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Field Trip Guidebook

Stratigraphy and Structure of the Murphy Belt, North Carolina

by

W. Robert Power
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Raleigh
1971

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STRATIGRAPHY AND STRUCTURE OF THE MURPHY BELT, NORTH CAROLINA

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INTRODUCTION

The Murphy Marble belt is a sinuous, northeast-trending structure that extends nearly 100 miles between Cartersville, Georgia and Bryson City, North Carolina. It occupies a position between the Unaka Ranges on the western side of the southern Appalachians and the Blue Ridge on the eastern side. Metasediments exposed in the belt are surrounded by and distinctly different from the Great Smoky Group of the Ocoee Series. Keith (1907) was the first to name and describe these rocks. He interpreted them to be younger than the surrounding Great Smoky formation and hence possible correlatives with the Chilhowee Group of Cambrian age. Most subsequent workers have agreed with these general interpretations, but important problems regarding the structure and lithostratigraphy have not been resolved and the stratigraphic terminology and correlations within the belt are confused. Until these problems are resolved the true regional significance of the rocks must remain in doubt. For this reason Forrest started detailed mapping of the belt in the Murphy quadrangle in 1968 and has since extended his mapping to cover most of five seven and one-half minute quadrangles – the Murphy, Peachtree, Marble, Andrews, and Hayesville quadrangles, all in North Carolina.

As a result of this mapping, we believe that we can demonstrate a consistent lithostratigraphic homotaxis for the entire belt, and that the folding is far more complex than previously supposed owing to multiple deformation. We also believe that a number of proposed major faults do not exist.

Figure 1 is an index to geologic mapping in the belt. For a concise summary of the regional setting we recommend Hadley (1970).

The following 7 ½-minute quadrangles cover the area of the field trip:

Murphy, North Carolina[1]
Marble, North Carolina[1]
Andrews, North Carolina[1]
Culberson, North Carolina
Mineral Bluff, Georgia
Hayesville, North Carolina
Peachtree, North Carolina

1.Formal stops to be made in these quadrangles.

LITHOSTRATIGRAPHY

We contend that a lithologic homotaxis with respect to units of the Murphy Marble belt extends from Cherokee County, North Carolina to Cherokee County, Georgia. We claim that the same homotaxis is displayed by the symmetrical arrangement of rock-stratigraphic units across the belt in North Carolina demonstrating a major fold which we interpret as a syncline. Although none of these ideas are new, important details of the homotaxis have been misinterpreted in the past because of faulty correlations and doubtful structural interpretations. We think that our interpretation is consistent with previous mapping, is correct, and will lead to more nearly correct regional and structural interpretations.

Our interpretation of the stratigraphic section is summarized in Figure 2, which also shows terminology as used by other authors. The succession of strata is the same as mapped by all authors in the west limb of the fold. Our differences with Keith and with Hurst involve structural interpretations – we have eliminated some faults – and our differences with Fairley, we believe, are primarily semantic. For simplicity we forego a separate summary of previous interpretations and discuss our differences with other authors as they occur in describing the section. Based on the synclinal hypothesis we place the youngest rocks in the center of the belt.

Nantahala Formation

The Nantahala formation consists of dark colored, even-textured, laminated to thin-bedded argillite. It is composed predominantly of fine-grained quartz with subordinate feldspar and varying amounts of biotite, graphite, and pyrite. The color ranges from light gray to black depending on the amount of dark minerals present. Individual layers range in thickness from paper thin to about one inch. They commonly are persistent over the width of an outcrop, but in places the lighter layers pinch and swell. Encrustations or “blooms” of gypsum are common and typical of the formation. The most conspicuous and recognizable feature of the formation is the regular alternation of laminae in various shades of dark grey and bluish black.

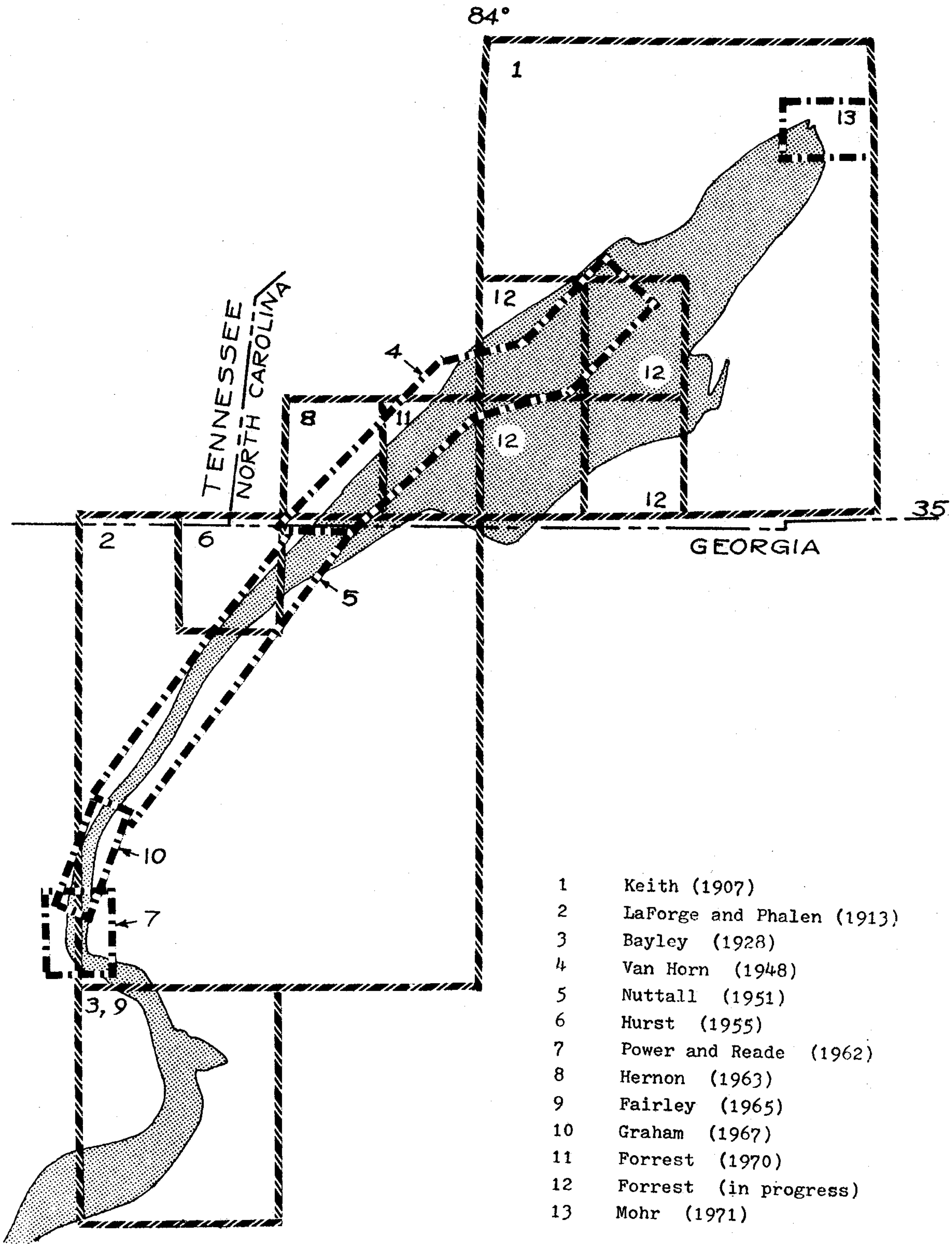


Figure 1. Index to geologic mapping in the Murphy Belt.

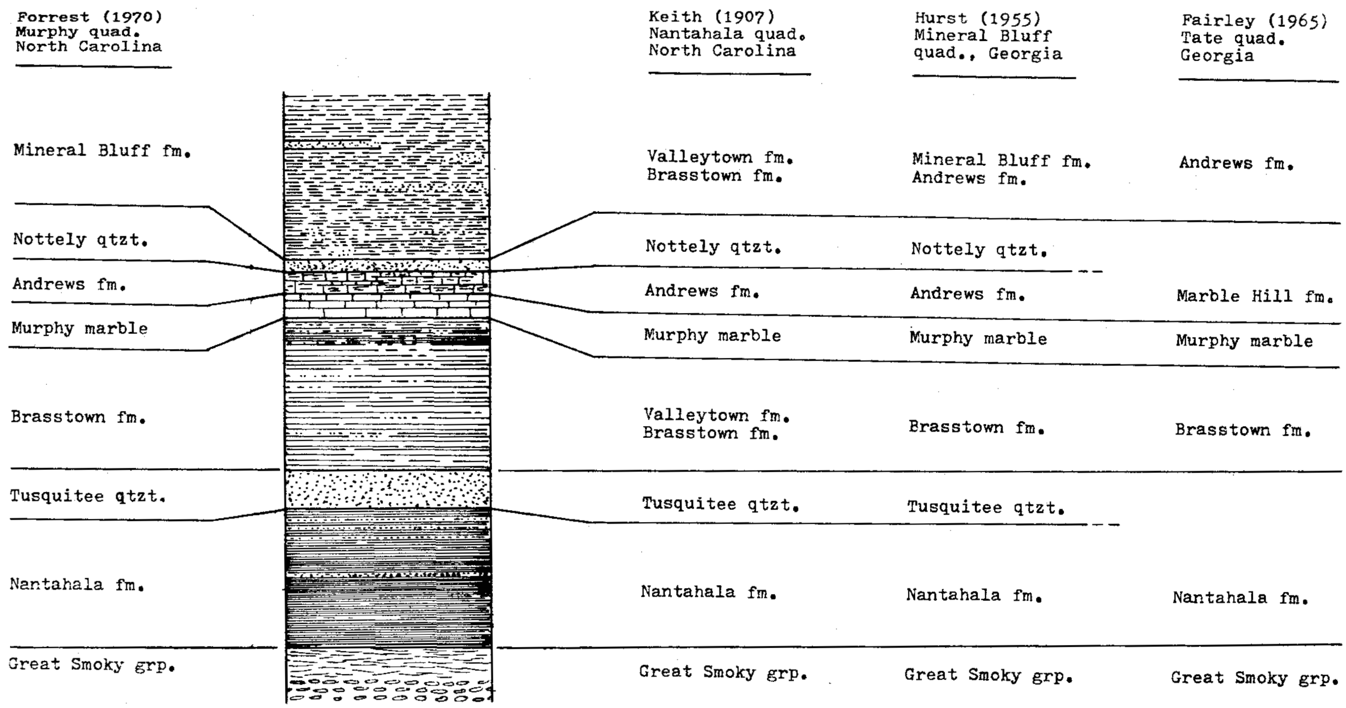


Figure 2. Correlation chart for rocks of the Murphy Belt.

The upper part of the formation contains laminae and beds of buff to almost white feldspathic quartzite. These increase in number and thickness irregularly upward. Near the top of the formation they predominate and the formation passes by gradual transition into the overlying Tusquitee formation.

Most previous workers have called the Nantahala formation a slate, but the easiest fissility parallels bedding so we prefer to call the rock argillite in accordance with the A.G.I. Glossary of Geology (p. 15).

The Nantahala formation was named by Keith (1904, 1907) and has been recognized by all subsequent workers. It forms two sub-parallel outcrop belts in the Murphy quadrangle. The western belt has been traced south as far as the Tate quadrangle, but the eastern belt is un-recognizable south of the Ellijay quadrangle (Fairley, 1965, p. 18).

The contact relationships with the underlying Great Smoky formation were studied by Nuttall (1951) who concluded that the two formations were conformable. No one has found any evidence to contradict this conclusion. Biotite schist lies between typical Nantahala argillite and the first prominent conglomerate of the Great Smoky formation. We have placed the contact at the base of the distinctly laminated unit and so agree essentially with the conclusion of Hadley (1970, p. 256).

The character of the Nantahala apparently changes southwestward along the strike by a diminution in the amount of quartz. Quantitative data is scarce, but most workers in Carolina and northernmost Georgia agree that the composition is mostly quartz. Fairley (1965, p. 14) on the other hand reports as little as 20% quartz in one specimen. The number of quartzite intercalations decrease southward and the overlying Tusquitee quartzite does not occur at all as a recognizable unit south of Ellijay, Georgia, except for some doubtful small intercalations at Whitestone (Power and Reade, 1962).

Tusquitee Quartzite

The Tusquitee quartzite is a light buff to white, feldspathic quartzite with numerous thin intercalations of black argillite. It is the culmination of increasingly numerous intercalations of white quartzite in the top of the Nantahala formation and is completely gradational with that unit. Hadley suggested that the two units “are more feasibly considered as a single formation” (1970, p. 255). Hurst (1955, p. 47) said that the formation is gradational into both the overlying and underlying units. Keith (1907) named the formation and considered all the white quartzites to be the same unit. He interpreted many as synclinal folds within the Nantahala formation. We reject this interpretation as apparently does Hadley (1970) and other recent workers. We do recognize a prominent quartzite, thicker than other intercalations and present in two parallel outcrop belts, essentially separating

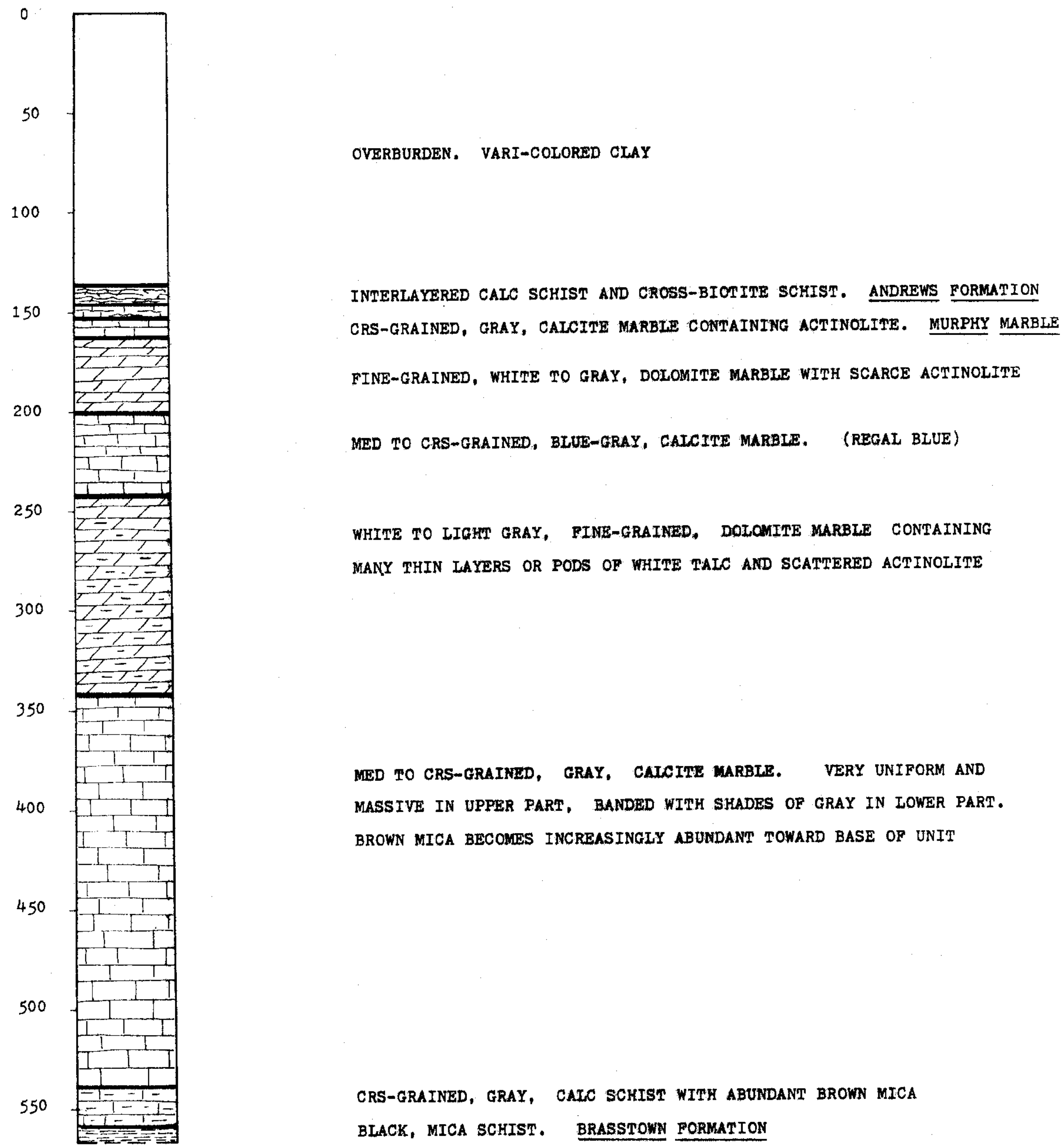


Figure 3. Section through Murphy Marble from core drilled about one mile north of Regal, NC.

distinctive lithologies of the Nantahala and Brasstown formations. We, therefore, treat it as a separate formation, the Tusquitee quartzite.

The Tusquitee formation occurs in two outcrop belts that extend southwestward nearly to Ellijay (LaForge and Phalen, 1913), but it is not recognized in the Tate quadrangle. Power, and Reade (1962, p. 12) suggested that a few thin quartzite beds at the top of the Nantahala formation at Whitestone, Georgia, may represent the Tusquitee formation, but these thin layers are no more than what it typical throughout the Nantahala formation near Murphy. The disappearance of the Tusquitee formation southward is further confirmation of facies changes in the Nantahala formation suggested earlier.

Brasstown Formation

The Brasstown formation is a thick sequence of gray to dark gray, thin-bedded schist and micaceous quartzite. Individual layers commonly range in thickness from about 0.5 to 5 cm. The schist typically contains randomly oriented porphyroblasts of biotite in a fine-grained matrix. These rocks have been called “cross-biotite schists.” Many layers and lenses of calc-silicate granofels (so-called “pseudodiorite”) contain porphyroblasts of hornblende and garnet in a quartz, feldspar matrix. These are lighter in color than the bulk of the rock. In outcrop the formation has a pronounced banded appearance that is typical and distinctive. Black, graphitic argillite near the base of the formation strongly resembles Nantahala argillites and would be included with that formation were it not for the Tusquitee quartzite which is more mappable. The bulk of the Brasstown formation differs from the Nantahala in that graphite is scarce or absent, quartz is less abundant, the apparent grain size in fresh exposure is greater, and the banding or layering is slightly thicker.

The Brasstown formation occurs in two sub-parallel outcrop belts that are continuous southwestward to the Tate quadrangle. Near Jasper, Georgia, the formation is quarried extensively for flagstone. It consists of alternating layers of micaceous quartzite and mica schist. The rock splits easily along the schist layers leaving slabs of micaceous quartzite 2 to 10 cm. thick. Quantitative data are absent, but the quartz content and thickness of individual layers appears to increase slightly to the southwest from the Murphy quadrangle.

Keith (1907) named the Brasstown and another unit, the Valleytown formation which he placed stratigraphically between the Brasstown and the Murphy marble. Hurst (1955) found no valid distinction between the units and lumped all rocks between the Tusquitee formation and the Murphy marble together as the Brasstown formation. Fairley (1965) followed the usage of Hurst and we concur. Actually, rocks mapped as Valleytown by Keith are included not only in the Brasstown of our usage, but also in the Murphy marble in the center of the syncline. In order to account for this position, Keith (1907) proposed a large thrust fault. We find no evidence for this fault. We find rocks in the center of the syncline different from the Brasstown formation as herein defined and believe them to be younger than the Murphy marble in agreement with Hurst (1955). Thus, some rocks that Keith mapped as Brasstown and Valleytown formation are included in our Mineral Bluff formation.

Murphy Marble

The Murphy marble is the most distinctive unit in the belt. It consists of calcareous marble and dolomite with varying amounts of impurities. It is quarried for dimension stone and crushed stone in both North Carolina and Georgia. It has been studied more than any other unit because of its economic importance.

Figure 3 is the log of a core drilled across the marble at the now defunct Universal Materials Company, about two miles northeast of Murphy and in the southwestern corner of the Marble quadrangle.

Talc occurs in the marble at several places and is mined by the Hitchcock Corporation a few miles south of Murphy. The marble crops out discontinuously from Ballground, Georgia, to Topton, North Carolina. Two outcrop belts are distinguished throughout most of the area. In North Carolina the western belt is more or less continuous from the Georgia border to Topton (Van Horn, 1948). The eastern belt crops out discontinuously from the border to Peachtree, but has not been found further north. In Georgia both belts are recognized as far south as Blue Ridge (LaForge and Phalen, 1913). From Blue Ridge to Tate outcrops become scarce and discontinuous and two distinct belts cannot be recognized. At Tate the marble is thickest and most studied, but the structure is extremely complex (see Fairley, 1965).

The marble changes little in character throughout the belt. Both calcite and dolomite marble occur at both ends, but whereas the dolomite marble appears to lie on top of the calcite in North Carolina, the reverse appears to be true at Tate (Reade, 1965). Common accessory minerals include graphite, biotite, amphibole, talc, and pyrite.

Andrews Formation

The Andrews formation is a thin calcareous schist that overlies the Murphy marble. It was so named by Keith (1907, p. 5) and we agree with his definition and limitations. Hurst (1965, p. 53) re-defined the formation so as to include a thick overlying sequence of pelitic schist. The redefinition was based upon what we believe to be a faulty correlation of overlying quartzites and so we return to Keith's original definition.

In the Murphy quadrangle the Andrews formation consists of alternating layers of marble and cross-biotite schist. The layers are paper thin to several feet thick. The color is greenish gray to dark blue-gray. The marble layers are generally impure containing abundant micas. Some are dolomitic. Accessory pyrite is ubiquitous.

Fresh exposures are rare, but the formation weathers to a distinctive varicolored saprolite. Brown iron ores occur abundantly as lenses and concretions in the weathered residue as was noted also by Keith who stated, "The feature which makes this (Andrews) schist of particular importance is the development therein of deposits of brown hematite," (1907, p. 5). The contact between Andrews and the Murphy marble is gradational.

The Andrews formation occurs in parallel outcrop belts on both sides of the syncline. On the west limb it is immediately overlain by the Nottely quartzite, but the Nottely is absent on the east limb and the Andrews is overlain by pelitic schists of the Mineral Bluff formation.

The Andrews formation as herein defined has not been recognized in published work south of the Murphy quadrangle. LaForge and Phalen (1913, p. 7) thought that limonite-bearing clay occurring between the Murphy marble and Nottely quartzite represented the Andrews, but was too narrow to show on their map. Graham (1967) also found limonite between the marble and overlying schist.

Hurst re-defined the Andrews formation to include all of a "metasedimentary sequence 1400-1800 feet thick (that) lies between the Murphy marble and the Nottely quartzite," (1955, p. 53). This thick pelitic sequence does not exist between the Murphy and Nottely on the west limb of the syncline. There is a thick pelitic sequence between the Murphy marble and a second quartzite on the east limb. Hurst correlated this second quartzite with the Nottely quartzite, we think, erroneously. This correlation is the key to what we consider a misuse of the name "Andrews" since 1955 and will be discussed in detail later.

Hurst described a "calcareous schist containing nodes and thin lenses or beds of limonite" at the base of his redefined Andrews formation (1955, p. 54). This calcareous schist represents the Andrews formation as defined by Keith (1907).

Power and Meade (1962) correlated a pelitic unit with the Andrews, an interpretation we now think in error. Fairley, following Hurst, used the name Andrews for overlying pelitic schists and introduced a new name, the Marble Hill hornblende schist for "calc-schists and biotite-hornblende schists (that) lie between the Murphy marble and the garnet-mica schists of the Andrews formation," (1965, p. 30). We contend that the Marble Hill hornblende schist is the true lithologic correlative of the Andrews formation as defined by Keith. The pelitic schists are younger and belong to the Mineral Bluff formation.

Nottely Quartzite

The Nottely quartzite is an orthoquartzite that immediately overlies the Andrews formation on the west side of the syncline only. It is thin to medium-bedded, medium grained, and contains abundant cross-bedding. The cross-bedding shows the top of the formation to be east confirming the synclinal nature of the major structure.

The Nottely quartzite forms a nearly continuous outcrop belt from near Tomotla in the Marble quadrangle southwestward to the Mineral Bluff quadrangle. It has not been recognized south of the Mineral Bluff quadrangle. Hurst (1955, p. 54) found a second quartzite parallel to and approximately 1500 feet southeast of the one described above. He correlated the two in a syncline. In so doing he was forced to hypothesize a major fault on the west flank of the syncline because a thick pelitic sequence intervenes between the eastern quartzite and the eastern outcrop of Murphy marble in the Mineral Bluff quadrangle, but no corresponding schist intervenes on the west. Figure 4, shows Hurst's interpretation of the structure and an alternative that we favor, namely that the eastern quartzite is a separate, stratigraphically higher unit.

Arguments in favor of our hypothesis are as follows:

1. The overlying pelitic unit contains many thin discontinuous quartzite units as shown by Van Horn (1948) and current mapping by Forrest.
2. A quartzite parallel to the Nottely and about 2200 feet southeast in the Murphy quadrangle contains cross-bedding that shows the same facing as the Nottely as defined above.
3. Although Hurst found facing criteria in the western quartzite of the Mineral Bluff quadrangle, his map shows none in the eastern quartzite.
4. If Hurst's structural interpretation is correct then the fault which cut out the pelitic "Andrews" on the west

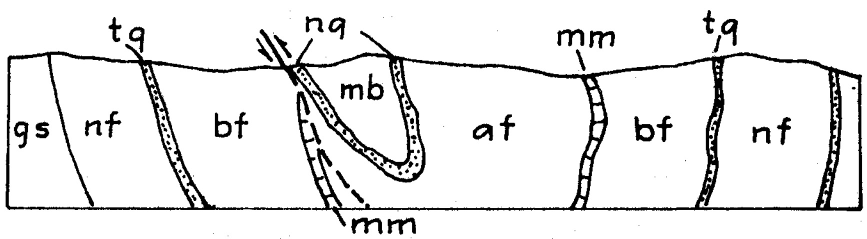


Figure 4a. Cross section across Murphy Marble Belt in Mineral Bluff quadrangle, after Hurst (1955).

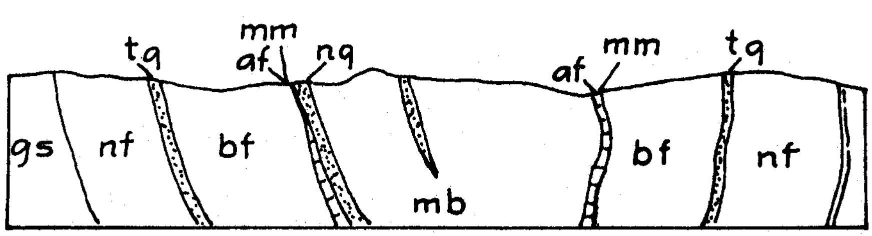


Figure 4b. Alternative interpretation of structure in Mineral Bluff quadrangle favored by authors of this report.

gs, Great Smoky grp.; nf, Nantahala fm.; tq, Tusquitee fm.; bf, Brasstown fm.; mm, Murphy marble; af, Andrews fm.; mb, Mineral Bluff fm.

limb is continuous for at least 25 miles eliminating the pelitic unit and bringing the Murphy marble into contact with the Nottely quartzite for that distance (see Van Horn, 1948, Hernon, 1963, and Forrest, 1970). This we think is highly unlikely.

Mineral Bluff Formation

The Mineral Bluff formation is a pelitic schist with intercalated quartzites, sandy lenses and rare calc-silicate granofels. The principal lithology is quartz-sericite schist or phyllite. Thin to thick layering results from varying quartz content of the rock. With decreasing mica content the rock grades into almost pure quartzite. The quartzite layers are generally no more than a few feet thick but rarely reach several tens of feet. Magnetite and illmenite are widely distributed throughout the formation and staurolite and garnet are locally abundant. Minor beds of graphitic schist, blue slate, garnet-mica schist, and cross-biotite schist occur throughout the formation.

The Mineral Bluff formation was named by Hurst (1955, p. 55). It occupies the central portion of the Murphy belt throughout its length. It includes rocks mapped as Brasstown and Valleytown by Keith (1907) and by LaForge and Phalen (1913). It includes most of the Andrews formation of Hurst (1955) and all of the Andrews formation of Fairley (1965). It includes unit 7 of Power and Reade (1962) and the muscovite-chlorite schist of Graham (1967).

The relationship between the Mineral Bluff formation of the Murphy quadrangle and its proposed correlative in the Tate quadrangle (i.e. Andrews of Fairley) needs some elaboration. Fairley states (1966, p. 37), “A thin calc-schist, the Marble Hill formation, overlies the Murphy Marble … The schists above … cannot be traced into the Andrews formation of the Mineral Bluff Quadrangle, but they are considered correlative on the basis of similar lithology and by their occurrence at approximately the same stratigraphic level.” Fairley further describes the “Andrews” as a “garnet-mica schist which in places has either staurolite or kyanite or both” (1965, p. 37). He also states that the formation contains calcareous facies consisting of micaceous marbles and calc-schists. The principal difference between the “Andrews” of Fairley and our Mineral Bluff formation is that in the Murphy quadrangle the unit contains sandy, quartzitic intercalations whereas in the Tate quadrangle it contains calcareous intercalations. We believe that these differences represent regional facies changes similar to those proposed for the Nantahala formation. This hypothesis is reinforced by the disappearance of both the Tusquitee formation and the Nottely quartzite southward in Georgia. We think that these differences may represent differences in distance from the source area at the time of deposition.

STRUCTURAL GEOLOGY AND METAMORPHISM

Most workers in the Murphy belt have interpreted the structure as a syncline (Keith, 1907; LaForge and Phalen, 1913; Bayley, 1926; Hurst, 1955; Fairley, 1965), but others have proposed that the belt is an anticline (Van Horn, 1948), a window (Stose and Stose, 1944), or a monocline (Graham, 1967). We believe that there is a major syncline centered along much of the belt, but that the total picture is much more complex. The “Murphy Syncline” is but one of a number of major isoclinal folds that have been modified by at least three episodes of subsequent deformation. Evidence for each of these will be shown on the trip.

Following the suggestion of Tobisch and Fleuty (1969) the various folding episodes are assigned a geographic name. This type of terminology avoids chronological and correlation problems, and, like the stratigraphic name, serves to suggest a type area for the folding event. For brevity and convenience each phase will also be assigned a numbered subscript (F_1, F_2, F_3, F_4). It should be remembered that these numbers may have local significance only.

Murphy Phase (F_1)

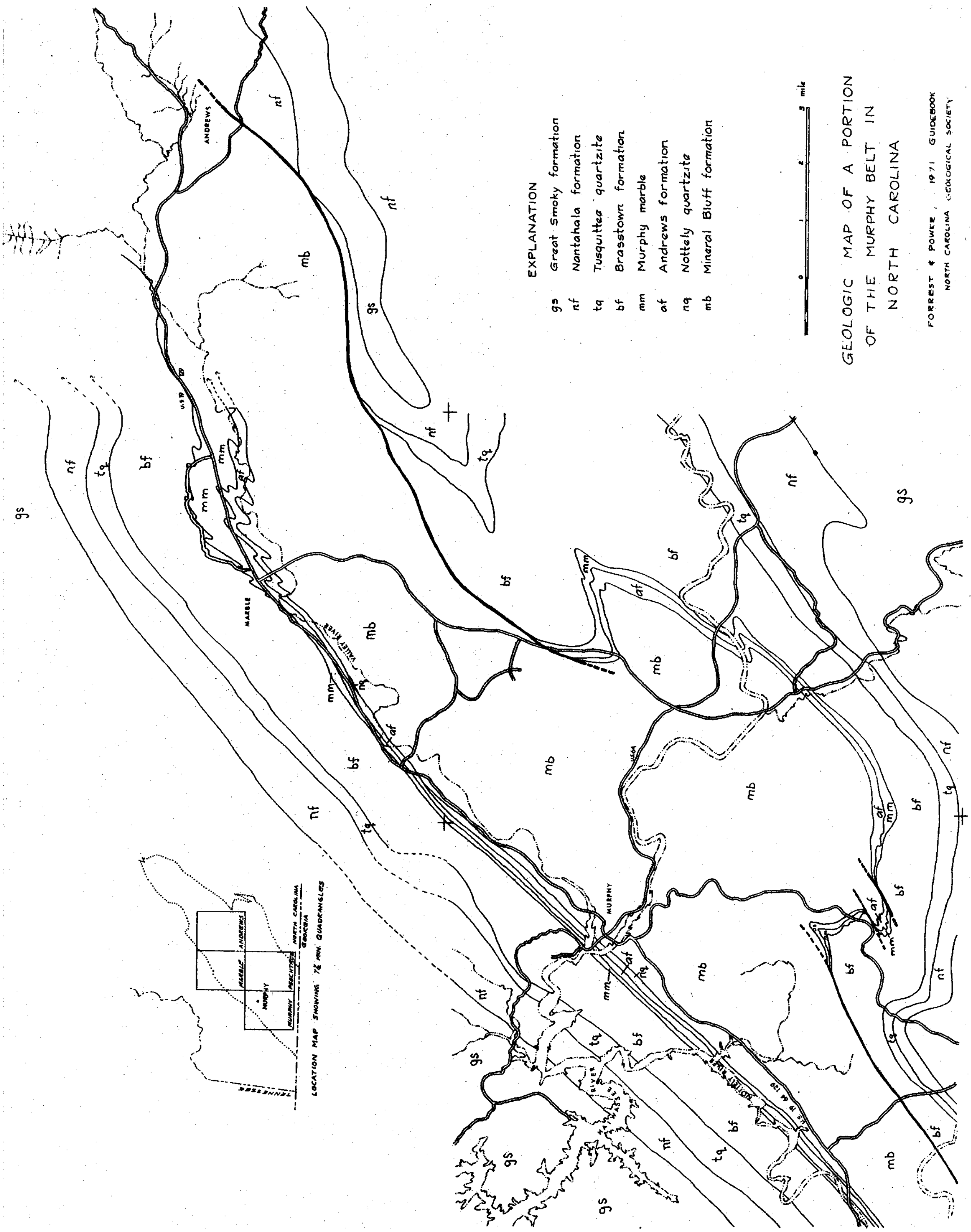
The earliest folds yet found in the Murphy belt are tight, narrow isoclines, visible only at the map scale. The “Murphy Syncline” mapped by Hurst (1955) is of this generation. It can be traced from Mineral Bluff to the southwest corner of the Murphy quadrangle as a relatively simple syncline overturned slightly to the northwest. In the Murphy quadrangle and areas to the northeast the syncline was refolded during later episodes. An F_1 anticline in the Andrews quadrangle exposes Great Smoky rocks in its core. This anticline demonstrates that the first phase of folding did more than produce a simple syncline; it probably produced a series of tight and deep isoclines. The original orientation of the axial plane of these folds is unknown.

The only macroscopic evidence for F_1 is an S_1 schistosity that parallels bedding. No faults associated with this event have been found.

Hanging Dog Phase, (F_2)

The regional dip of bedding is northwest along the northwestern side of the Murphy belt. A shallower, northwest-dipping schistosity (S_2) cut bedding and is, we think, axial plane to F_2 folds. The bedding-cleavage relationships indicate that the rocks are on the overturned limb of a large, relatively open synform with northwest-dipping axial plane. To our knowledge no other structures overturned to the southeast have been in the southern Appalachian region.

No small scale folds or faults have been found which can be attributed to this phase of folding.


EXPLANATION
gs Great Smoky formation
nf Nantahala formation
tq Tusquittee quartzite
bf Brasstown formation
mm Murphy marble
af Andrews formation
nq Nottely quartzite
mb Mineral Bluff formation
0 1 2 3 mile
GEOLOGIC MAP OF A PORTION OF THE MURPHY BELT IN NORTH CAROLINA
FORREST & POWER, 1971 GUIDEBOOK
NORTH CAROLINA GEOLOGICAL SOCIETY
ANDREWS
MARBLE
VALLEY RIVER
MURPHY
LOCATION MAP SHOWING 7½ MIN. QUADRANGLES
NORTH CAROLINA
GEORGIA

Martin's Creek Phase, (F_3)

A southeast-dipping crenulation cleavage (S_3) cuts the S_2 schistosity along the northwest side of the belt. It is axial plane to F_3 folds. The crenulation cleavage becomes more intense southeastward across the strike where it transposes the S_2 schistosity and becomes the dominant secondary foliation in the center of the belt. This type of transition from crenulation cleavage to schistosity was observed by White (1949) in east-central Vermont. On Sunday we will see outcrops that demonstrate this transition.

Large F3 folds have been mapped in the vicinity of Martins Creek and Andrews, North Carolina. All the major faults that we find in the Murphy belt are probably contemporaneous with the F3 folding event.

Marble Phase (F_4)

Near Marble, the axial planes of F_3 folds are nearly recumbent. This results from an F_4 folding event. A northwest-dipping crenulation cleavage (S_4) is associated with this folding. The S_4 cleavage has never been observed as a penetrative foliation. The effects of F_4 are more apparent northeastward and near Andrews the axial planes of F_3 folds are overturned (Stop 5, Road Log III).

Metamorphism – Polymetamorphism

Preliminary petrologic studies reveal two periods of progressive, regional metamorphism associated with F1 and F2 events reached their peak of intensity after deformation (post-kinematic) were followed by a retrogressive event accompanying F3 folding. See Road Log III, for discussion and evidence. No metamorphism associated with F4 has been found.

Summary of Structural Features seen in the Murphy Belt.

Structural features of the Murphy belt and their terminology are listed and defined below:

- S_0 Bedding, original compositional layering.
- S_1 Schistosity parallel to bedding on the limbs of isoclinal folds.
- S_2 Schistosity dipping to the northwest where undisturbed and forming axial planes of F_2 folds.
- S_3 Crenulation cleavage, slatey cleavage, and schistosity related to F_3 folds.
- L_{2X0} Lineation caused by intersection of S2 and S0.
- L_{3X0} Lineation caused by intersection of S3 and S0.
- L_{2X3} Lineation caused by intersection of S2 and S3.

ROAD LOG I – SATURDAY MORNING

We will congregate at the entrance to the Columbia Marble Company off U.S. 19-129 approximately two miles north of Marble, North Carolina. Look for signs and student assistants who will direct parking. The parking lot is a short walk from Stop 4 of the afternoon (Road Log II). The buses will take us back to the center of Murphy where the road log officially begins.

The objective for Saturday morning is to examine the upper part of the Great Smoky formation.

0.0 Intersection of U.S. 64 and U.S. 19 at center of Murphy. Go west on Tennessee street.

0.4 Cross one lane bridge and immediately turn left on dirt road parallel to Hiawassee River. Outcrops of Brasstown formation on right. Confluence of Hiawasee River and Valley River on left.

1.0 **Stop 1.** County quarry. The Brasstown formation is exposed in a county road quarry. Lithologies are thin-laminated, garnetiferous, cross-biotite, quartz-sericite schist with scarce interbeds of impure quartzite. Small scale cross-lamination in several quartzites at the northwest end of the quarry indicate that the top of beds is to the southeast. These beds are therefore right side up.

Pods of calc-silicate granofels are interlayered with the schist. These are the "pseudodiorite" of Keith (1913) and later workers. They have been described in many areas of the southern Appalachians. Keith first thought these rocks to be quartz diorite sills and he attributed their emplacement to a late igneous event restricted to parts of southwestern North Carolina and northern Georgia (1907). Keith later became convinced of a metasedimentary origin and he renamed the rocks "pseudodiorite" (Keith, 1913). Hadley (1970) suggested that the rocks be called calc-silicate granofels on the basis of their mineralogy and texture. We concur. Most workers agree that the granofels pods are metamorphosed calcareous concretions and beds (see Fairley, 1965 for references). Are the pods in this exposure concretions, or could they be boudinaged beds?

Several secondary structural features are noteworthy. Bedding (S_0) strikes northeast and dips steeply southeast. A schistosity (S_1) defined by alignment of mica parallels compositional layering (S_0). A cleavage (S_3) formed by microscopic crinkling of S1 dips southeast at an angle less than S_0. Another schistosity (S2) found elsewhere is not visible here. The S3-S0 relationship shows that these rocks are on the northwest limb of an antiform (F_3) overturned to the northwest. How can these beds be right side up, yet on the overturned limb of a fold?

The intersection of S_1 (parallel to S_0) with S_3 forms a prominent southwest plunging lineation (L_{3X1}) which parallels F_3 fold axes in this area. A faint crinkle lin-

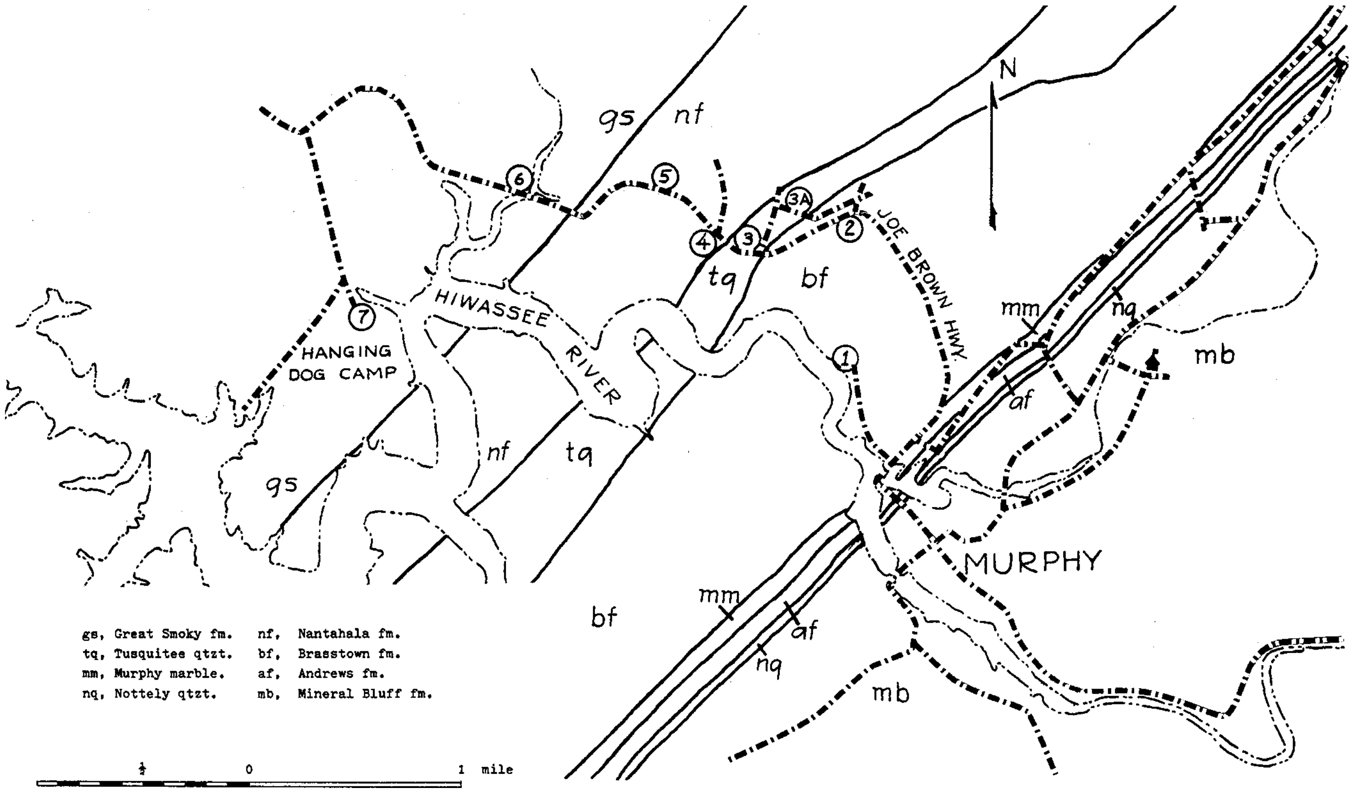


Figure 5. Road Log I

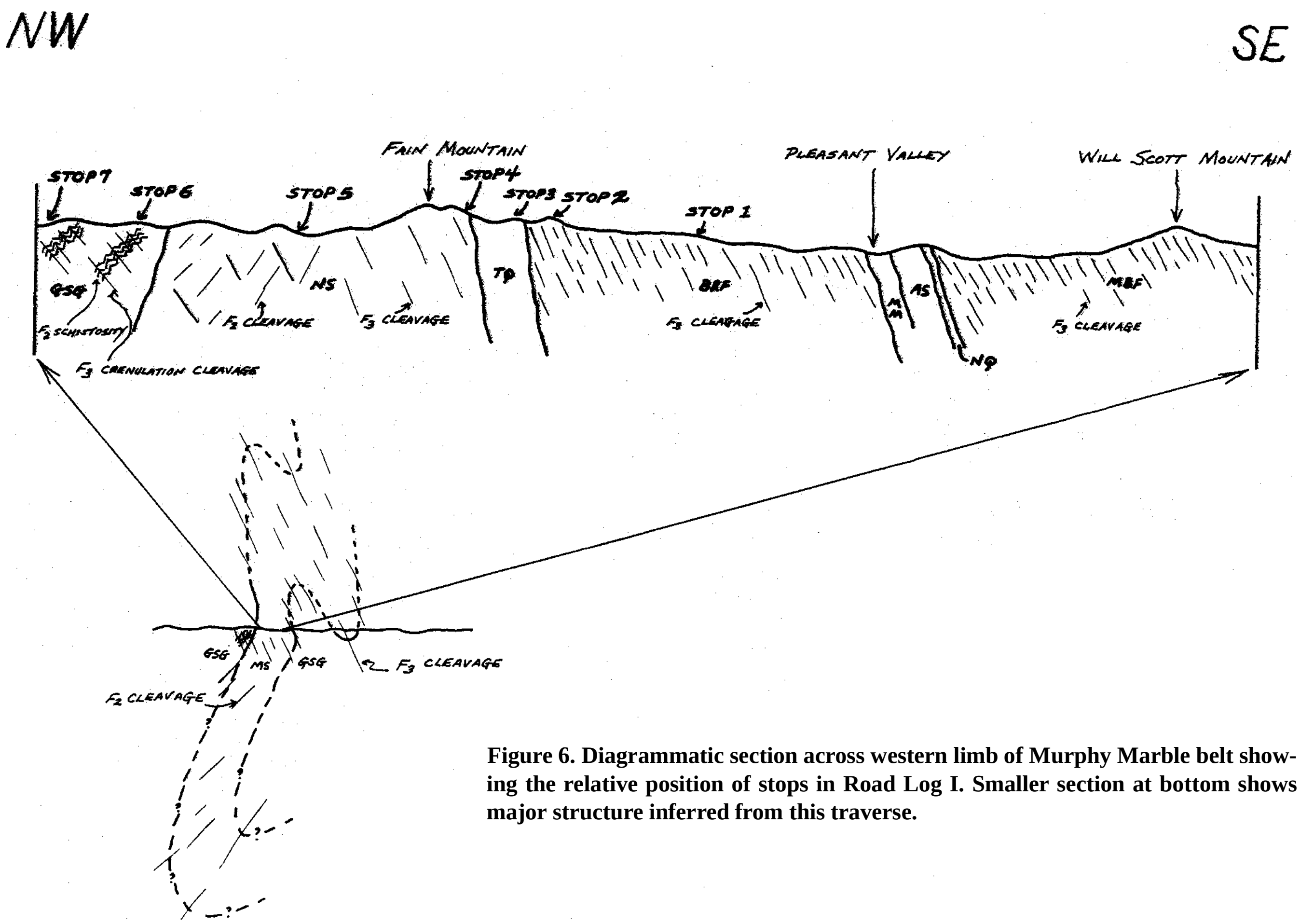


Figure 6. Diagrammatic section across western limb of Murphy Marble belt showing the relative position of stops in Road Log I. Smaller section at bottom shows major structure inferred from this traverse.

eation plunging southwest on S1 surfaces at a steeper angle than L_{3X1} is also visible. This crinkling is not associated with any visible foliation. Could it be an a-lineation, or the intersection of an incipient crenulation cleavage with S_1? In some places S_3 appears to truncate the lineation, but the age relationships are not clear. Can you find any evidence?

A strange thing about these exposures is the lack of megascopically visible folds. One almost suspects that the compositional layering is a transpositional structure, but we have been unable to find a single preserved fold nose. Look for yourself.

How about the environment of deposition? The exposure shows a monotonous repetition of similar beds. Are they turbidites? deep water? shallow water? or what?

1.0 Return to Tennessee Street.

1.6 Turn left on Tennessee Street which becomes the Joe Brown Highway.

1.8 Cross trace of Murphy Marble.

2.1 Outcrops of Brasstown formation on left.

3.1 **Stop 2.** Pull off road on right, abandoned quarry site in Brasstown formation. The lower part of the Brasstown formation is exposed in an abandoned quarry. The rock is a thinly-laminated, blue-black, garnetiferous argillite. Cross-biotite porphyroblasts are less well developed. The lithology is intermediate between typical Brasstown as exposed in Stop 1 and typical lithology of the Nantahala formation.

Can you find evidence for multiple deformation? How did the depositional environment differ from that of Stop 1?

Continue on Joe Brown Highway. Discontinuous outcrops of Brasstown formation on left.

3.8 **Stop 3.** Pull into turn off on left side of road at junction of Joe Brown Highway and SR 1361 on right. Green frame house on right side, just above road.

Tusquitee quartzite is exposed in the bank behind a green frame house. The exposure is in the backyard of a private residence, so please tread lightly.

This is typical Tusquitee lithology – a feldspathic, white quartzite with thin, wispy intercalations of black argillite. The high feldspar content of the quartzite causes it to weather readily and explains why the Tusquitee is rarely a ridge former. The fine, sandy saprolites of the Tusquitee have been used since pioneer times as an abrasive for scrubbing and cleaning wooden floors.

Optional Side Trip from Stop 3

(0.0) Take dirt road (SR 1361) to right (north).

(0.3) Stop 3A. Ridge Crest. Tusquitee formation crops out in road.

(0.6) Brasstown formation on right.

(0.7) Turn right on Joe Brown Highway.

(1.3) **Stop 3.**

Continue on Joe Brown Highway.

3.8 Continue on Joe Brown Highway.

3.9 Tusquitee formation on right.

4.0 **Stop 4.** Mau Gap. Humble Oil Station on right. Junction with SR 1331 and Joe Brown Highway. Contact between Nantahala and Tusquitee. This is the upper part of the Nantahala formation. The exposure shows typical black argillite of the Nantahala with numerous intercalations of white feldspathic quartzite similar to the Tusquitee. The contact between the two formations is gradational and of necessity somewhat arbitrary. Is the distinction valid or should they be considered one formation as suggested by Hadley (1970)?

Continue on Joe Brown Highway.

4.4 **Stop 5.** Quarry in Nantahala formation on right.

The Nantahala formation is exposed in an abandoned quarry. Leave bus, descend gravel road on north side of highway, cross creek and enter quarry to left.

The rock is blue and black argillite with intercalated dark argillaceous quartzite, with a few pods of calc-silicate granofels. Pyrite is abundant, generally occurring in layers parallel to bedding. Gypsum blooms and encrustations are abundant.

Bedding strikes northeast and dips northwest. The structural domain is different from previous stops. It is controlled by F_2 folds. Coarse, northwest dipping foliation which shows prominently on the quarry wall is an S_2 cleavage. L_{2X0} plunges gently to the northeast. In a few places an indistinct, non-penetrative S3 cleavage dips southeast. L_{3X0} plunges to the southwest.

These rocks are overturned to the southeast. This is known because of facing criterial in adjacent areas and from the S_0-S_2 relationships. S^2 dips less than S_0; therefore, the beds are on the northwest limb of a synform overturned to the southeast.

What depositional environment do these rocks represent? How about the Tusquitee and the rocks of Stop 4? Are these offshore deposits in deep water? and does the Tusquitee represent a regression of the seas?

Continue on Joe Brown Highway, outcrops of Nan-

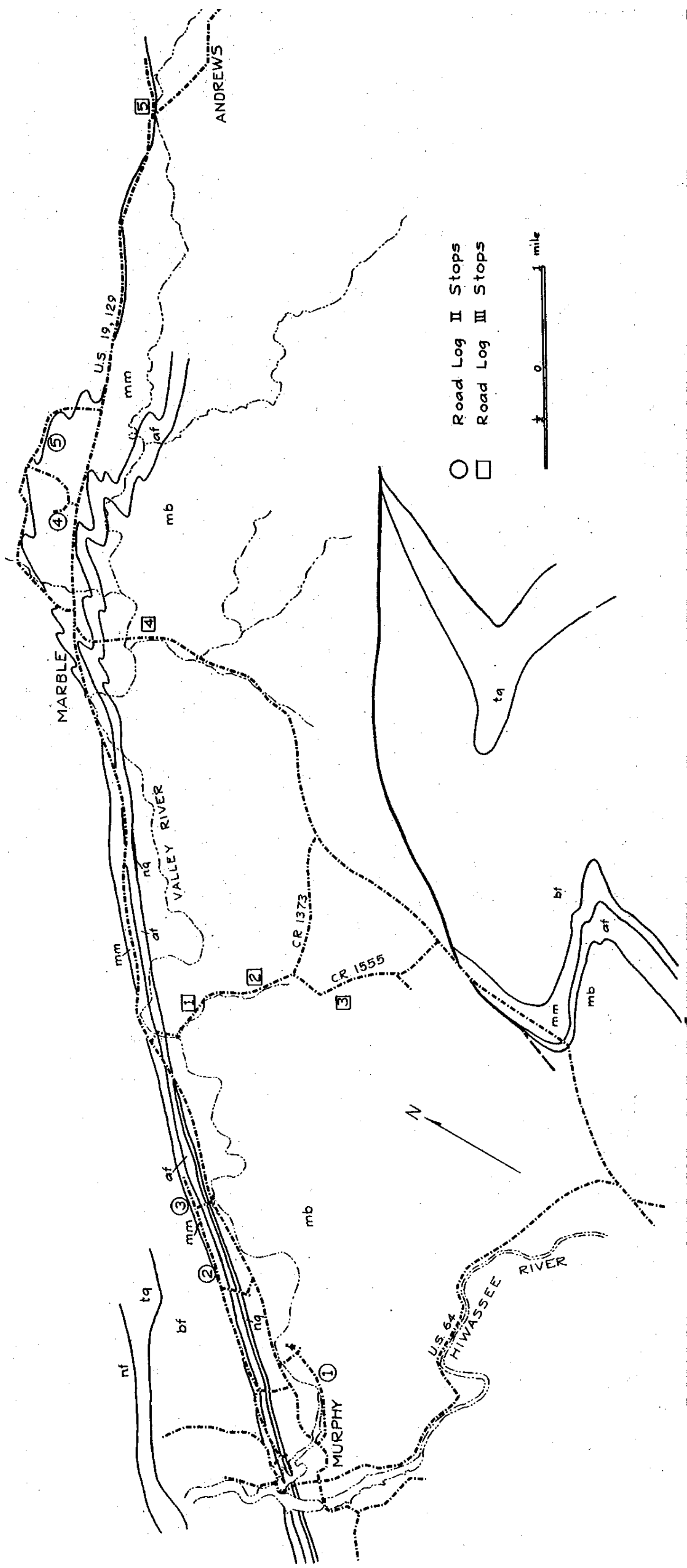


Figure 7. Road Log II and III

tahala formation on both sides of road.

4.9 Approximate contact between Nantahala fm. and Great Smoky fm.

5.1 **Stop 6.** Cross bridge outcrop on right.

Interbedded garnet-staurolite-mica schist, metagreywacke, and metaconglomerate of the Great Smoky group are exposed in a roadcut. Staurolite is always found in the Great Smoky, never in the Nantahala. What does this imply about the isograd?

S_0 dips northwest; S_2 dips northwest less steeply as a well-developed penetrative schistosity. S_1 is not found. S_3 is a southeast dipping crenulation cleavage. S_2 and S_3 are especially well developed in the outcrops on the east side of the bridge. A schistosity at the northwest end of the outcrop dips southeast. Is this S_3 which has locally transposed S_2?

Pebbles in the metaconglomerate are elongated. They plunge southwest approximately parallel to L_{3X0}. This elongation will be seen better at Stop 7.

Continue on Joe Brown Highway.

5.5 Turn left on paved road into Hanging Dog Campground.

6.5 National Forest Service Pay Station.

6.6 Turn left into second campground area. Lunch.

Stop 7. Lunch will be served at Hanging Dog Campground. Those who finish early may inspect excellent exposures of Great Smoky conglomerate along the shoreline opposite the campground area, provided the lake level is sufficiently low.

Bedding (S_0) and S_2 schistosity dip northwest and are cut by southeast dipping S_3 crenulation cleavage. Elongate pebbles in the metaconglomerates plunge to the southwest. Also note graded bedding in the conglomerates indicating tops to the southeast.

Large fragments of blue gray mica schist occur in some conglomerate beds. Elsewhere a conglomerate was found to fill a channel cut in a schist layer and fragments of the schist are included in the conglomerate. Were these schist or mudstone when they were eroded and deposited with the conglomerate? Do the conglomerates represent turbidites or fluvial beds in a fining upward sequence?

Return to Murphy.

Road Log II - Saturday Afternoon

This afternoon we will examine the upper half of the Murphy marble to the Mineral Bluff formation.

0.0 Intersection of U.S. 64 and U.S. 19 in center of Murphy.

0.4 Turn right on Sunset Street just beyond Mooreland Heights Court.

0.6 Cemetary on right. Sunset Street becomes gravel road.

1.0 Mineral Bluff formation on right.

1.1 **Stop 1.** County quarry in Mineral Bluff formation.

Abandoned road quarry at the base of Will Scott Mountain exposes the Mineral Bluff formation. Lithologies are thinly laminated to thin bedded garnet-mica schists, metagreywacke, and calc-silicate granofels. A pervasive S_3 cleavage is axial plane to F_3 folds. The F_3 folds tend to be similar in the more pelitic units, concentric in the metagreywackes and granofels. However, folds in some granofel units show evidence of flow into the nose and hornblende pophryoblasts are aligned in the S_3 direction. Boudinage of many granofel units suggest extension along S_0 which is probably related to F_1 folding.

Northwest dipping kink bands cut S_3 and their intersection with S_3 parallels F_3 axes. The kink bands are therefore thought to have developed during the stage of movement in the S_3 surface. An incipient northwest dipping S_4 crenulation cleavage also cuts S_3. A mineral-streak lineation is common on S_3 surface. Could this be an a-lineation?

Continue on gravel road.

1.4 Turn left on paved road. High School on right.

1.6 Junction with U.S. 19-129. Turn right.

2.5 Turn left on S.R. 1368.

2.9 Abandoned marble quarry on right. Quarry has been filled, but waste blocks are visible.

3.0 Turn right on S.R. 1366 – gravel road.

3.2 **Stop 2.** Regal marble quarry.

Murphy marble is exposed in the Regal Blue quarry operated by the Columbia Marble Company of Marble, North Carolina. This is a graphitic, calcite marble that is used for buildings and monuments. The Regal

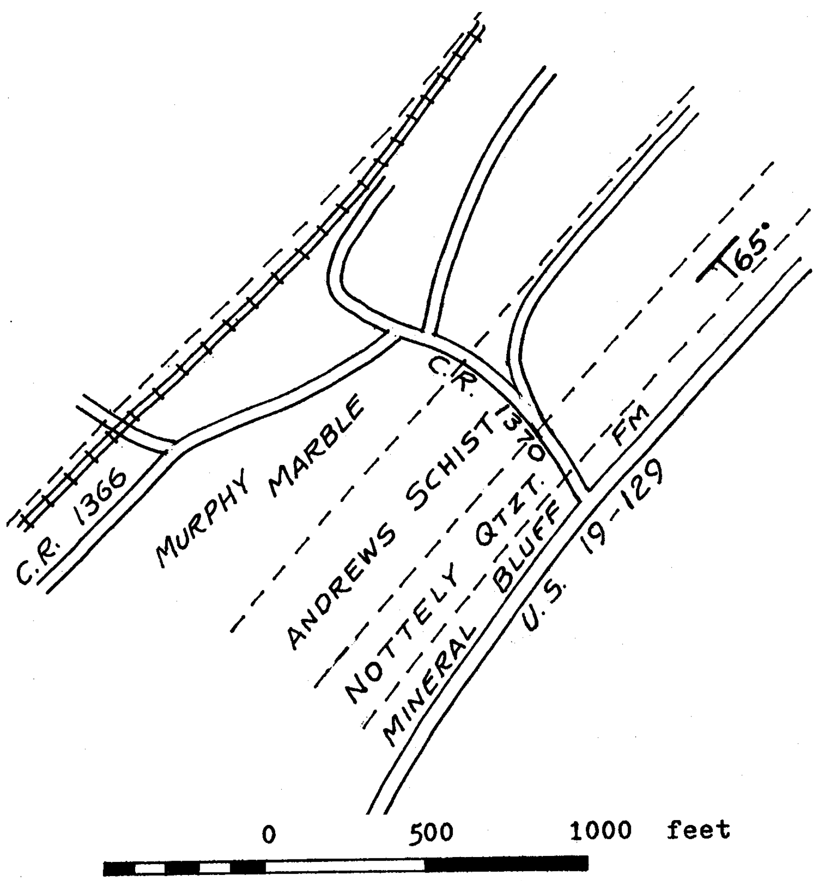


Figure 8. Geologic sketch map, Stop # 2, Road Log II

Blue is a relatively thin layer of calcite marble in the upper dolomitic part of the formation. The layer which is about 50 feet thick here thins northward to a few feet in a dolomite quarry north of Marble (Stop 4). An isoclinal fold with a steep southeast dipping axial plane can be seen on the north quarry wall.

Continue on S.R. 1366 which follows trace of Murphy Marble.

3.9 Enter community of Regal, North Carolina, S.R. 1366 becomes paved.

4.0 Stop 3. Junction of S.R. 1366 and S.R. 1370.

The Andrews formation, Nottely quartzite, and Mineral Bluff formation are exposed in a gap through the ridge held up by the Nottely quartzite. The Murphy marble underlies the swampy valley to the west where an old dimension stone quarry has been infilled. The new roadcut exposes typical lithologies of the Andrews formation – interbedded cross-biotite, quartz-sericite schist and impure marble. Large chunks of this material are scattered along the west side of the road. Note that the saprolite in the road cut contains seams and concretions of limonite which is typical of the Andrews formation.

Follow the road southeast through the gap to outcrops of Nottely quartzite and cross-biotite schist of the Mineral Bluff formation. The Andrews formation is distinguished from the Mineral Bluff formation by the calcareous interbeds in fresh exposures and by typical vari-colored saprolite containing abundant limonite in weathered outcrops.

Question: How many generations of cross-biotite porphyblasts can you distinguish?

Continue east on S.R. 1370.

4.1 Junction with U.S. 19-129. Turn left. Outcrops of Mineral Bluff formation on left. Ridge on left held up by Nottely quartzite.

5.3 Nottely quartzite pinches out where ridge abruptly ends. Enter Tomotla community.

6.0 Brasstown formation crops out along railroad tracks.

6.7 Tomotla community.

6.9 Murphy marble on left. Andrews formation saprolite on right.

8.6 Brasstown formation on left.

8.8 Enter Marble, North Carolina.

9.6 Palmer's Museum on left.

10.6 Turn left at Columbia Marble Company sign.

10.7 Cross railroad track and turn left.

10.8 **Stop 4.** Columbia Marble Company.

The Murphy Marble is exposed in quarries operated by the Columbia Marble Company. The quarry opposite the company office and plant is in the upper dolomitic part of the formation. A thin layer of blue graphitic marble can be seen in the quarry wall. This is the Regal Blue layer. The dolomite is quarried for use as roofing chips, terrazo, agricultural lime, and road stone.

The Columbia Marble Company quarries dimension stone from the lower calcitic part of the formation northeast of the plant (Stop 5).

Site trip to Marble Quarries.

From U.S. 19-129 turn left (west) at Columbia Marble Company sign. Cross railroad track as before, but turn right (north) at fork in road – 0.0 mileage.

0.3 Junction with S.R. 1400. Keep to right.

0.4 Two abandoned dimension stone quarries on right. Many waste blocks visible.

0.45 Go left at fork in road. Right fork leads to abandoned quarries.

0.6 View of Valley River Mountains to right.

0.8 Junction with paved road. Turn right. Outcrops of Brasstown formation on left.

0.85 Cross bridge over Welch Mill Creek. Road on right leads to abandoned marble quarry.

1.2 Turn right on gravel road.

1.3 Valley River Mountains to left. Broad valley underlain by Murphy Marble.

1.4 **Stop 5.** Dimension stone quarry in Murphy marble.

Calcareous marble of the Murphy marble is exposed in a dimension stone quarry. This type of coarse-grained, gray, calcareous marble is typical of the lower half of the formation. At the base, near the contact with the Brasstown formation, coarse, brown mica becomes abundant in the marble. Layers of micaceous marble outline nearly recumbant folds exposed in parts of the quarry.

Return to paved road.

1.5 Turn right on paved road.

1.7 Brasstown formation on left.

2.3 Junction with U.S. 19-129, turn right to Murphy.

ROAD LOG III – SUNDAY MORNING

On Sunday morning we will examine outcrops that best display the structural history and complexity of the area. The road log starts at the center of Murphy, but we will congregate at Odell's Restaurant at mileage 1.2.

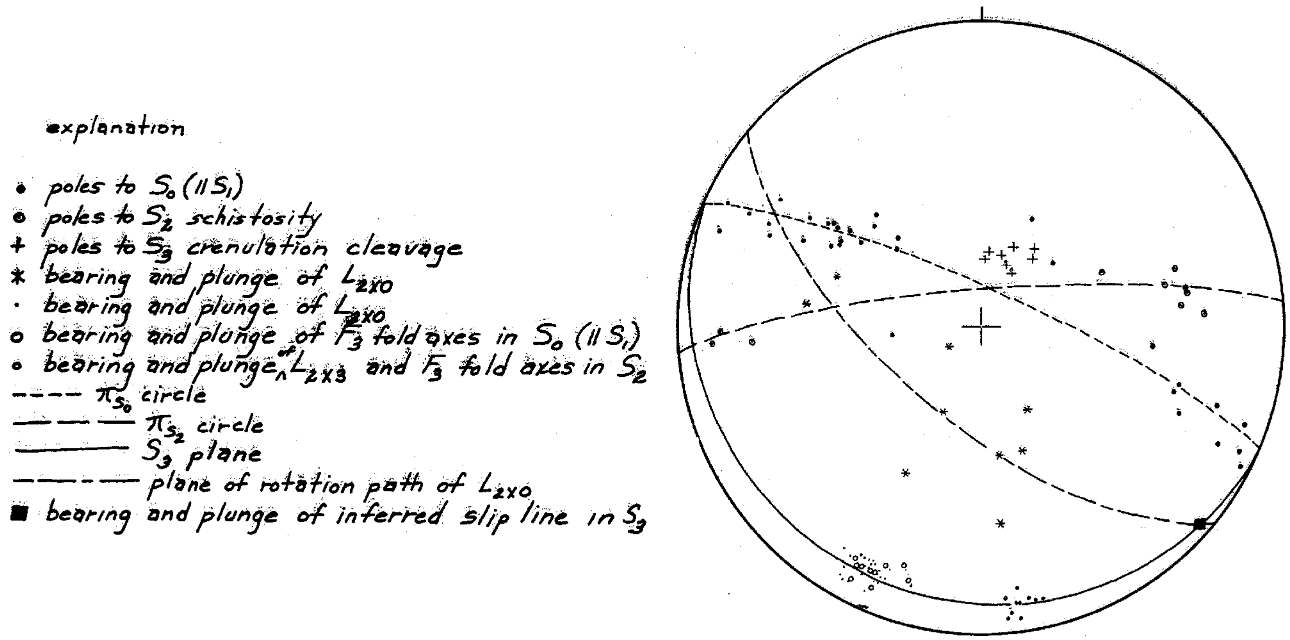


Figure 9. Orientation diagram of structural elements at STOP 1, ROAD LOG III. Data are plotted on the lower hemisphere of an equal area net. S-plane and π circles were fitted by eye and are only approximate. The inferred S_3 slip line is based on the assumption that L_{2X0} was straight before folding and that F_3 folds formed purely by slip.

0.0 Center of Murphy; intersection of U.S. 19-129 and U.S. 64. Proceed north on U.S. 19-129 (Valley River Avenue).

1.2 O'Dell's Restaurant on right. Nottely quartzite under ridge on left.

1.6 Valley River on right side of road.

2.6 Enter community of Tomotla; sign on right.

3.3 Mineral Bluff formation crops out on left side of road.

3.8 Saprolite on Mineral Bluff formation for next 0.3 miles.

4.5 Nottely quartzite pinches out at north end of prominent ridge…for next 0.5 miles we cross the unexposed trace of the Andrews formation and Murphy marble.

5.0 Turn right on S.R. 1373.

5.1 Cross one lane bridge over Valley River. Murphy marble is exposed in small outcrops along river bank on left side of bridge; the Andrews formation, on right side in the bed of the river.

5.4 Junction with S.R. 1554. Continue to left on S.R. 1373. (There are excellent exposures of Mineral Bluff formation in road cuts 0.5 miles up S.R. 1554).

5.7 **Stop 1.** Mineral Bluff formation. Please leave hammers in car. This is a delicate outcrop. Lithologies are garnet-mica schist and metagreywacke.

The structural features of this outcrop are summarized in Figure 4.

Three S-surfaces are distinguished: S_1 schistosity is parallel to bedding and is folded with bedding into southwest plunging folds; S_2 schistosity cuts across bedding and is folded into a system of southeast plunging folds; S_3 is a nearly recumbant, southwest dipping crenulation cleavage which is axial to open folds in S_0, S_1, and S_2.

This is F_3 folding. At the east end of the outcrops the folds become much tighter and the S_3 cleavage is fanned (Figure 10). As we proceed east along this road we will see the progressive transition of S_3 from a crenulation cleavage into a penetrative foliation.

Continue east on S.R. 1373. Discontinuous outcrops of Mineral Bluff formation in roadcuts on left.

6.5 **Stop 2.** The Mineral Bluff formation consists of garnet-mica schist, metagreywacke, and calc-silicate granofels. The southeast dipping schistosity in the outcrop is S_3. Bedding and earlier schistosities have been transposed into near parallelism by shear in the S3 plane. Close inspection shows isoclinal fold noses in the metagreywacke beds. The "fishscale" structure of S_3 is probably caused by interference with the earlier schistosities. An incipient S_4 crenulation cleavage dipping northwest crinkles S_3.

Continue on S.R. 1373.

6.7 Outcrop of Mineral Bluff formation shows same structural features as at Stop 2.

7.0 Junction with S.R. 1555. Bear right on S.R. 1555.

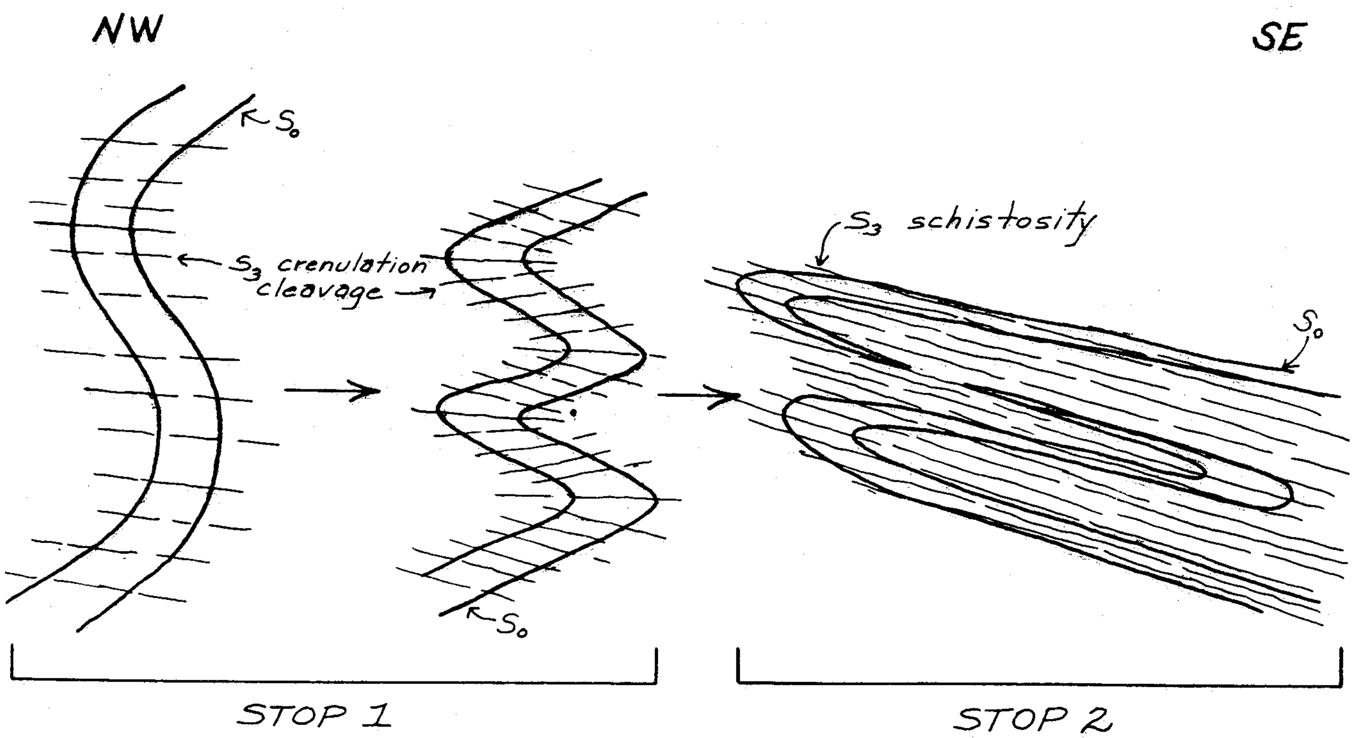


Figure 10. Diagrammatic sketch showing progressive change from open to isoclinal folding in F_3 folds as seen in stops 1 and 2, Road Log III. Note also the accompanying transition of S_3 from a crenulation cleavage to schistosity.

7.6 **Stop 3.** Fine-grained, low-grade, quartz-sericite phyllite of the Mineral Bluff formation. In contrast to previous outcrops the Mineral Bluff formation here shows only one secondary foliation, S3, dipping steeply to the southeast. If the outcrop is clean you may see F_3 folds. These have a similar-type geometry formed by slip on S_3 surfaces. Movement on these surfaces is shown by numerous small boudinaged quartz veins in the S_3 plane. Intersection of bedding and S_3 produces a lineation plunging almost directly down the dip of the cleavage.

Continue on S.R. 1555.

8.9 Exposure of Mineral Bluff formation in road cut.

9.2 Junction with S.R. 1533. Turn left and proceed on S.R. 1533.

9.5 Cross fault zone between Murphy marble and Mineral Bluff formation.

9.6 Junction with paved road. Turn left and proceed north.

10.3 Exposures of Mineral Bluff formation in roadcuts for next 3 miles. Murphy marble has been cut out by fault and the Brasstown formation is in fault contact with Mineral Bluff formation near base of Braden Mt. on right.

13.8 Crestline of Snowbird Mountains is directly in front behind Marble, North Carolina. The contact of the Great Smoky and Nantahala formations is near the top of this range.

14.9 **Stop 4.** Mineral Bluff formation. This schist contains many interesting micro- and macro-textures and structures that are not readily visible in outcrop. We urge you to collect specimens for making slabs and thin sections. Quartz, sericite, biotite, garnet, staurolite, and sillimanite (?) are present. For the mineral collectors, staurolite weathered out of the schist is abundant in the bank at the west end of the outcrop.

Figure 11, shows some of the more interesting textural relationships which are described below.

Figure 11A, shows porphyroblasts of staurolite and biotite. Opaque ores define a compositional banding (S_0) and a parallel foliation (S_1), both of which are folded (F_2). These are preserved as relic textures in staurolite and biotite porphyroblasts which, therefore, must have grown after F_2. Garnets from this outcrop contain relic inclusions from S_1 and commonly are included within staurolite. They, therefore, grew after F_1, but possibly before F_2.

Figure 11B, shows an F_2 fold in thin section. S_1, defined by the alignment of sericite, quartz, and opaque ore, was folded during F_2. Fascicular bundles

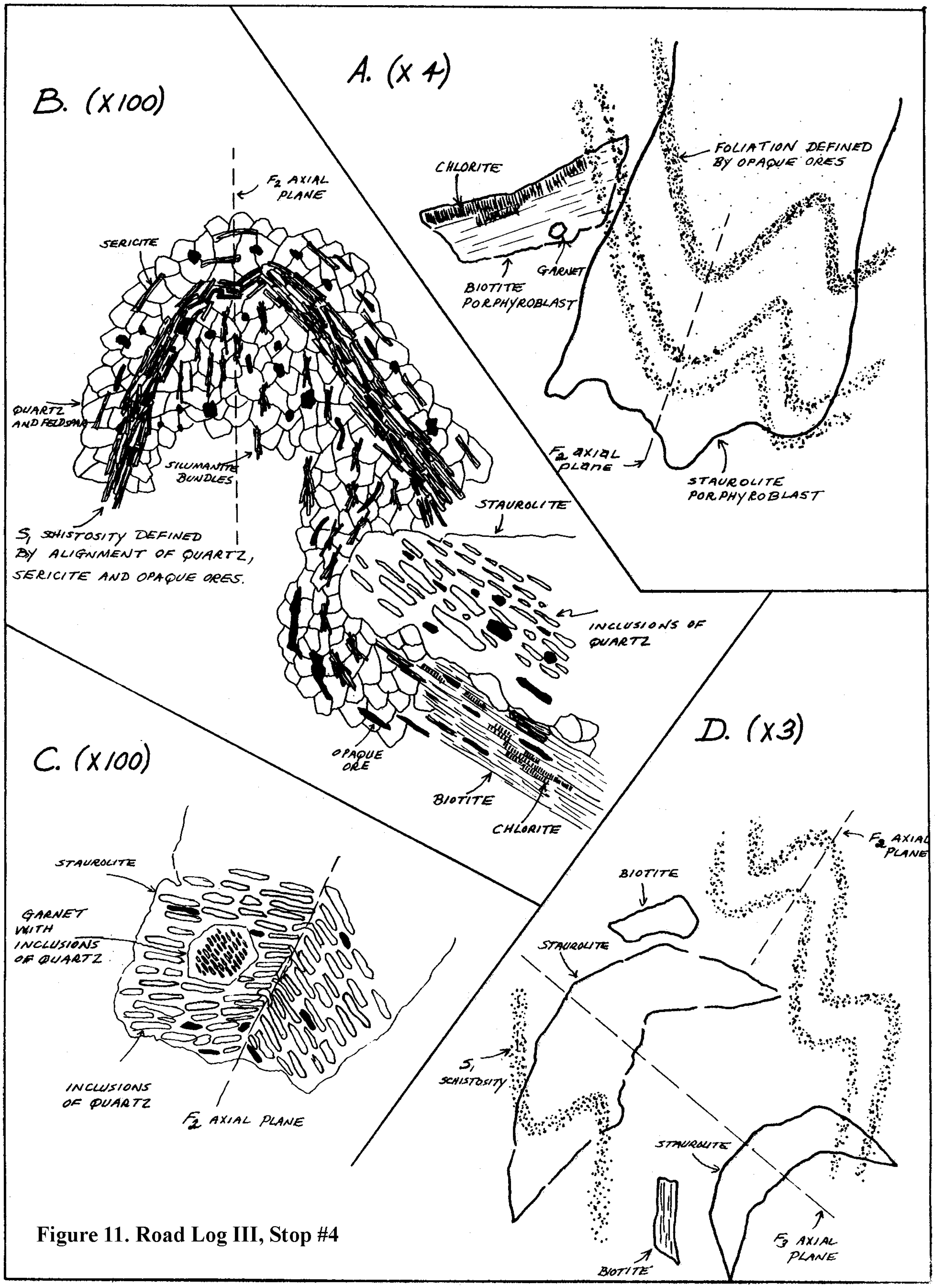


Figure 11. Road Log III, Stop #4

of sillimanite (?) parallel the axial plane of F_2 or else crystallized mimetically after F_2. The axial plane bundles the S_1 foliation bend around the end of the staurolite porphyroblast. Is this compaction? or does it result from the force of crystallization? Biotite contains inclusions aligned with S_1 and is partially altered to chlorite.

Figure 11C, shows a large porphyroblast of staurolite. Quartz inclusions outline a relic schistosity (S_1) which was kinked, probably during F_2 folding. A garnet inclusion within the staurolite contains quartz inclusions defining a relic schistosity also thought to be S_1, but rotated along with the garnet during a later event.

Figure 11D, shows porphyroblasts of staurolite which are bent or folded, presumably during the F_3 event.

In summary we make the following tentative conclusions from the textural and structural relationships:

1.) F_1 folding was accompanied by growth of sericite and elongate quartz defining S_1.

2.) F_1 folding was followed by growth of garnet.

3.) F_2 folding was accompanied by or followed by growth of sillimanite.

4.) A period of staurolite growth followed F_2. This may have been contemporaneous with growth of sillimanite if the sillimanite grew mimetically.

5.) Folding during F_3 affected all other textures. It bent and cracked staurolites around southeast-dipping axial planes. Retrogressive chlorite could have formed from biotite during this event.

Continue toward Marble, North Carolina.

15.1 Cross bridge over Valley River.

15.8 Junction with U.S. 19-129 in Marble. Turn right and proceed north on U.S. 19-129.

15.9 Palmer's Museum on left. This contains an excellent collection of local rocks, minerals, Indian artifact, and pioneer memorabilia. It is well worth the stop if you have the time.

17.0 Entrance to Columbia Marble Company.

17.4 View of Konaheeta Valley and the Valley River Mountains. This broad valley is underlain by the Murphy marble.

19.6 Exposures of Brasstown formation saprolite on left. The road follows the contact between the Brasstown formation and Murphy marble.

19.8 Andrews-Murphy municipal airport on right.

20.8 Exposures of Brasstown saprolite on left.

21.2 **Stop 5.** Turn left on S.R. 1386, pull over to right and stop. The Valley River is to the right, exposures of Brasstown formation to the left.

Garnet-mica schist of the Brasstown formation. F_3 and F4 folds are superposed here. F_3 fold axes plunge to the northeast, F4 axes to the southwest. Note the basin and dome type interference pattern produced by the intersection of the two axes. S_3 schistosity (axial plane to F_3 folds) is nearly recumbent to slightly overturned to the northwest owing to rotation around F_4 axes.

End of trip.

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