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Rosenfeld, John L.

Eaton, Gordon P.

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STRATIGRAPHY, STRUCTURE, AND METAMORPHISM IN THE MIDDLE HADDAM QUADRANGLE AND VICINITY, CONNECTICUT

By

John L. Rosenfeld, U.C.L.A. and Gordon P. Eaton, Wesleyan

STRATIGRAPHIC RELATIONS

Four anticlines of gneiss, mantled by predominantly schistose metamorphic rocks, crop out in the area immediately east of the Triassic Border Fault near Middletown, Connecticut. The stratigraphic section in this area is remarkably like that found many miles to the north, in western New Hampshire. Within the mantling strata are two major unconformities, characterized by superimposed strata of a coarsely clastic sedimentary facies.

The upper of these unconformities is believed to represent the Taconic orogeny. A syncline containing rocks of the Bolton group*, which overlies this unconformity, has been traced northward to Quabbin Hill in central Massachusetts, only a few miles from areas where Siluro-Devonian rocks, dated by fossils, strike southward from New Hampshire. The similarity of the Bolton group, both in lithology and sequence, to the Clough, Fitch, and Littleton formations of western New Hampshire is indisputable. It is improbable that structural complications in the area of Quabbin Reservoir could alter correlation of these formations with the Bolton group.

The lower of the two unconformities is distinctive in that superjacent metasedimentary rocks rest on others of predominantly volcanic origin and also on massive granitoid rocks which show a discordant relationship with the metavolcanics, but which do not cut the overlying metasediments. The rocks above this unconformity (Collins Hill formation) are similar to those of the Partridge formation of southwestern-most New Hampshire and southeastern Vermont.

The unconformity at the base of the Collins Hill formation does not parallel that at the base of the Bolton group. The areal distribution of the Collins Hill formation relative to that of the Bolton group suggests that the major axis of folding in the Collins Hill formation is oriented slightly counter-clockwise to the axis around which folding took place in the Bolton group (at a later time).

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* For names of stratigraphic units and locations of geologic structures, reference should be made to the accompanying stratigraphic section, geologic map, and structural cross sections.

Beneath the lower unconformity there is considerable contrast in the composition of the separate masses of gneiss. In the southern portion of the Glastonbury "dome," the rock is predominantly a massive granitic gneiss in which one occasionally finds dark-colored, mafic-rich schlieren. In the Killingworth dome, the amphibole-rich, stratified rocks of the Middletown formation are separated from the underlying and conformable stratified plagioclase gneisses of the Monson gneiss with difficulty. Similar relations obtain along the west side of the band of Monson gneiss that extends northward toward the type locality in Massachusetts. The smallest gneiss mass, centered at Maromas, seems to have had a hybrid origin. In it, granitic gneiss similar to the Glastonbury gneiss exhibits numerous apophyses which extend into gneisses and amphibolites along its eastern margin. The latter rocks have been mapped as Middletown formation because of compositional similarity to that unit in its type locality. It would seem reasonable to infer that the Monson gneiss is missing in this dome as a result of intrusive transection.

STRUCTURE

Structurally, the anticlines of the Middle Haddam area are similar to the mantled gneiss domes of Eskola (1949). These domes form a portion of a long chain to which Billings (1956) has given the name, "Bronson Hill Anticline." Actually, in the Middle Haddam area, only the mass centered about Killingworth appears to be a dome in the classical sense of the word. The two anticlines in which the Glastonbury and the Monson gneisses appear in the northern part of the Middle Haddam area, are highly elongate, extending northward across most of central Massachusetts. The mass of gneiss centered about Maromas appears to occupy the core of a recumbent fold. In cross section, all of the domes appear to have radii of curvature that are large relative to those of the rather tightly-folded, bounding synclines. Minor structural elements associated with the domes, such as drag folds and deformed pebbles (the pebbles are stretched over the domal crest of the Killingworth dome, as well as the flanks), suggest that in large part, the central masses of gneiss moved upward relative to the mantling strata. J. B. Thompson (1952) has suggested that this upward movement of the gneiss cores might possibly have resulted from buoyant forces dependent on the relatively low density of the gneiss. Shear phenomena show some exceptions, however, and it is possible that these exceptions reflect a classical type of deformation dependent on regional horizontal compression.

One of the most distinctive features of the Bronson Hill Anticline is the en echelon character of many of the gneiss domes. This en echelon character shows up very well in the Middle Haddam area and far to the north in New Hampshire. It is also evident in other chains of domes in areas to the west. Evidence of a possible cause of this en echelon arrangement appears on a regional scale north-northeast of Great Hill in Portland. Along the east side of the Bolton group, the Collins Hill formation disappears northward as a result of pinching out beneath an angular unconformity. The Collins Hill formation is not present along the west side of the Bolton group within the Middle Haddam area or in areas immediately to the north. It reappears farther north along the west side of the Bolton group, and is well exposed in the Ellington Quadrangle. This suggests that the Collins Hill formation was folded about an axis counter-clockwise to the axis around which folding took place in the Bolton group. If this difference in orientation of axes reflects a change in the direction of maximum principal stress, it might be possible to explain the en echelon character of the domes as the result of two stages of deformation (evidence for which is presented). This interpretation contrasts with the one presented previously by the writers (Rosenfeld and Eaton, 1956).

METAMORPHISM

The distribution of metamorphic grade relative to the axis of the Bronson Hill Anticline and the anticlinal axis extending northward toward Monson, Massachusetts, is of considerable significance. Metamorphism is symmetrically disposed about the Bronson Hill Anticline, with rocks in the sillimanite zone appearing along its axis and rocks in the kyanite zone appearing along the axes of the bounding synclines. Rocks of the sillimanite zone also appear to the east, along the western boundary of the Monson gneiss. The isograds do not spread apart in areas adjacent to the Glastonbury gneiss to any greater extent than they do around the Killingworth dome which has a core of stratified rocks including recognizable metasedimentary types. This would seem to be a further argument against a syntectonic origin for the granitic rocks that now constitute the Glastonbury gneiss. If this gneiss had been a granitic magma at the time of metamorphism, its higher temperature should be reflected in the metamorphism of the surrounding rocks, and in particular, in the expansion of the higher grade zones adjacent to such granitic rocks. Thus it would seem that the metamorphic evidence is consistent with the stratigraphic evidence which suggests that the rocks now represented by the Glastonbury granitic gneiss were in place (and cold) at the time the overlying sedimentary rocks were deposited.

An additional feature of interest is the nature of the sillimanite isograd. Instead of a sharp line on the surface of the earth, on one side of which kyanite appears and on the other side of which sillimanite appears, the sillimanite isograd has, on its "high grade" side, a rather broad zone in which both kyanite and sillimanite can be observed to co-exist. In many cases, fine-grained clots of sillimanite show by their approximately-equivalent size and shape that they are pseudomorphs after the kyanite porphyroblasts with which they co-exist. This type of occurrence clearly indicates a sequential relationship in which sillimanite developed later than kyanite. At other places within the sillimanite zone, the finely dispersed sillimanite apparently resulted directly from chemical reactions that took place within the sillimanite zone rather than by polymorphic transition from kyanite porphyroblasts. It would appear that tectonic movement along the anticlinal axes carried rocks from the kyanite stability field into the higher temperature field in which sillimanite was stable. Consideration of the stability fields of these two minerals, as determined from experimental work by Clark and others (1957) does not tell us whether such a transition resulted from the predominant influence of falling pressure or rising temperature. The direction of polymorphic transition is contrary, however, to that expected as the result of increasing depth of burial under conditions of a "normal" geothermal gradient. If the writers can evaluate the importance of the buoyant mechanism of doming mentioned above, it may be possible to show that falling pressures played an important role in the transfer of kyanite-bearing rocks into the sillimanite field of stability. Current petrologic study is aimed at the determination of the direction of the horizontal thermal gradient at the time of metamorphism. Elsewhere in western New England there is ample evidence around some domes that thermal gradients are directed away from the anticlinal axes. If a similar relationship holds for the Bronson Hill Anticline within the Middle Haddam area, then it is probable that the "arrival" within the sillimanite zone was the simultaneous result of falling pressures and rising temperatures.

Simultaneous consideration of metamorphic facies variations, reasonably-constructed structure sections, and an examination of the pebbles and cobbles in the immediately-adjacent rocks of Triassic age along the Eastern Border Fault suggests a functional relationship from which it should be possible to deduce a certain amount of information concerning the vertical distribution of metamorphism.

The Bolton group occurs in a tightly-folded syncline extending for many tens of miles north of Great Hill (in Portland). As a result of its northward plunge at Great Hill, this group is not found anywhere in the Eastern Highlands to the south. In the Triassic rocks immediately west of the Border Fault, clasts representative of certain distinctive lithologies in the Bolton group are not found in recognizable abundance south of Duck Hill, near the straits of the Connecticut River. They are very abundant north of that area. This evidence leads to the conclusion that the Triassic rocks of the Portland formation immediately adjacent to the Border Fault were derived largely from an area only a little more than three miles wide, directly to the east.

Examination of the clasts derived from the Bolton group indicates that they represent a distinctly lower grade of metamorphism than that now observed in the provenance area to the east. In the eastern area, the distinctive schists of the Bolton group contain large staurolite porphyroblasts. The clasts in the Triassic conglomerate derived from this same member of the Bolton group do not contain staurolite, although they are quite abundant. Furthermore, these clasts are remarkably similar to the same member of the Bolton group as it appears in lower grades of metamorphism in areas far to the north. This contrast in metamorphic grade implies that a lower grade of metamorphism existed in the provenance area at the time the Portland formation was deposited, and because of erosion since late Triassic time, metamorphic rocks formed at an equivalent level in the crust are no longer exposed in the Eastern Highlands.

The disparity in the grade of metamorphism of the clasts and the grade of metamorphism in the provenance area is a measure of the amount of erosion to which both the Bolton group and the Portland formation have been subjected since the time of sedimentation. The disparity likewise indicates that the slope of the isogradic surfaces was less than that of the stratigraphic surfaces. It remains to determine the amount of erosion of the metamorphic rocks of the Eastern Highlands since the close of deposition of the Triassic rocks. The flat nature of the Killingworth dome and the presence of clasts in the Portland formation that are diagnostic of distinctive strata in the Killingworth dome suggest that there can have been scarcely more than one mile of erosion in the straits area since the close of Triassic deposition. It would seem, therefore, that there was a relatively steep vertical metamorphic gradient in the Bolton group near Great Hill. The writers are engaged in a study of the sedimentary inversion represented by clasts in the successively older formations of the Triassic and the relationship of this inversion to the skyward extrapolation of metamorphic and stratigraphic structure sections*

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* Study of the clasts in some of the older Triassic strata suggests a distinct breach in metamorphism within the Eastern Highlands provenance area at the time of sedimentation. The co-existence of clasts of fine-grained dolomite, limestone, and anthracite (?) coal, with clasts of garnetiferous mica schist and microcline pegmatite, highlights the possibility that Carboniferous rocks may have rested unconformably on the higher grade metamorphic rocks of the Eastern Highlands during the early part of Triassic deposition. As corroborative evidence, a possible fusulinid was found in one of the dolomite clasts. Further study is being carried on to clarify the meaning of these recent finds.

POSSIBLE ORIGIN OF PEGMATITES

Considerable interest attaches to the relationships of the pegmatites of the Middle Haddam area. They have been much studied, and there has been considerable theorizing concerning their origin. Furthermore, there have been continuing studies of the radioactive ages of certain minerals within these pegmatites, leading to recent values in the neighborhood of 260 million years.

Rather large, semi-concordant pegmatites are found throughout the Middle Haddam area, but they appear to be particularly abundant within the Collins Hill formation. The stratigraphic studies discussed above indicate that these pegmatites did not have a magmatic origin related to the granitic gneisses such as the Glastonbury. The rocks that are now Glastonbury and Maromas gneiss were in place before the Collins Hill formation was deposited.

Field study has yielded little evidence that the lenticular pegmatites have roots extending to a deeper magmatic source. In recent years, many geologists have been attracted to a metasomatic origin for certain pegmatites. This would seem to be ruled out for microcline-bearing pegmatites within the Collins Hill formation. To create microcline from pre-existing muscovite schist would involve a considerable change in the potassium: aluminum ratio, and it is difficult to see how this could take place without similar alteration occurring in the highly-aluminous kyanite and/or sillimanite schist member, low in the Collins Hill formation. The writers have been considering the possibility that the pegmatites originated as a result of local lateral secretion during metamorphism. With this hypothesis, the greater abundance of pegmatites within the Collins Hill formation might be explained as the result of fluxing action due to the evolution of carbon dioxide and H_2O, both of which must have been given off in great quantities during the metamorphism of the pelitic rocks and "dirty" carbonate rocks of the Collins Hill formation.

GEOPHYSICAL DATA

More than 300 observations of gravity have been made in the Middle Haddam area to aid in the interpretation of geologic structure. To date, corrections have not been made for all of the stations occupied, but those lying along a closely-spaced profile across the overturned syncline containing the Bolton group indicate the following:

a) The syncline containing the Bolton group and the syncline lying unconformably beneath it, containing the Collins

Hill formation, extend to a combined depth of nearly 9,000 feet.

b) The axial plane of the syncline is overturned at the surface, but assumes a more nearly vertical attitude at depth.

c) The Mount Parnassus Basin of Lundgren is relatively shallow, the combined thicknesses of the Brimfield (Cremation Hill schist) and Hebron formations not exceeding 2,500 feet at Marlborough.

ACKNOWLEDGEMENTS

In conclusion, we would like to acknowledge our debt to previous workers in the area, and to contemporaries in adjacent areas with whom the writers have worked very closely. Of former workers, the writers are particularly indebted to J. G. Percival, whose report on the geology of Connecticut remains a classic of descriptive geology, and to Lewis G. Westgate, whose unpublished manuscript on the crystalline rocks of the Farmington Folio was made available to the writers. Westgate's text and map included most of the area studied. Percival's most important contribution was his separation of the rocks mapped by the writers as Bolton group and those mapped as Collins Hill formation. Westgate, and later investigators, "lumped" these rocks into a single unit. Westgate's contribution lay in an accurate delineation of the schist-gneiss boundaries of the area. A judicious synthesis of Westgate's and Percival's maps would result in a geologic map very similar to the one presented here.

Of contemporaries working in adjacent areas, the writers are particularly indebted to Lawrence Lundgren, George Snyder, Richard Goldsmith, Roberta Dixon, and John Sanders. Many of the hypotheses tested by the writers in the Middle Haddam area owe their origin to the work of M. P. Billings and J. B. Thompson many miles to the north, in western New Hampshire. *

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* The writers have also benefited from discussion with Norman Herz.

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