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.

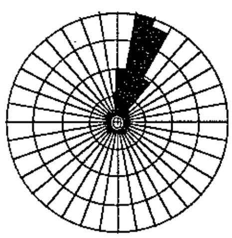

Figure 2a. Unidirectional rose diagram of foliation, N=116
Outer circle=29.1%

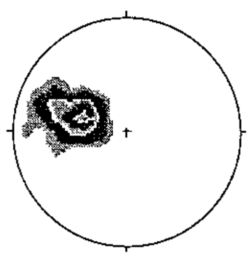

Figure 2b. Equal-Area Stereoplot of poles to foliation, N=116
Contour interval=2%

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.

REFERENCES

Karabinos, P., Saffer, D., Leftwich, J., and DeSimone, D., 1996, Structural controls on the orientation and location of major ridges and valleys in the Taconic Ranges, Western New England and Eastern New York: Ninth Keck Research Symposium in Geology, Abstracts Volume, 12-17.

Ratcliffe, N. M., Potter, D. B., and Rolfe, R. 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.

Joints. The majority of joints in the area trend approximately east-west. Figure 3 shows a unidirectional rose diagram of strikes of joints. While the plot shows clearly the east-west trend, we observed several times at a single outcrop multiple joint sets with noticeably different orientations. In particular, we noticed what we think is a conjugate joint set: one with a strike slightly north of west and the other with a strike slightly south of west. At one outcrop, we recorded these prominent conjugate joints striking 280° and 245°, respectively. However, because the difference between these joints falls within the range of regional variation, they do not show up as two clearly distinct sets on Figure 3, and could simply reflect local and regional variation within a major east-west joint set. Nearly all the joints measured dipped to the north.

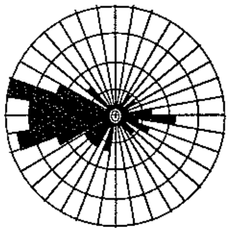

Figure 3. Unidirectional rose diagram of joints, N=82
Outer circle=11.0%

Stream orientations. Figure 4 shows orientations of streams segments measured in 125-meter intervals, located above an elevation of 360 m. We did not include stream segments located below 360 m because they were in the valley and flowed dominantly through aluvium or colluvium; in addition, the Green River, which flows to the north through the valley along the western border of our area, would dominate the results if it were included in the data set. We did not include stream segments with stream order 1 because, in our experience, they flowed mostly through hillslope material above bedrock; discarding these segments enhanced trends in the resulting rose diagram. The resulting group of stream segments flowed on or near bedrock, and were judged to be most likely to show influence of bedrock on stream course.

Figure 4 reveals two strong orientations; one approximately 010° to 030° and another approximatley 290° to 310°. In addition, a third, less prominent trend is clear at 070° to 080°.

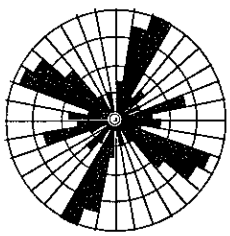

Figure 4. Bidirectional rose diagram of trends of streams of order 2 or higher located above elevation 360 meters, N=93
Outer circle=12.9%

Bedrock structure. We made several observations concerning bedrock structures in the area:

1) The Walloomsac Formation is generally found in thin, less than 250-meter-wide bands across our area, with the lithologic contacts trending approximately parallel to foliation (Figure 1). The Walloomsac is everywhere intensely deformed and contains isoclinal folds and boudined and folded quartz veins. It was commonly found in fault contact with the Greylock Schist. Where fault contacts are not visible, they were inferred based on the intense deformation and location of the thin Walloomsac slivers within large blocks of Greylock Schist.

2) We saw no evidence for large scale folding in the Hopper region. The foliation attitudes exhibited in Figures 2a and 2b suggest that the units are consistently oriented.

3) Kinematic indicators, with rare exception, indicate a tops-to-the-west shear sense.

DISCUSSION

Structures and tectonics. A map of this region published by Ratcliffe and others (1993) presents a folded-thrust model to explain the surface outcrop patterns in the Hopper region. The authors propose that a single sheet of Greylock Schist was thrust over the autochthonous rocks of the Walloomsac and Stockbridge Formations, and that the entire package was isoclinally folded.

The uniformity of foliation attitudes measured (Figures 2a and 2b) suggests that there is little large-scale folding in the units; we interpret the uniformity not as the result of intense isoclinal folds but rather as a consistent tops-to-the-west shear which has rotated the foliation into the dominant orientation. Furthermore, if some of the blocks of Greylock Schist shown in the cross-section in Figure 1 were overturned limbs of recumbent folds, we would expect to see kinematic indicators in those regions indicating the sense of shear not of tops-to-the-west but instead tops-to-the-east. Our imbricate thrust model is consistent with a tops-to-the-west geometry.

We propose a model for the structural evolution of the Hopper region involving a sequence of imbricate thrusts, in which the large horses are composed of Greylock Schist, with smaller slivers of Walloomsac Formation, and occasionally Stockbridge Formation marble, occuring as smaller blocks between the major horses (Figure 1). We suggest that the Greylock Schist was thrust over the autochthonous Walloomsac and Stockbridge Formations during the Taconian orogeny. Later, faults propogated into the foot wall and dragged some of the Walloomsac and Stockbridge Formation rocks as slivers between imbricate thrust sheets up away from the sole thrust separating Greylock Schist from underlying Stockbridge and Walloomsac formations. These slivers now appear between thrust sheets of the Greylock Schist in the Hopper region, explaining the surface outcrop pattern exhibited in our geologic map (Figure 1).

We believe this model, as opposed to the folded-thrust hypothesis, better accommodates the field observations.

Structural controls on geomorphology. Orientations of stream segments located above 360 m in the Hopper region are largely controlled by regional bedrock structures, including dominant foliation and joint patterns. Second-and-higher order streams above elevation 360 m show two prominent orientations (Figure 4). The strong orientation of 020° to 040° is remarkably similar to the dominant strike of foliation, also between 020° and 040°, as displayed in Figure 2. The other main stream orientation trends between 290° and 320°. As discussed previously, two prominent joint sets each trend approximately east-west (both dip steeply to the north): one at 270° to 300°, and one at 240° to 270° The prominent 290° to 320° stream orientation probably reflects the influence of the joint set which trends approximately 270° to 300°. Even if the conjugate pair was actually a single set showing regional variation, the slight disparity between stream orientation and joint orientation could be the result of long term evolution of the streams: a stream flowing to the west (no streams in the area flow to the east) along strike of a north-dipping joint would adjust its trend gradually to follow the dip of the joint and trend slightly north of its original orientation.

Figure 4 also shows a third, less prominent stream orientation trending 250° to 260°. This orientation closely matches the trend of the other conjugate joint, at 240° to 270°.

Field observations support the correlation between structures and stream orientations. At a scale smaller than that recorded by measuring the streams in 125-meter segments, we observed, particularly in Bacon brook, the streams closely following the strike of the foliation. In Hopper Brook, the stream takes a number of right-angle turns as it alternately follows the dominant joint set and a local, less prominent north-south set.

Other streams in our area do not flow over bedrock. These streams generally lie below elevation 360 m. The Green River flows mostly through unconsolidated material in one of the common major north-south valleys of the project's study area. The large valleys, commonly underlain by Stockbridge Formation marble, trend parallel to foliation and most lithologic contacts. The orientation of these north-south valleys, which commonly trend close to 020°, is probably controlled by the location of the marble. Marble, which is less resistant to weathering than phyllite, would be preferentially eroded by emerging streams, and the valleys would form where the marble was located, provided it outcropped in long bands which would facilitate the development of linear valleys. Regional tectonics involving a folded thrust would require the streams to first cut down through the overlying phyllite before reaching marble, and would need some mechanism to explain the long linear nature of the valleys. While the folded thrust model is certainly possible, our model suggests an attractive alternative: slivers of marble brought closer to the surface along planar fault surfaces by imbricate thrusts are immediately susceptible to erosion, and could create the long linear valleys.

CONCLUSIONS

- We propose a model of the structural evolution of the Hopper region involving a sequence of imbricate thrusts which have dragged slivers of the Walloomsac and Stockbridge Formations to the surface between thrust sheets of Greylock Schist.
- Stream segment orientations in the Hopper Region are largely controlled by the foliation and joints in the bedrock.

WORK CITED

Ratcliffe, Nicholas M., Potter, Donald B., and Stanley, Rolfe S., 1993, Bedrock geologic map of the Williamstown and North Adams quadrangles, Massachusetts and Vermont, and part of the the Chesire quadrangle, Massachusetts, Misc. Investigation Series Map I-2369: U.S. Department of the Interior, U.S. Geological Survey.

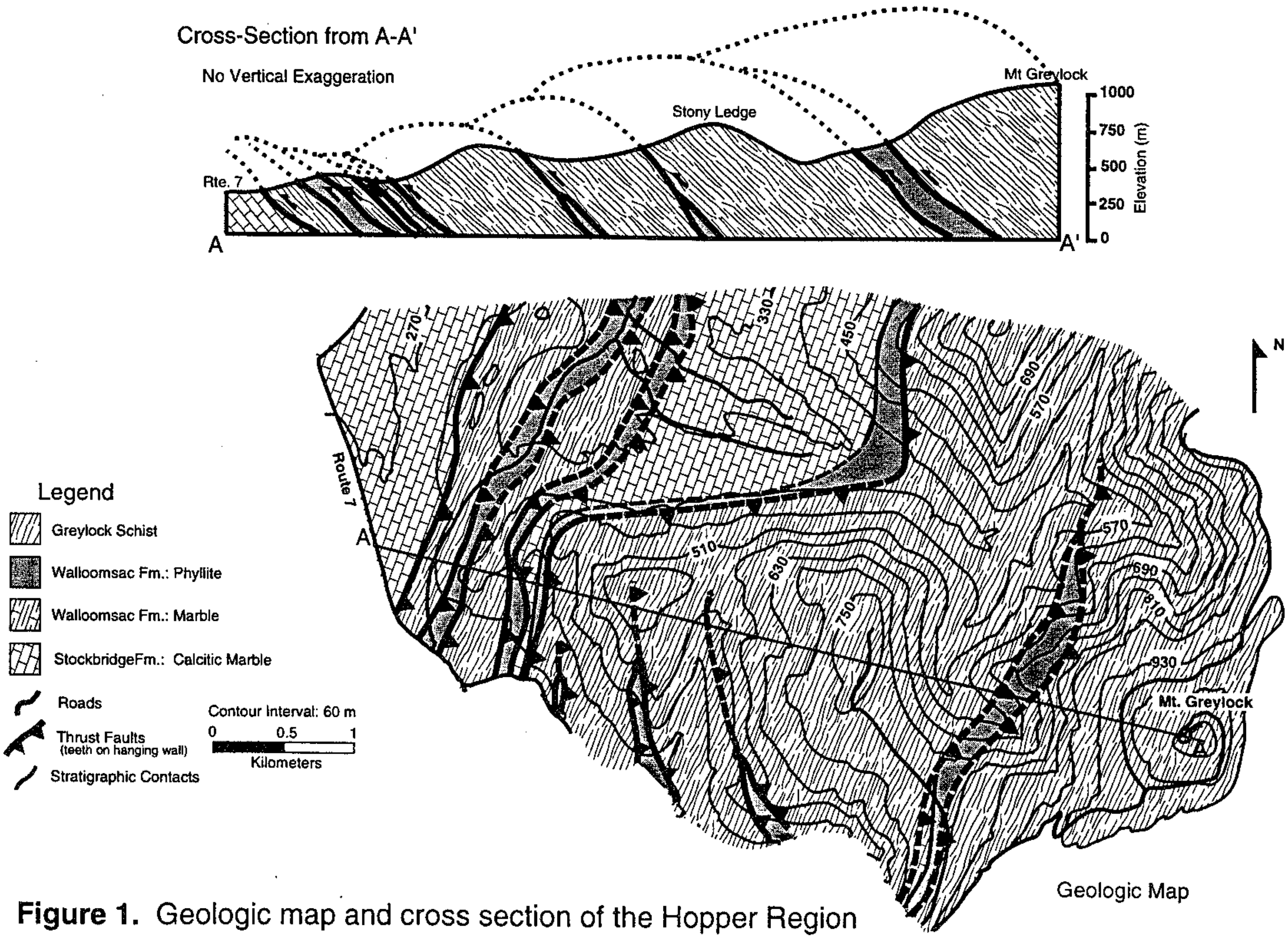

Figure 1. Geologic map and cross section of the Hopper Region

GEOLOGY OF THE CLARKS FORK REGION, PARK COUNTY, WYOMING

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