DISCUSSION.

*THE RECORD OF DEFORMATIONAL MOVEMENTS SHOWN BY PETROFABRIC ANALYSES.**

A rather extensive treatise dealing with the "Geology of the 'Martic overthrust' and the Glenarm Series in Maryland and Pennsylvania"[1] has appeared recently. This is the result of an exhaustive investigation of certain areas in Pennsylvania and Maryland that have been remapped by Cloos. The problems that were the particular object of the investigation are: 1, the age of the Glenarm series (based more particularly upon the age of the Wissahickon formation); 2, the structural and stratigraphic relations of the Wissahickon formation to the sequence of lower Paleozoic rocks that rest upon the pre-Cambrian Baltimore gneiss.

The book deals with the problems from the point of view of field mapping, metamorphism, petrography, chemical composition and petrofabric analysis, and the conclusion reached by the authors is stated as follows[2]: "The author believes that in this area the Wissahickon schist cannot be pre-Cambrian and a thrust sheet over Paleozoic sediments because of the total lack of any structures or mineralization which is restricted to it."

The present brief analysis of certain aspects of this work was stimulated by the fact that the result of the petrofabric analysis has been quoted briefly in a recent publication[3] as showing that "neither the field nor petrofabric facts, support the 'thrust' hypothesis and the pre-Cambrian age of the Wissahickon schist."

It is not the object of this paper to discuss the field facts nor the megascopic structure. The authors of the Special Paper acknowledge that "field mapping under ideal conditions is not always objective"[4] and that in the previous geologic maps "the outline of the Wissahickon overlap in the Martic Hills over the known Paleozoic

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[1] Cloos, Ernst, and Hietanen, Anna: 1941, Geology of the Martic Overthrust and the Glenarm Series in Pennsylvania and Maryland. Geol. Soc. Am., Special Paper 35, 1-100.

[2] op. cit. p. 191.

[3] Fairbairn, H. W.: 1942, Structural Petrology of deformed rocks Addison-Wesley Press, Inc., Cambridge, Mass., p. 102.

[4] op. cit. p. 1.

sequence is essentially correct, with the exception of the 'famous' fensters west of New Providence which do not exist."[5, 6]

No more is it the aim of this present paper to discuss mineralogical or chemical petrology of the rocks involved. To do justice to the vast amount of interesting ideas presented as a result of the extensive work of Cloos and his associates would require an exhaustive discussion outside the present brief limits. But it does seem desirable here to sound a note of warning as to the extent to which the results of petrofabric analysis can be used to prove or to disprove discordance of structure and multiple periods of orogeny, particularly as petrofabric analysis is rapidly coming into more extensive use in this country as a tool for the investigation of structural problems.

The fundamental basis of structural petrology is that the arrangements in space of certain individual rock constituents shows the nature and the direction of the movements of these constituents in coming to their present positions, in other words it indicates something about how a rock was brought to its present condition. Where the arrangement of the individual constituents forms a distinct pattern instead of a helter-skelter scattering of positions it shows that these constituents were striving for a *preferred* position or positions in which they would be best adapted to the movements that were affecting them.

"Certain individual constituents" may seem a vague and meaningless way of expressing the elements that moved to bring about the present state of a rock. However, this vagueness is unavoidable because the mobile elements may be of such a varied nature. They may be crystals or groups of crystals. They may be amorphous

[5] op. cit., p. 6.

[6] It might be noted in passing that the existence or non-existence of these windows of limestone within the confines of the Wissahickon formation has no bearing upon the point at issue, viz., the structural relation of the Wissahickon formation to the underlying rock. These two windows were originally outlined in U. S. Geological Survey Bulletin 799 by dotted lines, tentatively delimiting areas of relatively low and flat country, in which outcrops of the schist had not been found and in which evidence from wells indicated the presence of hard water, suggestive of limestone, either at the surface or a short distance below the surface. (By an unfortunate oversight of the authors in reading map proof the second, easternmost area was delimited in a full line instead of a broken line). The fact that Cloos has found nine outcrops of schist within the areas undoubtedly improves the map and may well necessitate the removal of limestone from the surface map, but it does not preclude the possibility that limestone underlies the schist at shallow depth, nor does the possible position of limestone below the schist in any way indicate whether the schist rests on the limestone in depositional contact nor whether it rests on the limestone in thrust position. It would merely indicate the attitude of the thrust plane if such exists. One wonders to what these areas owe the qualification of "famous."

elements, as lava pebbles in a conglomerate or breccia that is forming or being deformed. They may be ions, as in the precipitation of calcite in a vein, where, as the mineral grows from solution, the individual ions move into a new and relatively fixed position that has a definite relation to the vein walls and also to the flow or stagnation of the solutions that are precipitating calcite. Similarly in the deformation of mineral grains by intragranular gliding it is the ions of the space lattice that change their position in the process of plastic slip.

Now what are the elements that carry the movement in the processes of rock deformation and rock metamorphism? These processes may be intimately connected because metamorphic rocks may be and usually have been deformed, but deformed rocks are, of course, not always metamorphic. What is involved in the movement when a large block of the earth's crust is moved over another block by thrusting, as in the Lewis overthrust, the Heart Mountain overthrust, the "chaos" of the Death Valley region? In the "chaos" it is easy to see that large blocks of rock have participated as entities in the movement, arriving at their present position in a tangle of irregularly distributed and gigantic debris. In the Lewis overthrust the strata have moved in a more orderly fashion and the block or blocks that have overridden the underlying floor have moved freely *en bloc* without disarranging the disposition of the overriding elements and without essentially affecting the rocks underlying the thrust plane. The writer has collected perfectly determinable Cretaceous fossils a few feet below a great thickness of pre-Cambrian Belt rocks in Glacier National Park. Neither the rocks that are overridden nor the overriding rocks are in themselves metamorphosed. Sandstones remain sandstones, argillites remain argillites, and so forth. Incredible as it may seem these great blocks of the earth's crust do move far from their original position without registering in the structure of the moving block or of the static block any evidence of their displacement. Without fossil evidence these gigantic displacements might entirely escape observation, and without fossil evidence certainly could not be proved even if they were suspected.

In the same way the rocks of Central Pennsylvania have been thrown into great folds without metamorphism. Apparently one layer has slipped bodily upon another layer, while the individual layers have been flexed into relatively wide arcs. The moving elements here have been individual beds or possibly individual grains in these beds that have taken up the movements by intergranular readjustment. So far as we know there is no indication of any penetrative movement that has reached down within the original grain boundary.

What happens when rocks are moved under metamorphosing influences? The movement then becomes more and more penetrative as the rock alteration becomes more intensive and more pervasive. The smallest units of rock fabric, down even to the field of ionic attraction, rearrange themselves in response to the deforming movement and this response to the movement may cause even a complete rearrangement of the space lattice in individual atoms. This intragranular rearrangement, which is often combined with an intergranular rearrangement, is what gives us the picture of the deforming movements in metamorphic rocks. But a *complete* penetrative rearrangement of the rock elements in a metamorphic rock does not give us a picture of the movement plan under which the rock was formed before metamorphism and says nothing in itself about whether the rock was originally sedimentary or igneous or metamorphic. It merely gives us the movement picture of the *latest* imprint in the record of the rock history.

If the penetrative rearrangement of rock elements is *incomplete*, some of the fabric elements or some parts of the rock fabric may have escaped the effects of the latest movement and in them there may be preserved the record of some earlier events of the rock history. But if the second record shows a different record from the earlier one it means that the movement plan of the second event was sufficiently different from the movement plan of the first event to imprint a different pattern on the rock fabric and so to alter the symmetry of the first movement pattern. If the two movement plans coincide, as in "posthumous folding," the symmetry of the fabric arrangement will not be altered and the evidence of polymetamorphism will be lost. To what extent two movement plans must be different in order to alter the fabric symmetry requires a very thorough and careful investigation. This will become apparent at once to any investigator who has studied some of the great, but totally elusive unconformities in unmetamorphosed rock series.

The writer has spent a number of months in studying the relation of the pre-Cambrian Belt series to the overlying Paleozoic rocks along the eastern front of the Rocky Mountains near Helena, Montana. The metamorphic condition of both pre-Cambrian and Paleozoic rocks is identical, the lithology of individual beds of argillite or sandstone is indistinguishable. However, the stratigraphic section of the Belt formations is quite different from the Paleozoic section, the Belt being a dominantly argillaceous and arenaceous series while the Paleozoic section is predominantly carbonate rocks. The greatest angular discordance that has been observed in following the pre-Cambrian unconformity for a distance of 50 miles is 25°. Over much of the distance the rocks are in perfect structural conformity and where post Paleozoic folding has thrown both series into steep, or even overturned position, the structure of the underlying and overlying beds is identical. Therefore in many places the distinction between pre-Cambrian and Paleozoic rocks rests upon taxonomic differences and upon fossil evidence. If these rocks had been subjected to an orogenic disturbance under conditions leading to metamorphism of both series the evidence of structural discordance would be even harder to find than it is at present and if the metamorphism had been accompanied by a penetrative movement that caused a preferred orientation in the fabric, there would be only one movement recorded in the fabric symmetry.

Similarly if the Paleozoic and Mesozoic rocks of the Heart Mountain overthrust in Wyoming or of the Keystone thrust in the Spring Mountains of Nevada, where evidence of structural unconformity is lacking or difficult to find, should be deformed under conditions that would cause a preferred orientation of the fabric elements, there would be no evidence in petrofabric analysis of anything but one event that had reorganized a series of rocks totally regardless of the relative ages or superposition of the rocks involved.

Moreover, if these rocks were repeatedly deformed under conditions that led to polymetamorphism, the evidence of the polymetamorphism might be either destroyed by a complete rearrangement of the fabric under the latest imprint, or else might be impossible to find in the fabric if the movements had all taken place under the same orientation of movement plan.

Therefore the original premise of the recent investigators of the Martic overthrust that a thrust surface would strongly influence the fabric is only true in that any strongly developed plane of discontinuity will act as a conducting path for the deforming movement and therefore influence the fabric. If the thrust plane has the same attitude as the other *s*-planes above and below the thrust, all these planes of relative discontinuity will carry the movement in the same path and result in the same fabric pattern above and below the thrust. Petrofabric analysis might or might not show a structural discordance involving a lack of parallelism of bedding, but the fact that it did not show such a discordance would in no sense preclude the possibility that thrusting might have produced an abnormal stratigraphic sequence without involving structural discordance in the rock section that has been deformed.

Granting the correctness of Cloos' interpretation of his petrofabric diagrams and the soundness of his petrofabric analysis, we can certainly grant his conclusion, namely, that "all structural elements . . . are common to all formations" and that "comparison of structural field study and fabric analysis shows the closest similarity" and "deformation in all rocks in the area is the same . . . There is no evidence of thrusting. The schist rests upon the limestone and the contact resembles a conformable boundary between calcareous and shaly beds."[7]

But these conclusions cannot be extended to the statement that there was no inversion in the stratigraphic sequence that was being deformed, nor that there was no polymorphism, nor more than one orogeny in a region simply because petrofabric analysis has only revealed one deforming imprint that has affected all the rocks involved in the movement alike.

The immense amount of interesting factual material presented by the work of Cloos and Hietanen deserves the thanks of every subsequent worker upon the problems involved, and the petrofabric diagrams in this book are a basis upon which to build further and more intensive petrofabric investigation. But in fairness to those who are studying structural petrology of deformed rocks it must be emphasized that petrofabric analysis is a record of the latest movement involved in the history of a rock and that although earlier movements may or may not appear under the imprint of the latest movement the fair interpretation of the record permits us to say only that the influence of one movement is shown without making any assertion as to what preceded that movement except in those, probably somewhat unusual, cases where a change in movement symmetry can be recognized and can be safely ascribed to more than one episode of deformation. ELEANORA BLISS KNOPF.

[7] op. cit., p. 187.

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