrops outlining an unsymmetrical pitching anticline. The farther table to the right illustrates the common types of rock folds. The farther table to the left shows a series of outcrops which illustrate how faults produce offset.

upon the table by merely boring a hole in the top of the table with a $\frac{1}{4}$ inch bit, and passing the projecting portion of the bolt through it. Before tightening the wing-nut the block may be given any desired azimuth (strike) in reference to section lines, which through adjustment of the table have already been made the cardinal directions. By first loosening and then tightening the wing-nut of the horizontal bolt each outcrop block may be given any desired inclination (dip). The broad surface of the block thus represents the surface of a rock layer in the exposure. The position of each block may be described in terms of its distances from the boundary lines of the numbered sections. The blocks

are painted, some white and others Venetian red, so as to represent the different petrographic types—let us say, limestone and red sandstone. A square form of outcrop block four inches on an edge looks somewhat better and is in most respects quite as satisfactory as the larger one, but a compass needle is apt to be affected by the iron bolts when a measurement of the strike is made. Some of the blocks shown in the views are, however, of this size.

An almost infinite number of demonstrations and exercises are possible with the use of this simple apparatus. The various types of synclinal and anticlinal fold—symmetrical, unsymmetrical, and overturned—may be shown in comparison by fastening pieces of stout paper to the outcrop blocks by means of thumb tacks (see Fig. 4 at right), or they may be illustrated successively in a single fold through adjustments in the dip. The relation of stroke and dip to pitch, so difficult to make clear in the absence of models, is here rendered comparatively easy. In Fig. 4 at the right towards the front, a group of outcrops of limestone

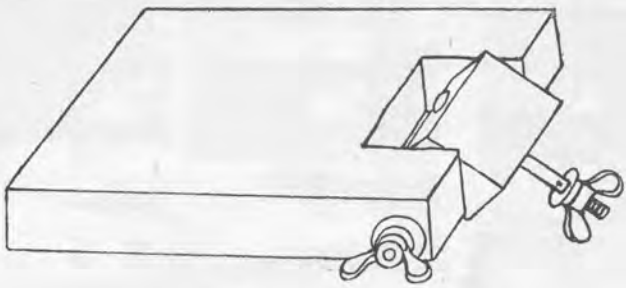

FIG. 5.—An outcrop block.

and overlying sandstone betrays an anticline pitching south (to the left). To bring this out clearly a piece of stiff paper is fastened by thumb tacks to the limestone outcrops and thus restores the missing portion of the fold—the "air saddle." For such a structure the paper is not competent to support its weight, so a strip of poster board is fastened beneath it in the broad portion of the arch attached by brass rivets such as are in use for paper fasteners (the M'Gill type). The relation of the varying strike and dip to the pitch is seldom grasped at a glance, and the student is therefore required to measure and record the dip and strike as well as to determine the location of each outcrop, in order to prepare a map on the basis of his observations. This map is afterward compared with the model (see Fig. 6). Small clinometer compasses are provided for this purpose and the strike observation measured at the top of the block as far as possible from the iron bolts. The observations are taken down on section paper so as to locate each outcrop without the necessity of written notes, the strike and dip being indicated by the T-shape symbols of Dana. A practical problem in the form of a steeply pitching unsymmetrical anticline is represented on one of the nearer tables of Fig. 4, and in the students' notes by Fig. 7.

How the process of folding in rocks shortens the crust and distorts or deforms the beds themselves through the accommodation of layers, is forcibly brought home to the class by the simple device illustrated in Fig. 8. This model is prepared by sawing from a three-inch plank a strip one inch wide in the form of an unsymmetrical anticlinal fold. Two exactly similar piles of strips of white paper an inch in thickness and of the same length as the straightened anticline, are marked on the long edge with a series of tangent circles provided with vertical and horizontal diameters. These circles may represent any structures within the rock beds; let us say, the pebbles of a conglomerate. On

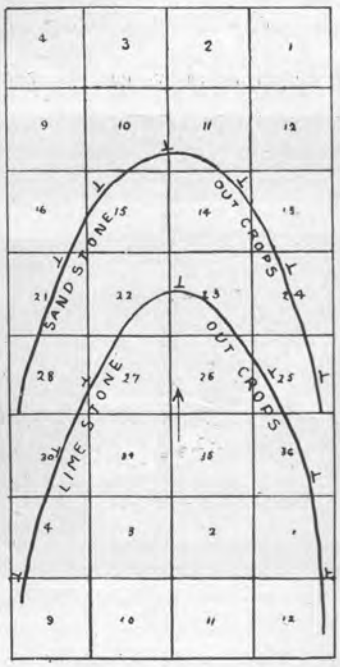

FIG. 6. Students' map of outcrops to show the relation of strike and dip to pitch.

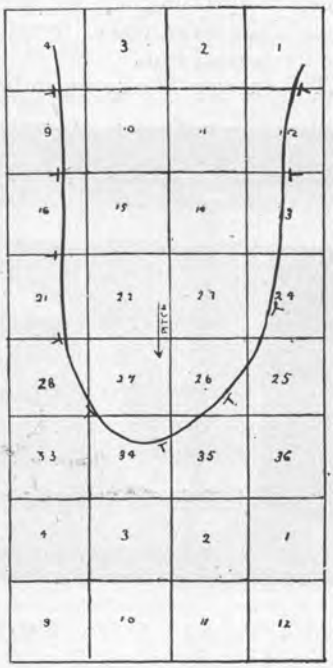

FIG. 7. Students' map of outcrops which outline an unsymmetrical, pitching anticline.

placing now one of the piles of paper in the space cut out from the plank and fastening the two parts of the model together, except within the arch of the folds the circles are changed into ellipses through the accommodation of the sheets of paper just as they would be in rocks through accommodation of the rock laminæ. The greater distortion occurs in the steeper limb of the fold, and the axis of greatest distortion or slide is that which in a more extreme case of folding—a sharply overturned anticline—would develop into a plane of rupture or thrust. The amount of crustal shortening is here indicated by placing the unbent pile of paper beside the folded one. Thus all these more or less complex changes within the rocks in the process of folding are given a striking demonstration without the resort to mathematical treatment. The

student thus learns why, if he is searching for a conglomerate in a region where the rocks have been complexly folded, almost his only chance of finding it is to search in the arches of the anticline where the pebbles have been so little changed as to be still recognisable.

To illustrate the subject of faulting the writer has already described a piece of apparatus [1] in which wooden blocks of different sizes are floated upon water and held in unstable positions through the medium of a vice, so that when the compression is released they at once adjust themselves to their natural positions of flotation to the accompaniment of faulting. The swelling of the wooden blocks used in this experiment soon gave trouble in operating, and the apparatus has since been much improved through the substitution for the wooden blocks of small boxes made from galvanised iron.

The outcrop blocks which have been described above can be used to

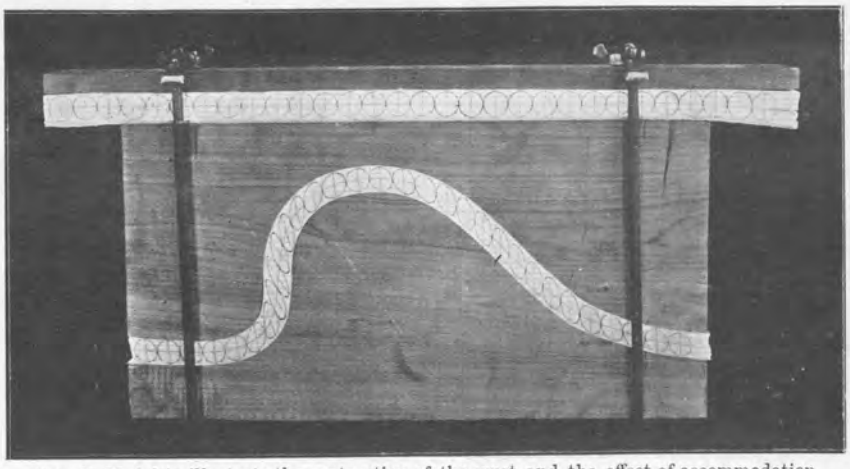

FIG. 8. Model to illustrate the contraction of the crust and the effect of accommodation between layers in the deformation of rocks.

especial advantage in illustrating the subject of faulting, and particularly the effect of faults in offsetting lines of outcrop. The combination of faults with folds may here be made particularly instructive because the portions of the folds once above the present eroded surface may be restored in the paper arches for a clearer understanding of the subject (see Fig. 4).

It is not alone for the purpose of demonstrating the fundamental principles of structural geology that the outcrop blocks here described are adapted. They may serve also in the working out of difficult original problems, and for this purpose several tables may, if required, be placed side by side and the outcrops entered accurately from the field notes. Thus there are brought into a single general view and with the aid of restored air saddles what in the field has been seen in small sections only.

[1] *Earthquakes*, D. Appleton and Co., New York, 1907, pp. 34-36, pl. 3.