Mountain geomorphology: An investigation of mountain building mechanisms and their affect on stream orientations

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INTRODUCTION

The orientation of streams that have high gradients are greatly affected by the bedrock that they flow through. They can be affected by both the lithology and structures in the rock such as faults, folds, foliation, and joints.

The purpose of our study was to analyze the geology of an area in the central part of the Berkshire Mountain Range, Massachusetts to examine relationships between regional tectonics and present day geomorphology. This abstract presents two mechanisms for the evolution of the area: thrust slivers and folded thrusting. It also presents correlations between bedrock structures and stream flow orientations.

GEOLOGIC SETTING

Our study area is located south of Williamstown in the Cheshire and North Adams USGS 7.5' by 15' quadrangles. The area is bounded by Route 7 to the west, Rockwell Road on the east, Roaring Brook to the north, and Pratt Hill to the south (Figure 1). This area was mapped previously by Ratcliffe and others (1993).

The geologic units found in the area belong to the Stockbridge and Walloomsac Formations and the Greylock Schist, which is equivalent to the Nassau Formation. The Greylock Schist (Early Cambrian to Late Proterozoic) and Stockbridge Formation (Early Ordovician to Early Cambrian) overlap in age (Ratcliffe, 1993); however, their environments of deposition were different. The Greylock Schist originated from slope and rise deposits while the Stockbridge Formation originated from limestone deposited on the continental shelf of Laurentia. The Walloomsac Formation (Middle Ordovician) is a syn-orogenic flysch formed from sediment shed from advancing thrust sheets during the Taconian Orogeny.

The Greylock Schist in this area is a medium to dark gray schist and the Stockbridge Formation is represented by gray, coarse-grained calcitic marble. The Walloomsac Formation in our area consists of two members: a black, graphitic phyllite and an easily eroded, highly micaceous, sandy calcitic marble.

These units were deformed during the Taconian Orogeny (450-470 Ma). In this event, a magmatic arc collided with the ancient continent of Laurentia. The collision caused the faulting, folding, and metamorphism in western New England.

METHODS

We performed our field work over a two-week period, focusing on streams and ridges where we found the most outcrop. We mapped our stations using topographic maps and an altimeter. We used a protractor to measure the orientations of 0.5 cm sections of the streams on the topographic maps. We sub-divided the stream data based on the average slope of each stream. Those streams with an average slope $< 10\%$ tend to be at low elevations, generally strike north-south, and are usually higher-order streams. The streams with an average slope $\geq 10\%$ tend to lie at higher elevations, generally strike east-west, and are usually first order streams. We plotted this stream data and our structural data (i.e., foliation and joint orientations) on stereonet diagrams for analysis.

DATA

The outcrop patterns in our study area strike essentially north-south. This pattern is especially prevalent in the southwestern corner of the area. The only anomaly in this pattern is around the most prominent ridge "Sugarloaf" (Figure 1). Here the outcrop pattern and location of the contacts that we observed are concentric about the ridge.

shear. The joints we measured strike in two prominent directions. The most prominent set strikes 110° and the other set strikes 030° (Figure 5). Jointing was easier to recognize and measure in the marble than in the other lithologies. Therefore, our data set may favor jointing orientations present in the marble.

Our upper elevation stream data set, which is a measure of stream orientations above 390 meters, shows a bimodal distribution of 140° and 200° (Figure 6a). The lower elevation stream data set shows one prominent orientation of 190° (Figure 6b). The streams above 390 meters are smaller first and second order streams which flow down the flanks of mountains. The streams below this level are higher order streams which run through the dominant north-south trending valleys (Figure 7).

Interpretations

The two stream data sets we collected, although showing similar mean vectors (within 20°), show that stream flow direction is controlled by different factors at different elevations. In the upper stream data set, the mean vector, which represents the average stream orientation, is 168°. However, there are two distinct groups of stream orientations which are not similar to the average orientation direction. These two orientations of 140° and 200° correspond to the primary and secondary joint sets of 110° and 210° (Figure 5 and 6a). Upper elevation streams can follow either set of joints, however, streams that flow down the western slopes tend to follow the secondary joint set while streams that flow down the eastern slopes tend to follow the primary joint set. Some upper elevation streams also alternate between joint sets and therefore create distinctly sharp bends. Since the trend of the dominant foliation is parallel to that of the secondary jointing it is difficult to determine whether foliation or jointing controls the less dominant stream orientation.

The lower elevation streams have an average orientation of 175°. There is only one dominant orientation, as opposed to two in the upper streams. This dominant orientation of the lower streams is 195°. Therefore, these streams could only be affected by secondary joints. The prominent stream orientation also matches the strike of the regional foliation. As streams move downward into the valleys and reach the marble lithological contact, they are increasingly affected by regional foliation and bedding than by joints.

We believe the bedrock geology of our study area is dominated by imbricate faults. We base this on the following evidence: If the rocks were extensively folded, we would expect to find more variation in the strike and dip of the bedding and foliation. The sense of shear in the small scale folds shows top to the west movement. Although the number of contacts we observed directly was small, every contact showed signs of thrusting. There is no symmetrical pattern to the lithologies we mapped. Even if folding could explain this pattern, we did not see an abundance of complex structures that normally accompany folding. We observed outcrop scale features, such as deformed marble slivers encased in schist, (8 meters) which could have only been transported to their present locations by fault drag. These features show evidence of large displacement on fault surfaces.

Conclusions

- Imbricate thrust faults dominate the structure in the area.
- Streams above 390 meters are influenced by the primary joints, secondary joints and foliation.
- Streams below 390 meters are influenced by foliation and secondary joints.

References Cited

Ratcliffe, Nicholas M., Potter, Donald B., Stanley, Rolfe S., 1993, Bedrock Geologic Map of the Williamstown and North Adams Quadrangles, Massachussetts and Vermont, and part of the Cheshire Quadrangle, Massachussetts: U.S. Department of the Interior, U.S. Geological Survey. MI-2369

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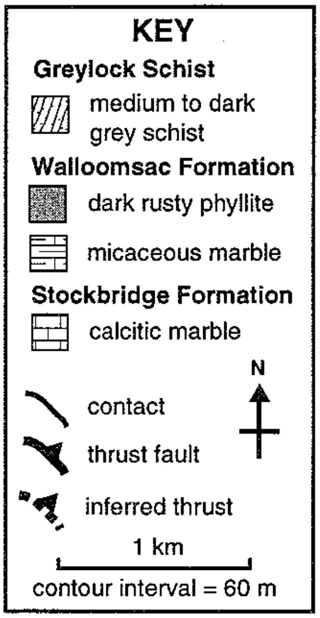


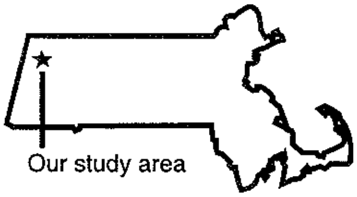
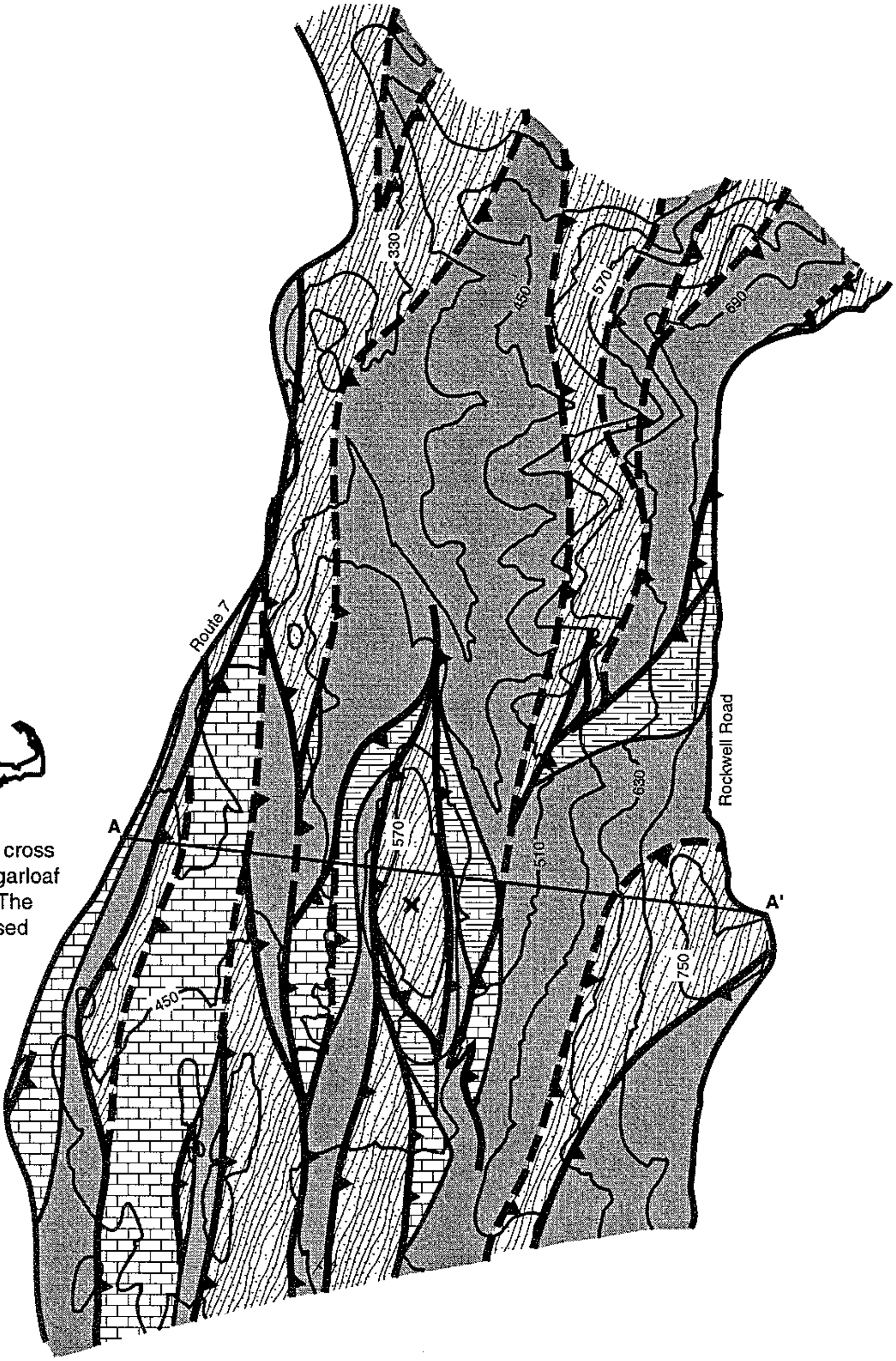
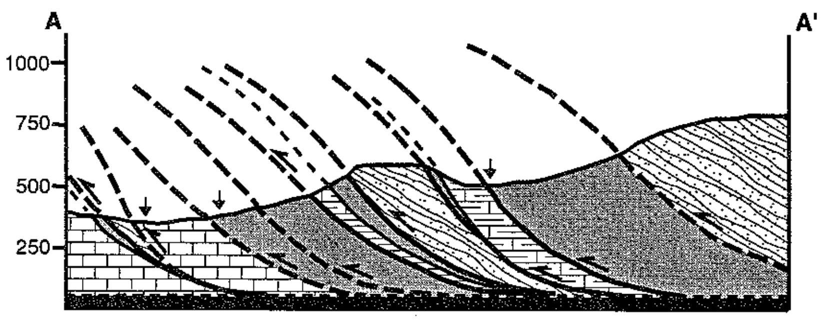


Figure 1: Geologic map and cross section of the study area. Sugarloaf ridge is marked with an "X". The cross section geometry is based on a duplex model for deformation. The vertical arrows in the cross section show the locations of streams.





The strike and dip of the dominant foliation is very uniform over the entire study area, having an average strike of N 18° E and dipping at 34° (Figure 2). A later crenulation cleavage is developed in many locations, dipping to the east approximately 10 degrees steeper than the dominant foliation.

Joints are not so uniform in strike as the foliations, but they tend to dip at high angles, averaging 78° (Figure 3). We determined the orientations of two major joint sets: one striking N 10° E to N 30° E and the other striking approximately due east. One could argue, however, that the second joint set could be divided into two different sets: one striking N 60° E to N 80° E and the other striking S 50° E to S 80° E.

Small-scale isoclinal folds are common in all lithologies. Most of the isoclinal folding is asymmetrical and indicates a transport direction to the west. We did find some symmetrical isoclinal folding in the schists and phyllites that resembles the small-scale folding one would expect to find in the hinge of a large fold. Direct evidence for large-scale folding, such as changes in the sense of asymmetry, however, is sparse in our area and we were only able to confirm meter-scale folding at three locations and all occur in marble. We found evidence for bedding in the marble, but there were no preserved primary structures to indicate the facing direction. Centimeter-scale duplexes and quartz boudins sheared parallel to the foliation planes are common (Figure 6). The transport direction indicated by these structures is usually to the west, in the up dip direction of the foliation.

Our stream data are plotted on rose diagrams in figures 4 and 5. Figure 4 shows the streams with a slope < 10%. The north-south trend of these streams is evident from the diagram. These data could, however, be subdivided into two sets of streams; the first set is striking N 10° W to N 20° W and the second set is striking N 10° E to N 20° E. Figure 5 shows the streams with a slope ≥ 10%. The dominant trend of these streams is N 70° E to due east. Note, however, that there is a less prevalent trend striking N 60° W to N 70° W.

INTERPRETATION

In our interpretation of the geology of our study area we considered two mechanisms of deformation: simple thrust slivers and folded thrusts. The thrust sliver mechanism is supported by the uniformity of the foliation measurements which suggests that the area is perforated by west- directed thrust faults. It is also supported by the numerous small-scale duplexes and boudined quartz veins that indicate the same westward transport direction. The linear outcrop pattern does not contradict this mechanism in most places. One exception to this is the outcrop pattern around Sugarloaf. Ratcliffe and others (1993) explained this using a klippe in his geological map. This could very well explain the outcrop pattern around Sugarloaf. The data could fit a model that puts a doubly or singly plunging folded thrust underneath the ridge.

Folded thrusts are widely used to explain the geology of the Berkshires and we did find some support for it occurring in our area. One of these are the symmetrical isoclinal folds that we found occasionally in the phyllite which indicate that they could be located in the axial plane of a very large fold. We did not see any indication of the facing direction, so we could not support very large-scale folds with our other data. The prevalence of the isoclinal folding and the high degree to which much of the rock in our area is foliated, however, suggests that strain was very high during metamorphism. This high strain could have erased any original bedding or other signs of facing directions.

Though it is likely that both mechanisms are responsible for the outcrop pattern we see in our area, the amount of data in support of thrusting slivers greatly outweighs the data in support of folded thrusting. We therefore based our map and cross section on a thrust sliver model (Figure 1).

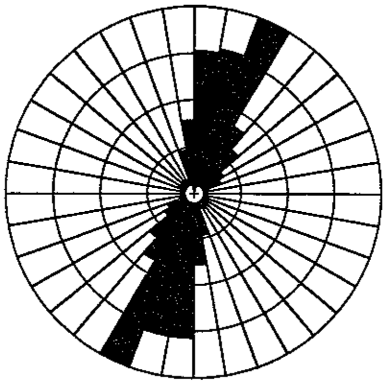
In light of the previous discussion, the stream data shows some very striking correlations with our structural data. The streams with a slope < 10% are following the strike of the foliation (compare Figures 2 and 4) and the trend of contacts and thrusts in our area (Figure 1). The course of streams with a slope ≥ 10% follow the strike of the most prominent set of joints in the area (compare Figures 3 and 5). We therefore conclude that the higher-order streams at lower elevations in our area are being controlled by the foliation, the thrusts, and probably also the lithologies of the rocks that make up the thrust slivers. The lower-order streams at higher elevations are being controlled by jointing in the rocks.

CONCLUSION

We cannot rule out the possibility that a folded thrust model accounts for some of the deformation in our area. The majority of our data, however, supports a model of deformation dominated by westward moving thrust slivers. The higher-order streams in our area are being controlled by the strike of these thrust slivers and the lower-order streams are being controlled by the dominant set of joints.

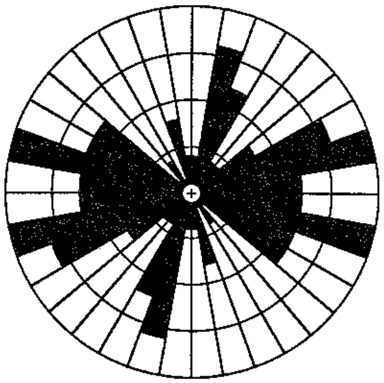
REFERENCES CITED

Ratcliffe, Nicholas M., Potter, D.B., and Rolfe, S..S., 1993, Bedrock geologic map of the Williamstown and North Adams quadrangles, Massachusetts and Vermont, and part of the Cheshire quadrangle, Massachusetts,: U.S. Geological Survey Miscellaneous Investigations Series map I-2369, 2 sheets.



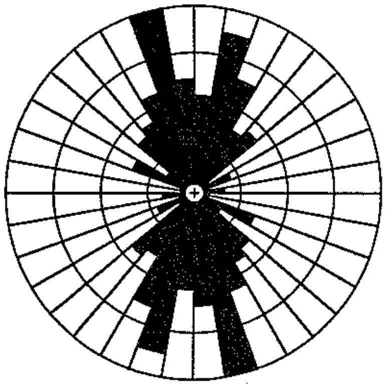
N = 173 Maximum Percentage = 22.0 Vector Mean = 17

Figure 2: Rose diagram showing the strike of the dominant foliation.



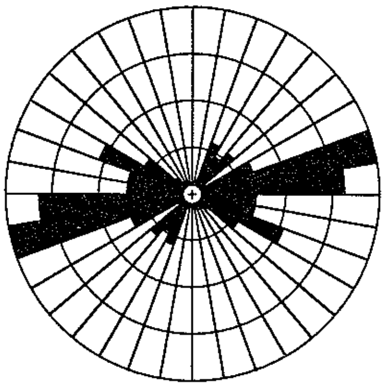
N = 42 Maximum Percentage = 11.2 Vector Mean = 78

Figure 3: Rose diagram showing the strike of all joint measurements taken in the field.



N = 161 Maximum Percentage = 14 Vector Mean = 358

Figure 4: Rose diagram showing the trend of streams with a slope < 10%.



N = 81 Maximum Percentage = 21 Vector Mean = 83

Figure 5: Rose diagram showing the trend of streams with a slope ≥ 10%.

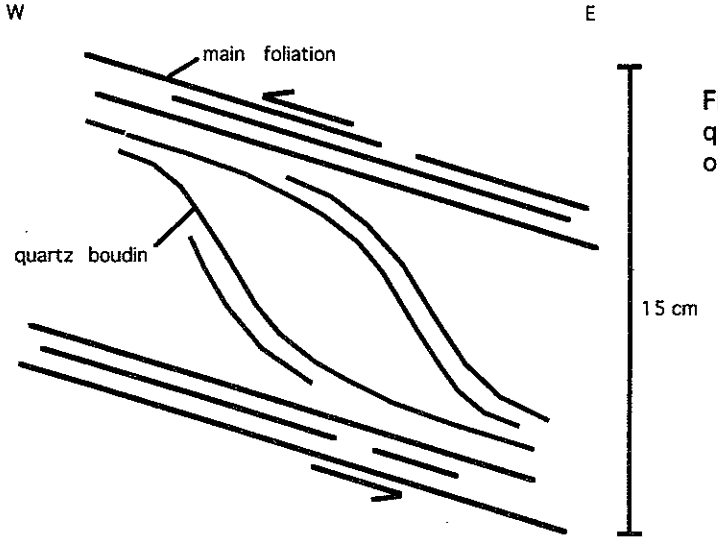


Figure 6: Cross section of a typical quartz bouden sheared in the direction of motion.

Structural Controls on the Geomorphology of Brodie Mountain

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INTRODUCTION AND GEOLOGIC SETTING

The Taconic Mountains of western New England are dominated by a series of largely parallel, north-northeast trending ridges and valleys. Our study investigated the structural and lithological controls on the topography and geomorphology. The study area is located on the northern end of Brodie Mountain in Berkshire County, Massachusetts. The area is bounded by Routes 7 and 43 south of Williamstown, Massachusetts, with a total relief of 460 meters (Fig. 1).

Exposed rocks on Brodie Mountain, as mapped by Ratcliffe and others (1993), include units of the Stockbridge, Walloomsac, and Nassau Formations. The Stockbridge Formation (Early Cambrian to Early Ordovician in age) is a series of calcitic and dolomitic marbles representing continental shelf sedimentation. The Nassau Formation, Late Protorozoic to Early Cambrian in age and equivalent to the Greylock Schist mapped by Abeyta and Steffen (this volume), is partly coeval with the Stockbridge Formation but was deposited on the continental slope and rise (Ratcliffe and others, 1993)). The Walloomsac Formation (Middle Ordovician) is mineralogically similar to the Nassau Formation, but is distinguished from it by its dark grey or black color and the common occurrence of graphite. It was probably derived by erosion of accretionary wedge sediments (Karabinos, personal communication).

METHODS

Two weeks of field work consisted of a series of traverses across the field area. Our traverses focused on stream drainages and logging roads to maximize outcrop density. To determine our location, we used USGS topographic maps and altimeters. Measurements of stream orientation were taken from the topographic maps. Streams were divided into 125 meter increments and the orientations of all the increments were plotted on rose diagrams.

RESULTS

The Nassau and Walloomsac Formations alternate on the eastern slope of Brodie Mountain. The Nassau Formation is thick near the summit and on the western slope of the mountain. In outcrop we observed small scale interlayering of the Nassau and Walloomsac Formations. The Stockbridge Formation structurally underlies the Nassau Formation on both the east and west sides of Brodie Mountain.

The small scale structures we observed included sets of imbricate faults as well as rotated quartz boudins which, as kinematic indicators, display a top to the west sense of shear.

Foliation measurements were quite consistent throughout the area, striking 017° and dipping 27° to the southeast on average with a standard deviation of 6° on the strike (Fig. 2a and 2b).

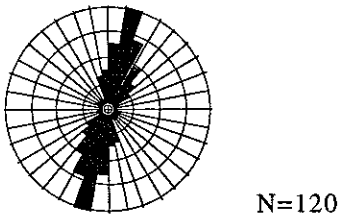

Figure 2a. Rose diagram of strike of foliations. Largest petal is 22%.

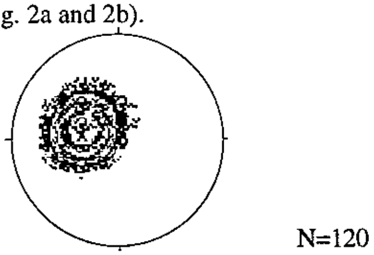

Figure 2b. Kamb contour diagram of poles to foliations. Contour interval = 2.0 sigma.

We observed distinct joint patterns on the east and west flanks of Brodie Mountain. On the eastern slope the average strike of the prominent joint set was 085° and a minor joint set was present with an average strike of