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Geology of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina

By

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Open-file report

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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[In pocket]

EDITOR'S NOTE

This report comprises the only completed parts of a manuscript on the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina, that was being written by Robert M. Hernon at the time of his death in June 1965. Geologic maps and sections of these quadrangles, at a scale of 1:24,000, were released to open-file on Sept. 16, 1964. The various sections of the report have been arranged in a logical sequence, although not necessarily in the order the author might have planned. Except for minor editing, the text is the author's original rough draft. Preparation of this report has been a joint effort with my colleague A. R. Kinkel.

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Geology of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina

By Robert M. Hernon

GENERAL GEOLOGY

The three quadrangles of this report span a belt of northeast-striking rocks that include older strata of the Ocoee Series (later Precambrian) in the middle part of the mapped area, younger Ocoee units to the west, and formations of the Murphy marble belt (Cambrian) on the east. The central and western parts are underlain by rocks of the graywacke-siltstone suite, whereas the eastern third is underlain by rocks showing shelf sea characteristics or alternation of shelf and geosynclinal types (Hurst, 1955, p. 33, 38-40).

Tabular amphibolite masses are known regionally in the metagraywacke unit and the Brasstown Schist and in strata southeast of the outcrop of Nottely Quartzite in the southeast corner of the Persimmon Creek quadrangle (Van Horn, 1948, sheet 1). These rocks are in part known to be of basaltic composition and have been called gabbro or diorite. A volcanic origin must be considered for the conformable sheets, but both intrusive and extrusive masses may be present.

Metamorphic assemblages are chlorite-sericite in the northwest one-sixth of the area, sericite in the extreme southeast corner, and garnet, biotite, amphibole, and staurolite in much of the intervening area. Staurolite is restricted to thin strata believed to have favorable composition. Kyanite is apparently restricted to underground localities near Ducktown and to the contact of the Hughes Gap and Hothouse Formations in the Mineral Bluff quadrangle, which adjoins the Isabella quadrangle on the south (Hurst, 1955, p. 34-35).

Strata of about the west one-fourth of the mapped area dip at flat to medium angles, interrupted by narrow strike belts characterized by steep dips with tops facing northwest. A wider belt along map unit 2 (fig. 1) is overturned to the northwest with some faulting in evidence along the southeast boundary. Strata of the southeast corner of the mapped area dip consistently southeast at intermediate angles. Between these two areas, the strata are much folded and for the most part show medium to high angles of dip. Much of this central area shows mild to strong folding of the foliation. Crinkling and crinkle cleavage are characteristic. Attitudes of the slaty cleavage and schistosity strongly suggest that much folding took place subsequent to metamorphism. In general, axial plane cleavage and schistosity dip southeast in the western part of the area, steeply southeast or northwest in the central part, and steeply to moderately northwest in the eastern part; in the extreme southeast corner they dip southeast, approximately parallel to the bedding of rocks of the Murphy marble belt. These observations are based on cleavage and schistosity readings made where these are but little deformed. Reliable readings cannot be made in many places in the central area because of severe to moderate folding of cleavage and schistosity.

Graded bedding is a common feature of the arenaceous geosynclinal rocks between unit 3 of the west and the Nantahala Slate of the east part of the mapped area (fig. 1). Grain size varies from conglomerate to silt. The range most reliable for determination of tops of beds seems to be from sand sizes to silt, though both recrystallization during metamorphism and saprolitic weathering seriously obscure this range in many places. Many conglomerate and granule beds may lack convincing gradation, and oligomictic quartz-pebble conglomerates may show poor grading in either direction or none at all. Thick arenaceous beds commonly show little reliable gradation, though some may show gradation in both size and type of material at the top. Rocks of the Murphy marble belt as exposed in the mapped area show little or no graded bedding.

Determinations of tops of beds utilizing graded bedding were classified in the field according to character of gradation and number of cycles of graded sediment, and were later grouped into three classes. First-class determinations are those which would seem to be clearly acceptable to visitors in the field. Second-class determinations are less reliable but are considered usable, particularly in areas where few graded beds could be observed. These are shown by a separate symbol. Third-class determinations are of poorer character and are not shown on figure 1.

The use of attitudes determined by graded bedding in structural interpretation requires emphasis on beds or members of higher competence. Thin-bedded rocks, and even some sequences of intermediate competence, may show much folding of several orders of magnitude. Lack of reliable key beds and sparse outcrops prevents elucidation of such folding in many areas, and consequently a good determination of attitude is safely applied only in its immediate locality. A combination of graded bedding with good axial plane cleavage or schistosity is helpful in interpreting structure, but deformation of cleavage as a result of late folding limits its use, particularly in incompetent rocks.

Lack of reliable key beds and scarcity of outcrops prevent positive recognition and definition of faults, particularly strike faults. Strike faults of considerable displacement may well exist and indeed are suspected in places, but thus far are uncertain and undefined. A few strike faults were observed locally, but these seem to have minor displacement. Minor northwest faults are common but can be mapped only in restricted areas.

Positive correlation of units across the central area is not attempted at present owing to lack of reliable key horizons and fossils, and to facies changes. Hurst and Schlee (1962, p. 17, 21) suggested correlations that can be defended, but other correlations can also be proposed. Regional mapping to the northeast, which is the direction of plunge of major structures of the mapped area, may solve the problem, provided that rock units can be followed around these structures.

The geologic history of the region may be summarized as follows:

1. Deposition of the Ocoee Series.
2. Possible interval.
3. Deposition of rocks of the Murphy marble belt.
4. Lithification. Iron and sulfur in dark siltstone and shales were aggregated into cubic pyrite porphyroblasts in certain beds, mostly very thin ones. Disseminated pyrite in sandstone is of uncertain age.
5. Dynamothermal metamorphism with development of axial-plane cleavage and schistosity, and deformation of pyrite cubes.
6. Thermal metamorphism with regional large-scale recrystallization. Development of metacrysts in cross position: chlorite, biotite, amphibole, muscovite, staurolite, chloritoid, garnet (or continued growth of garnet), and, locally, kyanite. These minerals disrupted the slaty cleavage and schistosity. Development of pseudodiorite.
7. Long cooling period.
8. Strong deformation of the region. Large folds appear to have been closed by as much as several tens of degrees. Slaty cleavage and schistosity were mildly to severely deformed. Numerous minor folds of several orders of magnitude were formed or closed; rotation of slaty cleavage of as much as 120° has been observed in such a fold. Fracture cleavage (much is crinkle cleavage) was weakly to strongly developed. Shear zones were formed or reactivated (Ducktown vein-shears).
9. Sulfides were deposited, and alteration of older minerals to sericite and chlorite seems to have taken place at this time. Some evidence suggests that this may have been a major time of deposition of ore sulfides, but overlapping deposition during post-kinematic metamorphism is not eliminated. Pervasive regional deposition of iron sulfide along slaty cleavage and schistosity took place possibly late in, but probably after, the dynamic stage of thermal metamorphism. Ore sulfides cut, fill in fractures and interstices, or replace interstitial material of unoriented silicates which had been deformed in places. Schistosity seems to be more marked near veins along shear zones. The late (postmetamorphism) period of folding deformed the schistosity along the vein

zones, producing coarse crinkles and small folds of several orders of magnitude. The form and spatial attitude of parts of ore bodies show relation to coarse crinkles and minor folds. The coarse crinkles appear to grade by increase in amplitude into the minor folds whose amplitudes range from a foot or so to tens and possibly hundreds of feet.

OCOEE SERIES

The Ocoee Series as used by King, Hadley, Neuman, and Hamilton (1958, p. 951) for sedimentary rocks of later Precambrian age in the Great Smoky Mountains, rests unconformably on earlier Precambrian granite and gneiss and is overlain by rocks of the Murphy marble belt of Cambrian age. The Ocoee is subdivided into, from oldest to youngest, the Snowbird Group, Great Smoky Group, several unclassified formations, and the Walden Creek Group. A large part of the area discussed in the present report is underlain by rocks correlated tentatively with the Great Smoky Group as used by Hurst (1955).

The name Great Smoky Group was used by Hurst (1955, p. 8-9) for a sequence of metasedimentary rocks in the Mineral Bluff quadrangle, Georgia, Tennessee, and North Carolina, which lies immediately south of the Isabella quadrangle. Hurst subdivided the group into four formations, from oldest to youngest the Copperhill, Hughes Gap, Hothouse, and Dean. King, Hadley, Neuman, and Hamilton (1958, p. 957) used the name Great Smoky Group but said that correlation of the various formations between the Great Smoky Mountains and northern Georgia was not yet possible.

Metagraywacke

Definition and distribution

The south-central, northwest, and north parts of the Isabella quadrangle and the southeast part of the Ducktown quadrangle are underlain by dominantly sandy metasediments, which are well exposed in the denuded Copperhill-Ducktown area. These rocks are part of the Copperhill Formation of Hurst (1955, p. 9); Hurst named it after the town of Copperhill, Tenn., near the southwest corner of the Isabella quadrangle. However, because this name has not been adopted by the U.S. Geological Survey, and because the upper part of the formation has been assigned to a new formation, the name is not used in this report and the formation is referred to as metagraywacke.

Excerpts from Hurst's description (1955, p. 9-21) follow: "About 60% of the Copperhill formation is metagraywacke, about 30% is mica schist; the remaining 10% is metaconglomerate, quartzite, and meta-arkose. [Separation of the schist unit previously discussed changes these proportions, reducing the schist to perhaps 20 percent.] * * * The metagraywacke and mica schist are interbedded throughout the formation. At places they alternate rhythmically, each bed of metagraywacke grading upward to mica schist. * * * More commonly, the alternation is irregular, and succeeding beds differ in thickness. Metaconglomerate, quartzite, and metaarkose are prominent at only a few horizons. They are interbedded with, and usually gradational to, metagraywacke. The strata range in thickness from a fraction of an inch to 50 feet, but are mostly less than four feet thick. Metaconglomerate and metagraywacke beds are the thickest. The schist layers rarely exceed eight feet in thickness, commonly they are only a few inches thick.

"Lithologic changes occur both laterally and vertically. Some beds lense-out within a distance of a few hundred feet. Other beds have wide lateral extent, particularly the thicker schists. A few horizons that are characterized by the predominance of a single rock type maintain their lithologic character for miles, even though the beds that mark the horizon vary greatly in number and thickness from place to place.

"The interbedded relationship of these rocks, their composition, widespread graded bedding, and rounded pebbles of quartz, feldspar, and slate all clearly indicate a sedimentary origin. The metagraywackes, quartzites, and metaarkoses represent arenaceous sediments; the schists represent silts and clays. * * * Few of the schists contain more than 85% mica. Few of the metaarenites contain more than 40% feldspar or 75% quartz.

"The coarser rocks are gray where unweathered. During weathering they change to a lighter color, as their feldspar is kaolinized and their biotite leached. The color of the schists depends to a large extent on their biotite content. A few schists are exceptionally dark because they contain fine, disseminated, opaque matter, either iron oxide or carbonaceous matter, sometimes both."

Stratigraphic relations and thickness

According to Hurst (1955, p. 9), "The base of the [Copperhill] formation is not exposed in the Mineral Bluff quadrangle, but may be observed in the Ducktown Basin, where it consists of thick, locally conglomeratic metagraywacke beds underlain by staurolite-mica schist." The top of the metagraywacke in the Isabella quadrangle is placed between the area underlain by dominantly sandy metasediments and the area to the east and northeast underlain by metasediments that contain silty and argillaceous beds in contrasting amounts. The indefinite contact shown reflects sparse exposures of rock or saprolite and gradation between the two units; over part of its length the boundary appears to be a fault. The contact as drawn undoubtedly departs somewhat from a stratigraphic horizon owing to lack of positively recognizable key beds and probable interfingering of lithologies. Despite these deficiencies, it does conform to the main plunging structures.

The northwest limit of the formation is chosen where a change from dominant graywacke to a zone with contrasting amounts of silty and argillaceous rocks is noted. This boundary is of uncertain nature and is shown as an indefinite contact; it may be in part or entirely a fault.

The thickness of the metagraywacke is indeterminate. A minimum thickness of about 4,000 feet is involved in the Coletown syncline, assuming no significant duplication of beds. The total thickness in the Ducktown and Isabella quadrangles probably exceeds 6,000 feet.

Lithology

Little can be added to Hurst's detailed descriptions, nor are significant changes evident between the two areas.

Metagraywacke

Metagraywacke, with variants toward arkose, feldspathic quartzite, subgraywacke, silty graywacke, and conglomerate, constitutes an estimated 80 percent of the formation. Metagraywacke is the dominant rock. It is in beds ranging in thickness from a foot or so to several tens of feet and is gray to dark gray in fresh exposures. It alternates with generally thin beds of schist representing silty to argillaceous sediments. It is itself in places sheared to gneiss, or to schist where shearing is extreme; planar structures of these sheared and reconstituted rocks may cross true bedding at considerable angles but commonly are close to the bedding.

Original bedding is obscure within the usually massive thicker beds. It may be indicated by conglomeratic streaks or by conglomeratic interbeds. Attitude of bedding is best determined where well-defined schist or phyllite beds alternate with metagraywacke, but is not satisfactorily determinable in many isolated outcrops of massive layers.

Grain size may vary erratically, and small pebbles and granules may be scattered through part or all of a metagraywacke bed. Erratic slabs of dark slate as much as a foot long and rare rounded pebbles of slate are observed in the graywacke. Many beds show grading over part or all their thickness. Some thicker beds are crudely graded over a small size range; others may show excellent grading from coarse-grained rocks to silty and argillaceous layers. Many graded cycles are interrupted within the sand sizes. Well-defined graded bedding is common in thin- to medium-bedded strata, and several cycles are commonly present.

Sedimentary characters are clearly evident in most of the metasandstones. Where strongly sheared and recrystallized, sedimentary features are largely destroyed, though quartz granules and small pebbles may be preserved even in schist. Where original character is destroyed, the products are biotite-gneiss, fine-grained mica-gneiss, or mica schist.

In places, these are in narrow zones known to be associated with sheared-out folds. Hurst (1955, p. 11) described the texture of typical metagraywacke as follows:

"Original clastic shapes are usually preserved by the quartz and feldspar grains of medium size and larger. These grains are set in a granoblastic to schistose matrix of fine quartz and feldspar and fine to coarse mica."

Schistosity is commonly visible in metagraywacke unless weathering has been severe. The mica may be well oriented or may diverge widely from a plane. In some exposures, lentils with poor orientation of mica are surrounded by gneissic graywacke in which the mica plates are much nearer parallelism. The lentils appear largely to have escaped shearing during recrystallization.

Hurst (1955, p. 12-16) described the mineralogy. His nine modal analyses are summarized below, by range in percent:

Quartz--------	31.8-71.1
Plagioclase---	12.4-26.9
K-feldspar----	0 -13.7
Biotite-------	4.1-24.0
Muscovite*----	2.6-13.3
Calcite-------	0 - 4.1
Apatite-------	0 - .5
Black opaque--	.1- 1.2
Zircon--------	0 - .2
Chlorite------	0 - 5.0

*One rock contained 42.3 percent muscovite.

Other accessory minerals are titanite, tourmaline, leucoxene, epidote, and garnet. I have observed probable monazite.

The plagioclase identified by Hurst ranges in composition from andesine to oligoclase. This range is also indicated by my thin sections. Some of the twinned plagioclase is zoned in this same range, the zoning apparently being preserved from the original source of the sediment. Much of the plagioclase is untwinned and lacks zoning.

Emmons and Laney (1926, p. 16) reported common orthoclase but Hurst (1955, p. 14) found it in few of his specimens. I have seen only a few grains of microcline in my thin sections, though much search has been made for potash feldspar. Occasional granules or small pebbles from conglomeratic beds have been identified in index liquids as microcline. However, porous pulverulent pebbles may be the remnants of much weathered potash feldspar.

Biotite is the common mica and in some sections is the only mica. It is brown to pale brown with dark pleochroic halos about zircon and rare monazite(?). It may be interleaved with muscovite or chlorite, and may be partly or entirely altered to chlorite near fractures.

Discrete muscovite plates occur like those of biotite. They may interleave with biotite but in places appear to cut across biotite cleavage. Muscovite appears to be more abundant in strongly sheared rock.

Calcite is common in small amounts. It is distributed irregularly and appears to have replaced the other common constituents. Islands of quartz or feldspar in calcite have in places the same optical orientation as external grains of the same mineral.

Ilmenite, zircon, leucoxene, apatite, chlorite, garnet, epidote, titanite, pyrrhotite, and pyrite are common minor constituents. Chlorite varies from a trace to several percent and is commonly an alteration product of biotite and in places of garnet. A rare euhedral biaxial mineral with high relief and prominent alteration halos where it is in or adjacent to chlorite or biotite is provisionally identified as monazite. Some thin sections have euhedral grains of tourmaline.

Metaconglomerate

Conglomerate beds are fairly common in the metagraywacke in addition to the rather common pebbles and granules scattered through some of the beds. Conglomerates crop out at various places in the Ducktown mining district, in Stansbury Mountain and ridges to the south, and elsewhere. They range from thin discontinuous lenses to beds 15 feet thick. Some of the thicker beds may actually be lenses. Metaconglomerate is most prominent in graywacke but also is in schist and coarser quartzitic phases.

The typical metaconglomerate is composed of quartz pebbles and granules, with generally smaller amounts of feldspar clasts of similar size. These are set in a sandy matrix that may make up a third to a half of the rock. The pebbles in general are less than a half-inch across and apparently their size is determined by the grain size of the rock from which they were derived. Erratic slabs of dark slate are generally sparse and may attain lengths of a foot.

Rare pebbles of gneiss an inch or more in diameter have been observed, and well-rounded pebbles of fine-grained sericitic quartz schist as much as 3 inches long are scattered through dark mica schist on the south slope of Reese Mountain northeast of Ducktown.

The metaconglomerate beds are rarely well sorted and then only in a few thin beds with a large proportion of quartz pebbles and granules. These beds are similar to pebbly metagraywacke, and differ mainly in the larger proportion of granules and small pebbles. The base of a metaconglomerate may be sharply defined, and in places metaconglomerate beds fill what appear to be channels. Deformation may produce forms that mimic channels, and therefore certain identification of channels is in many places impossible.

Metasandstone

Metasandstones are conspicuous in places because of their fine to medium even-grained texture and superior resistance to weathering and erosion. They are high in quartz, are somewhat feldspathic, and contain some argillaceous or silty material. All are mica quartzites in which biotite greatly predominates over muscovite except in shear zones. The mica may show little orientation but commonly is sufficiently oriented that the term schistose quartzite may be applied. The schistose beds appear to be most commonly associated with the more silty and argillaceous parts of the formation.

Schist

The schists in the metagraywacke range from near-phyllite to coarse schist. Most are mica schists, either sericite-schist or sericite or muscovite schists with small amounts of biotite. Colors of the mica schist include greenish gray, silvery gray, brownish gray, and brown; Hurst (1955, p. 17) termed them "drab." The phyllitic varieties may be light to dark silvery gray to nearly black; rarely a faint purplish tinge seems to be a relic of original reddish color of the sediments.

The schists that were derived from metasandstones by severe shearing and recrystallization commonly show remnants of sandstone on breaks across the schistosity. These contrast with schists derived from silty and argillaceous sediments, which have no relic sedimentary textures.

The phyllitic varieties may show only the sheen of sericite. In others, flakes of muscovite and biotite are identifiable, and these phyllites grade through intermediate varieties to typical schists. Many schists and some phyllitic schists contain metacrysts of almandiferous garnet. Biotite metacrysts lying across the schistosity are present in many layers but are entirely absent in others. Chlorite may also be in cross position. Staurolite metacrysts are noted in some schists at and southeast of the westernmost (Burra Burra) ore zone of the Ducktown district, and its projection on regional strike. Staurolite is much more common near the ore zones than elsewhere in the district, which may indicate that alteration in and near these zones was favorable to its development; the fact that it occurs in graywacke as well as schist favors such an interpretation. In other formations, distant from known major mineralized zones, staurolite is restricted to thin zones in phyllite and schist that had an original favorable composition.

Kyanite has not been recognized in the schists, or other rock types, at the surface. It is associated with staurolite in a disturbed mica schist of the Calloway mine above the 18 level.

Much of the schist and phyllite of the metagraywacke is crinkled. The crinkles may be open and of minute amplitude or may be acute with amplitudes ranging from a small fraction of an inch to 2 inches. Where the rocks are moderately to severely crinkled, a crinkle cleavage is prominent; this cleavage governs the fracture of the rock in both natural and artificial exposures. The crinkle cleavage has the appearance of slaty cleavage in such areas and some recrystallization appears to have occurred along the fractures. The older cleavage also seems to have been dragged into parallelism; it can easily be seen with the hand lens on cross-breaks if weathering is not too advanced, but it may be entirely destroyed in places.

The minerals of the schists are much the same as those of graywacke, but the proportions differ. Micas are much more abundant, as are garnet and, in some rocks, quartz. White mica ranges from sericite to muscovite. Biotite may be in plates along the schistosity, or lie across the schistosity, or both. Garnet is generally well formed with a much smaller percentage of inclusions than the garnets of metagraywackes. Monazite has been positively identified. The darker phyllites contain probable graphite.

Pseudodiorite

The term "pseudodiorite" was applied by Emmons and Laney (1926, p. 19-21) to nodular, lenticular, and pipelike masses in the metagraywacke, composed mainly of plagioclase, quartz, hornblende, and (or) biotite, with garnet, epidote (usually clinozoisite), and lesser amounts of other minerals. I shall refer to this type as lenticular pseudodiorite. A second type of pseudodiorite was described as bedded pseudodiorite by Hurst (1955, p. 28). This type occurs as beds and as greatly elongated thin lenses parallel to the bedding. Both types are described in detail later in this report, under "Metamorphism."

Map units northwest of the metagraywacke

[Ed. note: Hernon left no formal description of the map units shown northwest of the outcrop of the metagraywacke (fig. 1) and labeled, from southeast to northwest, slaty unit, unit 1, unit 2, and unit 3. Unit 1, 6,000-8,000 feet thick, consists of a sequence of silty and argillaceous layers alternating with sandy layers (graywacke) and granule and pebble conglomerate. About 60 percent of the unit is fine-grained metasedimentary rocks. Unit 2, 400-600 feet thick, is metaconglomerate. Unit 3, 4,000 feet thick or more, is made up of greenish-gray to dark-gray slate and fine-grained quartzite, and is about 90 percent fine-grained metasedimentary rock. These units are much folded, their age with relation to the formations southeast of the metagraywacke is uncertain, and no correlations are attempted.]

Wehutty Formation

Definition and distribution

The Wehutty Formation has been named (Hernon, in press) for the settlement of Wehutty, N.C. These rocks were included in the upper part of the Copperhill Formation by Hurst (1955).

The Wehutty Formation underlies an irregular area that constitutes about one-third of the Isabella quadrangle along its east boundary and also underlies about the northwest third of the adjoining Persimmon Creek quadrangle. The slaty belt along the northwest boundary of the metagraywacke formation, referred to as the slaty unit on figure 1, may be a partial equivalent of the Wehutty Formation. Uncertainties are many, however, so this correlation is merely suggested herein; the problem may be resolved by future mapping to the north.

The mostly poor roads leading northwest and southeast from Mt. Olive church, northeast of the center of the Isabella quadrangle, provide the best and least-interrupted exposures of the formation in the Wehutty area. The old State Road through Postell, N.C., has fair exposures of part of the Wehutty, and interrupted exposures may be seen along the tributary Allen Branch road and nearby lumber roads. The upper beds are well exposed along the wagon road of upper Persimmon Creek, southeast of Wolfpen Gap, Isabella quadrangle. The cuts along U.S. Highway 64 and minor tributary roads, southeast of Franklin Gap, Isabella quadrangle, also expose the upper strata.

Stratigraphic relations and thickness

The base of the Wehutty Formation was arbitrarily drawn where the available information indicates change from predominant metasandstone to an alternating sequence in which argillaceous and silty beds are abundant. In some places, as in the ridge east of Stansbury Gap, advantage was taken of mappable layers in drawing the contact. Where exposures are poor, it was necessary to visually integrate the available lithologic information over pertinent areas on strike and to sketch the contact. Other workers would undoubtedly draw the contact somewhat differently, but the differences would probably be minor.

The upper contact is clearcut and is placed at the top of a conglomeratic member that can be traced with confidence across the map area. This contact corresponds to the base of the Hughes Gap Formation of Hurst (1955) and marks a change from a sequence on the northwest having dominantly dark schists and phyllites to a sequence on the southeast characterized by dominantly light colored sericitic and muscovitic schists.

Folding and probable faulting of this generally incompetent formation make estimates of its thickness uncertain. Its minimum thickness probably exceeds 4,000 feet; the total may be 50 to 100 percent greater.

Lithology

The Wehutty Formation is composed of schist, ranging from fine-grained phyllitic varieties to those of medium grain, alternating with metasandstones ranging from impure quartzite to metagraywacke. The arenaceous rocks may be pebbly and have thin conglomerate layers. Quartz-pebble conglomerates are conspicuously more common and better sorted in the upper 3,000 feet or so of the formation. The proportion of originally argillaceous and silty sediment is generally about half or more, but a number of zones hundreds of feet thick are composed largely of metamorphosed sand and gravelly sand. It was possible to map some of these thicker metasandstones over varying distances as shown on figure 1.

Schist

A much greater proportion of schist distinguishes the Wehutty Formation from the metagraywacke, and the light- to dark-gray phyllites and schists are much more abundant than they are in the similar overlying Hughes Gap Formation, in which light-colored mica schist and muscovite or sericite schist prevail. Schistosity of finer grained beds of the Wehutty Formation is evident; it may be mildly to greatly deformed.

The schists range in color from light silvery gray to nearly black, and from typical schist to beds that could be described as glossy phyllite, usually with visible porphyroblasts. The schistosity is usually conspicuous but in some areas and beds the orientation of mineral grains is much less evident macroscopically, particularly where the rock is crowded with garnet or with micaceous minerals in cross position. Some of the dark graphitic layers are slaty in appearance except for warping of the cleavage. Deformation of the schistosity ranges from slight warping to acute crinkling, in places with larger folds.

The minerals of the gray schists are biotite, sericite, plagioclase, quartz, garnet, chlorite, tourmaline, apatite, zircon, opaque matter, and staurolite. Biotite in many beds is of two sizes: small flakes that are oriented along the schistosity, and much larger books that are in cross position. Biotite is typically brown, but a few small flakes are olive green. Muscovite, or sericite, is abundant and with biotite defines the schistosity. Plagioclase is a major constituent in some laminae and also occurs as rare to sparse grains in quartz-rich laminae. It ranges from andesine to sodic oligoclase, the latter being most common. In the thin sections studied, quartz is much more abundant than plagioclase. Garnet is commonly in euhedral crystals with a low percentage of inclusions. Some chlorite is a pale-greenish low-birefringent variety, commonly intimately associated with biotite. A second type of chlorite, in part dusty, is pleochroic from olive or brownish green to colorless, or to pale tan or green. The index of cleavage flakes is near 1.62, and the mineral may be either positive or negative. This type is associated closely with staurolite as large masses or is in smaller masses in cross position that may contain rare uniformly oriented remnants of biotite. Green chlorite, possibly original, forms prominent porphyroblasts in cross position in some biotitic schists.

Tourmaline is in rare olive-green or olive-brown grains. Zircon is in small grains and presumably is the mineral at centers of pleochroic halos in biotite and chlorite. The opaque matter includes iron sulfide, commonly pyrrhotite, dark-gray tabular masses of faintly magnetic iron ore believed to be ilmenite, and dusty to somewhat platy material, part of which is graphite or carbonaceous matter, and the rest unidentified.

Euhedral staurolite is in beds an inch to a few inches thick, interlayered with other schists in the middle and upper part of the Wehutty Formation. Some of the schist is well banded and thinly banded, as in a unit of the upper part of the Wehutty Formation described by Hurst (1955, p. 17) as varved schist. The staurolite crystals range in length from a fraction of an inch to perhaps 3 inches. Twins are not abundant, and most single crystals are well formed, particularly in finer grained rocks. Staurolite is poikiloblastic in varying degrees. Single crystals may show nearly clear parts and other parts thickly set with inclusions and dark opaque dust, probably graphite. These phases have no constant relation to borders of well-formed crystals and seem to represent differences in replaceability of two or more varieties of schist. Other crystals show rather evenly spaced inclusions throughout, mainly quartz. Alteration of staurolite to sericite or muscovite is apparently rare except for thin zones along the margins of crystals. The sericite of such zones is in part oriented at high angles to the crystal faces.

Metasandstone

The most characteristic metasandstone is micaceous feldspathic quartzite in which biotite predominates over muscovite. Muscovite may nearly equal biotite in some layers but ordinarily is much less abundant and may be present in only trace amounts. The feldspar is sodic oligoclase to medium andesine. Much of it is untwinned and may not show cleavage. A few grains show zoning. In the typical micaceous quartzite, feldspar is less than 25 percent. Mica, mainly biotite, may be as low as 5 percent, and carbonate commonly ranges from 1 to 8 percent. Other minerals are tourmaline, zircon, sphene, garnet, leucoxene, chlorite, and apatite, in small or trace amounts. Potash feldspar was not found despite careful search. Radioactive material of low birefringence is in part metamict zircon, but other grains may be metamict monazite.

Typical feldspathic quartzite varies toward orthoquartzite by decrease in feldspar, or it may vary toward graywacke by increase in mica but without showing any content of rock fragments. Scattered granules and small pebbles of quartz, and thin conglomerate are other variations.

Some beds of deeply weathered metasandstone are apparently metamorphosed graywacke and arkose like those in the metagraywacke. These seem to be scarce, however.

Metaconglomerate

The better sorting of materials in the Wehutty Formation as compared to the metagraywacke is evident in the conglomerates as well as in the other rocks. This is particularly true in the upper half or so of the formation where conglomerates show a smaller range of pebble size, and pebbles are largely to almost exclusively quartz, set in a sand matrix. These quartz-pebble conglomerates are also characteristic of, and more abundant in, the overlying Hughes Gap Formation. Some conglomerates or conglomeratic beds are more like those of the metagraywacke, particularly in the lower half of the Wehutty. These commonly show a larger proportion of feldspar pebbles, continuous gradation in size of fragment from small pebbles to sand, a lesser degree of rounding, and much less persistence in thickness and extent of individual beds, than is true of the quartz-pebble conglomerates.

The pebbles of the quartz-pebble conglomerates are relatively evenly sized and well rounded but are flattened by flowage. The matrix shows a large proportion of quartz and lacks the rock fragments of metagraywackes. These conglomerates are interbedded with schists and with feldspathic mica quartzites.

Hurst considered the beds between the mainly metasandstone portion of his Copperhill and Hughes Gap Formations as transitional in character, and stated (1955, p. 33): "The Hughes Gap metaconglomerate is typically oligomictic * * * in contrast to the polymictic metaconglomerate of the Copperhill Formation." His transitional beds constitute the upper part of the Wehutty Formation, but apparently much of the lower part of the Wehutty is cut out in the south part of the Isabella quadrangle, probably by faulting, and fails to extend into the Mineral Bluff quadrangle.

Hughes Gap Formation of Hurst (1955)

Definition and distribution

Hurst (1955, p. 21-35) named this formation for Hughes Gap in the central north part of the Mineral Bluff quadrangle. It is well exposed in roadcuts of the type area. Hurst estimated its thickness at 4,000-6,000 feet. The following quotes from Hurst's detailed description define the lithology of the formation:

"The Hughes Gap formation is characterized by garnet-mica schist, staurolite schist, metaquartz conglomerate, quartzite, and pseudodiorite. In addition to these rocks, there are beds of metagraywacke and mica schist, particularly near the base of the formation. The strata range in thickness from a fraction of an inch to more than 50 feet. They are mostly less than 10 feet thick. Changes in thickness and lithology are common along strike.

"* * * Garnet-mica schist, interstratified with mica schist, quartzite and pseudodiorite, makes up thick zones in the Hughes Gap formation.

"* * * The staurolitic beds are restricted to certain zones in the Hughes Gap formation. Where zone boundaries transgress bedding, they do so by the interlensing of staurolitic and non-staurolitic beds. Within the zones, staurolite schists are interbedded with metaquartz conglomerate, quartzite, and with schists that differ from the staurolitic schists only by the absence of staurolite.

"* * * The staurolite-bearing schists include quartz-mica schist, garnet-mica schist, graphitic mica schist, sericite schist, and gradational types. At any one locality the staurolite may be found predominantly in one type of schist, or in two or more types that are interbedded with each other and with rocks that lack staurolite. The thickness of the beds is mostly less than three feet, rarely greater than ten feet.

"* * * The conglomeratic zones in the Hughes Gap formation are usually about 50 feet thick, and contain more or less quartzite, as well as some schist, in addition to metaconglomerate. The thickest zones are 200-300 feet thick, and are usually traceable less than one-half mile. They lense-out by interleaving with beds of schist and quartzite. Some of the zones end abruptly.

"* * * the metaconglomerate in the Hughes Gap formation is characterized by the preponderance of quartz pebbles, by a sandy matrix, by interbedding with orthoquartzite, and by occurrence in lense-shaped or more irregularly-shaped deposits. The quartz pebbles are well-rounded, sized and mostly less than an inch in diameter.

"Under the microscope, the pebbles are seen to be mosaics of small quartz grains which have interlocking or even sutured boundaries * * *. The matrix is fine quartz and sericite, or quartz, biotite, and muscovite. Where the metaconglomerate tends toward the polymictic type, fine feldspar, often of more than one variety, as orthoclase and oligoclase, occurs also in the matrix. Small, well-rounded grains of zircon are locally abundant.

"* * * The purest quartzites in the Hughes Gap formation are associated with metaquartz conglomerate * * *. The beds rarely exceed five feet in thickness. The grain size ranges from fine to coarse. The largest grains have been deformed like the pebbles in the metaconglomerate.

"Most of the quartzites are impure. Some of them contain hornblende and garnet as accessory minerals, others contain biotite, or biotite and muscovite. Their varietal minerals are usually the same as the essential minerals in the associated beds."

The Hughes Gap Formation underlies a northwest-striking belt 3,500-6,000 feet wide that crosses the Isabella quadrangle near the southeast corner and continues across the adjacent Persimmon Creek quadrangle through its northeast corner. Natural exposures are few and small except along Hiwassee Lake reservoir, particularly at and below the maximum water level. Erosion along trails, minor roads, and timber skids exposes saprolitic material, and less weathered to nearly fresh rock is exposed in roadcuts.

Stratigraphic relations and thickness

The base of the Hughes Gap Formation is placed at the same horizon as shown by Hurst just south of the south boundary of the Isabella quadrangle, at the top of a prominent member of the Wehutty Formation composed of feldspathic mica quartzite and metagraywacke with pebbly portions and conglomerate beds. Other features of the contact have already been described (p. 12 and 15). The top of the formation in the Mineral Bluff quadrangle was placed by Hurst (1955, p. 34) at a layer of quartz-kyanite schist. I failed either to recognize or to find this layer in the present area and therefore chose an arbitrary contact at about the same horizon. This contact is drawn just southeast of the last known staurolitic beds and quartz-pebble conglomerates characteristic of the Hughes Gap Formation. Actually, conglomeratic beds are known southeast of this line, but typical quartz-pebble conglomerate is sparse or missing in the adjacent part of the Hothouse Formation insofar as observation is permitted by sparse exposures of rock.

The true thickness of the formation is indeterminate because of much folding and probable but unmappable faults. It is probably between 3,000 and 5,000 feet.

Lithology

The Hughes Gap Formation has many features in common with the Wehutty Formation. It differs in the predominance of light-colored schist over dark phyllitic schists, and is characterized by mildly to acutely crinkled schists alternating with a lesser but appreciable amount of metasandstone. The mica schists are mostly light colored because of dominant muscovite, but beds of gray schist like those of the Wehutty Formation recur.

Much of the light-colored schist contains garnet, and staurolite schists are common and are particularly abundant in the northwest part of the belt. Staurolite is most common in the light-colored schists but is also present in thin beds of the darker phyllitic schists as in the Wehutty Formation. Staurolite may be partly to completely altered to muscovite.

The color of the dark coarser grained schists is due to biotite, and that of the dark phyllitic varieties to graphite and biotite. Opaque weakly magnetic material, probably ilmenite, is scattered through the schists but is most evident in the lighter colored varieties. Pyrrhotite or pyrite is present in very small amounts; the former is dominant. Iron sulfide appears to be missing in much of the light-colored schist. Biotite is in flakes about equal in size to white mica, and in some beds forms larger elongated books in cross position as well. It may be smeared out, particularly in highly crinkled schist, and may be partly altered to light-green chlorite.

Mineralogy of the gray phyllitic schists is like that of the gray schists of the Wehutty Formation. A little of the gray type is characterized by greenish-gray color but the reason for the color difference is unknown.

Metasandstone

The metasandstones range from metagraywacke and metaarkose to feldspathic quartzite and impure orthoquartzite, all micaceous with biotite greatly predominating over white mica. Some beds or parts of beds have scattered granules and small pebbles of quartz. Pseudodiorite lentils like those in the metagraywacke unit (Copperhill Formation of Hurst) seem relatively sparse.

A small amount of iron sulfide is easily seen in fresh metasandstones. Most of it, and in most specimens all of it, is pyrrhotite. It occurs as irregular ragged masses and stringers, whose long dimensions are generally oriented with the schistosity where that structure is pronounced.

Metaconglomerate

The typical conglomerate of the Hughes Gap Formation is composed of small ellipsoidal quartz pebbles set in a sandy matrix. Some conglomerate layers are interbedded with schist but most are in impure quartzite, feldspathic quartzite, or metaarkose. Many beds are very well sorted in respect to the pebbles, particularly those interbedded in schist and quartzite. Some in feldspathic metasandstones are well sorted, but others may show spaced to crowded subrounded to rounded pebbles that range in size from about an inch down to granules, set in rather evenly sized sand. The pebbles of the latter conglomerate are mostly quartz but a few appear to be of gneiss or a fine-grained granitic rock; the sand is feldspathic and biotitic. Crowded pebbles are decidedly flattened with long axes about parallel with fold axes. Not all are flattened with the flow structure, for conglomerates of some localities show consistent flattening about parallel with crinkle cleavage, as southeast of Bryant Mountain in the southeast part of the Isabella quadrangle. These may have been rotated during crinkling of the flow cleavage and development of the false cleavage.

Pseudodiorite

Pseudodiorite is in layers a few inches to a few feet thick, interbedded with various schists and with quartzite and feldspathic quartzite. It seems more abundant than in the Wehutty Formation. Hurst (1955, p. 28-32) described the pseudodiorite of the Hughes Gap in detail; part of his description (p. 28) is as follows:

"The pseudodiorite in the Hughes Gap formation occurs in beds * * * that are mostly less than three feet thick, but rarely attain a thickness of more than 50 feet. It is interstratified with mica schist, garnet-mica schists, quartzite, staurolite schist, and occasionally with metagraywacke. The bedding planes are sharp; however, variations in texture and mineralogy are conspicuous within the beds. For the most part, these variations are planar and parallel to the bedding, and reflect differences in composition and grain size in the original sediment.

"The pseudodiorite is composed essentially of quartz, plagioclase, and hornblende. Epidote and garnet are nearly always present, and commonly are major constituents. The relative amounts of these five minerals differ greatly from bed to bed, as well as within the beds."

Hothouse Formation of Hurst (1955)

Definition and distribution

Hurst (1955, p. 35-40) named the Hothouse Formation for Hothouse Creek, which flows from the northeast corner to the central part of the Mineral Bluff quadrangle. Parts of his description follow:

"* * * The principal rock types are metagraywacke and mica schist, which are interbedded throughout the formation. The other major rock types are metaconglomerate and quartzite.

"The base of the formation is characterized by the predominance of mica schist. The thickness of the schist beds is usually less than two feet but sometimes more than 25 feet. The schist is fine- to medium-grained, and consists mainly of muscovite, biotite, and quartz. The mica content ranges from 40% to more than 90%, with muscovite the dominant variety. The biotite is typically red-brown. * * * The feldspar is usually oligoclase or andesine. Potash feldspar occurs in some beds. Almandine garnets are sparingly present in crystals less than one-eighth inch in diameter.

"The schists weather to fine, micaceous saprolite in which adjacent beds often have different colors. Dark yellowish orange (10YR 6/6), grayish red purple (5RP 4/2), and pale reddish brown (10R 5/4) are typical colors. This thin-banded, varicolored saprolite, which is very slippery when wet, is a characteristic feature of the base of the Hothouse formation.

"The middle part of the formation consists mainly of interbedded metagraywacke and mica schist. The beds vary greatly in thickness from place to place, but tend to thicken upward in the section. This part of the formation is lithologically indistinguishable from the Copperhill formation."

The Hothouse Formation underlies a northeast-trending belt 12,000 to 13,000 feet wide that crosses the Persimmon Creek quadrangle from the southwest to the northeast corner. It also underlies the extreme southeast part of the Isabella quadrangle. Natural outcrops are few, and most of the exposures of rock and saprolite are in roadcuts and along eroded trails and minor roads.

Stratigraphic relations and thickness

Hurst (1955, p. 38-40) discussed the upper contact of the Hothouse Formation with his Dean Formation and stated that the Hothouse metasediments "belong to the graywacke suite." He considered his upper member (here excluded) as a hybrid zone transitional to the metasediments of the Dean Formation which were formed in a different depositional environment. He also stated (p. 40) that:

"The hybrid zone changes in character along strike within the Mineral Bluff quadrangle. It is anticipated, therefore, that the relative thickness of the Hothouse and Dean formations and the manner of transition from one to the other may be radically different in other areas."

I had difficulty in finding criteria to separate the Hothouse and Dean Formations in the present area. The most practical seems to be the appearance of the staurolite schists and quartz-pebble conglomerates that characterize the Dean Formation. The boundary was so chosen, and as a consequence the thin upper part of Hurst's Hothouse Formation is thereby included in the Dean Formation. This interpretation in no way denies the transitional nature of the contact but is a solution to a practical mapping problem.

The location of the northwest contact of the Hothouse Formation was discussed in the preceding section on the Hughes Gap Formation. Both upper and lower contacts as drawn for the present area are based on the same criterion; that is, to leave the Hothouse Formation essentially free of staurolite schist and of typical well-sorted quartz-pebble metaconglomerate.

The Hothouse Formation is known to be folded, but the size of folds is in doubt owing to lack of positively recognizable key beds. Faults are suspected in places but I was unable to map them. The thickness was estimated by Hurst to be 8,000-11,000 feet.

Lithology

The Hothouse Formation is composed of schist and a seemingly lesser amount of metasandstone. The weakness of highly feldspathic rock under weathering probably causes the proportion of metasandstone to seem less than it actually is. Some more resistant metasandstones in the central part of the area are feldspathic biotite quartzite. The schists and metasandstones alternate, and some schist members are apparently thicker than the thickest metasandstone members. Thick schist members are prominent along both the northwest and southeast contacts, but insofar as rock exposures permit observation, the main central portion is characterized by alternation of schist and metasandstone at short intervals. Interfingering of the two is indicated in places, but how much is original and how much is due to structural causes is not clear.

Schist

Much of the Hothouse Formation is light-colored mica schist, crinkled in varying degrees. The content of biotite may be small, but some beds, and thin layers in banded schist, are dark because of its abundance. Some layers of schist are essentially biotite-free or have scattered elongated biotite books in cross position. Others have much biotite in cross position in a much crinkled sericitic or muscovitic matrix. Garnetiferous schist seems less common than in other formations.

The schists are mostly fine grained but range from phyllitic varieties to medium-grained schist. Any of these may superficially appear coarse grained because of porphyroblasts of garnet or biotite.

A few thin beds of silvery-gray to gray phyllitic schist are known but these are rare in the formation. Some sandy biotite schists are sheared fine-grained impure sandstones. These grade into rocks of even-grained and gneissic character.

The minerals of the typical schists include abundant muscovite or sericite and quartz, generally much smaller amounts of biotite, variable amounts of andesine or oligoclase, minor proportions of clinozoisite and zoisite, greenish epidote, garnet, chlorite, and accessory apatite, tourmaline, zircon, and opaque iron ores. Sulfides appear to be missing or are present only in very small amounts.

Biotite is in flakes associated and oriented with white mica flakes of about the same size. It also is in elongated books of much larger dimension set in various orientations across the schistosity. Cross-biotites of some much-crinkled schists show smooth undistorted cleavage faces and appear to have grown after deformation of the schistosity.

Biotite ranges from deep brown to reddish brown in color; less commonly it is a peculiar olive green.

Plagioclase is oligoclase or andesine; twinned grains are few, and most determinations were made on the basis of index of refraction and optic sign. Plagioclase in most thin beds is present in much smaller amount than quartz, but some interbedded layers are largely plagioclase with micas and but little quartz.

Members of the epidote group are present in most thin sections. Clinozoisite is the typical mineral but zoisite is also present in some specimens. Light-green epidote is localized along and near some cross fractures. Some thin sections of schist from a quarry along North Carolina Highway 294 near the center of the Persimmon Creek quadrangle contain an epidote-like mineral that is overgrown with normal epidote and is marked by pleochroic halos where it contacts biotite. Portions may show low birefringence and a faint tan color. Parts with higher birefringence are pleochroic from colorless to a faint greenish tint. It is identified as allanite though none of it has the characteristic brown color of metamict allanite.

Garnet may be missing or may be present in small to moderate amounts as euhedral to subhedral porphyroblasts with generally a small percentage of inclusions.

Chlorite may be in large to small plates or in divergent groups of plates of green color. These may be interleaved with other micas or occur alone, and appear to be original. Some chlorite is clearly derived from biotite.

Dark elongated specks are abundant in the light-colored schists. Most of these are weakly magnetic. Thin sections show tabular, weakly magnetic plates oriented with the schistosity; these are identified as ilmenite. Other thin sections show both tabular forms and subhedral equidimensional forms. The latter are magnetite and appear to be more common in the biotitic bands.

Other accessory minerals include common apatite, olive-green tourmaline in subhedral grains, and zircon in tiny crystals in biotite and chlorite as well as in a few larger rounded detrital grains.

Metasandstone

The metasandstones of the Hothouse Formation are so deeply weathered and sparsely exposed that description of these rocks is necessarily inadequate. Judged from incomplete observation, these metasandstones differ from those of the metagraywacke unit in being finer and more evenly grained and having fewer or no rock fragments. Some are conglomeratic and contain poorly sorted conglomerate beds.

Well-sorted quartz pebble conglomerates like those of the Wehutty and Dean Formations are few or lacking.

All metasandstone is feldspathic and impure. Some is classed as metagraywacke but with a generally small content of evident rock fragments. Much seems to have been clay- and silt-bearing sand with a small to moderate range in grain size. All metasandstone contains biotite with subordinate white mica in some beds, and much of it can be described as biotitic metagraywacke and impure feldspathic biotite quartzite. Beds vary widely in thickness but alternations with mica schist are most commonly at intervals of 5-10 feet over parts of the section. Graded bedding is much less evident than in the metagraywacke unit, but this may in part be due to poorer exposures.

Thin sections show the metasandstones to be schistose to nearly granoblastic rocks characterized by interlocking grains of feldspar and quartz. The schistosity is primarily defined by the mica laths, although weak orientation of other mineral grains may be evident. The feldspar and quartz grains are irregular and crudely equidimensional in most thin sections. Original clastic forms are rarely recognizable, which together with the lack of potash feldspar appears to indicate thorough recrystallization. Moreover, there is little evidence of relict graywacke-type matrix or of rock fragments. Whether or not these features were completely destroyed by recrystallization or existed only in small amount is problematical. Perhaps my thin sections fail to adequately represent the nature of metasandstones in a deeply weathered area, but it seems probable that recrystallization was thorough and that potash feldspar, with the possible exception of microcline, was not stable under the metamorphic conditions prevailing.

Pseudodiorite

Pseudodiorite of nodular and bedded types is observed in some metasandstones and sandy schists of the Hothouse Formation. These pseudodiorites appear not to differ in any important way from those of the underlying formations. Pseudodiorite seems to be less abundant in the Hothouse Formation than in the adjacent Wehutty and Dean Formations.

Dean Formation of Hurst (1955)

Definition and distribution

The Dean Formation was named by Hurst (1955, p. 40-45) for Dean Ridge in the eastern part of the Mineral Bluff quadrangle, Georgia. Excerpts from his description follow:

"* * * The Dean formation crops out in a one-half mile wide belt on each limb of the Murphy syncline. * * * The thickness of the formation is 2500-3500 feet.

"The Dean formation, like the Hughes Gap formation, shows marked horizontal variations, abrupt vertical variations, and many breaks in lithologic sequence, some of which might be the result of erosion rather than non-deposition.

"The best exposures are along Dean Ridge, north of Mineral Bluff, and along Georgia highway 5, northwest of Blue Ridge.

"* * * Staurolite-mica schist, X-biotite [cross-biotite] schist, metaquartz conglomerate, quartzite, and pseudodiorite are the principal rock types. They are interbedded with less amounts of gray slate, of phyllite, and sericite schist. Metagraywacke and metaarkose are locally present. Except for the abundance of X-biotite schist, and the absence of quartz-kyanite schist at the top, the Dean formation is lithologically indistinguishable from the Hughes Gap formation.

"* * * One of the most distinctive rocks in the quadrangle is X-biotite schist, also called 'spangled biotite gneiss' and 'speckled schist.' The rock has a light-colored, fine-grained, groundmass which is thickly studded with coarse, shiny black to dark brown biotite crystals * * *.

"The X-biotite schist is generally interbedded with impure quartzite and pseudodiorite."

Keith (1907, p. 4), in his description of the Nantahala Formation, noted an upper banded slate and a lower portion characterized by schists that "strongly resemble the slate and schist beds in the Great Smoky conglomerate." The Murphy 30-minute quadrangle, which includes the present area, was mapped by Keith and Hayes, and the field sheets were later compiled by P. B. King for release in 1950 as an open-file map. This map shows two members of the Nantahala Formation that correspond to Keith's lithologic description. Hurst (1955, p. 43) stated:

"* * * Keith (1907, p. 4) and LaForge and Phalen (1913, p. 6) mentioned that staurolite schist and metaconglomerate occur in the lowest part of the Nantahala. These beds are now relegated to the Dean formation, and the Dean-Nantahala boundary is drawn at the base of the dark slate."

This separation by Hurst is a useful one that divides the formations at a marked change in lithology.

The Dean Formation as here delimited underlies a northeast-trending belt about 4,500 feet wide that crosses the Persimmon Creek quadrangle and passes through the center of the east boundary.

Stratigraphic relations and thickness

The arbitrary contact chosen as the boundary between the Hothouse and Dean Formations of the present area was discussed on page 20. This contact appears to be somewhat lower in the section than that selected by Hurst in the nearby Mineral Bluff quadrangle. Rock exposures in the northeast half of the belt are too few to closely control the contact, and it has therefore been sketched on the basis of strike and width of outcrop to the southwest.

The upper contact, also poorly controlled by exposures of rock, was drawn to separate the light-colored schists of the upper part of the Dean Formation from the dark rocks of the Nantahala Slate. It therefore corresponds to the contact as defined by Hurst (1955, p. 43-45), who also discussed its nature.

The thickness of the Dean Formation as mapped can only be estimated from its width of outcrop and dip. Schistosity-bedding relations suggest folds, but their magnitude is indeterminate. Small folds can be seen in places. The thickness must be between 3,000 and 4,500 feet.

Lithology

The Dean Formation of the Persimmon Creek quadrangle is composed of fine-grained muscovite or sericite schists, light-colored mica schist, cross-biotite schist, and minor gray phyllitic schist, all with interbedded feldspathic metasandstones and pseudodiorite. It is particularly characterized by many staurolitic beds and thin to moderately thick quartz-pebble conglomerates. A prominent metasandstone and quartz-pebble conglomerate member near the top of the formation is shown on the map. As pointed out by Hurst, the Dean Formation is essentially identical lithologically with the Hughes Gap Formation.

Schist

Schist is the dominant rock of the formation. Attitudes are determinable from numerous mostly thin interbeds of metasandstone and metaconglomerate. The schist may be slightly to acutely crinkled, most of it showing moderate to severe deformation of the cleavage.

The dominant schists exposed are sericite and muscovite schist, ranging from phyllitic to medium-grained varieties, and light-colored mica schist, both similar to the light-colored schists of the Hothouse Formation. Garnet is a common mineral in much of the schist, ranging through several feet or tens of feet of beds or restricted to thin beds alternating with thin garnet-free layers of otherwise similar character. It may be sparsely to abundantly present as well-formed porphyroblasts. Other minerals are quartz, biotite, chlorite, slightly magnetic plates (probably ilmenite), other opaque minerals, apparently minor feldspar, and accessories much as in previously described formations. Where acutely crinkled with great development of false cleavage, the biotite is smeared out and largely altered to green chlorite. Biotite is sufficiently abundant in some beds to term the rock mica schist, but white micas prevail. Small prisms of tourmaline are disseminated in sericite schist on Beech Creek at the east boundary of the Persimmon Creek quadrangle and are particularly abundant along a fracture cleavage.

Variations from white mica and two-mica schists include cross-biotite and staurolitic beds. The schist may show sparse elongated biotite books in cross position. Where much crinkled and sheared by false cleavage, these books may be rotated to the false cleavage as well as smeared out.

The staurolitic beds are sericite or muscovite schists and mica schists, similar to the described types except for the small to large euhedral staurolite porphyroblasts. These may be oriented in any direction but tend to lie along the false cleavage where it is well developed. Many staurolitic beds also contain garnet.

Schists with abundant cross-biotite porphyroblasts have been described in detail by Hurst (1955, p. 40-43). Many layers in the Dean Formation of the Persimmon Creek quadrangle are cross-biotite rocks, but those with large and abundant cross-biotite books appear to be less common than in the Mineral Bluff quadrangle.

Minor amounts of gray slaty schists are usually in thin bands. They appear similar to gray phyllitic schists previously described.

Metasandstone

Metasandstone beds are mostly thin but may be as much as 50 feet thick if thin schist layers are ignored. Most of these are relatively even grained but others are pebbly and contain conglomerate. They are feldspathic and micaceous with biotite the dominant mica. Well-defined graded bedding is rarely recognizable, owing in part to deep weathering.

Metaconglomerate

Well-sorted quartz-pebble conglomerates a few inches to 40 feet thick are characteristic of the Dean Formation. They are very similar to those of the Hughes Gap Formation and the upper part of the Wehutty Formation. They are interbedded with impure quartzite and schist and, though variable in thickness, may persist for miles if thick. The pebbles are flattened by flowage, but the plane of flattening is about parallel to the false cleavage in places, probably because of rotation during development of that cleavage and associated crinkles.

Pseudodiorite

Pseudodiorite bodies of lenticular shape are noted in metasandstone that approaches graywacke in character, but the abundant and characteristic type is bedded pseudodiorite. Many of these beds might be called hornblende quartzite or pebbly hornblende quartzite. The thickness ranges from a few inches to several feet. Bedded pseudodiorite of the Dean Formation does not appear to differ appreciably from that of the previously described formations.

RELATIONS OF ROCKS OF GREAT SMOKY AGE TO THOSE OF THE MURPHY MARBLE BELT

Hurst (1955, p. 43-45) has emphasized the lithologic change across the contact between the Dean Formation of the Great Smoky Group and the Nantahala Slate of the Murphy marble belt, as well as the changing character of the metasediments below the Nantahala. Furcron (1953, p. 36-37) discussed the possibility that this contact is an unconformity. The abrupt change in degree of development of schistosity and crinkling across the contact in the Persimmon Creek quadrangle suggests that the two groups had different histories. This change does not seem to result from lithologic differences inasmuch as the rocks of the Murphy marble belt, which for brevity hereafter will be referred to as the Murphy sequence, include many argillaceous sediments. The strikingly lesser development of crinkling in the Murphy sequence can be explained as a direct result of the absence or poor development of schistosity in that sequence as compared to the adjacent Great Smoky Group.

The mineralogy of the two sequences of metasediments is about the same. Both have prominent cross-biotite porphyroblasts that seem to have grown later than the minerals of the matrix and hence later than the schistosity of the Great Smoky Group. It would thus seem that the Great Smoky Group has been subjected to early dynamic metamorphism followed by thermal metamorphism under light directed stress, but that the rocks of the Murphy sequence were affected by thermal metamorphism alone under light stress.

Several explanations appear:

(1) The Murphy sequence consists largely of thin-bedded sediments with few thick competent beds or members, unlike the Great Smoky Group, which includes many metasandstone units. If the bedding at the present surface was nearly parallel to the axial planes of asymmetrical folds, the shearing stress might have been relieved by slippage along the numerous bedding planes of the Murphy rocks. The evident cleavage in these rocks is bedding cleavage.

(2) The two sequences may be separated by a fault of considerable magnitude. If such a fault exists it must be near the bedding, for

no decisive evidence such as disappearance of units has been noted. None of the usual physical distortion of rocks has been recognized in the field. Although such evidence of faulting may be restricted to a narrow unexposed zone in an area of few outcrops, nevertheless the pattern of the maps by Keith (1907; King, Keith, and Hayes, 1950) and Hurst (1955) does not suggest a fault of large magnitude.

(3) The decreasing depth of burial in some way may have inhibited development of crosscutting schistosity.

(4) The rocks of the Murphy sequence may have been subjected to less shearing stress, perhaps because of greater distance from a fault.

(5) The two groups may be separated by a disconformity or an angular unconformity of small degree unrecognized at the present surface, the older group having been affected by stress sufficient to develop flow cleavage prior to deposition of the younger group. After deposition of the younger group, both were subjected to thermal metamorphism under light stress. Decisive evidence favoring this hypothesis has not been recognized in and near the Persimmon Creek quadrangle. Choice between these and other possible hypotheses must be left open at present.

ROCKS OF THE MURPHY MARBLE BELT

Nantahala Slate as restricted by Hurst (1955)

Definition and distribution

The Nantahala Slate is well exposed in the gorge of the Nantahala River between Topton and Hewitt, Macon and Swain Counties, N.C., and was named for that locality by Keith (1904, p. 6; 1907, p. 4). The separation into two members by Keith and the elevation of the lower member to formational status (Dean Formation) by Hurst are described on page 24. The Nantahala Slate, as restricted by Hurst, is a relatively homogeneous unit characterized by dark banded slaty phyllite and schist with occasional thin beds of light-colored quartzite in the upper half.

The Nantahala Slate underlies a northeast-striking belt 2,400 to 3,700 feet wide that crosses the southeast part of the Persimmon Creek quadrangle.

Stratigraphic relations and thickness

The base of the Nantahala Slate is poorly exposed in the present area. Some alternation of white sericite schist with dark slaty bands suggests a thin transitional zone, but no decisive information is at hand.

The upper contact appears transitional into the Tusquitee Quartzite, for light-colored quartzite beds become more abundant upward, and choice of that contact is arbitrarily made in places. A quartzitic zone with numerous thin slaty interbeds has been assigned to the Tusquitee Quartzite on the present map. This zone appears to be more argillaceous to the southwest.

Small-scale folding is observed in the Nantahala, and strike faults may be present though unmapped. The thickness is therefore in doubt; it may be as little as 1,800 feet to the southwest, but to the northeast either the true thickness is greater or the outcrop width has been increased by structural causes.

Lithology

The outstanding characteristics of the Nantahala Slate are its dark color and slaty appearance, and the thin banding resulting from alternation of gray to black argillaceous layers with lighter colored silty to fine-grained sand layers. Thin dark impure quartzitic beds are interbedded with the slates, and in the upper half light-colored quartzite beds are sparingly present and increasingly abundant upward. Their character is like that of the overlying Tusquitee Quartzite. The quartz-pebble conglomerates and staurolitic beds characteristic of the Dean Formation are absent; a single loose staurolite crystal found southeast of Ranger School probably came from some locality in the Dean Formation.

The Nantahala Slate seems less metamorphosed than the underlying Dean Formation and the overlying Brasstown Schist, as judged from the finer grain. The mineralogy is essentially the same as in the neighboring formations, however, except for the probable absence of staurolite. Garnet is present but is not common. Ottrelite reported by Keith (1907, p. 4) in the Nantahala quadrangle has not been recognized in the present area.

Slate, phyllite, and schist

The dominant rocks of the Nantahala range in grain size from slate and phyllite to fine-grained schist. Some varieties of phyllite as well as schist show small biotite metacrysts that may cross the cleavage. Some beds are slate in general appearance, though white mica and small metacrysts of biotite are commonly visible under the hand lens. The dark color tends to mask the crystallinity, and true slate seems rare. Bedding cleavage is well developed in the fine-grained beds.

Much of the slaty rock is banded, the laminae and thin layers of the dark rock alternating with light-colored fine-grained to silty sand layers. Under the microscope, mica is abundant, white mica usually predominating in the dark layers and biotite in the sandy layers. The micas may show little orientation or locally may be oriented with the bedding. In places, incipient orientation of mica in one or two planes at considerable angles to the bedding can be seen. Many layers of the banded slaty beds show small biotite books that are much larger than the bulk of the micas. These may tend to parallel the bedding but commonly stand at any angle to the bedding. Quartz commonly shows elongation about parallel with the bedding.

The minerals of the dark slaty bands include white mica, biotite, quartz, plagioclase, and minor amounts of dark-gray platy ilmenite, tourmaline, leucoxene, zircon, apatite, and dusty opaque material that is probably graphite. The probable graphite gives these bands their dark color.

The sandy layers have the same minerals but total mica is less, biotite predominating; quartz and plagioclase are more abundant, and ilmenite is scarce as is the opaque dust. Some grains of tourmaline have green centers with a partial brown outer zone. Zircon, apatite, and some tourmaline grains are rounded. Small amounts of chlorite are found in both types of layers; some of it is an alteration product of biotite. The feldspar is oligoclase, rarely twinned; no potash feldspar was found in thin section despite careful search. Sulfides are nearly confined to the sandy layers, in which they form irregular bodies with many inclusions. Masses of pyrrhotite greatly predominate; they show thin outer rims of marcasite in places. Rare small grains of chalcopyrite are associated with pyrrhotite.

The Nantahala lacks well-defined schistosity and thus contrasts markedly with the adjacent Dean Formation, in which schistosity is well developed and in many places is strongly deformed by crinkling, commonly accompanied by well-marked crinkle cleavage. The lithologic change is abrupt, which suggests that the Nantahala Slate and the formations to the southeast have had a different history than have the Dean and older formations. The obvious bedding cleavage seems to conform in attitude to the crinkle cleavage of rocks northwest of the Nantahala Slate. If so, lack of prominent crinkling in the Nantahala and younger formations may have resulted from lack or sparseness of schistosity that could be crinkled.

Pseudodiorite

Typical nodular or bedded pseudodiorite appears to be missing, but amphibole-bearing material does exist, for instance, in a roadcut about 3,000 feet east-southeast of the Ranger School, in the central south part of the Persimmon Creek quadrangle. This mass of unknown shape is associated with the crest of what appears to be an anticlinal roll in the slate.

The amphibole of this rock is characterized by curved columnar or coarsely fibrous structure. Its indices are about $Na = 1.647$, $Ng = 1.665$, and the birefringence is about 0.18; $(-)2V$ is large.

X ranges from pale brownish green to pale yellowish green, Z is bluish to brownish green, and Y is colorless to very pale tan or yellow. These properties suggest actinolitic hornblende. Pleochroism and birefringence vary in prismatic direction and seem to represent differences in orientation of prisms, though variations in composition may also contribute.

Biotite is common but much less abundant than hornblende. It may be in irregular aggregates intergrown with a micaceous colorless mineral whose maximum birefringence is first-order white, or is intergrown with the amphibole fibers. Some biotite is in thick books with ragged boundaries and contains oriented to unoriented grains of a faintly pleochroic white to light-tan micaceous mineral, possibly a chlorite.

A small amount of plagioclase in irregular grains and aggregates shows strong relief against balsam, and very fine twinning. It is at least as calcic as labradorite.

A little quartz is present, as is a member of the epidote group, probably clinozoisite. Gray iron ore is in abundant irregular generally elongated masses; some appears to be ilmenite.

Quartzite

Beds of quartzite in the upper half of the Nantahala range in thickness from about a foot to several feet and are nearly white despite superficial and intergranular iron stain. They are fine- to medium-grained somewhat feldspathic metasandstones that locally may be glassy due to pronounced cementation by silica.

Thin usually dark micaceous quartzite is evident in places in the lower part of the Nantahala. Beds of coarse metasandstone a few inches thick near the base of the formation are interbedded with sericite schist and dark phyllite.

Tusquitee Quartzite

Definition and distribution

The Tusquitee Quartzite was named by Keith (1907, p. 4) for the Tusquitee Mountains in the south-central part of the Nantahala quadrangle about 6 miles south of Andrews, Cherokee County, N.C.

The Tusquitee as mapped forms a northeast-striking band 500 to 1,000 feet wide that crosses the southeast corner of the Persimmon Creek quadrangle. Some of the apparent variation in thickness may result from structural causes, but lensing of members is also suspected. The best exposures of the formation are in roadcuts about 5,500 feet southeast of the Ranger School.

Stratigraphic relations and thickness

The Tusquitee Quartzite appears to grade into the underlying Nantahala Slate by increase in thickness and number of dark slate beds. The upper contact is not exposed, and slaty rock near it is poorly exposed. The thickness seems to range between 400 and 800 feet.

Lithology

The Tusquitee is medium- to thin-bedded light-colored fine- to medium-grained feldspathic quartzite containing laminae and mostly thin beds of dark slate. As mapped, one or two thicker slaty members are indicated within the formation. Whether these are true members or are enclosed as a result of structural deformation is not clear. The thickness of the Tusquitee is apparently much greater in the Persimmon Creek quadrangle than in the Mineral Bluff and Nantahala quadrangles, and insofar as exposed, the lower part is thinner bedded and contains much more slate than the upper part. Though duplication by structure may well be a factor, the available lithologic evidence indicates that the thickness is indeed greater in the present area than in the Nantahala or Mineral Bluff quadrangles. The lower slaty part seems to become slatier to the southwest, but outcrops are too limited for one to be sure.

The quartzite beds range from glassy silicified rock to rock that under weathering disintegrates like sandstone. The minerals are quartz, oligoclase, muscovite, and accessory tourmaline, zircon, and opaque minerals. Iron sulfides locally have escaped weathering. Hurst (1955, p. 47) recorded perthite but no other K-feldspar; none was recognized by me. The dark slaty beds and laminae are identical with the dark slaty bands and beds of the Nantahala Slate. They are like those of the overlying Brasstown and Valleytown Formations also except that they are less coarsely recrystallized. The metasandstones resemble the silty sand layers and beds of both the overlying and underlying formations. The general impression is of continuous deposition of similar sediments, the sandy phase being emphasized during the Tusquitee episode.

Conglomerate appears to be a minor constituent in the Persimmon Creek quadrangle. The conglomerates are thin, and quartz pebbles and granules greatly predominate. No pseudodiorite has been recognized in the Tusquitee of the present area. No diagnostic graded bedding was observed by me.

Brasstown and Valleytown Formations

Definition and distribution

The Brasstown and Valleytown Formations were named by Keith (1907, p. 4-5) for Brasstown Creek and for Valleytown, Clay, and Cherokee Counties, N.C. Hurst (1955, p. 48-51) discussed the difficulty in recognizing the contact between them as described by Keith and by other investigators, and also stated that Keith's sequence is not entirely usable in the Mineral Bluff quadrangle. He applies the name Brasstown to the whole sequence of rock between the Tusquitee Quartzite and the Murphy Marble.

The same problems obtain in the Persimmon Creek quadrangle, although perhaps in lesser degree. The upper half of the sequence has more and thicker beds of coarse sandstone than the lower half, and an indefinite contact can be drawn on this basis where sufficient rock exposures exist. For this reason and the fact that Keith showed both formations on the open-file map of the Murphy 30-minute quadrangle (King and others, 1950), it is thought best to use both formations now despite the difficulties.

The Brasstown and Valleytown Formations underlie northeast-trending bands, each 1,600 to 1,900 feet wide, that cross the southeast part of the Persimmon Creek quadrangle, the Brasstown being northwest of the Valleytown.

Stratigraphic relations and thickness

The Brasstown Formation is believed to be conformable with the Tusquitee Quartzite. The Valleytown Formation appears to be conformable with the overlying Murphy Marble, but the contact is not exposed in the Persimmon Creek quadrangle. Keith (1907, p. 5), in his description of the Murphy Marble near Nantahala River where the rocks are relatively fresh, stated: "* * * it passes downward into the Valleytown formation by interbedding with the slates of the latter." Van Horn (1948, p. 28, and pl. 1, p. 31), who had access to diamond-drill core, recorded a transition zone between the Valleytown Formation and the Murphy Marble.

These rocks were mapped and described by Van Horn (1948, p. 6-8, 19), who concluded that they and other formations were overturned to the northwest. He based his opinion on cleavage studies and fractures in beds of marble. Inasmuch as this interpretation differs from that of Keith and of Hurst (1955, p. 48-49), I attempted to find definitive evidence to resolve the problem. Graded bedding did not provide unequivocal determinations of tops of beds, and cleavage was difficult to interpret because of the weak development of flow cleavage, the prominence in places of fracture cleavage, and the prominence of cleavage about parallel with the bedding. Moreover, deep weathering and cover seriously limit observations. Most oriented specimens of unweathered rock lack well-defined schistosity, and only a suggestion of graded bedding of compositional type was noted in one thin section. In thin sections of two specimens, schistosity defined by fair- to well-oriented mica dips at angles as much as 17° steeper than the bedding, and crinkle cleavage dips 10° to 25° flatter than the bedding. The crinkles are asymmetrical, and crinkle cleavage is weakly to moderately developed.

The evidence is not decisive, but taken in conjunction with cross-bedding and a graded bedding recorded by Hurst (1955, pl. 3) in the Tusquitee and Nottely quartzites, and with cleavage-bedding relations in the Andrews Schist determined by me, the formations are provisionally regarded as a sequence with tops facing southeast, in agreement with the interpretations by Keith and Hurst.

The thickness of the Brasstown and Valleytown Formations is estimated at 1,450 to 1,700 feet each. No evidence of folding other than small drag folds was noted.

Lithology

Slate, metasandstone, and schist

The Brasstown and Valleytown Formations are thin-bedded metasediments characterized by many gray to dark-gray banded members in which thin dark slaty beds alternate with thin beds of silty to fine-grained sand of somewhat lighter color. Where well exposed, the bands are seen to pinch and swell almost rhythmically. This dominant type of rock has a few thin beds of fine- to medium-grained sandstone in the lower half of the Brasstown Schist. The basal 100-150 feet of the Brasstown is unexposed, but Hurst (1955, p. 49-50) recorded black schist and gray to black banded slates "whose lowest layers are interstratified with the underlying Tusquitee quartzites." Biotite books in random orientation are common in much of the Brasstown and thin garnetiferous bands are prominent.

The upper half of the sequence, the Valleytown Formation, differs somewhat from the Brasstown. Beds of light- to medium-gray medium-grained metasandstone that may show coarser layers and may be as much as 15 feet thick are present; the banding is less prominent on the average than in the Brasstown, as are cross-biotite rocks and garnet-rich layers. The beds near the top are dominantly argillaceous silty sand with thin beds of fine- to medium-grained sandstone, both converted to mica schist. Banding is less conspicuous and more uneven than in lower beds. The topmost beds are unexposed in the Persimmon Creek quadrangle but elsewhere are similar and as previously described they are gradational into the Murphy Marble.

The argillaceous laminae, and thin layers of the typical banded rock of the two formations, generally show dominant white mica but with some biotite of about the same size. Quartz is usually the main mineral, with many of its grains flattened parallel to the bedding. Dusty opaque material is believed to be largely graphite. Garnet, as well-formed metacrysts, is abundant to sparse in numerous thin layers but is missing in others. Accessory minerals are platy ilmenite, tourmaline, zircon, and chlorite.

The coarser grained sandy layers contain less mica. White mica dominates over biotite in the very light colored bands, but biotite is the dominant mica in darker layers. Some sandy layers with little mica have biotite predominating over muscovite. Other minerals of the sandy bands are garnet, leucoxene, a little chlorite, zircon, green tourmaline, sphene, and apatite. Pyrrhotite is the dominant sulfide but pyrite has been identified. Some irregular dark-gray grains may be magnetite.

Many layers of the above types also contain more or less equidimensional books of biotite as much as 10 to 25 times as large as the platy micas. These commonly are randomly oriented but are parallel with the bedding in a few layers. Less common are thin bands of white quartz-sericite schist with abundant euhedral garnet metacrysts, or with randomly oriented biotite books. Feldspar was not certainly recognized in some thin layers, but others, especially the coarser sand layers, contain oligoclase. The plagioclase rarely shows a little twinning. I did not recognize any potash feldspar in these fine-grained rocks.

Hurst (1955, p. 50, 51) described strongly banded beds exposed in a quarry about 125 feet below the Murphy Marble, the darker bands having garnet and small biotite porphyroblasts. His average of mineral analyses (in percent) of four thin sections follows:

Biotite----	27.74	Muscovite-----	3.43
Quartz-----	25.86	Chlorite------	2.05
Andesine---	11.99	Black opaque--	1.37
Carbonate--	23.63		
Garnet-----	3.94		
			100.00

The carbonate content is high and suggests that the beds are in the transition zone into the Murphy Marble.

Most of the beds of coarser metasandstone are deeply weathered in the present area. The best preserved are medium grained with coarser grained layers in some beds, both with a few scattered granules. They are varyingly micaceous with scattered muscovite flakes and irregular small areas and crude bands in which biotite is relatively abundant. Scattered rusty spots in part represent sulfides but others may be remnants of slightly ferriferous carbonate. The beds are feldspathic and contain sodic plagioclase.

Thin sections of Brasstown and Valleytown rocks show some orientation of mineral grains, particularly the micas. A usual direction, evident in micaceous laminae or bands, is parallel with the bedding. This direction of orientation is much less evident in the sparingly micaceous sandy bands and may be locally missing or weakly developed even in the micaceous bands. Metacrysts may show orientation of matrix micas with part of their boundaries. In places away from metacrysts, one or two directions of orientation at angles to the bedding may be weakly to moderately developed in sandy bands. Two such directions of incipient orientation suggest weak development of both sets of theoretical shears. The fine-grained sandy mica schist at the top of the Valleytown shows good orientation of micas both parallel with the bedding and locally slightly steeper than the bedding; this better orientation may be an effect of greater mica content as is true of thin micaceous bands at lower stratigraphic levels.

Pseudodiorite

Both formations contain thin beds of pseudodiorite, generally an inch to 6 inches thick. These beds are lenticular as may be seen in walls of quarries. Horizontal extent exceeds width of exposures, which are rarely more than a few feet across. The thinness of the beds probably reflects the thin-bedded character of the Brasstown and Valleytown Formations. Pseudodiorite seems to favor the banded fine-grained members. Hornblende quartzites like those of the Dean and Hughes Gap Formations were not observed.

The bedded pseudodiorite is like that previously described, and is composed of calcic feldspar, hornblende, garnet, biotite which is essentially restricted to the margins, pyrrhotite (also more abundant near the margins), and the usual accessories. Thin short lenses and knots of curved actinolitic hornblende like that in the pseudodiorite of the Nantahala Slate appear to be rare.

Amphibolite

A layer of green-gray amphibolite was mapped by Van Horn (1948) in the Nantahala gorge northeast of Hewitt, N.C. It seems to be strictly concordant with the bedding and about 300 feet below the Murphy Marble. Van Horn considered it and others to be diorite sills. I favor a volcanic origin but the evidence is not decisive. No outcrops of similar rock were observed in the Persimmon Creek quadrangle, but an amphibolite bed was mapped by Van Horn near the top of the Valleytown Formation about 1 mile northeast of the east edge of the Persimmon Creek quadrangle.

Murphy Marble

Definition and distribution

The Murphy Marble was named by Keith (1907, p. 5) for the town of Murphy, Cherokee County, N.C., through which its outcrop area passes. Originally it was thought to be all pure marble, but now is known to contain talc lenses, lime silicates, and thin schist beds.

The Murphy Marble underlies a narrow northeast-trending belt that crosses the Persimmon Creek quadrangle near the southeast corner. Natural exposures are rare, and its weakness under erosion results in topographic lows. Good natural exposures are in the Nantahala gorge about 30 to 35 miles northeast of the east edge of the Persimmon Creek quadrangle.

Stratigraphic relations and thickness

The transitional relations of the Murphy Marble with the Valleytown Formation have been described on page 33. Lack of exposures and deep weathering prevent study of the contact with the Andrews Schist in the Persimmon Creek quadrangle. Keith (1907, p. 5) stated of the Murphy: "Upward it passes into the Andrews schist through several feet of interbedded marble and schist. This transition can best be seen at Marble Creek * * *." Marble Creek is near Regal, N.C. Van Horn (1948, p. 28, and pl. 1, p. 33) recorded a transition zone into "ottrelite schist," the Andrews Schist of Keith. Hurst (1955, p. 52) noted interbedding with the Andrews as exposed in the Campbell quarry on Cutcane Creek 1.1/2 miles northeast of Mineral Bluff, Ga.

The thickness of the Murphy Marble in the Persimmon Creek quadrangle is indeterminate; however, it is not over 200 feet thick near the south boundary of the quadrangle. Keith (1907, p. 5) reported 150 to 500 feet. Van Horn (1948, p. 28) indicated a section, synthesized from drill holes and surface data, that has a thickness of 330 feet, and discussed (p. 9) the variation in thickness caused by displacement by sandy and shaly facies. I have observed apparent change in facies, part of the marble giving way to coarse- to medium-grained calcareous sandstone. Hurst (1955, p. 51-53) stated that the thickness ranged from zero to 250 feet in the Mineral Bluff quadrangle.

Lithology

Van Horn (1948, pl. 1, p. 33) showed a geologic map of an area near Kinsey, N.C., and a cross section controlled by diamond-drill holes. He indicated zoning of the formation, summarized below, for the entire interval between the Andrews Schist and the mica schist member of the Valleytown Formation, a thickness of about 350 feet.

Andrews Schist
- Transition zone
- Coarse marble
- Blue marble
- Gray marble
- Mottled marble
- White (talc-bearing) marble
- Gray slaty marble
- Transition zone

Mica schist of the Valleytown Formation.

Two exposures of marble near the south border are the only ones known in the Persimmon Creek quadrangle: an island remnant in a water-filled quarry, and a small remnant of dolomitic marble in residuum, exposed in a railroad cut about 800 feet northeast of the quarry. The latter is apparently near the southeast contact, for schist is exposed a few feet away in the south wall of the cut. A little impure talc was noted in the north wall of the cut. Marble and (or) talc have been mined extensively from the belt in the interval extending from a point 1 3/4 miles northeast of Ranger, N.C., to a point near Hewitt, N.C., in the Nantahala gorge, and also southwestward in Georgia.

Published analyses (Hurst, 1955, p. 53) and field tests indicate that the marble ranges in composition from calcitic to dolomitic, with 0.1 to 10.70 percent insoluble matter. Impurities, excluding those resulting from interbeds of shaly and sandy sediments, are white and light-brown mica, actinolite and tremolite, talc, vein-quartz, chlorite, tourmaline, zircon, graphite(?), pyrite, pyrrhotite, and magnetite. Van Horn (1948, p. 25) reported a concentrate, derived from a talc lens in the Murphy Marble, containing rounded grains of rutile, zircon, epidote, zoisite, garnet, ilmenite, magnetite, quartz, and unidentified minerals. He (p. 10) also reported galena along joints in the marble. Hurst (1955, p. 52) reported chalcopyrite among other minerals previously mentioned.

The occurrence of talc masses and their features are described in detail by Van Horn (1948, p. 22-53). According to him, commercial talc lenses are restricted to the central zone of fine-grained white dolomitic marble, and talc elsewhere in the Murphy Marble is in scales, partings, small pockets, and talcose slates.

Andrews Schist

Definition and distribution

The Andrews Schist was named by Keith (1907, p. 5) for the town of Andrews, Cherokee County, N.C. In the Persimmon Creek quadrangle, it is practically unexposed but occupies a narrow northeast-striking zone that separates the Murphy Marble and the Nottely Quartzite. It crosses the quadrangle near the southeast corner.

Stratigraphic relations and thickness

Study of either contact of the Andrews Schist is impossible in the present area. Its relationship to the Murphy Marble elsewhere is described on page 37. The relationship to the Nottely Quartzite is well seen along the Valley River within Murphy, N.C. In this area, schist gives way abruptly to quartzite but beds of similar schist recur stratigraphically higher within the quartzite. Deposition appears to have been essentially continuous from the Andrews to the Nottely.

The thickness of the Andrews Schist can be estimated from the horizontal separation of the Murphy Marble and the Nottely Quartzite, which ranges insofar as determinable from 275 to 400 feet. Its thickness would appear to range from 250 to 375 feet when correction is made for angle of dip. Hurst (1955, p. 53) reported a thickness of 1,400-1,800 feet. The reason for this large difference in thickness is uncertain; however, Hurst included in the lower part of his Andrews Formation a sequence of calcareous schist that may be part of the Murphy Marble as mapped in the Persimmon Creek quadrangle.

Lithology

The character of the Andrews Schist is variable in the region, though much of the variation in texture may result from differences in metamorphism. Keith (1907, p. 5) described it as calcareous schist with prominent ottrelite metacrysts in the Nantahala quadrangle. It is a distinctive cross-mica unit near Murphy, N.C., where part of it is well exposed. The metacrysts in my collections from the Murphy area are biotite books and well-formed garnets, the biotite having random orientation. The formation is little exposed southwest of Murphy into Georgia but appears to be similar in character. Hurst (1955, p. 53) reported a few exposures of the lower part which, he stated, "corresponds to Keith's Andrews schist." He reported nodules and thin lenses or beds of limonite near the base. The only exposure in the Persimmon Creek quadrangle is of deeply weathered fine-grained schist in a railroad cut near the south border.

The cross-biotite schist from the Murphy area has poor to good schistosity in the fine-grained matrix. The schistosity in places shows fine crinkles set on larger gentle folds and is disturbed by the numerous porphyroblasts of biotite.

Crinkle cleavage is observed in places and it dips more flatly than the bedding. These disturbances of the schistosity have thus far prevented clear determination of schistosity-bedding relations other than the fact that they either coincide or meet at a small angle. In places the schistosity dips more steeply than the bedding, but this may be a result of tilting caused by the larger broad crinkles.

In thin sections the rock shows numerous large equidimensional books of brown biotite. Garnet metacrysts of about equal size may be abundant but in the parts of the formation observed, garnetiferous beds are scarce. In places, muscovite and biotite books much smaller than the large biotite books are present. The mica metacrysts, particularly those of biotite, have few to many inclusions of matrix minerals. Smaller irregular generally elongate masses of pyrrhotite are sparse to abundant. These may form interrupted stringers which, like individual grains, are oriented parallel with the schistosity. Carbonate grains range in size from that of the matrix minerals to ten times that size. Leucoxene is erratically distributed in small amount. A dark-gray unidentified iron ore forms irregular grains.

The foregoing minerals are set in a fine-grained matrix of quartz, feldspar, biotite, a smaller amount of muscovite, and unevenly distributed grains of carbonate. Quartz greatly predominates over feldspar in some layers, but the latter is common or predominant in others. The plagioclase is in part twinned, and many grains show irregular zoning. The outer zone is more calcic than the inner in well-oriented grains, and extinction angles indicate bytownite or anorthite. The centers are difficult to determine but appear to be andesine and oligoclase. No potash feldspar was recognized. Accessories include apatite, tourmaline, and zircon.

The bedded pseudodiorite of the Andrews Schist is in thin layers and does not appear to differ significantly from pseudodiorite of other formations.

Nottely Quartzite

Definition and distribution

The Nottely Quartzite was named by Keith (1907, p. 5) for its excellent exposures along Nottely River, Cherokee County, N.C. It underlies a narrow northeast-trending belt about 200 feet wide in the southeast corner of the Persimmon Creek quadrangle.

Stratigraphic relations and thickness

Neither contact of the Nottely Quartzite is well exposed in the Persimmon Creek quadrangle, but its position between similar schists in the region, as well as the presence of similar schist beds within the quartzite, suggests that it represents an episode of sand deposition in a continuous sequence. It is conformable with the enclosing rocks.

The thickness in the Persimmon Creek quadrangle and nearby areas is about 200 feet. It has good topographic expression in the Persimmon Creek and Murphy 7 1/2-minute quadrangles, but is locally planed off in areas of the Nottely River flood plain. Its outcrop in general parallels and borders the lowlands developed on the adjacent relatively weak Andrews Schist and Murphy Marble.

Lithology

The Nottely Quartzite consists mainly of light-colored to white thin- to locally medium-bedded slightly feldspathic quartzite, with argillaceous beds an inch or so to a few feet thick. Generally the sand grains are well cemented, and the rock locally is a glassy mass in which individual grains are not evident. The grain size ranges from fine to medium. Some thin beds are composed of very fine grained sericite and quartz. Partings and thin beds of dark slate and siliceous schist are present in and near the Persimmon Creek quadrangle and are reported by Hurst (1955, p. 54, 55) in the Mineral Bluff quadrangle to the southwest. Along the Valley River at Murphy, N.C., layers of quartz-sericite schist and beds of schist with medium to large cross-biotite books are well exposed.

A bed of sandy fine- to medium-grained marble about 2 1/2 feet thick is also exposed at this locality; it is at the southeast boundary of the quartzite exposures, apparently at or near the top of the formation. In thin section the marble ranges from slightly sandy marble to calcareous sandstone. The purer marble contains sand grains, mostly quartz, pale mica (probably phlogopite) in ragged masses of random orientation, pyrrhotite in numerous elongate irregular grains, and sparse sand-size grains of zircon. The carbonate grains are commonly elongate and are in places oriented parallel with or at a small angle to the bedding. This marble is probably the one reported by Van Horn (1948, p. 14).

Mineral Bluff(?) Formation of Hurst (1955)

Definition, distribution, and thickness

The Mineral Bluff Formation was named by Hurst (1955, p. 55-56) for exposures near Mineral Bluff, Ga. The use of this name for the rocks that lie southeast of the Nottely Quartzite in the Persimmon Creek quadrangle is tentative for several reasons: (1) exposures of these rocks are few in and near the quadrangle; (2) the preserved thickness in the type area is 800 feet or less whereas that in the Persimmon Creek quadrangle is probably several thousand feet or more; and (3) Keith showed a fault a short distance southeast of the Nottely Quartzite in the Nantahala quadrangle (1907) and in the Murphy 30-minute quadrangle (King and others, 1950). A reliable interpretation of the structure and attitude of these beds and their relations to Hurst's type area would require much study of rocks of the Murphy marble belt from within the Nantahala quadrangle to the Mineral Bluff quadrangle. Keith and also Van Horn (1948) showed wedging out of units southwestward through Murphy, N.C., and Keith showed it along the aforementioned fault. Hurst (1955) showed a strike fault also, but drew it on the northwest side of the Nottely Quartzite.

The rocks southeast of the Nottely Quartzite in the Persimmon Creek quadrangle, despite the small area of exposure, do resemble the Mineral Bluff Formation. They also resemble the rocks exposed along the highway in and east of Murphy.

The Mineral Bluff(?) Formation occupies the southeast corner of the Persimmon Creek quadrangle and continues farther southeast. Its outcrop width is about 5,500 feet, measured at right angles to regional strike. Structural information and reliable readings for determinations of tops are lacking in and near the pertinent area. An oriented specimen taken just south of Murphy from similar rock shows that the schistosity dips more flatly southeast than the bedding, the angle between being small. The bedding and schistosity are parallel where observed in the present area. No estimate of thickness can be made from available data except that the thickness is probably not less than several thousand feet. Stratigraphic relations are also unknown except that these rocks lie southeast of the Nottely Quartzite and are unknown or unrecognizable in the area to the west as far as the metagraywacke unit near Ducktown. The basal beds are conformable with the Nottely Quartzite near the highway bridge at Ranger, N.C. These facts suggest that the formation is younger than previously described formations, a conclusion supported by the lesser degree of metamorphism of the Mineral Bluff. Various problems must be left unsolved until a definitive study of the rocks of the Murphy marble belt is made.

Lithology

Lithology can be studied in but few localities of the Persimmon Creek quadrangle: along North Carolina State Highway 60 about on strike, along a bend of the Nottely River, in isolated fresh exposures of saprolite where trails or farm roads are eroded, and in a few cuts on minor roads. The rocks are deeply weathered and are stained by iron oxide.

The rocks about 400 to 600 feet east of the Nottely Quartzite are fine-grained gray-green schist or phyllite. Similar rock of gray-green to gray color is exposed along the highway in the Culberson quadrangle immediately south about 1,300 feet from the Nottely Quartzite. There, a few thin beds contain limonite pseudomorphs after cubic pyrite. A few fresh saprolite exposures on strike of the intervening covered interval are derived from dense phyllite or very fine grained schist of unknown color. Along the highway in the Persimmon Creek quadrangle and 2,000 to 2,500 feet distant from the Nottely Quartzite are very fine grained phyllites and schists, some of which show banding; some of these beds preserve gray to dark-gray color. Near the south margin of the quadrangle in a highway cut is much weathered phyllite with elongate metacrysts of chloritoid(?) (see p. 43) and irregular spots. Farther northeast on strike at about the same horizon is an interbed of metasandstone of medium to coarse grain. The bedding and schistosity are parallel at this exposure of deeply weathered rocks. Along the bluff of the Nottely River near the corner of the quadrangle are exposures of gray slaty schist with thin beds of fine-grained to silty metasandstone. The bedding and cleavage are parallel. These isolated exposures are spaced at distances of 3,700-4,500 feet from the outcrop of the Nottely Quartzite. The most distant observed exposures from the Nottely Quartzite (about 6,000 feet) are nearby in cuts along a minor road south of the Nottely River in the Culberson quadrangle. The rock is dark- to light-gray slaty phyllite.

The bedding is not directly determinable in most of the exposed rock described, but the cleavage is clear. As bedding and cleavage are sensibly parallel where bedding is clearly determinable, the cleavage readings at other points probably represent the bedding. Search for graded bedding and other features indicative of tops failed, and consequently the structure is not certainly known. Most of the bedding and cleavage symbols in the phyllitic schists (fig. 1) strike more northerly than the strike of the Nottely Quartzite, suggesting a discontinuity between them, perhaps a fault or a fold axis. A part of the phyllite may be overturned to the northwest.

The best preserved rock shows good alinement of three platy minerals; two of these are chlorite and sericite, the other is an iron-stained pleochroic mineral which is probably chlorite, though it may be biotite. Quartz is abundant but feldspar was not recognized. The quartz occurs as recrystallized elongated aggregates oriented parallel with the cleavage, as well as in small grains between the micas. Platy grains of ilmenite are oriented with matrix mica and some layers show relatively large metacrysts of magnetite. Yellow, brown, and red iron oxide is an abundant product of weathering.

The phyllite with elongate metacrysts shows recrystallized patches associated with local crinkles. Quartz, chlorite, and mica (possibly much weathered chlorite or biotite) are all much coarser grained in the crinkles than the matrix minerals and are oriented in various directions. Isolated large to small metacrysts of prismatic habit are mostly destroyed by weathering or are represented by iron-oxide aggregates or by holes in thin sections. Some prisms have considerable biotite(?), quartz, and other material; others seem to have been nearly monomineralic. Some are clearly associated with the recrystallized areas of the local crinkles. The remnants of the monomineralic metacrysts have the following properties: simple twins whose composition plane parallels the long axes; pleochroism pale bluish gray to colorless; extinction inclined, maximum observed inclination 20°; biaxial, but undetermined sign; maximum birefringence observed about 0.009. The iron oxides appear to represent indigenous decay products, but may be introduced. The properties seem to fit chloritoid best, but platy pseudohexagonal sections in which remnants of the mineral are preserved are lacking.

METAMORPHISM

The rocks of the Ocoee Series and of the Murphy marble belt have been metamorphosed to various degrees in two seemingly continuous episodes. The earlier, a time of dynamothermal metamorphism, resulted in development of slaty to schistose rocks and probably mild open folding. The later, a time of continued thermal metamorphism after relaxation of stress, is characterized by large-scale regional growth, particularly in phyllite and schist, of unoriented minerals that deform and cut the schistosity developed during the first episode. Minerals such as flaky biotite, muscovite, quartz, plagioclase, and chlorite are common first-episode minerals. Those occurring as unoriented relatively large metacrysts, such as thick biotite, amphibole, staurolite, kyanite, and chlorite, seem to belong entirely to the second episode. Garnet may have originated during the first episode, but much of its growth took place during the second.

The three mapped quadrangles (fig. 1) diagonally span metamorphic terrane characterized by a central area whose mineral assemblages belong to the almandine-amphibole facies, flanked on both sides by assemblages belonging to the greenschist facies. The mapped quadrangles and reconnaissance traverses indicate that these areas are oriented in a northeasterly direction, along the regional strike.

Figure 2 shows isograds that represent accumulated information on the index minerals biotite, garnet, and staurolite. Hornblende seems to be as definitely limited as the others and its threshold as now known is therefore shown. The limits of occurrence of these minerals are based mainly on hand-lens examination, with local checks utilizing the microscope. Deep weathering and scarcity of outcrops in many places affect the accuracy of location of the lines; in particular, control of the southeasternmost garnet and biotite isograds is poor. However, their positions are approximately correct, and certainly they are shown in their proper sequence.

The extreme northwest and southeast areas are characterized by fine-grained oriented chlorite intimately associated with oriented sericite. This subfacies persists across strike well beyond the mapped area.

Distances between isograds, as now known, are, from northwest to southeast:

Chlorite-biotite-------	Minimum 6 1/2 miles
Biotite-garnet---------	Maximum 1 1/4 miles
Garnet-staurolite------	About 3 1/4 miles
Staurolite-staurolite--	About 9 miles
Staurolite-garnet------	3/4 to 1 1/2 miles
Garnet-biotite---------	Minimum 1 3/4 miles

These figures suggest more rapid decline of intensity on the southeast side.

The hornblende threshold lines lie between the garnet and staurolite isograds so far as observed; in the northwest part of the mapped area the hornblende line is nearer the staurolite isograd.

In the northwest part of the mapped area, epidote is identified in thin sections of rocks both southeast and northwest of the amphibole line. In the southeast part of the mapped area, information is too scarce to permit a statement as to the limits of epidote but members of the epidote group are generally associated with hornblende throughout the central region of highest intensity and also occur in places where hornblende is absent. Chloritoid(?) is common in certain beds exposed in cuts of North Carolina State Highway 60 which passes near the southeast corner of the Persimmon Creek quadrangle. Rare molds of a chlorite or a chloritoid-like mineral were observed near the garnet isograd in the Ducktown quadrangle.

Kyanite is known only near the Calloway vein, Ducktown district, in close association with staurolite, and along the Hughes Gap-Hothouse contact in the Mineral Bluff quadrangle (Hurst, 1955, p. 34-35). Strike lines extended through these localities are about 5 miles apart. If kyanite exists in the area between, it is unrecognized; staurolite, however, is common throughout in beds of proper composition. Present information seems inadequate to propose a kyanite zone between the staurolite isograds.

The degree of recrystallization is rarely if ever complete enough to entirely destroy the original features of the sandy and coarser grained sediments, though they may be more or less destroyed where shearing was intense. Even in such shear zones, deformed quartz pebbles and granules usually persist. Migration of materials does not destroy the bedding surfaces between fine-grained and coarser grained sediment, but selective flowage of fine-grained sediment is evident in places. Silty and argillaceous sedimentary layers are recrystallized to coarsest grain in the central belt, where mineral assemblages indicate maximum intensity of metamorphism.

In this section, slaty cleavage and schistosity are discussed, lithologies of the various metamorphic zones are described from northwest to southeast as far as the southeast limit of the staurolite zone, and finally two specific rocks, pegmatites and pseudodiorite, are considered.

Slaty cleavage and schistosity

Slaty cleavage is conspicuous in silty and argillaceous beds of the northwest half of the Ducktown quadrangle. Increasing intensity of metamorphism southeastward is marked by increasing glossiness in slate, gradation into phyllite and schist, and a sequence of mineral isograds. Farther southeast, fine- to medium-grained schist and phyllitic schist represent the silty and argillaceous sediments. Intensity of metamorphism declines in the southeast corner of the mapped area where phyllitic schist dominates.

Slaty cleavage in the northwest half of the Ducktown quadrangle varies in intensity. Typical slate alternates with less cleaved rock that in places approaches argillite in appearance. Most rock in the phyllitic stage is markedly schistose, but some beds weather massively and close inspection is required to reveal the schistosity.

The fine-grained metasediments of the central part of the mapped area are typical schists. Argillaceous schists of this area are generally finer grained than those derived from beds of silt and sandy silt. These typical schists extend southeastward to the Nantahala Slate, which marks an abrupt decline in grain size to fine-grained schist and slaty phyllite. The Nantahala Slate and other fine-grained metasedimentary beds farther southeast are mostly fine-grained schists with some fine- to medium-grained beds, showing poor to good mineral orientation. The Mineral Bluff(?) Formation is fine-grained schist and phyllite except where it is sandy or conglomeratic.

The sandy to conglomeratic metasedimentary rocks generally lack obvious schistosity in the southeastern and northwestern areas. They may show cleavage that meets the bedding at larger angles than the slaty cleavage of adjacent fine-grained metasedimentary layers. In thin section, they may show weak slaty cleavage in fine-grained interstitial material. Some of the cleavage, however, is most probably a fracture cleavage of later origin.

In the central half of the mapped area the coarser grained rocks are in places decidedly schistose. Where schistose they are clearly sheared with development of oriented mica, particularly biotite. They commonly retain most of their sedimentary character but locally are highly schistose with preservation only of granules or larger clastic fragments. The vein zones of the mining district are marked in many places by highly schistose rock that represents linear strike zones of intense shearing during and after metamorphism. Markedly schistose, sheared sandy layers may be seen at intervals for about 2 miles west of the mining district, and also to the east as in the vicinity of the indefinite east contact of the metagraywacke unit shown near the south margin of the map.

Deformation of slaty cleavage and schistosity.--Slaty cleavage and schistosity were physically affected after development by two separated geologic processes. An earlier episode of thermal metamorphism seems to have immediately followed dynamothermal metamorphism. Under nonstress conditions much mineral growth continued, producing conspicuous widespread unoriented porphyroblasts which deform and destroy schistosity by replacing and engulfing the oriented minerals. Widespread centers of recrystallization involving local concentrations of calcium carbonate produced lentils and nodules of pseudodiorite in which schistosity is almost completely destroyed.

The later process, one of strong directed stress, resulted in widespread mild to severe deformation under much cooler conditions. Schistosity and slaty cleavage were warped, folded, and crinkled as part of the deformation. Some white mica and chlorite were formed, and biotite in places seems to have been healed after cataclasis. This deformation of schistosity is believed to be a feature of major regional significance. Where such deformation is mild, slaty cleavage and schistosity retain determinable relations to bedding and to folds of the older generation, relations that strongly suggest that the schistosity is the axial plane type. Slaty cleavage and schistosity were mildly to severely deformed by closing of the older folds, development of new folds and shear zones, probable reactivation of older shear zones, and development of fracture cleavage, much of which is crinkle cleavage and slip cleavage in the finer grained less competent beds.

The slaty cleavage of about the northwestern half of the Ducktown quadrangle shows some broad but minor variations in attitude that depart from the ideal orientation of axial plane cleavage. A few minor folds show marked tendency of the slaty cleavage to wrap around these structures. Many other late folds undoubtedly exist but cannot be defined owing to sparse outcrops. Within this northwest area, slaty cleavage dips moderately about southeast except near the minor later folds and warps described. The cleavage locally is finely crinkled, but with few exceptions the crinkles have very small amplitudes. They plunge gently or are horizontal.

Farther southeast, a gradual and somewhat intermittent increase in crinkling of the slaty cleavage, and general steepening of its southeastward dip, are indicated by numerous observations. Crinkles are mainly of small to moderate amplitude. In places, a steeply plunging intersecting set of small crinkles probably marks the plunge of minor folds. In well-exposed minor folds, departure of cleavage from ideal axial plane position may be as much as 30° or more. Inasmuch as the fanning of the cleavage is symmetrically disposed with respect to the axial planes, it is believed to be a result of tightening of the folds.

Farther to the southeast, the site and amplitude of crinkles and percentage of crinkled beds increase, but alternation of more strongly deformed strike zones with less deformed zones is still characteristic. Dip of schistosity is generally southeastward at increasingly steep angles. In and near the west part of the mining district, vertical and steep northwest dips of schistosity are much more common. Crinkling ranges in degree from mild to severe, and this characteristic continues southeastward through the Isabella and Persimmon Creek quadrangles to about the southeast contact of the Dean Formation. Fracture cleavage, usually associated with crinkles, is common, with predominating southeast to east dips at medium angles that most commonly are less than those of the bedding throughout this broad area of crinkled and folded cleavage. The degree of crinkling, measured by amplitude and tightness of the crinkles, is greatest in the broad area where folding and schistosity are at their maximum. Rotation of schistosity in folds whose dimensions are measured in tens to perhaps a few hundreds of feet is prominent also and shows an observed maximum range of 110°.

The greater part of the mining district, as well as the northeast prolongation of its zone of folding, is characterized by steep to northwest-dipping schistosity. Attitudes of schistosity were measured where the schistosity is but mildly crinkled and folded; at many places it is too deformed to permit satisfactory generalization of its dip except in a graded bed where its original attitude with respect to the bedding is preserved.

The broad zone between the mining district and the belt underlain by the Dean Formation is characterized by northwest dips of the schistosity wherever its attitude can be satisfactorily determined. The southeast part of the Hothouse Formation and the adjacent Dean Formation show variable dips of schistosity in both directions. In this area, slip cleavage dipping southeast at intermediate angles is exceedingly common in many schist beds and members, and it controls rock fracture to such an extent that it appears to be true schistosity. Hand lens and microscope examination, however, demonstrate the severe crinkling and the dragging of true schistosity into the fracture cleavage.

The formations of the Murphy marble belt show an abrupt change in attitude of the schistosity, for in them it dips southeast in seeming conformity with the bedding. This bedding cleavage is persistent and may be poorly to perfectly developed. In thin sections of medium- to fine-grained granoblastic schists, suggestions of one or two subsidiary schistosities at intermediate angles to the bedding can be observed but these seem not to be common. The reason for the parallelism of the schistosity and bedding is uncertain, but I suggest that the thin excellent bedding of most of the rocks of the Murphy marble belt and the dip of the bedding at 50°-70° SE. are responsible. Such dip may have been about parallel to axial planes of major folds of the area, and adjustments during metamorphism may have preferentially followed the generally excellent bedding. Some exposures of rock and saprolite show crinkling of the bedding schistosity, but crinkling and crinkle cleavage are in general minor phenomena in the southeast corner of the Persimmon Creek quadrangle and nearby areas to the east and south. A few minor folds in these formations seem to involve the bedding cleavage, but exposures of folds are few and inadequate.

Metamorphic zones

Northwestern chlorite zone

The chlorite zone of the northwestern part of the mapped area occupies about half of the Ducktown quadrangle and extends west of it for miles; its southeast limit, the biotite isograd, is moderately well controlled. The rocks of this zone include much of unit 1, all of unit 2, and part of unit 3. Fine-grained metasedimentary rock makes up from about 60 percent to over 90 percent of the rocks of the chlorite zone in the Ducktown quadrangle.

The characteristic chlorite is a colorless to very pale green fine-grained oriented type, intimately associated with oriented sericite. This type of chlorite extends southeastward in decreasing amounts beyond the biotite isograd to approximately the garnet isograd. Chlorite is most abundant in beds of fine-grained silty to argillaceous metasediment, and in similar material that occurs as matrix between sand grains or larger detrital fragments.

The sand and pebble fragments in the chlorite zone retain their original margins and mineralogical character, though minor replacement along their borders by sericite, calcite, and albite(?) is evident. The dominant detrital minerals are quartz, some of it opalescent quartz; plagioclase, commonly twinned and ranging from andesine to calcic albite; and microcline as granules and in small pebbles of arenaceous to conglomeratic beds. Minor detrital minerals include titanite, tourmaline, zircon, metamict material probably after zircon, and rarely recognized altered biotite. Calcite, commonly present in small amounts particularly in sandy beds, is believed to be an original constituent of the sediments, but appears to have been mobile enough to adjust to recrystallization. Recrystallization of plagioclase in the chlorite zone is either lacking or minor; marginal alteration to albite is clear in places. Development of new minerals aside from the oriented chlorite-sericite association is minor. Leucoxene may be common as small grains and is presumably derived from ilmenite, for remnants of a dark opaque mineral remain, but its time of origin is uncertain. Ilmenite appears to be largely detrital, as most grains lack regular tabular form, though some are raggedly tabular. Very small unaltered opaque grains are probably detrital magnetite. Epidote appears to be rare, and whether detrital or metamorphic is uncertain. Rutile is in small slender prisms, some of which show geniculate twinning; the prisms may contact a number of grains of other minerals in the chlorite-sericite portion of the rock. Black opaque featureless material of the fine-grained rock is carbon of seemingly unorganized character.

Metacrysts are rare in rocks of the chlorite zone. The commonest are carbonate masses in slate and fine-grained slaty quartzite. The masses are crudely rhombohedral and comprise an inner part crowded with inclusions and an outer part which is practically free of inclusions and which is in optical continuity with the interior. The texture of inclusions in the interior is different from that of the main part of the rock. The interior weathers somewhat rusty, and its carbonate effervesces more slowly than that of the overgrowth, which appears to be normal calcite; the inner part may be ferriferous calcite. The metacrysts typically show a sweeping extinction that may crudely indicate four subdivisions arranged in diagonal position. The central part of the metacrysts shows strain, and one is split in two by rock material which shows excellent orientation cleavage continuous with the general slaty cleavage of the rock. The inclusions of the various carbonate metacrysts tend to be parallel to each other. These facts seem to indicate that the inner parts of the metacrysts developed in the sedimentary rock before the slaty cleavage was developed, that the rhombs were deformed and strained during the episode of directed pressure, and that the clear calcite overgrowths and relatively coarse associated green chlorite were mineralogical features added late in, or after, the period of development of slaty cleavage. Such age of the clear calcite is supported by its tendency to extend along the slaty cleavage.

Pyrite, commonly as cubes or interfering cubes, is randomly oriented and distributed along the bedding of dark carbon-bearing fine-grained metasediments. It seems to have been produced from materials originally present in the sediments, for it is delicately controlled by the bedding and shows no recognized control by structure. The crystals of pyrite most probably grew by accretion of nearby materials before or during initial metamorphism, for many cubes are now distorted even where the bedding dips evenly at low angles. Moreover, inclusions of the host rock in pyrite crystals seem to lack slaty cleavage, and slaty cleavage of the host rock seems to deflect around the crystals. Pressure-shadow aggregates of calcite and quartz have developed on opposite sides of pyrite crystals, the sides that face along rather than across the schistosity. The calcite in pressure shadows is coarse and occupies the space next to the pyrite, whereas the outer ends of the aggregates consist of coarse lamellar quartz which near pyrite tends to orient itself perpendicular to the cube faces and farther out tends to parallel the slaty cleavage. Pyrrhotite may be present in the calcite as small masses, some of which are elongated parallel with the slaty cleavage.

Pyrrhotite is common to abundant in much of the fine-grained rock, particularly the dark slates. It is in thin lentils that are strikingly alined with the slaty cleavage and must have formed late in, or after, the development of that cleavage.

A second and later type of pyrite is common in dark slates of some localities. It forms thin lenticular crusts of very small crystals in vugs, the lentils being oriented parallel with the slaty cleavage. These appear to have been formed from the solid similarly oriented pyrrhotite lentils. If true the alteration may be represented by the following equation:

$$2\ FeS \rightarrow FeS_2 + \text{mobile } Fe$$

Loss of iron could account for the vugs.

Northwestern biotite zone

The northwestern biotite zone is about a mile wide and, like the other zones, trends northeast, more or less parallel with the regional strike. The threshold line for biotite represents observational data and will probably be moved slightly into the chlorite zone as now delineated, as a result of further observations. The zone is entirely within a sequence of silty and argillaceous layers alternating with sandy layers. The degree of recrystallization and the grain size of new minerals are greater than in the adjacent chlorite zone to the northwest. Fine-grained metasediments range from slaty phyllite to fine-grained schist.

Biotite is sporadically present near the isograd and is by no means always present in specimens taken throughout the zone. It occurs near the isograd as groups of minute grains in metasandstone, and in some specimens identification by use of the hand lens requires checking by microscopic methods. Biotite has been noted in thin sections of rock at the isograd as very small slivers interleaved in parallel position with sericite and chlorite.

Fine-grained metasediment and the similar matrix of sandy graywacke differ little in mineralogy from rocks of the chlorite zone, aside from sporadic biotite content, decrease in chlorite content, greater abundance of unoriented metacrysts, and increase in average grain size. Sericitic mica persists, and occasional metacrysts of muscovite are present. Carbon may be abundant and may obscure other fine-grained minerals as it does in some layers of the chlorite zone.

Sandy and conglomeratic beds and sandy parts of graywackes retain much of their original sedimentary features and mineralogy. Potash feldspar is essentially missing in thin sections of both fine-grained and arenaceous metasediment, but is preserved in granule and pebble conglomerate except, apparently, where shearing is intense. Subgraywacke shows excellent preservation of original clastic grains, particularly quartz. The opalescent quality of some quartz grains seems to be preserved much more commonly in subgraywacke than it is in typical graywacke.

Most plagioclase grains retain clastic shapes, have normal twinning, and are more or less dusty. The clastic grains are commonly oligoclase and calcic albite. Their margins show evidence of attack, including rims of clear untwinned albite, and replacement by white mica, quartz, and calcite. Both original plagioclase and albite rims may show mechanical effects. Plagioclase in rocks of higher metamorphic grade than those of the biotite zone commonly lacks original twinning, is clear, seldom shows visible cleavage, and has interlocking texture. It is believed to have completely recrystallized in response to its changed environment. By comparison, the clastic plagioclase of the biotite zone is believed to be essentially unchanged except for the slight alteration to albite.

Minor detrital minerals of the metasandstones include zircon (in part metamict), titanite (in part leucoxenic), and tourmaline which may be bicolored. The tourmaline is not in euhedral prisms as part of it is in higher grade rocks, and its bicolored character is therefore probably original.

Clinozoisite is sparse or missing in thin sections. Calcite is probably original but appears to have been mobile, for it replaces the minerals bordering the intergranular spaces it occupies.

Opaque iron-oxide minerals are in general difficult to determine. Powdered samples generally show weakly magnetic particles with a rare more strongly magnetic particle. It is probable that ilmenite is present and possibly a little magnetite. Most commonly, the dark mineral is in irregular aggregates, and in fine-grained metasediment it may be mixed with much carbon, probably graphite, judged from reflectivity. At and near the garnet isograd, fine-grained schists are speckled with shiny black plates of ilmenite.

Pyrrhotite is common to abundant, particularly in the fine-grained metasediment. It is in thin lenses distributed along the schistosity as in the chlorite zone. In places it is parallel to the bedding but only where schistosity and bedding are about parallel so far as known. Differential abundance of the pyrrhotite lentils coincides with bedding at least in places. Cubic pyrite is much less common than in the chlorite zone, and it is tempting to ascribe this to mobilization of original pyrite to form pyrrhotite, accompanied by loss of sulfur or reaction of the freed sulfur with indigenous iron. However, cubic pyrite may have been originally sparse.

The vuggy lentils of extremely fine grained pyrite, just described in the section on the chlorite zone (p. 49), are in places abundant in the biotite zone in fine-grained metasediment. The vuggy lentils are oriented with schistosity as in the chlorite zone.

Metacrysts are common but most are unidentified because of complete weathering. Some completely weathered individual metacrysts appear to have been a micaceous mineral, probably chlorite. Another unidentified mineral is represented in a single specimen by molds, some of which are partly filled by ferruginous material that may be indigenous. It occurs as unoriented single crystals 3 to 8 mm long and in crude sheaflike or radial aggregates. The molds indicate that the mineral has one good cleavage, and it may have been a chlorite or a chloritoid.

Schistosity may or may not be macroscopically evident in metasandstones and coarser rocks. However, orientation in the graywacke matrix is easily seen in most thin sections. Many of the larger clastic grains are crudely oriented with schistosity, and smaller grains, especially of quartz, appear to have been extended by flattening parallel to the shistosity and probably by secondary growth. Cataclastic extension by shearing parallel to the schistosity is evident in places.

Northwestern garnet zone

The northwestern garnet isograd is best known near the Kimsey Highway, U.S. Highway 64, and the Ocoee River. Its position is less clearly controlled in the southern and northern parts of the Ducktown and Isabella quadrangles as a result of fewer exposures of rock. The northwest garnet zone is about 3 1/4 miles wide where best defined. It straddles the boundary between unit 1 and the metagraywacke unit and extends to the northwesternmost veins of the Ducktown mining area, the position of the northwestern staurolite isograd as now known.

At and near the garnet isograd, garnet is restricted to thin widely spaced layers of argillaceous phyllite and schist, insofar as determinable. Owing to weathering, garnet of near-surface rock is completely to partly destroyed leaving dodecahedral cavities with varying amounts of indigenous iron. Fresh garnet is red to pale pink and violet, rarely almost colorless, and so far as known is almandiferous. Some garnet in dark phyllites may be dark macroscopically though thin fragments have a reddish color. In fine-grained metasediments it is euhedral but in metasandstone may have ragged margins or be in irregular masses commonly showing partial crystal form. Most garnet contains inclusions, usually in minor amounts. Two-stage growth is suggested in places by inclusion-free outer layers surrounding a sharply delimited central part with abundant inclusions. The reverse also has been seen, the inclusions being in the outer part, many of them an opaque material, possibly graphite. Most sections of garnet show essentially uniform inclusion content or lack a sharp boundary between the central and outer parts.

The finer grained metasediments of the garnet zone are like those of the biotite zone, but southeastward where the garnet zone is in the metagraywacke unit, graywacke beds are much more abundant than subgraywacke and fine-grained metasediments. However, thin layers of fine-grained metasediment continue to alternate with graywacke; dark argillaceous layers recur, but there seems to be a greater percentage of silty graywacke in the fine-grained suite.

Biotite is of two distinct types: relatively small thin books and flakes oriented with the schistosity, and thicker much larger unoriented metacrysts that cut across and replace the older oriented minerals. Most rock is too weathered to permit certain identification of micaceous metacrysts. Some are biotite; others are chlorite, some of which obviously replaced biotite.

Muscovite may range from a trace to amounts in excess of biotite. It is mainly the oriented variety and is generally much less abundant than biotite. Scarce metacrysts may be present. Abundant oriented muscovite seems to be associated with severe crinkling in some rocks. Such schist may show much to moderate amounts of dusty to stringy opaque material in and near the muscovite- (or sericite-) rich bands, suggesting alteration of iron-bearing minerals, such as biotite, to white mica. Weathering is an obscuring factor in interpretation of most specimens, however.

Oriented chlorite, characteristic of some rocks to the west, seems to disappear near the garnet isograd. Unoriented chlorite metacrysts have been mentioned above. A still later chlorite is an alteration product of garnet, fills openings, and may replace oriented biotite near the veins. Its development in places seems to be associated with structural deformation of metamorphosed rock some time after primary metamorphism ceased.

Quartz grains of fine-grained metasediments are usually elongated along the schistosity, as are lenses of quartz aggregates. Plagioclase is sparse in thin sections and tested grains seem to be sodic oligoclase. Some feldspar may be mixed in very fine grained aggregates. Potash feldspar is apparently absent in the phyllites and schists. Some opaque material is segregated with other fine-grained minerals as streaks and irregular lenses. It seems to be carbon (probably graphite) and ilmenite. Ilmenite in hexagonal plates speckles some schists and phyllites. Leucoxene is an alteration product of ilmenite and seems most abundant in highly crinkled schists.

Metasandstones of the garnet zone show schistose structure at many localities, and in shear zones schist with a somewhat mylonitic appearance may be produced, seemingly without great disruption of the bedding. Granule and small-pebble conglomerates show flattening and extension of the pebbles. Schistosity is refracted at the interface between metasandstone and fine-grained metasediment. Metasandstones and metaconglomerates contain both new and relict minerals as in the chlorite and biotite zones, but degree of reconstitution is greater. Grains of quartz and feldspar may retain general clastic shapes though marginal attack is evident. It would be difficult to determine whether or not plagioclase has been modified in composition. Larger clastic fragments and fine-grained quartz-sandstone pebbles are commonly well preserved. The original grain size of sandstones is approximately preserved, for a sandstone bed may be but a short distance from a silty sand bed. Development of interlocking texture shows that recrystallization of sand sizes has been considerable, and impure silty sands give the impression of much recrystallization because of the amounts of new minerals and their intimate physical relations.

Potash feldspar is identified in granule and pebble conglomerates of the garnet and higher grade zones. A little has been identified in larger sand sizes but not in fine- or medium-grained metasandstones. Biotite is almost always present in the metasandstones and coarser rocks. Muscovite may be absent but is usually present in lesser amounts than biotite. Garnet seems to be lacking or nearly so in the coarser metasediments near the garnet isograd but is sparse to common farther southeast. Opaque minerals of the metasandstones include both ilmenite and magnetite as identified by strength of magnetism and shape of grains.

Minor minerals of the metasandstones include titanite, apatite, zircon (in part metamict), and tourmaline. These are detrital with possibly some secondary growth, particularly on tourmaline.

Complete or nearly complete localized reconstitution of graywacke resulted in formation of nodules and lentils of pseudodiorite. This reconstitution destroys or nearly destroys original schistosity and is therefore assigned to the second, or thermal, episode of metamorphism. The detailed description of pseudodiorite in the Ducktown region is on pages 62-69.

Appearance of pseudodiorite also marks the first occurrence of amphibole, so far as known, along a traverse in a southeasterly direction from the northwest corner of the mapped area. The congruence of the amphibole threshold line with the pattern of isograds (fig. 2) suggests that it may also be treated as an isograd where rocks have compositions like those in the area thus far described.

Sulfides are nearly all oxidized in most exposed rock of the garnet zone. Pyrrhotite lenses are present, and fine-grained pyrite has also been recognized. In dark phyllite, oxidized sulfides in lenses are abundant in certain sedimentary bands but as in the biotite zone are oriented with the schistosity. It is generally impossible to determine whether the individual oxidized lens was pyrrhotite or pyrite, but pyrrhotite probably greatly predominates. In a quarry at the north margin of the Isabella quadrangle near the 20-minute meridian line, pyrrhotite lenses are abundant. Cubic pyrite seems to be rare or missing except underground along the northwesternmost veins (at the staurolite isograd) where the origin is most probably different.

In the rocks of the chlorite and biotite zones, the slaty cleavage and schistosity are but little affected by later deformation. A little minute crinkling is locally evident. Near the garnet isograd, crinkling of schistosity is increasingly evident and ranges from mild to severe across the garnet zone and for some distance farther southeast. Proportion and prominence of unoriented metacrysts increase in the same direction, as does the average size of grain of the whole rock.

Staurolite zone

The staurolite zone is considered here to occupy the entire area between the staurolite isograds, a distance of about 9 miles. The seeming restriction of kyanite to a single known line in the mapped area (along the Calloway vein) or to two lines, projecting the line mapped by Hurst in the Mineral Bluff quadrangle in Georgia (not found in present area), is believed to preclude definition of a kyanite zone.

The staurolite zone includes about half of the area underlain by the metagraywacke unit, most of the Wehutty Formation, and all of the Hughes Gap and Dean Formations. I have not found staurolite in the Hothouse Formation, whose composition may have been unfavorable; however, this is due in part to my use of staurolite as one criterion in drawing the arbitrary contacts between the Hothouse Formation and the enclosing Hughes Gap and Dean Formations. The various formations embrace graywacke, silty graywacke, argillaceous layers, siltstone, feldspathic quartzite, thin siliceous dark beds that are probably metamorphosed chert, graywacke conglomerate, and quartz-pebble conglomerate. Alternation of rock types is the rule at all localities. Staurolite in the metagraywacke is mainly in schists that appear to be in the lowest stratigraphic position in the district, and close to the shear zones that were a factor in localizing the veins. Some of the staurolite-bearing rock near the veins was originally coarser grained than the original argillaceous metasediment of distant staurolite schist. Emmons and Laney (1926, p. 18) reported staurolite of the mining district in rocks ranging from "dense dark schist to a fairly coarsely granular graywacke." Away from the mining district, staurolite is in ferriferous argillaceous schist and phyllite, mostly of dark color.

Staurolite of schists and phyllites is mostly in well-formed crystals that range in length from a fraction of an inch to about 3 inches. Southwest of the Old Polk County mine, giant broken and sericitized staurolites litter the hillside; some of these are believed to have attained a length of 8 inches or more. Staurolite belongs to the unoriented suite of minerals that grew mainly or entirely in the second or thermal episode of metamorphism. It commonly contains numerous inclusions of the older minerals, dominantly quartz and ilmenite, that may retain relic schistosity, though commonly in rotated position. Some staurolite metacrysts may in part be clear of inclusions or nearly so, with other parts of the same crystal crowded with them. Other minerals of the second episode, such as garnet and unoriented metacrysts of biotite, are also engulfed by the outer parts of staurolite metacrysts, but these are considerably smaller than metacrysts of the same minerals of the adjacent matrix.

Abundance of staurolite away from the mining district is believed to have been controlled entirely by original composition of the host rock. Delicately banded argillaceous schist (possibly varved) will contain staurolite metacrysts within thin layers not macroscopically different from adjacent thin layers that contain only metacrysts of biotite and garnet. The occurrence of staurolite in graywacke of the mining district and its giant size near some vein zones seem to indicate that pressure-temperature and chemical conditions in the mining district favored exceptional growth of staurolite.

Fine-grained metasediments of the staurolite zone are metamorphosed to schist of fine to moderately coarse grain. Dark argillaceous metashale appears to retain its original fine grain better than other varieties of fine-grained metasediments. The schists produced from fine-grained originals include a wide variety of types, many of which have abundant unoriented metacrysts, collectively including thick biotite books, chlorite, garnet, kyanite, and staurolite.

A detailed list of schists would be long; major types are biotite schist, two-mica schist, quartz-mica schist, and sericite and muscovite schist, all of which may have varieties defined by garnet, graphite, cross-biotite, cross-chlorite, staurolite, and combinations of these. Besides chlorite derived from other minerals by alteration, large elongate unoriented cross-chlorite metacrysts are abundant in many dark schists, especially those of the Wehutty Formation. These are grayish to a drab olive green and have prominent lamellar twinning. They cut across schistosity replacing various minerals and have relations suggesting that they grow along incipient crinkle cleavage, or, in other orientations, along the axes of other bends in the schistosity. Projections of their long axes at an angle to the schistosity may be marked by elongate muscovite aggregates. The chlorite metacrysts seem to have grown late in the time interval characterized by deformation of the schistosity, for some grains are slightly bent. These bent crystals may possibly represent an earlier mineral completely altered to chlorite; however, the former mineral was probably not metacryst-biotite inasmuch as chlorite metacrysts elsewhere that clearly replace biotite have pleochroic halos inherited from the replaced biotite.

Opaque minerals include, besides graphite, ilmenite and magnetite. Both have been identified in the same rock by shape and magnetic tests. Ilmenite shapes are noted in many thin sections, and lack of closely associated titanium minerals probably indicates that they are still ilmenite. Magnetite is an abundant mineral along the veins and is present in some specimens over much of the staurolite zone. Ilmenite, however, probably greatly predominates in normal schists, including some schist in the wallrock of veins.

Other minor minerals are tourmaline, apatite, titanite, leucoxene, epidote group, and zircon. Some tourmaline prisms are euhedral and may be bicolored, almost certainly resulting from secondary growth during metamorphism. A single locality in the Dean Formation shows abundant tourmaline prisms arranged in the planes of secondary or false cleavage. Apatite may be shapeless or show evidence of hexagonal outline. Zircon may be partly metamict. Epidote is widespread in the zone, but is rare in rocks other than pseudodiorite. Abundant green epidote in a quarry near the center of the Persimmon Creek quadrangle is localized by cross fractures. A thin section of schist from the Wehutty Formation of the Persimmon Creek quadrangle has epidote with a thin partial rim of a radioactive mineral which seems to be allanite.

Sulfides of the schists of the staurolite zone are pyrrhotite and pyrite. Their abundance as seen in thin sections and in artificial or natural exposures of fresh rock seems to be less than in zones of lower metamorphic grade. Dark carbon-bearing schist in the Wehutty Formation, and in small amount in the Dean Formation, in places contains typical thin lenses of weakly magnetic pyrrhotite oriented along the schistosity, and these and other dark schists where weathered may contain lenticular cavities along the schistosity that are partly filled with reddish-brown indigenous iron oxide. Both pyrite and pyrrhotite are present in pseudodiorite in very minor amounts. Pyrite may show subhedral form but is predominantly shapeless both in thin sections and in fresh rock. Very little pyrite in cubic form was observed, and none of the vuggy lenticular type of pyrite that occurs in places within the metamorphic zones to the northwest was recognized, but this does not eliminate the possibility that some oxidized lentils may have been such pyrite rather than pyrrhotite.

Part of the reason for the scarcity of iron sulfides in country rock distant from the ore bodies could be original lack of materials in much of the rock. Deep weathering is another factor, as it imposes limits on observation. However, the seeming absence of sulfide from some dark schists, together with the intensity of metamorphism, suggests that the minerals may have been destroyed or their formation inhibited, leaving iron to enter into staurolite, chlorite, garnet, and biotite, sulfur being lost to the system. The sulfides that survived or formed in some dark schists may owe their existence to the low permeability of these rocks to sulfur.

The schists show severe to mild crinkling, minor folding, and closure of all sizes of earlier folds. Where crinkling is evident, secondary or false cleavage may be prominent to nearly absent. Where crinkling is moderate to severe, displacement along the shear surfaces is evident, and the false cleavage controls weathering and fracturing. Drag of the schistosity along the shear surfaces, probably accompanied by some recrystallization or new development of muscovite, produces an appearance of true schistosity such that close examination of cross breaks is necessary to identify it as strain-slip cleavage. Casual inspection of such rock can easily result in error, particularly in schists with a high content of muscovite or in places where saprolitization is advanced.

The effects of the late deformation on metacrysts may also be marked. Staurolite may be rotated as shown by oriented inclusions, broken, and marginally to completely altered to muscovite or muscovite plus chlorite. Staurolite of a schist from the Calloway mine is deformed and essentially completely altered. The outer part is chlorite (with minor muscovite) oriented about perpendicular to the crystal faces. The interior is an unoriented aggregate of muscovite with minor chlorite grains that probably represent inclusions of biotite and perhaps garnet. On the surface staurolite may seem to disappear along the strike of a staurolite-bearing bed; in places this may result from a failure of the mineral to develop to recognizable size, but in others staurolite is replaced by muscovite pseudomorphs that weather out and cannot be recognized unless fresh rock is available. Secondary minerals that replace staurolite lack orientation or, if partly oriented among themselves as in rim-chlorite, lack consistent orientation with the schistosity of their host schist.

Biotite metacrysts may be bent in crinkled and folded schist, or may be smeared out with partial to complete alteration to green chlorite. In the walls of veins, as in the crinkled hanging-wall schist of the Burra vein, both oriented biotite and metacrysts of biotite are partly to completely altered to pseudomorphs of chlorite. Garnet metacrysts may show chloritization along fractures, and in a few localities they are selectively chloritized, in part or in whole. One such locality shows broken pseudodiorite in which an open space was formed; this former opening is completely filled with an aggregate of green chlorite, and the adjacent part of the pseudodiorite and host rock shows chloritization of both garnet and biotite. This locality shows clearly that late deformation developed open spaces in strong rock and that these served as channelways. Metacrysts of kyanite in the wallrock of the Calloway mine seem to have survived without complete alteration, though mechanically affected. Sericitic streaks that cut across deformed schistosity probably were formed at the same time as the alteration of metacrysts. Where associated with staurolite or garnet metacrysts, the sericite streaks may pass into chlorite near these metacrysts.

Metasandstones, conglomeratic metasandstones, and metaconglomerate may lack evident schistosity or range from slightly schistose to markedly schistose graywacke gneiss or schist. If a graywacke-type matrix forms a larger proportion of the rock, schistosity is more evident, whereas arkose and feldspathic quartzite may show little schistosity. Shearing during dynamic metamorphism varied widely in intensity and seems to be more evident in areas of steep dip. Where this shearing is prominent, all the coarser rocks are schistose or gneissose. Granule conglomerate in an extreme case is converted to schist in which the flattened granules are preserved in orientation with the schistosity. The rock subsequently was strongly crinkled. Feldspathic quartzite relatively free of argillaceous material seems to be the rock most resistant to development of mineral orientation. It may be micaceous quartzite in which unoriented micas are evenly scattered throughout, but where shearing was strong the micas are well oriented and the rock may properly be called schistose quartzite or even quartz-mica schist.

Despite the degree of cataclasis and reconstitution, relict sedimentary features are evident at most places. Graded bedding, for example, may be recognized in coarser grained metagraywacke in localities throughout the area where it was an original characteristic. In shear zones, however, granulation and recrystallization may destroy the reliability of graded bedding as an indicator of tops of beds owing to the varying intensity of shearing.

Quartz (or quartzite) grains, granules, and small pebbles best survived metamorphism but show flowage, strain, and granulation, with evident healing of cataclastic effects by recrystallization. At places, as in some areas of the Dean Formation, the plane of flattening of pebbles departs widely from the schistosity of adjacent beds of fine-grained metasediment. The plane of flattening is nearly parallel to a well-developed strain-slip or crinkle cleavage of adjacent schist, which suggests that the flattened pebbles and granules were rotated to conform to the attitude of the abundant surfaces of shear. Plagioclase appears to have been partly to entirely recrystallized, probably with some composition change, inasmuch as it ranges in composition through oligoclase and into andesine. Recrystallized plagioclase is relatively clear, closely resembling quartz; it tends to interlock with adjacent grains, and unless strained later it generally lacks twinning and may lack visible evidence of cleavage. It may show continuous zoning without sharp breaks in composition. Some well-twinned plagioclase does occur and probably represents modified original detrital grains.

Potash feldspar is recognized in granule and pebble conglomerate at localities widely spread through the staurolite zone. The original detrital shapes are clearly evident, and tested fragments are microcline. Potash feldspar is rarely recognized in sandstone.

Biotite and muscovite are everywhere present though biotite generally is dominant. Muscovite may be absent or in trace to minor amounts in many layers. Biotite may be abundantly present in two forms as in other zones, the fine-grained oriented variety and the much larger unoriented metacryst type. It is typically brown to reddish brown in a considerable range of shades, but locally may be olive brown to olive green as in epidotized rock in a quarry in the Persimmon Creek quadrangle. Biotite near some thin shear zones and near veins may be partly to entirely altered to green chlorite. Such areas seem to have unusual amounts of leucoxene compared with specimens in which biotite is not chloritized.

Garnet is rather common in metasandstones but is sporadic in amounts. Much garnet is in irregular grains, and where such grains are grouped, crystal form is seldom apparent. All the garnet has many inclusions. As seen in thin section, garnet appears to be more abundant in areas rich in calcite, suggesting that it may have a large proportion of calcium garnet molecules.

Ilmenite and magnetite are common constituents of coarser metasediments, but ilmenite seems to greatly predominate in most specimens. Leucoxene masses commonly contain centers or scattered remnants of ilmenite. Titanite, zircon, apatite, and tourmaline are seen in thin section. Tourmaline may show probable secondary growth and may show either detrital form or, rarely, prismatic crystals. Carbonate, mainly calcite, commonly is present in at least trace amounts and may range from 5 percent to 50 percent in small areas of a thin section. It seems to have been somewhat mobile, as it fills intergranular spaces and replaces other minerals bordering them.

Members of the epidote group seem rare except in pseudodiorite. They are abundant only near and along fractures; in these places the mineral is true green epidote, whereas elsewhere it is optically nearer clinozoisite. Zoisite has been identified in specimens from a few localities. A few grains of a mineral from a quarry in the Hothouse Formation near the center of the Persimmon Creek quadrangle have partial overgrowths of epidote. The central part of these grains may be allanite, though the color is not the usual brown.

Monazite has been doubtfully identified in metasandstone from several localities.

The coarser grained rocks away from the mining district have a sulfide content ranging from zero to perhaps 1 percent. Both pyrite and pyrrhotite in shapeless masses are present but sporadic. They seem to favor areas of high carbonate as seen in thin section, though such areas may lack sulfide. It is believed that much of this iron sulfide represents original constituent materials of nearby fine-grained carbon-bearing sedimentary beds, part of which has migrated into the coarser grained permeable beds utilizing fractures and slaty cleavage or schistosity. A fuller description of pyrite and pyrrhotite of the staurolite zone was given on page 58. In the mining district, drill core from midway between known veins may show pyrite veinlets as well as shapeless masses.

Pegmatitic segregations

Metagraywacke and interbedded schist may contain small veins and irregular masses of micaceous pegmatitic material that appears to represent local exceptional recrystallization of materials "sweated out" of the adjacent rocks. These pegmatitic phases appear to be most abundant in the eastern part of the metagraywacke unit in the southern part of the Isabella quadrangle. The dimensions are a few inches to a few feet. The pegmatites are characterized by small books of white mica set at all orientations in a finer grained siliceous matrix. Some have a large proportion of coarse quartz with plates and small books of muscovite, and feldspar. Similar small masses of quartz may represent an extreme development. Micaceous veins, usually measured in fractions of an inch to inches or even a few feet, are, like the more pegmatitic material, seen mainly in the mining district and adjoining areas to the southeast, all in the metagraywacke. These may be largely muscovite, but some appear to be country rock that has been muscovitized. By increase in quartz, they seem to grade into more typical pegmatitic veins. Quartz greatly exceeds feldspar in crushed specimens. The feldspar seems to be mainly oligoclase.

Pseudodiorite

The term "pseudodiorite" was first used by Keith (1913), who recognized the metamorphic origin of the masses. A more proper term, "granofels," was proposed by Goldsmith (1959), but widespread use of the older term in the mining district suggests its use herein. Hadley and Goldsmith (1963, p. 102-104) referred to pseudodiorite of the Great Smoky Mountains as calc-silicate granofels.

The term "pseudodiorite" was applied by Emmons and Laney (1926, p. 19-21) to nodular, lenticular, and pipelike masses in the metagraywacke unit, composed mainly of plagioclase, quartz, hornblende, and (or) biotite, with garnet, epidote (usually clinozoisite), and lesser amounts of other minerals. Its origin was ascribed by them to metamorphism of calcareous concretions. This type will be referred to as lenticular pseudodiorite in this report. A second type was described by Hurst (1955, p. 28) as bedded pseudodiorite. It occurs as beds and as greatly elongated thin lenses parallel to the bedding.

Lenticular pseudodiorite

Lenticular pseudodiorite masses are ellipsoidal to nearly spherical in form, the sphericity seeming to increase with the massiveness of the host metasandstone. According to Emmons and Laney (1926, p. 19, 20), the masses in the district "generally lie parallel with the bedding and rarely if anywhere occupy the whole thickness of the bed." The parallelism to bedding seems to be a result of near parallelism of bedding and cleavage in much of the mining area, for in the greater part of the region the plane of maximum dimensions of the lenticular masses is oriented parallel to schistosity. Hurst (1955, p. 19), with regard to the Mineral Bluff quadrangle, wrote: "They may be in any position within a bed, but their longest diameter is always roughly parallel to the enclosing rock's foliation."

The nodules or lenses of pseudodiorite may range in size from an inch or two to masses several feet in diameter. The size seems to increase near shear zones. A graywacke bed 20 feet thick near the Isabella mine is largely a series of great spherical masses of pseudodiorite. Some of these seem to coalesce insofar as can be seen. Emmons and Laney (1926, p. 19-21) described pipes and dikelike bodies 1 to 50 feet long and a few inches to 2 or 3 feet thick; they also described the distribution of the minerals of some masses in concentric zones, the variations of the concentric structure, and the presence of nuclei of altered slate in many bodies. Such nuclei are lacking in many lenses, however, and in others are not at the centers of concentric pseudodiorite lenses.

Lenticular pseudodiorite lacks schistosity except for relicts preserved in the outer part of incipient pseudodiorite and, much more rarely, in fully developed pseudodiorite. The reconstitution of the metamorphosed host is marked by change in composition and (or) grain size of the older minerals and formation of new minerals, thereby essentially destroying older features such as schistosity. Where relict schistosity is preserved, it is marked by orientation of the original flaky biotite of the partly reorganized schistose country rock and, in places, by oriented opaque material, the original ilmenite of the host rock. Foliated pseudodiorite is noted in areas that have been strongly affected by a later shearing, as near veins. Commonly, only part of a lens is sheared to a gneissose product, the remainder retaining part to all of its original character. This shearing seems to be a part of the mild to severe deformation that affects schistosity over a large part of the mapped area.

Nodular and lenticular pseudodiorite is of two main kinds. One is characterized by coarse to fine aggregates of biotite usually without hornblende, the other by hornblende with small to moderate amounts of biotite. Where the two minerals are in contact, biotite penetrates hornblende, but it appears impossible to determine their relative age. Aggregates of biotite have a form in places that crudely suggests that of hornblende. Emmons and Laney (1926, p. 20) recorded such aggregates: "In some specimens dark bodies having exactly the form of the hornblende crystals consist wholly of biotite and minor amounts of quartz and feldspar." I have not observed pseudomorphs of such perfection and can only note the penetration described. Such penetrations could also result from molding of hornblende over biotite, or from simultaneous growth during which biotite possessed stronger crystallizing power. Other important minerals of both kinds of nodular pseudodiorite are brownish to yellowish garnet, possibly much richer in calcium than the reddish almandiferous garnet of the country rock, clinozoisite, zoisite, actinolitic hornblende, quartz, and plagioclase. Minor minerals include titanite, zircon, apatite(?), monazite(?), muscovite, traces of pyrrhotite and pyrite(?), ilmenite in part within leucoxene, magnetite, and small amounts of calcite. Intimate interlocking of the various mineral grains is characteristic.

Plagioclase is the dominant mineral. It varies widely in composition, probably reflecting the amount of calcium available from calcite and other minerals. Plagioclase from various localities ranges in composition from An_{15} to An_{80}. It may or may not be zoned over variable ranges. Zoned plagioclase usually lacks sharp divisions; rather, a continuous sweeping of the extinction is seen as the microscope stage is rotated. In one lens of pseudodiorite in impure feldspathic quartzite, both the pseudodiorite and the immediately adjoining host rock contain zoned calcic plagioclase that grades to oligoclase a few inches from the margin of the lens. Reversals of composition within a single zoned grain are noted in some thin sections, and some show reversed zoning throughout. Albite twinning is common in plagioclase of some pseudodiorites but generally in only a small proportion of grains. Pericline and albite combined grating twinning is very rare but has been noted in andesine.

Quartz is subordinate to feldspar, commonly a fourth to half as abundant, but in rare instances it is as abundant as feldspar. It closely resembles feldspar unless the cleavage or twinning of the latter is developed. Many grains of quartz show prongs that tend to follow grain boundaries. Quartz is usually disseminated throughout a thin section, but may vary somewhat in abundance.

Amphibole may be a minor or major constituent depending on the individual lens, or the position within a concentrically zoned, or spotted, lens. Color ranges from pale to dark green. One amphibole studied in detail is biaxial (-), 2V estimated at 80°, $Z_{\wedge}C$=18°-23°, pleochroism X=pale brownish yellow, Y=green with an olive cast, Z=bluish-green, β index of refraction about 1.668, and maximum birefringence 0.022. These properties suggest actinolitic hornblende. Forms of the amphibole are commonly crudely spindle shaped to prismatic, or crudely dendritic. Unless affected by later shearing and squeezing, orientation is lacking.

Garnet is always present but may be very unequally distributed, especially in zoned lenses. It usually shows some evidence of crystal form. Clinozoisite is common in all sections, ranging in amount from a few to perhaps 30 percent. Variation to calcic epidote has been noted, and some grains of zoisite were identified. Biotite in hornblende pseudodiorite tends to be associated with the hornblende. It is clearly a product of reconstitution except for rare small oriented biotite flakes, relicts of the schistose host rock.

Calcite is present in trace to minor amounts, but may be abundant in the central part of zoned lenses. Muscovite is in small amounts and may be entirely lacking in a thin section. Minor to trace amounts of iron sulfide show shapes and sizes different from host-rock sulfides and probably represent reassembled materials. The other minor minerals--zircon, apatite(?), monazite(?), titanite, and ilmenite--are probably partly or entirely relicts. Leucoxene is an alteration product of ilmenite. Magnetite is believed to be a new mineral at least in part. I failed to find K-feldspar in pseudodiorite by the method of scanning all contacts of rock slices against balsam.

Bedded pseudodiorite

Hurst (1955, p. 20-21, 28-32) used the term "bedded pseudodiorite" in the description of his Copperhill and Hughes Gap Formations. This type seems to dominate in thin-bedded formations and members, but assignment of much pseudodiorite to the bedded type is uncertain in localities where bedding and schistosity are parallel. Much bedded pseudodiorite is in fine-grained graywacke and impure quartzite beds and as beds alternating with fine-grained metasediments, now schist. It is common in the Wehutty, Hughes Gap, Hothouse, Dean, and Brasstown Formations. It is also found in the metagraywacke unit, particularly in schists that are stratigraphically lowest in the mining district. Near Murphy, N.C., it is present in the Andrews Schist and in beds east of the Tusquitee Quartzite, but was not found in the few outcrops of rock in similar stratigraphic position within the present area. The schistosity and bedding are essentially parallel in the formations southeast of the Dean Formation of the present area, and the question arises as to which controlled the orientation of bedded pseudodiorite. The quartzitic and cherty(?) hornblendic pseudodiorite beds commonly have much more quartz and less plagioclase than lenticular pseudodiorite in graywacke beds of the metagraywacke unit, and seem almost certainly to have formed from beds with original disseminated carbonate content.

The minerals of bedded pseudodiorite are quartz, plagioclase, amphibole, garnet, clinozoisite, and small amounts of chlorite, zircon, apatite, titanite, calcite, magnetite, ilmenite, tourmaline, iron sulfides, sphene, and monazite(?). Micas are minor constituents or are absent in my specimens, but a little biotite is not uncommon. A typical siliceous specimen contains about the following proportions of minerals: 62 percent quartz, 25 percent plagioclase, 10 percent hornblende, 1.5 percent garnet, 0.75 percent pyrrhotite, and traces of other minerals. Biotite and muscovite are lacking. Some of the plagioclase shows albite twinning whose maximum extinction angles indicate bytownite. It may also show continuous zoning. Garnet is associated with the hornblende-rich layers. Calcite is lacking in the thin section. Hurst (1955, p. 28-32) described the pseudodiorite of the Hughes Gap Formation in detail. His four modal analyses are summarized below, by range in percentages.

Quartz----------	21.3-49.8
Feldspar--------	22.9-43.3
Hornblende------	12.1-19.8
Clinozoisite----	2.1-39.5
Garnet----------	1.6- 4.0
Titanite--------	0 - 2.4
Calcite---------	0 - 1.6
Apatite---------	.3- .6
Colorless mica--	0 - .8
Black opaque----	1.2- 1.7
Chlorite--------	0 - .7
Zircon----------	0 - .15

The amphibole of bedded pseudodiorite seems to have a greater range in composition than that of lenticular pseudodiorite. Color may range from deep green to almost colorless in thin section. A seemingly minor part shows characters close to normal hornblende, but much seems to be actinolitic. Hurst (1955, p. 30) determined optical properties of an amphibole from a bedded pseudodiorite; he states: "These optical properties indicate a member of the actinolite-ferrotremolite series * * *."

Garnet may be scarce in bedded pseudodiorite but is abundant in some beds. It may be in ragged skeletal patches to nearly euhedral poikilitic crystals. Calcite commonly is with or within garnet and amphibole. Leucoxene is common and some contains remnants of ilmenite. Magnetite may be shapeless but some shows partly rectangular margins. Pyrrhotite is the dominant iron sulfide and some shows maximum magnetism. The chlorite is pale olive green with a brownish cast and closely resembles the unoriented chlorite metacrysts in dark schists of the Wehutty Formation. Most heavy minerals such as zircon, titanite, apatite, monazite(?), and tourmaline show detrital form, but some tourmaline is in euhedral prisms, probably due to overgrowth. Quartz grains in bedded pseudodiorite show flattening, probably relict from the general schistosity.

Nearly black bedded pseudodiorite of cherty appearance has been noted in place and as float in various parts of the Wehutty Formation. Its composition is much the same as other bedded pseudodiorite: quartz, labradorite or bytownite, hornblende, euhedral garnet, and accessories. Clinozoisite and epidote may be sparse or fairly abundant. Calcite is rare in specimens at hand and muscovite is rare or lacking. The texture of this variety of pseudodiorite is finely granoblastic in thin section. Amphibole-rich bands seem to represent bedding, for they parallel iron-rich bands showing much opaque gray mineral that has the shape of ilmenite. Magnetite is disseminated in small amount, and pyrrhotite may be in trace to minor amounts. The conclusion of Hurst (1955, p. 31) that bedded pseudodiorite of his area "is probably metamorphosed argillaceous chert and/or calcareous shale" also seems applicable in the present area. To these should be added impure calcareous feldspathic quartzite.

Origin of lenticular pseudodiorite

The theory that lenticular pseudodiorite developed from calcareous concretions (Emmons and Laney, 1926, p. 21) has received much support, and in the present area field relations seem to support this theory.

Such concretions occur throughout the mapped area except where metamorphism is most severe and probably excepting much of the rock east of the mining district, particularly east of the metagraywacke unit. They are present in places well within the amphibole threshold line, even within a few feet to tens of feet from pseudodiorite. Most are weathered out, leaving ellipsoidal cavities oriented with the schistosity. A small quarry at Stansbury Gap northeast of Ducktown in the Isabella quadrangle exposes fresh rock. Here, numerous bleached calcitic lenses are oriented with schistosity which stands at about 55° to the bedding. A typical specimen of a concretion shows certain features which are compared with the same features of the adjacent unbleached rock as follows:

	Calcareous concretion	Host rock
Biotite------	6 percent, mostly oriented	16 percent, oriented
Calcite------	Up to 30 percent	1 percent or less
Plagioclase--	Sodic oligoclase	Sodic oligoclase
Amphibole----	Absent	Absent
Garnet-------	Minor to trace	Absent?

About 35 feet north of the quarry in the roadcut is typical hornblendic pseudodiorite oriented along the schistosity. Such pseudodiorite was not seen in the quarry but garnetiferous lenses in the north wall are intermediate in mineralogy between the bleached lenses and typical pseudodiorite. These lenses lack hornblende, but their texture and the presence of large subhedral garnet are otherwise like that of normal pseudodiorite. The lack of amphibole can scarcely be attributed to pressure-temperature conditions in view of the short distance involved, nor can it be explained by lack of calcium, inasmuch as calcite is abundantly present in the bleached lenses. It seems more likely that all the available iron and magnesium were tied up in other minerals, particularly biotite, which is stable in both host rock and pseudodiorite, and garnet. Another locality with fresh rock is on Walkertown Creek 5,000 feet west of the Copper Basin Hospital, Ducktown quadrangle. Near the amphibole threshold line, typical pseudodiorite and intermediate garnetiferous rock are present. At both Stansbury Gap and Walkertown Creek, the bleached incipient pseudodiorites retain much of the original schistosity, but granoblastic recrystallization in the intermediate or garnetiferous stage has largely destroyed it. At both places, the beds with incipient pseudodiorite are quartzitic, but nearby graywacke beds have typical hornblende pseudodiorite. Original composition of the host rock seems to be the main factor governing the type of pseudodiorite.

Zoned pseudodiorites commonly show cores like the intermediate garnetiferous pseudodiorite described, surrounded by one or more layers with abundant hornblende. The centers may or may not have a small amount of hornblende. The relations suggest that growth of hornblende may have lagged behind the other minerals in time, particularly in view of evidence of diffusion such as alternation of concentric hornblende-rich and hornblende-poor layers. Bleached layers of graywacke that separate pseudodiorite from host rock, but which are otherwise like the host rock, probably lost most of their iron and magnesium to the pseudodiorite by diffusion.

In summary, the theory of Emmons and Laney that calcareous concretions in metasandstone localized the lenticular pseudodiorites of the Ducktown region is strongly supported both by field relations and by chemical and mineralogical changes that occurred.

Orientation of many calcitic concretions (and of pseudodiorite nodules and lenses) with the schistosity presents a problem. Several explanations might be invoked: (1) the concretions formed at great depth after development of schistosity; (2) they formed in the sedimentary rock before metamorphism and were mechanically rotated or reoriented during the dynamothermal episode; or (3) they were of premetamorphic origin, modified during the dynamothermal episode by migration of calcite under stress and thereby reconstituted and reoriented to their present positions. [Ed. note: Hernon did not discuss (1) in his manuscript.] In massive metasandstone, it seems unlikely that mechanical rotation could notably change the orientation of a single ellipsoid without evident distortion of the host rock around the mass. However, successive small displacements on closely spaced shears, now surfaces of schistosity, might reorient the mass somewhat akin to the process credited for development of shear folds. If true, perfect healing of the lens would have been required, for the boundaries of both bleached calcitic lenses and pseudodiorite are perfectly smooth. Therefore, the third of the possible explanations mentioned seems the most likely to me, in view of the common evidence that calcite migrated short distances during metamorphism.

Some lenticular pseudodiorite lenses, or masses of other shape, may have some other origin; for example, a parent calcitic lens formed along a fracture (Ross, 1935, p. 22).

I believe that processes and controls in development of both the lenticular and bedded types of pseudodiorite were essentially identical. In the lenticular type so abundant in metagraywacke, the distribution of the necessary calcium (as calcite) was mainly brought about by formation of concretions, but in the bedded type, the distribution of adequate calcite was dominantly an original sedimentary trait with but minor redistribution by concretionary process, a redistribution too limited to destroy relation to bedding or produce nodules and stubby lenticular concretionary masses on a large scale. Chemical processes seem to have been essentially the same in both types of pseudodiorite, the differences probably resulting from variations in composition.

A chemical study of a single lens of pseudodiorite and of lenses of intermediate and bleached types would probably elucidate the development. Each constitutes a manageable small system within its metasandstone environment. Except for some accessory constituents, recrystallization has been nearly complete. Phases can be separated for analysis or determined and counted optically. Continuous zoning of plagioclase in parts of some pseudodiorites and in adjacent host rock presents a seemingly minor problem. Analysis of minerals with numerous inclusions is more difficult. Quartz is in excess in all rocks involved, and calcite is in excess in most if not all lenses and is still present in wallrock. Water in fluid form must have been present though it was probably in large part a fugitive constituent. CO_2, freed from calcite upon incorporation of calcium in hornblende and garnet, was also a fugitive constituent. However, the relation of the partial pressure of CO_2 to environmental pressure and friction was such that unused calcite remained in the system throughout the episode of thermal metamorphism, an episode during which the pseudodiorite and such unoriented minerals of metacryst habit as biotite, garnet, and staurolite were formed in nearby host rock. Potash, except for that tied up mainly in micas, which are very minor phases in many pseudodiorites, seems to have migrated, according to the analyses recorded by Emmons and Laney (1926, p. 26). A high ratio of the activity of calcium to potash may have controlled fixation of iron and magnesium in amphibole rather than biotite, inasmuch as biotite is stable in both wallrock and pseudodiorite. Not fully understood is the difference between plagioclase within a pseudodiorite (commonly more calcic than oligoclase) and plagioclase in typical host rock (commonly oligoclase). Such oligoclase in host rock may exist next to or very near calcite. The answer may be simply variation in activity of calcium and (or) partial pressure of CO_2, but it may also be involved with the problem: why did one calcareous concretion alter to pseudodiorite in a given locality, and another nearby remain merely a bleached zone with a lesser amount of biotite, with calcite an important constituent? Perhaps ratios were controlling factors, or perhaps some unrecognized constituent was a catalyst that broke down energy barriers. Elucidation of the problems of these small well-defined systems would seem to be a highly attractive project for the qualified physical chemist with an interest in geology.

REFERENCES CITED

Emmons, W. H., and Laney, F. B., with the active collaboration of Arthur Keith, 1926, Geology and ore deposits of the Ducktown mining district, Tennessee: U.S. Geol. Survey Prof. Paper 139, 114 p.

Furcron, A. S., 1953, Comments on the geology of the Ellijay quadrangle, Georgia-North Carolina-Tennessee: Georgia Geol. Survey Bull., v. 60, p. 32-40.

Goldsmith, Richard, 1959, Granofels, a new metamorphic rock name: Jour. Geology, v. 67, no. 1, p. 109-110.

Hadley, J. B., and Goldsmith, Richard, 1963, Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee: U.S. Geol. Survey Prof. Paper 349-B, p. B1-B118.

Hernon, R. M., 1964, Geologic maps and sections of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina: U.S. Geol. Survey open-file report, 3 sheets.

______1968, The Wehutty Formation of North Carolina, in Cohee, G. V., Bates, R., and Wright, W., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1967: U.S. Geol. Survey Bull. 1274-A (in press).

Hurst, V. J., 1955, Stratigraphy, structure, and mineral resources of the Mineral Bluff quadrangle, Georgia: Georgia Geol. Survey Bull. 63, 137 p.

Hurst, V. J., and Schlee, J. S., 1962, Ocoee metasediments, north central Georgia-southeast Tennessee: Georgia Dept. Mines, Mining, Geology Guidebook No. 3, 28 p.

Keith, Arthur, 1904, Description of the Asheville quadrangle, North Carolina-Tennessee: U.S. Geol. Survey Geol. Atlas, Folio 116, 10 p.

______1907, Description of the Nantahala quadrangle [North Carolina-Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 143, 11 p.

______1913, Production of apparent diorite by metamorphism [abs.]: Geol. Soc. America Bull., v. 24, p. 684-685.

King, P. B., Hadley, J. B., Neuman, R. B., and Hamilton, Warren, 1958, Stratigraphy of Ocoee series, Great Smoky Mountains, Tennessee and North Carolina: Geol. Soc. America Bull., v. 69, no. 8, p. 947-966.

King, P. B., Keith, A., and Hayes, C. W., 1950, Geologic map of Murphy quadrangle, Tennessee-North Carolina: U.S. Geol. Survey open-file report.

LaForge, Laurence, and Phalen, W. C., 1913, Description of the Ellijay quadrangle [Georgia-North Carolina-Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 187, 18 p.

Ross, C. S., 1935, Origin of the copper deposits of the Ducktown type in the southern Appalachian region: U.S. Geol. Survey Prof. Paper 179, 165 p.

Van Horn, E. C., 1948, Talc deposits of the Murphy marble belt: North Carolina Dept. Conserv. Devel., Div. Mineral Resources Bull. 56, 54 p.

DEPARTMENT OF THE INTERIOR
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R. M. HERNON
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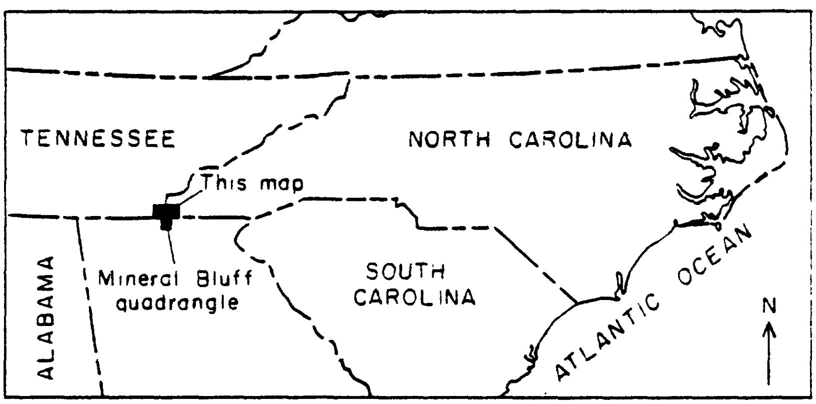
Copy of the geologic map at scale 1:48,000 is not available with this copy of the report. It may be consulted at the Geological Survey Library, 1033 GSA Bldg., Washington, D.C.; at 11 Post Office Bldg., Knoxville, Tenn.; at Division of Mineral Resources, Department of Conservation and Development, State Office Bldg., Raleigh, N.C.; or at Tennessee Division of Geology, Department of Conservation, G-5 State Office Bldg., Nashville, Tenn. However, copies of "Geologic Maps and Sections of the Ducktown, Isabella, and Persimmon Creek Quadrangles, Tennessee and North Carolina," by Robert M. Hernon, at scale 1:24,000 and open-filed in 1964, are available in this library for consultation.



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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.