Structural controls on valley and ridge orientation on the southeastern flank of Mount Greylock, Berkshire County, Massachusetts

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INTRODUCTION

Many of the ridges and valleys in Western Massachusetts and Eastern New York are oriented NNE. Glacial carving did occur during the Pleistocene, but glacial striations and crescentic marks in the region suggest that glaciers moved in from the northwest (330°) rather than the northeast; therefore they cannot be invoked to explain the observed orientation of valleys. The object of our study was to investigate the possible existence of a structural control on valley orientations by determining the relationships between structural and lithologic features, valley orientations, and tributary stream orientations.

GEOLOGIC SETTING

The area of study is the southeastern flank of Mount Greylock in the Cheshire $7^1/_2$' by 15' Quadrangle. Route 8 and Rockwell Road represent the East and West borders, respectively (Fig. 1). Topographic relief is approximately 670 m, from the Route 8 valley to the highlands occupying the northwest corner of our area.

The bedrock in the area is dominated by units of the Greylock Schist, the Stockbridge Formation, and the Walloomsac Formation. The Stockbridge Formation in the area includes a calcitic and a dolomitic marble with coarse-grained textures and a color ranging from light to dark grey. It was deposited in a shallow offshore environment on the continental shelf during the Cambrian and Ordovician. The Walloomsac Formation, an extremely dark grey, rusty, micaceous and graphitic phyllite with minor marble, may represent syn-orogenic sediment shed from advancing thrust sheets (Ratcliffe and others, 1993). Further offshore on the slope and rise of the continental margin, the Greylock Schist, a grey-green chloritic schist with albite and quartz, was deposited during the Late Proterozoic to Early Cambrian. During the Ordovician Taconian Orogeny, the collision of an arc with ancient North America resulted in westward-directed thrusting and the consequent emplacement of the Greylock Schist above the Stockbridge and Walloomsac Formations.

METHODS

A two-week field study of our area was concentrated along streams, roads, and trails. We located ourselves using topographic maps and altimeters. Lithologic samples were often taken because wet bedrock was difficult to identify in the field. We measured stream orientations from topographic maps in 5 mm increments, and plotted the data on rose diagrams. We plotted the orientations of two major ridges and one line of slope-change within our area, using best-fit lines to follow the topography.[1]

DATA

Dominant cleavage, or foliation, strikes very consistently between 000° and 040° within our area (Fig. 2). Dips range between 15° and 90° to the east, although the vast majority of dips are to the east between 25° and 50° Often, exact dip was difficult to measure because of the undulation in the surface, but even in cases such as these, an overall east dip was not difficult to discern. The trend of local ridges closely matches the foliation strike; the three ridges which we measured trend between 025° and 035° (Fig. 3). While the orientations of lithologic contacts were not measured, the map reveals that they, too, strike NNE (Fig. 1).

Our measured joints formed a maximum between 090° and 120° (Fig. 4). The measured set strikes almost perpendicular to the foliation, indicating that they are tectonic in origin (Leftwich, pers. comm.). While many joints

[1]The two ridges and single line of slope-change will all be referred to as "ridges" from here on.

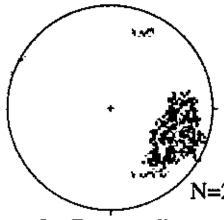

Figure 9. Contour diagram of lineations. Contour interval is 2%/1% area.

INTERPRETATIONS

Our cross-section (Figure 1) shows a duplex model to explain the tectonic evolution of the Brodie Mountain area. The evidence for this interpretation is as follows:

- We believe the small scale structures that we observed on traverses, such as imbricate thrust faulting and small duplexes involving quartz veins, are a small scale reflection of the large scale structural style (J. Leftwich, personal communication).
- The duplex model provides a plausible explanation for the alternating phyllite-marble packages that are seen throughout the Taconic Range and more specicifcally in our area. Existing geologic models for this area invoke a complexly folded thrust sheet in conjunction with erosion to explain not only the alternating marble-phyllite sequence, but also for the alternating sequence of the Nassau and Walloomsac Formations (Ratcliffe and others, 1993). The duplex model implies the stacking of alternate layers of phyllite and marble, allowing the marble to be eroded in a linear fashion, leaving the phyllite to create the ridges. On the other hand, the folded thrust model invokes the emplacement of a slab of phyllite over the marble, not accounting for the linear fashion in which the marble erodes (see Fig. 1 and Cross Section B mapped by Ratcliffe and others, 1993). Also, the small scale structures mentioned above are more consistent with the duplex model than with the folded thrust model.

The similarity between the orientations of the streams and the strike of major joint sets on both the east and west slopes of Brodie above 330 meters suggest that the joints control drainage patterns (refer to Figures 3-6).

Although the western slope may not have enough joint set measurements to be qualatatively compared to the eastern slope, because the stream orientation on the western slope followed the joint set so closely, we feel that perhaps an explanation for the two very different joint sets can be made. Although it is not certain, the lithologies and their sequences could help explain the different joint sets. On the east slope, there is an alternating package of the Nassau and Walloomsac Formations. On the west slope, there is a large mass of Stockbridge Formation butted up against Nassau Formation. Perhaps the joint sets formed differently because the lithologies on the slopes had different amounts of stress applied to them or had stress applied to them at different times.

The correlation between the orientations of the eastern and western branches of the Green River (routes 7 and 43, respectively) and the overall dominant foliation of both the eastern and western slopes of Brodie Mountain suggests that the dominant foliation and lithologic packaging controls the orientation of the river (refer to Figures 2b and 7-8).

CONCLUSIONS

- The duplex model is the most viable hypothesis to explain the geologic patterns and geometries in our study area.
- Jointing influences the orientation of streams flowing off of the mountain ridges.
- Lithology is the major influence on the orientation of the streams in the large valleys.
- On a regional scale, the drainage is controlled by large structures: major foliation and lithologies. Locally, on a small scale, joints control the orientation of low order streams.

REFERENCES

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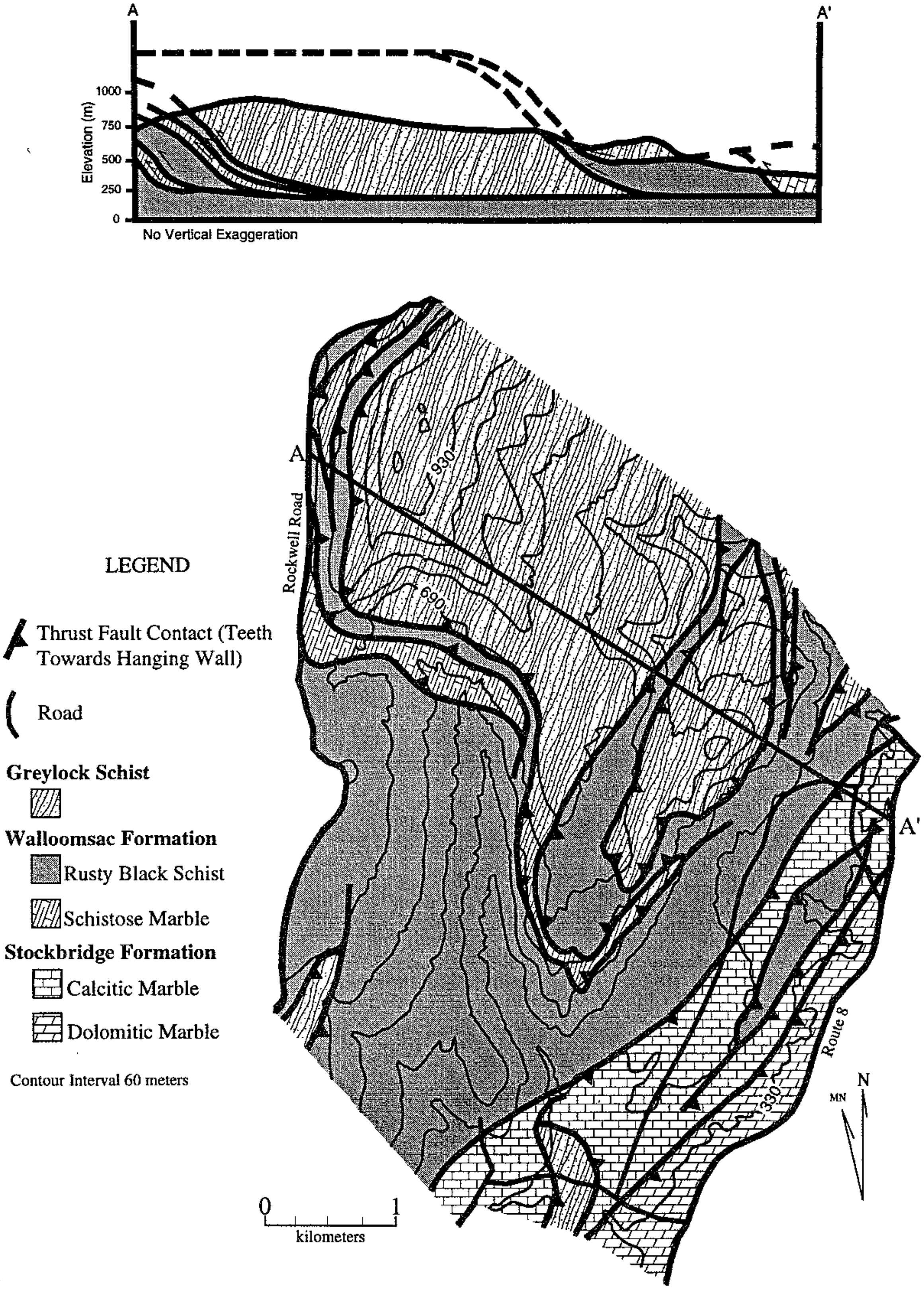

Figure 1. Geologic map and cross-section of the southeastern flank of Mount Greylock.

were vertical or near-vertical, those with more shallow dips were twice as likely to be southerly-dipping than northerly-dipping.

Stream orientations, when plotted, trend mainly NW-SE (Fig. 5). One stream orientation maximum, between 150° and 160°, did not appear to correlate with the joint orientation shown in Fig. 2. However, we were hesitant to dismiss altogether a correlation between the main joint trend and the second stream orientation maximum, which trends between 120° and 130° (Fig. 5). Till was not widespread because of the high elevations, and stream valleys were generally cut deeply enough to be flowing over bedrock in most of our area.

We were able to see evidence for east-to-west thrusting nearly everywhere in our area except for the Route 8 valley. Miniature duplexes with a top-to-west sense of shear were common along Rockwell Road, but sparse in other locations. Boudinaged quartz veins, though small, indicate a westward thrust direction as well. Many of the stretching lineations we saw trended approximately 100° and plunged approximately 25°. There are a handful of minor (<1 m scale) fold axes located in our area which dominantly trend NNE and plunge between 16° and 27°, but no evidence was found for large-scale folding.

The thickness of bedrock lithologies varies greatly within our area. While the Walloomsac Formation is widely exposed in the southern half of the area, it is only present in thin bands in the northern half. Dip measurements on foliation indicate that these bands are thin in terms of their structural thickness as well, especially when compared to the Greylock Schist.

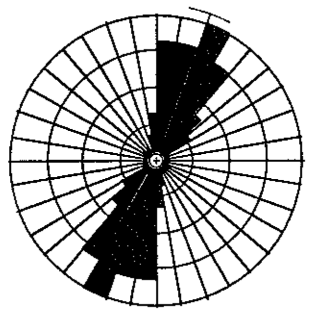

Figure 2. Rose diagram showing strike of foliation measurements. N=107 Max % = 20.6

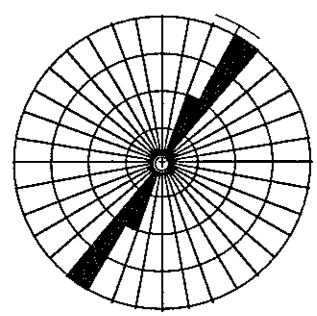

Figure 3. Rose diagram showing orientation of ridges. N=3 Max % = 66.7

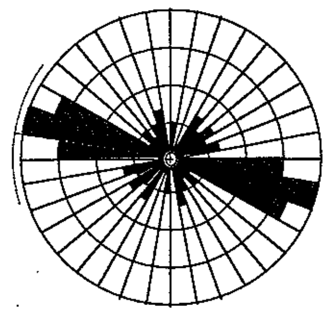

Figure 4. Rose diagram showing strike of joints. N=69 Max % = 17.4

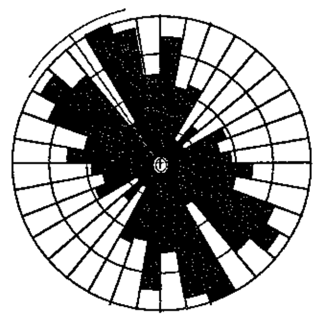

Figure 5. Rose diagram showing orientation of streams. N=238 Max % = 9.2

INTERPRETATIONS

Because the known depositional environments of the Stockbridge and Walloomsac Formations make a stratigraphic contact between them and the Greylock Schist impossible, the contacts which we found were necessarily the result of thrusting. The folded-thrust model, invoked by Ratcliffe and others (1993), uses regional folding of a single thrust surface to explain the repetition of layers of Greylock Schist, Walloomsac Formation, and Stockbridge Formation. Our data fail to show evidence for large-scale folding, both because of the regularity of the foliation measurements and the lack of a consistent symmetry of layering. While it is true that our cross-section shows alternating layers of Greylock Schist and Walloomsac Formation phyllite, the strongly varying thicknesses of these layers are not explained by the folded-thrust model (Fig. 1). Isoclinal folding requires much more mirror-like symmetry across the axial surface than can be seen in our area.

While minor fold axes can certainly be seen in our area, the dominance of a westward sense of shear made another model, the thrust-sliver model, much more convincing. Had large-scale folding occurred, evidence for a wider variety of shear directions would have been prevalent. Considering that synclines would have to occur at regular intervals between anticlines during thrusting of large-scale folds, it would have been as easy to find eastward kinematic indicators as it was westward ones. This was not what we observed. Additionally, the topographic relief of the area, when combined with the similarly large-scale of the proposed folds, would necessitate a larger range of foliation dips in our area, especially along an east-west traverse. This is true because the surface would be equally likely to intersect the large folds at areas of low dip as high dip. The fact that most of our dips were within a 25° range supports sliver thrusting such as would occur in the thrust-sliver model (Fig. 1).

The similarity of foliation strike to ridge orientation validates the hypothesis that there is a structural control on ridge orientation. Both ridges and valleys are oriented at 030°, and the kinematic indicators which we saw show a thrusting direction perpendicular to this azimuth (east to west, bearing approximately 300°). After the thrusting occurred, the layered formations were left striking 030° -- this determined the *orientation* of the ridges. The specific *locations* of the ridges were determined mainly by the resistance to weathering of the layers of Greylock Schist and Walloomsac Formation. The valleys likewise formed along the same orientation in the Stockbridge Formation, which is more easily weathered due to its calcareous composition.

The fact that one set of stream orientations is approximately 20° south of the dominant joint set which trends between 100° and 120°, is not necessarily a sign that joints do not control stream direction. While a correlation between the two seemed initially unlikely from a statistical standpoint, further analysis of joint dips suggests that joints may control stream flow, even though the correlation is not apparent in rose diagrams (Figs. 4 and 5). Joints are twice as likely to dip to the south as they are to the north, and most streams flow over southerly-dipping topography. Therefore, these two factors add a southerly component to stream flow direction. This enables stream orientation to deviate slightly from the average strike of joints. (Figs. 4 and 5).

CONCLUSIONS

- The structure in the area does control the orientation of ridges and valleys.
- The stream flow directions are influenced by joints strikes, joint dips, and the overall slope of the region, even though the joint strikes deviate from one maximum of stream orientations.
- The thrust-sliver model best explains the sequence of the lithologic units within the region.
- The location of valleys and ridges was determined by differential weathering between the schists and phyllites in the highlands and the calcareous units of the Stockbridge Formation in the lowlands.

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Structural control on geomorphology in the Hopper region, Northwestern Massachusetts

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INTRODUCTION

During the Taconian Orogeny (470-450 Ma) Late Proterozoic and Early Cambrian rocks of the Nassau Formation and Greylock Schist were thrust over younger strata of the Stockbridge and Walloomsac Formations. Thrusting resulted in a wide range of rock types over a limited area. The purpose of this study was to assess the possible effects of bedrock structure on geomorphology by comparing structural features of the area to current drainage patterns.

GEOLOGIC SETTING

Our area (Fig.1) is located on the North Adams, Massachusetts 7.5' by 15' quadrangle, and covers a group of valleys known as "The Hopper." Mt. Greylock, the highest point in Massachusetts, marks the eastern edge of our field area. The area covers approximately 20 square kilometers, and has a total relief of 800 meters.

The Late Proterozoic to Cambrian Greylock Schist predominates in the area (Fig. 1) and originated from muddy sediments deposited on the continental slope and rise. The Cambrian to Ordovician Stockbridge Formation represents carbonate deposits of the continental shelf (P. Karabinos, pers. comm.). The color and character of the marble varies greatly, but within this area it is calcitic, gray or white, and occasionally exhibiting a sugary texture. The Ordovician Walloomsac Formation originated as a syn-orogenic flysch deposit (P. Karabinos, pers. comm.) and includes both a graphitic, rusty-weathered phyllite and a schistose calcitic marble.

METHODS

Data was collected over a ten-day period. Traverses were made up stream beds and over ridges to maximize the collection of data. We recorded rock types and descriptions, and measured orientations of joints, foliations, crenulation cleavage, and minor folds. We measured stream orientations off the North Adams quadrangle map in 125-meter segments. Lithologic and structual data were compiled to produce a geologic map. Structural attitudes and stream orientations were plotted using stereonets and rose diagrams.

RESULTS

Foliation. The orientation of the dominant foliation is remarkably uniform: strike varies from 340° to 65°, but clusters strongly around the average strike of 017° (Figure 2a). Similarly, cleavage in marbles, which is usually sub-parallel to original compositional layering, has an average strike of 018°. Foliation and cleavage in all units dip to the east, varying between 012° and 083°, but generally between 040° and 060°. Figure 2b shows the uniformity of the foliation attitudes.

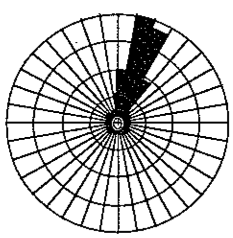

Figure 2a. Unidirectional rose diagram of foliation, N=116
Outer circle=29.1%

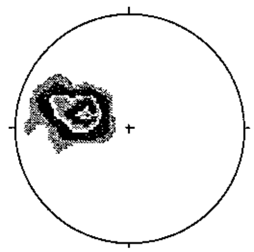

Figure 2b. Equal-Area Stereoplot of poles to foliation, N=116
Contour interval=2%