DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

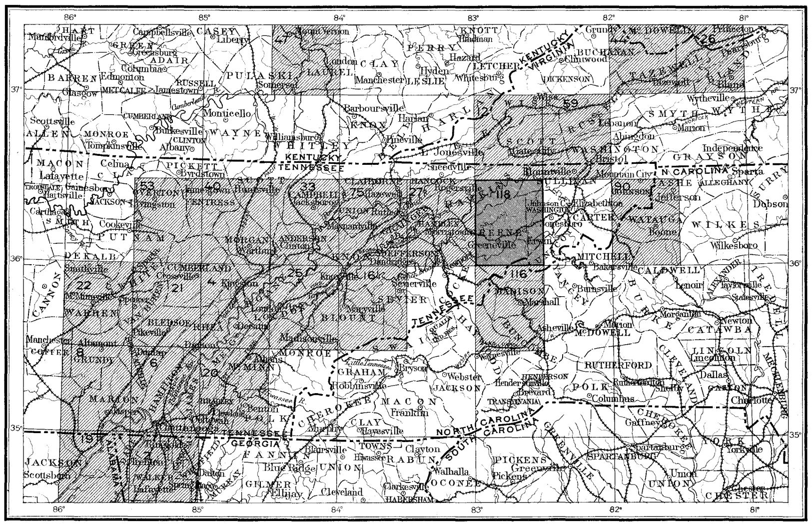
OF THE

UNITED STATES

GREENEVILLE FOLIO

TENNESSEE-NORTH CAROLINA

INDEX MAP



SCALE: 40 MILES-1 INCH

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LIBRARY EDITION

GREENEVILLE FOLIO
NO. 118

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS S. J. KUBEL, CHIEF ENGRAVER

1905

GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds: (1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

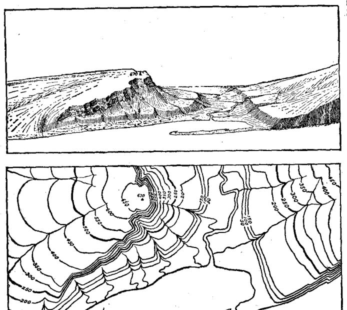


FIG. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The altitudinal space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

Scales.—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles in English inches, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic map.—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land, and the structure sections show their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

Sedimentary rocks.—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. In smaller portion the materials are carried in solution, and the deposits are then called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind; and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

Geologic time.—The time during which the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

(Continued on third page of cover.)

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. When two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains found in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.

Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not of their metamorphism.

Colors and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern, and is labeled by a special letter symbol.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary...	Recent........ Pleistocene....	Q	Brownish-yellow.
	Tertiary......	Pliocene....... Miocene....... Oligocene...... Eocene........	T	Yellow ocher.
Mesozoic	Cretaceous....	....	K	Olive-green.
	Jurassic	....	J	Blue-green.
	Triassic......	....	Ꝛ	Peacock-blue.
Paleozoic	Carboniferous.	Permian....... Pennsylvanian Mississippian..	C	Blue.
	Devonian.....	....	D	Blue-gray.
	Silurian......	....	S	Blue-purple.
	Ordovician....	....	O	Red-purple.
	Cambrian.....	Saratogan..... Acadian....... Georgian......	Є	Brick-red.
	Algonkian	....	A	Brownish-red.
	Archean	....	Æ	Gray-brown.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin.

The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and valleys and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 1, is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion, and these are, in origin, independent of the associated material. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterwards partly eroded away. The shaping of a marine or lacustrine plain, is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

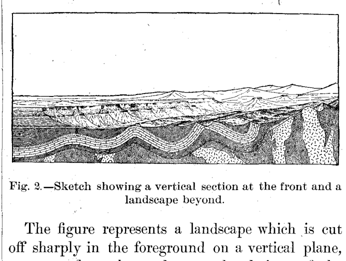


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

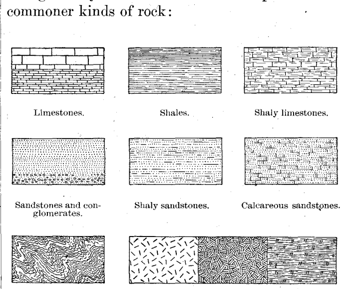


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be

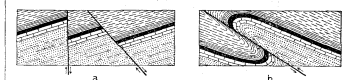


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum which appears in the section may be measured by using the scale of the map.

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

CHARLES D. WALCOTT,

Director.

Revised January, 1904.

DESCRIPTION OF THE GREENEVILLE QUADRANGLE.

By Arthur Keith.

GEOGRAPHY.

GENERAL RELATIONS.

Location. — The Greeneville quadrangle lies chiefly in Tennessee, but comprises also a portion of North Carolina. It is included between parallels 36° and 36° 30′ and meridians 82° 30′ and 83°, and contains about 963 square miles, divided between Greene, Hawkins, Sullivan, Washington, and Unicoi counties in Tennessee and Madison County in North Carolina.

In its geographic and geologic relations this quadrangle forms part of the Appalachian province, which extends from the Atlantic coastal plain on the east to the Mississippi lowlands on the west, and from central Alabama to southern New York. All parts of the region thus defined have a common history, recorded in its rocks, its geologic structure, and its topographic features. Only a part of this history can be read from an area so small as that covered by a single atlas sheet; hence it is necessary to consider the individual area in its relations to the entire province.

Subdivisions of the Appalachian province.—The Appalachian province is composed of three well-marked physiographic divisions, throughout each of which certain forces have tended to produce similar results in sedimentation, in geologic structure, and in topography. These divisions extend the entire length of the province, from northeast to southwest.

The eastern division of the province embraces the Appalachian Mountains, a system which is made up of many minor ranges and which, under various local names, extends from southern New York to central Alabama. Some of its prominent parts are the South Mountain of Pennsylvania, the Blue Ridge and Catoctin Mountain of Maryland and Virginia, the Great Smoky Mountains of Tennessee and North Carolina, and the Cohutta Mountains of Georgia. Also embraced in the eastern division is the Piedmont Plateau, a vast upland which, as its name implies, lies at the foot of the Appalachian Mountains. From New York to Alabama it stretches eastward and southward from their foot and passes into the Coastal Plain, which borders the Atlantic Ocean. The Mountains and the Plateau are separated by no sharp boundary, but merge into each other. The same rocks and the same structures appear in each, and the form of the surface varies largely in accordance with the ability of the different streams to wear down the rocks. Most of the rocks of this division are more or less crystalline, being either sediments which have been changed to slates, schists, or similar rocks by varying degrees of metamorphism, or igneous rocks, such as granite and diabase, which have solidified from a molten condition.

The central division of the province is the Appalachian Valley. It is the best defined and most uniform of the three physiographic divisions. In the southern part it coincides with the belt of folded rocks which forms the Coosa Valley of Georgia and Alabama and the Great Valley of East Tennessee and Virginia. Throughout the central and northern portions the eastern side only is marked by great valleys—such as the Shenandoah Valley of Virginia, the Cumberland Valley of Maryland and Pennsylvania, and the Lebanon Valley of eastern Pennsylvania—the western side being a succession of ridges alternating with narrow valleys. This division varies in width from 40 to 125 miles. It is sharply outlined on the southeast by the Appalachian Mountains and on the northwest by the Cumberland Plateau and the Allegheny Mountains. Its rocks are almost wholly sedimentary and are in large measure calcareous. The strata, which must originally have been nearly horizontal, now intersect the surface at various angles and in narrow belts. The surface differs with the outcrop of different kinds of rock, so that sharp ridges and narrow valleys of great length follow narrow belts of hard and soft rock. Owing to the large amount of calcareous rock brought up on the steep folds of this district its surface is more readily worn down by streams and is lower and less broken than the divisions on either side.

The western division of the Appalachian province embraces the Cumberland Plateau and Allegheny Mountains and the lowlands of Tennessee, Kentucky, and Ohio. Its northwestern boundary is indefinite, but may be regarded as extending from the mouth of Tennessee River in a northeasterly direction across the States of Illinois and Indiana. Its eastern boundary is sharply defined along the Appalachian Valley by the Allegheny front and the Cumberland escarpment. The rocks of this division are almost entirely of sedimentary origin and remain very nearly horizontal. The character of the surface, which is dependent on the character and attitude of the rocks, is that of a plateau more or less completely worn down. In the southern half of the province the Plateau is sometimes extensive and perfectly flat, but it is oftener much divided by streams into large or small areas with flat tops. In West Virginia and portions of Pennsylvania the Plateau is sharply cut by streams, leaving in relief irregularly rounded knobs and ridges which bear but little resemblance to the original surface. The western portion of the Plateau has been completely removed by erosion, and the surface is now comparatively low and level, or rolling.

Altitude of the Appalachian province.—The Appalachian province as a whole is broadly dome shaped, its surface rising from an altitude of about 500 feet along the eastern margin to the crest of the Appalachian Mountains, and thence descending westward to about the same altitude on Ohio and Mississippi rivers.

Each division of the province shows one or more culminating points. Thus the Appalachian Mountains rise gradually from less than 1000 feet in Alabama to more than 6700 feet in western North Carolina. From this culminating point they decrease to 4000 or 3000 feet in southern Virginia, rise to 4000 feet in central Virginia, and descend to 2000 or 1500 feet on the Maryland-Pennsylvania line.

The Appalachian Valley shows a uniform increase in altitude from 500 feet or less in Alabama to 900 feet in the vicinity of Chattanooga, 2000 feet at the Tennessee-Virginia line, and 2600 or 2700 feet at its culminating point, on the divide between New and Tennessee rivers. From this point northward it descends to 2200 feet in the valley of New River, 1500 to 1000 feet in the James River basin, and 1000 to 500 feet in the Potomac River basin, remaining about the same through Pennsylvania. These figures represent the average elevation of the valley surface, below which the stream channels are sunk from 50 to 250 feet, and above which the valley ridges rise from 500 to 2000 feet.

The Plateau or western division increases in altitude from 500 feet at the southern edge of the province to 1500 feet in northern Alabama, 2000 feet in central Tennessee, and 3500 feet in southeastern Kentucky. Its height is between 3000 and 4000 feet in West Virginia, and decreases to about 2000 feet in Pennsylvania. From its greatest altitude, along its eastern edge, the Plateau slopes gradually westward, although it is generally separated from the interior lowlands by an abrupt escarpment.

Drainage of the Appalachian province.—The drainage of the province is in part eastward into the Atlantic, in part southward into the Gulf, and in part westward into the Mississippi. All of the western or Plateau division of the province, except a small portion in Pennsylvania and another in Alabama, is drained by streams flowing westward to the Ohio. The northern portion of the eastern or Appalachian Mountain division is drained eastward to the Atlantic, while south of New River all except the eastern slope is drained westward by tributaries of the Tennessee or southward by tributaries of the Coosa.

The position of the streams in the Appalachian Valley is dependent on the geologic structure. In general they flow in courses which for long distances are parallel to the sides of the Great Valley following the lesser valleys along the outcrops of the softer rocks. These longitudinal streams empty into a number of larger, transverse rivers, which cross one or the other of the barriers limiting the valley. In the northern portion of the province they form Delaware, Susquehanna, Potomac, James, and Roanoke rivers, each of which passes through the Appalachian Mountains in a narrow gap and flows eastward to the sea. In the central portion of the province, in Kentucky and Virginia, these longitudinal streams form New (or Kanawha) River, which flows westward in a deep, narrow gorge through the Cumberland Plateau into Ohio River. From New River southward to northern Georgia the Great Valley is drained by tributaries of Tennessee River, which at Chattanooga leaves the broad valley and, entering a gorge through the Plateau, runs westward to the Ohio. South of Chattanooga the streams flow directly to the Gulf of Mexico.

DETAILED GEOGRAPHY OF THE GREENEVILLE QUADRANGLE.

Geographic divisions.—Within the limits of the Greeneville quadrangle two of the major divisions of the Appalachian Province are represented. The Appalachian Mountains occupy about 100 square miles in the southeastern portion of the quadrangle, this being but a small section of the great mass lying farther east and south. The small portions included within this quadrangle are called the Bald Mountains. The remainder of the quadrangle lies in the Great Valley and can be subdivided into three topographic districts. In the northwestern portion of the quadrangle lies the ridge district, embracing the Bays Mountains and the region lying northwest of Holston River. Between the Bays Mountains and the Bald Mountains lies an open valley composed mainly of low, rolling ridges and shallow valleys, a part of the Valley of East Tennessee. The northwestern part of this is the valley of Lick Creek, a low, gently rolling plain, varied here and there by small knobs of slight relief. From the southeast border of this valley to the foot of the Bald Mountains extends the plateau traversed by Nolichucky River.

Drainage.—The entire region is drained by tributaries of Tennessee River—Nolichucky, French Broad, and Holston rivers. All of them rise far beyond the limits of this quadrangle, and they receive here a very small proportion of their water. The ridge district and practically all of the area of the Bays Mountains are drained by Holston River. A small part of the south slope of the Bald Mountains is drained by French Broad River, which lies just outside of this quadrangle. The remaining and greater part of the quadrangle is drained by Nolichucky River and its tributary creeks. Holston River falls from 1300 to 1000 feet in this area. Lick Creek, the principal tributary of Nolichucky River, falls from 1400 feet at its head to nearly 1000 feet. The descent of Nolichucky River from 1500 to 1100 feet is unusually great for a stream of its size.

Topography.—The forms of surface differ much in these four districts. The variations in the topography depend very largely upon the influence of erosion on the different formations. Such rock-forming minerals as carbonates of lime and magnesia, and to a less extent feldspar, are removed by solution in water. Rocks containing these minerals in large proportions are therefore subject to decay by solution, which breaks up the rock and leaves the insoluble matter less firmly united. Frost, rain, and streams break up and carry off this insoluble remainder, and the surface is thus worn down. According to the nature and amount of the insoluble matter, the rocks form high or low ground. Calcareous rocks, leaving the least residue, occupy the low ground. Such are the various limestones and many of the shale formations. These leave only a fine clay after solution. The Shady limestone and Knox dolomite leave also, besides the clay, a large quantity of silica in the form of chert, which strews the surface with lumps and retards its removal. In the southeastern part of the quadrangle, where the dolomite contains less chert, its surface is reduced nearly as low as the surfaces of the other limestones. The least soluble rocks are the quartzites, sandstones, and conglomerates, and, since most of their mass is left untouched by solution, they are the last to be reduced in height. Apparently the rocks of the Cranberry granite form an exception to this rule, for they contain much soluble matter in feldspar, and yet maintain great heights. For this result the immense mass of the formation and the insolubility of the quartz are largely responsible.

Erosion of the sedimentary formations has produced a series of long ridges separated by narrow valleys, which closely follow the belts of rock. Where the formations spread out with a low dip the valleys and ridges are broad, and where the strata dip steeply the valleys are narrower. Each turn in the course of a formation can be seen by the turn of the ridge or valley which it causes. Conspicuous examples of this are the various Clinch sandstone mountains. Each rock produces a uniform type of surface so long as its composition remains the same, but with each change in composition the surface changes form. The limestones have disappeared through solution over much of each valley floor. Near the sandstone and quartzite mountains the residual clays of the limestone have been swept over with waste from the mountain-making rocks. This material forms the terraces and flood plains which lie along the streams that enter Nolichucky River on its south side, such as Camp Creek and Horse Creek. These deposits are very conspicuous and form practically one plain, which slopes gradually away from the foot of the Bald Mountains.

The Bald Mountains consist of a high, irregular range, much of it over 4000 feet in height, with lesser mountains and spurs sloping away toward the streams in all directions. Where it borders the Great Valley it presents a steep front of ridges and butts rising from 1000 to 1500 feet above the adjoining valley. Thus is seen in strongest contrast the results of erosion of soluble and insoluble formations. The streams fall rapidly from their sources until they emerge upon the valley at elevations varying from 1500 to 1800 feet. Their channels in the Cambrian quartzites and slates, which are wild, rocky, V-shaped gorges at their heads, suddenly open out on the limestone floor of the Great Valley.

In the ridge district, or northwestern portion of the valley, the surface consists of a series of long, parallel ridges and lines of hills separated by narrow valleys. The valley following the course of the French Broad is comparatively wide and open. The valleys in the Bays Mountains are deep and narrow. Between these two extremes are found valleys and ridges having many forms. Most of the minor valleys are 1100 or 1200 feet above sea, and above them the ridges rise to 1600 or 1700 feet. A few points in the Bays Mountains are considerably higher, Chimney Top, the highest, having an elevation of 3078 feet.

The valley of Lick Creek, as was stated, is broad and open and only gently rolling. Few of the knobs it contains rise more than 200 feet above the level of the streams, and most of its surface is between 1000 and 1200 feet above sea. The plateau lying south of Lick Creek Valley is considerably higher. The minor valleys are 1200 or 1300 feet above sea, and the ridges range from 1500 to 1700 feet. Nolichucky River and its principal tributaries have carved narrow canyons several hundred feet in depth. Outside of these the plateau is composed of low ridges and parallel lines of hills separated by smooth, open valleys.

GEOLOGY.

GENERAL GEOLOGIC RECORD.

Nature of the formations.—The formations which appear at the surface of the Greeneville quadrangle and adjoining portions of the Appalachian province comprise igneous, ancient metamorphic, and sedimentary bodies, all more or less altered since their materials were first brought together. Some of them are very ancient, going back to the earliest known period. They consist of four groups, of widely different age and character. These are: the igneous and metamorphic rocks, including gneiss, schist, granite, diorite, and similar formations; the volcanic formations, embracing rhyolite, basalt, diabase, and their alteration products; the sedimentary strata of lower Cambrian age, including conglomerate, sandstone, shale, and their metamorphosed equivalents; and the sedimentary strata ranging in age from lower Cambrian to Carboniferous, which comprise a great variety of limestones, shales, and sandstones. The oldest of these groups occupies the greatest area, and the lower Cambrian sandy strata the least. The materials of which the sedimentary rocks are composed were originally gravel, sand, and mud, derived from the waste of the older rocks, and the remains of plants and animals living at that time. All have been greatly changed since their formation, the alteration being so profound in some of the older gneisses and schists as to destroy their original nature.

From the relations of the formations to one another and their internal structures many events in their history can be deduced. Whether the crystalline rocks were formed at great depth or at the surface is shown by their structures and textures. The amount and nature of the pressure sustained by the rocks are indicated in a measure by their folding and metamorphism. The composition and coarseness of the sediments indicate the depth of water and distance from shore at which they were produced. Cross-bedding and ripple marks in sandstones indicate strong and variable currents. Mud cracks in shales show that their areas were at times above and at times below water. Red sandstones and shales like those of the Watauga and the Rome resulted when erosion was revived on a land surface long subject to decay and covered with a deep residual soil. Limestones show that the currents were too weak to carry sediment or that the land was low and furnished only fine clay and substances in solution. Conglomerates like those of the Bald Mountains indicate strong currents and wave action during their formation.

Principal geologic events.—The rocks themselves thus yield records of widely separated epochs from the earliest age of geologic history through the Paleozoic. The entire record may be summarized as follows, from the oldest formation to the latest:

Earliest of all was the production of the great bodies of Carolina gneiss. Its origin, whether igneous or sedimentary, is buried in obscurity. It represents a complex development and many processes of change, in the course of which the original characters have been largely obliterated. The gneiss is, however, distinct from and much older than any other formation yet identified in the province, and the time of its production is the earliest of which we have record.

During succeeding epochs masses of igneous rock were forced into the gneiss. The lapse of time was great; igneous rocks of many different kinds were intruded, and later intrusive masses were forced into the earlier. The granitic texture of some of the formations and the lamination and schistosity of others were produced at great depths below the surface.

Upon these once deep-seated rocks now rest, in the area east of this quadrangle, lavas which poured forth upon the surface in pre-Cambrian time. Thus there are in contact two extremes of igneous rocks—those which consolidated at a considerable depth, and those which cooled at the surface. The more ancient crystalline complex had therefore undergone uplift and long-continued erosion before the period of volcanic activity began. The complex may safely be referred to the Archean period, being immeasurably older than any rocks of known age. Whether these ancient lavas represent a late portion of the Archean or are of Algonkian age is not certain. The latter, however, is more probable, for they are closely associated with the Cambrian rocks. Yet they are separated from the Cambrian strata by an unconformity, and fragments of the lavas form basal conglomerates in the Cambrian.

Next, after a period of erosion, the land was submerged, and sandstones, shales, and limestones were laid down upon the older rocks. In these sediments are to be seen fragments and waste from the igneous and metamorphic rocks. The different sedimentary formations are classified as being of Cambrian or later age, according to the fossils which they contain. Remnants of these strata are now infolded in the igneous and metamorphic rocks, and the portions thus preserved from erosion cover large areas of the mountains. The submergence which caused their deposition began at least as early as the beginning of Cambrian and extended at least into Silurian time. It is possible that the beginning was earlier and the end not until the close of Carboniferous time; the precise limits are not yet known.

These strata comprise conglomerate, sandstone, slate, shale, limestone, and allied rocks in great variety. They were far from being a continuous series, for the land was at times uplifted and areas of fresh deposits were exposed to erosion. The sea gradually advanced to the east, however, and land areas which furnished sediment during the early Cambrian were covered by later Paleozoic deposits. The sea occupied most of the Appalachian province and the Mississippi basin. The area of the Greeneville quadrangle at first was near the eastern margin of the sea, and the materials of which the rocks are composed were derived largely from the land to the southeast. The exact position of the eastern shore line of this ancient sea is known only here and there, and it probably varied from time to time within rather wide limits. In the earliest Cambrian time it lay just east of the position of Flint Ridge.

Cycles of sedimentation.—Four great cycles of sedimentation are recorded in the rocks of this region. The first definite record now remaining was made by coarse conglomerates, sandstones, and shales deposited in early Cambrian time along the eastern border of the interior sea as it encroached upon the land. As the land was worn down and still further depressed the sediment became finer, until in the Cambro-Ordovician Knox dolomite very little trace of shore material is seen. After this long period of quiet came a slight elevation, producing coarser rocks; this uplift became more and more pronounced, until between the Ordovician and Silurian the land was much expanded and large areas of recently deposited sandstones were lifted above the sea, thus completing the first great cycle. After this elevation came a second depression, during which the land was again worn down nearly to base-level, affording conditions for the accumulation of the Devonian black shale. After this the Devonian shales and sandstones were deposited, recording a minor uplift of the land, which in northern areas was of great importance. The third cycle began with a depression, during which the Carboniferous limestone accumulated, containing scarcely any shore waste. A third uplift brought the limestone into shallow water—portions of it perhaps above the sea—and upon it were deposited, in shallow water and swamps, the sandstones, shales, and coal beds of the Carboniferous. Finally, at the close of the Carboniferous, a further uplift ended the deposition of sediment in the Appalachian province, except along its borders in recent times.

The columnar section shows the composition, name, age, and, when determinable, the thickness of each formation.

DESCRIPTION OF THE FORMATIONS.

Rocks of the Greeneville quadrangle.—The rocks of this district comprise three great classes—sedimentary, igneous, and metamorphic. The sedimentary rocks occupy almost all of the area of the quadrangle and include the chief varieties of that class of rock. They range in age from one of the oldest formations of the Appalachians nearly through the Paleozoic, including Archean, Cambrian, Silurian, Devonian, and Carboniferous periods. The Archean, Devonian, and Carboniferous are represented by only a few formations. The lower part of the Cambrian is very well developed and the lower part of the Silurian has a fairly full representation.

These rocks are divided into five distinct groups. The Lick Creek and Bays Mountain areas are underlain by Silurian rocks, chiefly younger than the Knox dolomite. Practically all of them are shales, argillaceous or calcareous, except the Bays sandstone and Clinch sandstone, which form the summits of the Bays Mountains. The ridge district northwest of Holston River includes all formations from the lower Cambrian Rome sandstone to the Carboniferous Newman limestone. The portion of the Great Valley included in the Nolichucky plateau is underlain mainly by the Knox dolomite. Between the folds of this formation are included many bands of the Athens shale, the Nolichucky shale, and the Maryville limestone, all of them being close to the Knox dolomite in position. These rocks are repeatedly brought to the surface by the different folds and lie in long, narrow belts. In the extreme southeast corner of the quadrangle, lying in the mountains, is seen an area of granite, including the only formations in the region which are not sedimentary. The remainder of the mountain district contains the lower Cambrian formations. These are mainly siliceous and comprise quartzites, sandstones, conglomerates, shales, and slates. The latter three groups are sharply defined and in most places are separated from one another by faults. The formations into which the rocks are separated will be described in order of age, beginning with the oldest.

ARCHEAN ROCKS.

CRANBERRY GRANITE.

Area.—The principal member of the Archean rocks in this quadrangle is the Cranberry granite, which lies in a single area southeast of the Cambrian sedimentary rocks. It is interrupted by three small areas of the Max Patch granite, the ends of larger bodies lying in the Asheville quadrangle. The granite forms a large and continuous mass that extends southwestward into the Asheville quadrangle and northeastward through the Roan Mountain and Cranberry quadrangles. The formation consists of granite of varying texture and color and of schists and granitoid gneisses derived from the granite. It is named from Cranberry, N. C., near which it is typically developed.

Included beds.—Included within the area of the Cranberry granite are small or local beds of metabasalt, metadiabase, metarhyolite, and pegmatite, which are too small to be shown on the map. The metadiabase and metarhyolite appear to be intrusive in the granite. They are undoubtedly of the same age as similar rocks in adjoining quadrangles—rocks of Algonkian age. The metarhyolite occurs in sheets and dikes that range from a few inches to a few feet in thickness. These are found here and there through much of the area of the granite south of Indian Creek, but from their small size it is doubtful whether the beds are continuous for any great distance. In this region, however, the prevalent metamorphism of the rocks, the heavy forest cover, and the small size of the outcrops make it impracticable to represent them on a map.

Character of the granite.—The granite is an igneous rock composed of quartz and orthoclase and plagioclase feldspar, with biotite, muscovite, and occasionally hornblende as additional minerals. Minor accessory minerals are magnetite, garnet, ilmenite, and epidote. The most notable variation of the rock is in its texture, due to variations in the size of the feldspar crystals. It ranges from a fine, even-grained mass, such as occurs along the lower part of Indian Creek, to coarse, rather porphyritic rocks, such as are found around the headwaters of that creek. The feldspar is by far the most prominent mineral, especially in the coarse varieties, and gives the rock a prevailing light-gray or white color. At many places near areas of Cambrian sediments the feldspars of the granite are filled with iron oxide, which gives a marked red appearance to the rock. This variety is often characterized by the presence of epidote in small veins and segregated masses.

Folding and metamorphism.—The granite suffered great changes during the deformation of the rocks, both by folding and by metamorphism, the latter being much the more conspicuous. As the rock was folded planes of fracture and motion were formed in the rock mass, along which metamorphism took place. As the process went on the quartz was broken and recemented, the feldpar was changed into mica, quartz, and new feldspar, and chlorite replaced part of the biotite and hornblende. Some of these minerals crystallized with their longer dimensions parallel, and so produced schists and gneisses of a fairly uniform dip over large areas. The results varied in extent from rocks with slight change, or with mere cleavage, to those completely altered to siliceous schists and gneisses. Thin, parallel layers and stripes composed of different minerals are of frequent occurrence, and the most extreme schists bear no resemblance to the original rocks. The thin sheets of metarhyolite which cut through the granite have also been extremely metamorphosed. The original flow banding is very seldom to be seen now. Here and there porphyritic feldspar crystals occur, but much the greater part of the rock is now fine black schist, composed chiefly of quartz and muscovite, with a small amount of the black iron oxides.

Weathering.—Under the action of the weather the varieties of granite behave very differently. The coarse granites are very durable and stand out in ledges and bold cliffs; the finer grades, by reason of the decomposition of their feldspars, weaken to a crumbling mass which does not outcrop much except on steep slopes. The schistose portions of the formation break up most readily, the planes of schistosity seeming to afford a ready passage for dissolving waters. In spite of its weathering the formation occupies high ground, on account of the great mass of its insoluble materials. Its heights are frequently rendered less prominent, however, by the superior hardness and greater eminences of the neighboring Cambrian formations. It forms round knobs, ridges, and mountains without definite system, whose crests and slopes are usually smooth and rounded. Many parts of its area are cultivated and the soils are light loams of fair depth and strength.

MAX PATCH GRANITE.

Area.—This formation is confined to two small areas in this quadrangle, each being the end of a larger area extending well into the Asheville quadrangle on the south. The western of these two areas extends into the main mass of the formation in Max Patch Mountain, Madison County, N. C., for which the formation is named.

Character. — The formation consists almost entirely of coarse granite, in places porphyritic, and in places of uniform grain. The minerals composing the rock are orthoclase and plagioclase feldspar, quartz, biotite, and a very little muscovite. Accessory minerals are a little magnetite, pyrite, and epidote, the latter occurring for the most part in secondary veins. Porphyritic crystals of orthoclase feldspar as long as one inch are not infrequently to be seen. These are most common in the eastern area, particularly in its extension into the Asheville quadrangle. In the western area the granite is chiefly of uniform grain and is more typical of the formation as a whole. In the porphyritic varieties the feldspars make by far the greatest part of the rock, giving it a dull whitish or light-gray color. As shown in the eastern area, the granite is not especially porphyritic and is more than usually light colored. Biotite is most prominent in the massive parts of the formation and causes a decidedly spotted appearance on account of the large size of the crystals.

Another variety of considerable extent is a coarse red granite, found in this quadrangle in the western granite area and in its extension through the Asheville quadrangle. This differs from the usual massive variety only in having many red or pink feldspars, which give a decidedly red color to the whole rock. Accompanying this red color in the feldspar there is generally a partial alteration of the biotite into chlorite and fibrous hornblende and of the feldspar into epidote and saussurite. Near the contact with the Cranberry granite this formation in many places has a medium or fine grain.

The formation is intrusive in the Cranberry granite. The evidence of this is not found in this quadrangle on account of the poor exposures of the contact of the two formations. As they are traced southwestward into the Asheville quadrangle, however, the Max Patch granite is seen to cut the Cranberry granite, and is therefore the youngest of the massive plutonic rocks in this region. The thin metarhyolite and metadiabase dikes already described cut both of these formations, and are accordingly younger.

Metamorphism.—The formation has suffered great changes by metamorphism. These are especially well shown by the porphyritic portions, where the change of form can often be measured. As in the Cranberry granite, the rock has been squeezed and mashed until a pronounced gneissoid structure has been developed. The change is most manifest in the growth of the new micas and in the elongation of the porphyritic feldspars, which have in places increased in length as much as three or four times their original length, assuming pencil-like forms. In other places, during the squeezing and slipping under pressure the large crystals were cracked and their fragments rotated until they are nearly parallel to the planes of schistosity. The mica flakes developed in similar planes, and the small grains of quartz and feldspar were broken and recomposed into quartz, feldspar, and mica. This produced a very gneissoid rock, or augen-gneiss, in which the porphyritic crystals were cracked and drawn out into separate eyes or strings. In this rock the amount of the distortion can be plainly measured in the less extreme cases by the intervals between the fragments of one crystal. The large feldspars retained their shape better than the finer groundmass, however, and the mica flakes in the latter are bent and wrapped around the large feldspars almost as if they had been fluid.

Another result of the deformation is the series of striated and striped surfaces which are common in this formation, as well as in the Cranberry granite. These are due to the linear growths of new minerals parallel to lines of motion in the rock. The dark stripes are composed in the main of fine crystals of biotite and fibrous hornblende, and the light stripes of quartz and feldspar, the new minerals having segregated in this unusual manner. This phenomenon is most common in the vicinity of the fault planes. The entire mass of the granite shows the effect of pressure so extreme as to overcome all the original strength of the rock.

Weathering.—As the formation is attacked by weathering its surface is but slowly reduced. Its siliceous composition, its massive nature, and its great body unite in maintaining the altitude of its areas. In the Asheville quadrangle, where it is best developed, the formation causes such elevations as Bluff Mountain, one of the most conspicuous points of the region. Frequent cliffs mark the course of the more massive beds, and ledges protrude at short intervals. The bowlders and waste from the formation are strewn for considerable distances over the adjoining Cranberry granite. Upon complete weathering the formation produces a reddish or brownish clay of no great depth, mixed with much sand and fragments of rock. Where the soils accumulate on gentle slopes they are strong and fertile, but in this region the formation usually occupies high and steep ground.

CAMBRIAN ROCKS.

With the deposition of the Cambrian rocks there came a great change in the physical aspect of this region. The sea encroached upon areas which for a long time had been dry land. Erosion of the surface and eruptions of lava were replaced by deposition of sediments beneath a sea. Extensive beds of these were laid down in some areas before other areas were submerged, and the sediments lapped over lavas and plutonic granites alike. In this quadrangle there are no bodies of the lavas, but they appear a short distance to the east in the Roan Mountain quadrangle. The waste from them all was combined in one sheet of gravel and coarse sand, which now appears as shale, sandstone, conglomerate, and rocks derived from them. The thickness of this first formation varies greatly and abruptly in this region, showing that the surface on which it was laid down was irregular. Subsequent formations of Cambrian age came in a great group of alternating shale and sandstone, followed by an immense thickness of limestone and shale. Fossils of Cambrian age, mainly *Olenellus*, are found as far down as the middle of the sandstone group. The strata lying between the fossiliferous beds differ in no material respect from those overlying. All are plainly due to the same causes and form part of one and the same group, and all are closely associated in area and structure.

SNOWBIRD FORMATION.

This formation is exposed in this quadrangle chiefly in a belt that extends along the south side of the Bald Mountains. It here rests in its normal position on the Archean granites. It also appears in a narrow band northeast of the Big Butt.

Character.—The materials derived from the waste of the granite are contained to some extent in this formation. They consist of pebbles and grains of quartz and feldspar, usually well rounded. In some places, however, these fragments are angular and show that they have been transported only a short distance from the parent body of the granite.

The formation as displayed in this quadrangle is composed chiefly of coarse and fine quartzite. With this are interstratified beds of conglomerate and arkose, as above noted, and subordinate layers of gray and black slate. Some of the quartzites contain considerable feldspar in small grains, while others are practically all composed of quartz grains. Most of these beds are of light colors, white or gray, but there are considerable variations in this respect. On Mill Creek in North Carolina, for instance, and on the lower course of South Indian Creek, the quartzites have a dark, bluish-black color, due to the grains of iron oxide between the quartz grains. When these beds are considerably weathered further oxidation of the iron gives the rock a rusty brown or red color. Another variety frequently seen on the northern prongs of South Indian Creek is a fine, greenish-gray sandstone or quartzite. In this rock there is considerable fine mica in addition to the usual feldspar and quartz, and to this mica, in part chlorite, is due the greenish color. Just before the formation passes southwestward into the Asheville quadrangle it is quite coarsely conglomeratic, and the same is true where it crosses the Rocky Fork of South Indian Creek. About midway between these points it is practically all composed of the dark bluish quartzite, the transition from one type to another being made within 3 miles. Accompanying this change from dark bluish quartzite to conglomerate is an increase in thickness from 700 feet to about 2000 feet. The average thickness in this region is about 1000 feet, as nearly as can be determined from the poor exposures and the much disturbed condition of the beds.

Metamorphism.—The chief changes which have been produced in this rock since it was deposited have been the silicification of the sandstone into quartzite. In those portions which were feldspathic some of the smaller grains of feldspar have been recrystallized into quartz and mica, giving a somewhat schistose structure. This was accomplished in the same manner as were similar changes, already described, in the granite. The interstratified slate beds also received their cleavage at the same time. In places, especially on the lower part of South Indian Creek, many of them have been thoroughly metamorphosed to black mica-schists. The coarse sandstone and conglomerate were less affected than the fine-grained beds.

Weathering.—The siliceous nature of the formation enables it to resist the attack of weather extremely well. Soils over its areas are thin and much interrupted by rock outcrops. The soil is sandy and poor in all places except in the hollows and coves, where considerable has accumulated. High, irregular ridges and mountains cover the areas of the formation. The crests of the ridges are sharp and the slopes steep, and they support but a scanty growth of timber.

HIWASSEE SLATE.

Extent and character.—The rocks of this formation occupy many areas in the Bald Mountains. Chief of these is a large, irregular one along the southern slopes of the range and next to the Snowbird formation. The name of the formation is derived from that of Hiwassee River, in Tennessee, which cuts a fine section though these strata. As displayed in this region, the formation consists almost entirely of slate of a bluish-gray or bluish-black color. When weathered this color becomes greenish- and yellowish-gray and yellow. On the southern side of the Bald Mountains the slates are somewhat coarser grained and are frequently marked with light-gray, siliceous bands of a sedimentary nature. On the northern slopes of the range the rocks are finer and more uniform, the slaty character is not so pronounced, and many of the layers are scarcely more than shales. In some of the beds mica in fine scales is a noticeable constituent. This was an original deposit in the strata and not a secondary growth, and it is seen in some of the least altered of the beds.

By far the most of the material composing the slates is argillaceous; to this is added here and there the micaceous and sandy material. In the extreme southwestern part of the range the deposits of sand were considerable enough to make distinct layers 8 or 10 feet in thickness, which locally developed into fine conglomerates. As nearly as can be determined the formation is from 1200 to 1500 feet in thickness.

Limestone.—The most noticeable variation from the slates, and one which most strikingly distinguishes this formation from the other slates of the region, is a series of calcareous beds which are interstratified at intervals with the slates. Thus far no outcrops of these limestones have been discovered within this quadrangle. It is possible, however, that some will be exposed as the forests are cleared away. In the principal belt of the formation, 2 miles beyond the southern border of this quadrangle, the limestone beds begin and are continued southwestward, with small intervals, entirely through the Asheville quadrangle. The limestone deposits vary considerably in short distances. That most commonly found is a blue or dove-colored limestone, containing many rounded grains of quartz sand. Associated with these are considerable thicknesses of blue or gray oolitic limestone. In places the siliceous material is so prominent that the rock becomes a calcareous conglomerate containing pebbles of quartz and feldspar. This latter phase is very local and passes in short distances into the more usual type. Occasional beds of limestone conglomerate are also to be seen, which indicate that the deposit was formed in shallow water, where erosion could affect the newly formed beds.

Metamorphism.—The strata of this formation have not been greatly metamorphosed by deformation. The principal result has been the production of slaty cleavage. This has not entirely obliterated the bedding in most cases where that was originally well marked. In the fine portions the original grain was uniform throughout. It is now very difficult to detect the bedding planes. Only in a few rare cases on the lower parts of South Indian and Mill creeks has the deformation been sufficiently extreme to produce mica-schists. These are very fine grained and dark bluish or black in color.

Weathering.—The rocks of this formation do not withstand the action of weather as well as those of the other Cambrian formations of the Bald Mountains. Weathering makes its way down the parting of bedding and cleavage, and the rock is broken up into small fragments and flakes. On the steep slopes, where the areas of the formation are upheld by the adjoining harder quartzites, there are frequent ledges and outcrops, and the soil is thin and sandy. In that area which adjoins the Snowbird formation the slates spread out considerably and cause low ground. This is more commonly the case where the calcareous beds come in toward the southwest. In these latter situations considerable soil accumulates and affords fair farming ground.

COCHRAN CONGLOMERATE.

Extent and character.—Several areas of this formation are to be seen in the Bald Mountains. It is named for its occurrence in Chilhowee Mountain on Cochran Creek in the Knoxville quadrangle. The formation consists, for the most part, of quartzites and sandstones, which frequently develop into coarse and fine conglomerates. White or light-gray colors prevail throughout the formation. The conglomerate beds are generally distributed throughout all the areas of the formation. They are most prominent, however, along the southern slopes of the Bald Mountains. The conglomerates exposed on Rocky Fork of South Indian Creek and on Mill, Shelton Laurel, and Paint creeks contain many pebbles that are as long as 2 inches. Much the greater part of these are of quartz and are well rounded. In the vicinity of Paint Creek there are also found in the conglomerate small pebbles of black metarhyolite derived from the formations of probable Algonkian age. Pebbles and grains of feldspar are of general occurrence in the conglomerates throughout their areas, but are most conspicuous along the southern side of the Bald Mountains. On Shelton Laurel and Indian creeks pebbles of black slate are characteristic of the formation. They appear to be derived from the underlying Hiwassee slate, as they resemble it in all particulars. The conglomerate on Rocky Fork of Indian Creek also contains pebbles of gneissoid granite. A few unimportant beds of slate are interstratified with the siliceous parts of the formation. These are most numerous where the conglomerate is best developed. The slates are dark bluish and gray and resemble the Hiwassee slate.

Thickness.—The formation is almost as variable in thickness as the Snowbird formation. From the coarseness of its fragments it is inferred that the formation was deposited under changeable conditions and by strong and variable currents. The fragments are coarsest and most variable along the southern and eastern portions of the formation, and there the thickness also varies most. From these facts it is reasonable to conclude that the shore line and the source of the sediments lay toward the south. The conglomerate is thinnest along the summit of the range in Big Butt, where it is hardly over 200 feet thick; from there its thickness increases in all directions. It is nearly 1500 feet thick along the northwestern front of the mountains, and somewhat more on South Indian Creek. The thickness in the former place is not well determined, on account of the presence of numerous faults, and may even exceed those figures.

Metamorphism.—The most striking change in the formation due to metamorphism is the conversion of many of the sandstones and fine conglomerates into quartzites, especially in the southern and eastern exposures. In the coarse conglomerates the feldspathic matrix has been affected more than the coarse fragments. Alterations in this proceeded in the same manner as in the similar minerals of the granites. Secondary quartz, feldspar, and mica were developed, and a limited amount of schistosity was produced. The secondary mica plates lap around the coarse pebbles, where the latter are of any considerable size. Some of the pebbles are cracked and dented by other pebbles, and the fragments are somewhat dislocated. These are usually recemented by the secondary quartz. The general bedded appearance of the rock, however, is seldom greatly altered.

Weathering.—The siliceous nature of the formation enables it to withstand erosion well. This is especially the case along the northwest front of the Bald Mountains, where the quartzites and fine conglomerates cause a line of bold butts to rise abruptly from the limestone valley. The general decrease of the thickness of the formation where it becomes conglomerate causes those portions to be more reduced than the others. This is most noticeable in the basin of Paint Creek. Along the main divides of the creek the conglomerate attains great elevations, being assisted in that result by the weakened power of the streams. In all cases, however, the formation makes sharp-topped ridges and steep slopes. The soils are thin, sandy, and full of bowlders, and are of practically no value for agriculture or timber. Many ledges and cliffs jut through the cover of soil, especially where the finer quartzites predominate. The waste from these spreads far over the adjoining formations.

NICHOLS SLATE.

Character.—The Nichols slate in this quadrangle consists entirely of fine-grained rocks, either shale or slate, according to the amount of their metamorphism. The strata are dark gray and bluish gray, and are sometimes marked with light-gray bands like the layers of the Hiwassee slate. The shales are usually micaceous, fine scales of mica having been deposited when the rock was formed. A very small amount of secondary mica was also developed as the strata were folded. Many of the layers of the formation are sandy as well as clayey, but the argillaceous character predominates. The formation also includes many thin layers and beds of quartzite and sandstone of the same character as the formations above and below. In the Asheville quadrangle, adjoining on the south, some of these constitute a bed large enough to be shown on the map. It has not been possible in this region, however, to separate the quartzites from the shales, owing to the disturbed condition of the strata and the rugged nature of the country. The formation is named from Nichols Branch of Walden Creek, in the Knoxville quadrangle.

Thickness.—There are considerable variations in the thickness of the formation. The best measures obtained vary from 400 to 700 feet, the beds which appear to be thickest being nearer the center of the mountain mass. Aside from these changes of thickness, which may be due in large part to the crumpling of the beds, the formation is rather uniform in appearance. As stated above, the chief result of metamorphism was a slaty cleavage, and in almost no case was the rock transformed into a schist.

Weathering.—The action of weather on the beds of this formation is similar to that on the Hiwassee slate. The beds are not especially soluble, but degenerate through their argillaceous components. The mass left by disintegration is comparatively soft and crumbling, and is worn down with relative ease. The areas of the formation are usually upheld by the quartzites adjoining, but form depressions between the ridges and knobs of the latter. Its soils are thin and dry and of small value, except here and there in the coves, where timber flourishes.

NEBO QUARTZITE.

Strata of this formation appear along the crests and the northwestern slopes of the Bald Mountains. They form the three highest portions of the range—Rich Mountain, Big Butt, and Camp

Creek Bald. Those which occupy the high points form irregular outcrops in synclines. The others are long, straight areas running nearly across the quadrangle.

Practically all of the formation is composed of quartzites and sandstones. Interbedded with these are a few minor layers of shale and slate, which appear only near the stream, where the sections are clean cut. It is possible that the amount of slate is greater than it would seem, being covered by the heavy vegetation. The formation is named from Mount Nebo Springs, on Chilhowee Mountain, in the Knoxville quadrangle.

Nearly all of the quartzites and sandstones are light gray or white, and all become white upon exposure. Most of the beds are fine grained, although some are coarse enough to be considered conglomerates. The slates are gray and bluish gray, argillaceous and sandy, and are usually much weathered and yellow. There is very little material in this siliceous strata except quartz. Originally this was all in the form of rounded grains of sand. Now, owing to the deposition of secondary silica during metamorphism, the original grains are closely cemented in many places. Frequently they break with a clean, conchoidal fracture entirely irrespective of the bedding planes and the granular structure. Silicification is the chief change produced in the formation by metamorphism.

Thickness.—The thickness of the formation varies considerably, running from 700 to 900 feet along the slopes of the mountains, and from 300 to less than 200 along the crests. The least thickness is shown on Big Butt. There, however, it is possible that the overlying slate bed might properly be included in the formation, so that the whole of it is not exposed.

Weathering.—The Nebo quartzite resists the weather better than any other of the Cambrian strata. Its purely siliceous composition makes it nearly free from the effects of solution. This is most apparent in the basin of Camp Creek Bald, which is nearly encircled by a line of high cliffs. The siliceous beds gradually break up through bedding planes and joint planes, chiefly by the action of frost. Slowly the fragments slide down the slopes and are removed by the streams, being carried to great distances before disintegration is complete. The soils covering the formation are very thin and sandy and support only the scantiest growth of timber.

MURRAY SLATE.

Areas and character.—One considerable area of this formation lies on the northwest slope of the Bald Mountains, and two similar beds of it occur in the Camp Creek Bald syncline and the Big Butt syncline. The latter, however, as was stated under "Nebo quartzite," is somewhat doubtfully referred to this formation. The formation was named from Murray Branch of Walden Creek, in the Knoxville quadrangle. It consists of shales and slates, and is practically indistinguishable from the Nichols slate. The strata are argillaceous, micaceous, and occasionally sandy. The micaceous character is most apparent in those shales which are the least altered. As in the Nichols slate, these strata are occasionally marked with light- and dark-gray bands, due to sedimentation. In the more slaty portions of the formation these bands are considerably less prominent, owing to the cleavage which has been developed.

Thickness.—Measures of the thickness of the formation are very hard to obtain. The beds are much contorted and their areas are covered with wash from the adjoining quartzite formations. As nearly as it can be estimated the formation varies from 300 to 400 feet in thickness.

Weathering.—This slate withstands erosion to about the same extent as the Nichols slate. It breaks down slowly into flags and small flakes, chiefly through the action of frost. Outcrops are very few except along the stream courses and the divides. The softness of the formation as compared with the adjoining quartzites causes it to occupy depressions and slopes between the quartzite ridges and spurs. Soils are thin and light upon the ridges and accumulate to considerable depths in the hollows. In the latter situations a good growth of timber is found.

HESSE QUARTZITE.

This formation occupies a small belt at the head of Bumpass Cove and three small areas southeast of Cedar Creek, at the border of the mountains. The latter outcrops appear on the anticline of Meadow Creek Mountain beneath the Shady limestone. The strata of this formation are composed almost entirely of white quartzite which can not be distinguished from many of the older quartzites. In these are included a few minor layers of argillaceous and sandy shale of the same character as the preceding shale formations. The quartzites are fine or medium grained in this quadrangle, and there are practically no variations in its appearance.

Around the end of Meadow Creek Mountain the formation passes upward into the Shady limestone through 25 to 30 feet of yellow sandy shale and calcareous sandstone. At the head of Bumpass Cove a few feet of sandy shales occupying the same position have a decided reddish-brown color. In both localities a few scolithus borings are found in the quartzite layers. These are the same in appearance as those which characterize the top member of the quartzite series throughout this region. The formation is from 700 to 800 feet thick, being of practically the same thickness in both the areas here shown. The strata of the formation resist weathering in the same manner as do those of the Nebo quartzite, but are somewhat less prominent than those. Ledges are frequent, but cliffs are rare. The soils are poor and sandy and of little use for any purpose.

SHADY LIMESTONE.

Areas and source.—Two areas of this formation are found within the quadrangle, both on the northwest slopes of the Bald Mountains. The formation is named for its occurrence in Shady Valley, Johnson County, Tenn. It consists almost entirely of limestone and dolomite of various kinds and is more or less crystalline. With the advent of this formation there was a change in the distribution of the land and sea, which was one of the most marked in Appalachian history. Sediments previous to this had been coarse and siliceous and were plainly derived from a neighboring land mass where erosion was active. In this formation the amount of shore material is very inconspicuous and far the greater proportion of the rock is carbonate of calcium. The rock is fine grained and uniform in composition over very large areas. The amount of erosion was, therefore, abruptly reduced at this time, probably by submergence of the land and recession of the shore toward the east and south. The conditions which obtained then remained constant, with small and local modifications, far into Ordovician time.

Varieties.—Several kinds of limestone are represented in the formation. For the most part they are of a bluish-gray or gray color and are apt to weather with a dull-gray or black surface. Some of the layers are mottled gray, blue, or white, and often seamed with calcite. The formation is nearly 1000 feet thick in this vicinity. In the area southeast of Cedar Creek beds of a coarse white limestone or marble are very conspicuous and occupy a considerable thickness near the bottom of the formation. These are not prominent in Bumpass Cove, although they are present. On these layers the black surface of weathered outcrops is most noticeable. A considerable percentage of carbonate of magnesium is contained in these beds.

Shales.—Thin seams of blue and gray shale occur in a few parts of the formation, and a few beds of red shale in the upper layers of this formation make a transition into the overlying Watauga shale. The latter does not outcrop in this quadrangle, but appears in large bodies on the south side of Meadow Creek Mountain in the adjoining Asheville quadrangle.

Silica.—Siliceous impurities in the form of sandy limestone are found in a few places in the formation, and silica in the form of chert is somewhat more common. The latter usually forms small, rounded nodules with gray surfaces and concentric gray and black bands inside. Another variety has the appearance of chalcedony and occurs in large lumps, a foot or two in diameter.

Weathering.—Weathering proceeds faster in this formation than in most others of the region. The rock dissolves, leaving a dark-red clay containing many lumps of chert. As these lumps are seldom abundant enough to protect the surface entirely from removal, the formation makes valleys and low hills. Its clays and soils are deep and strong and afford excellent farming land wherever they are not too much encumbered with wash from the siliceous formations. As a rule, however, the natural soils are very much altered and metamorphosed by this waste. In the red clays of this formation occur extensive deposits of brown hematite and manganese oxide.

ROME FORMATION.

Age and equivalents.—Three small areas of this formation cross the northwest corner of the quadrangle. The rocks of the Rome formation were deposited at practically the same time as those of the Watauga shale, which rest upon the Shady limestone. The name of the formation is taken from that of Rome, Floyd County, Ga. In this quadrangle the bottom of the Rome formation is not exposed, as the formation appears along a fault. In the Knoxville quadrangle and regions lying farther southwest there are found below the Rome the Beaver limestone and the Apison shale. The latter resembles the Rome very strongly and both are much like the Watauga shale. In the Roan Mountain quadrangle, adjoining this on the east, the Watauga shale outcrops extensively south and east of Johnson City. It there occupies a position with reference to the Knox dolomite and Nolichucky shale quite the same as that taken by the Rome formation in areas farther west. No fossils have been found in the Watauga shale. Its position in the sequence of Cambrian strata indicates, however, that it is equivalent to the Rome formation, Beaver limestone, and Apison shale.

Character and thickness.—The Rome formation is made up of red, yellow, and brown sandstones and red, brown, and green sandy shales, most of the sandstones being at the bottom. Few of the beds of sandstone are more than 2 or 3 feet thick, and none are continuous for any great distance. They are repeatedly interbedded with shale, and when one dies out another begins higher or lower, so that the result is the same as if the beds were continuous. The shales are very thin and contain frequent interbedded seams of sandstone. Brilliant colors are common in these strata. A few of the sandstone beds contain lime in such amount as almost to become limestones. There are about 600 feet of the formation exposed in this area, but its total thickness may be somewhat greater. The upper sandy shales are about 200 feet thick; the lower sandstones and shales, 400 feet. From the frequent changes in sediment from sand to sandy or argillaceous mud, and from the abundance of ripple marks on many beds, it is plain that the formation was deposited in shallow water, just as many mud flats are now being formed. Creatures, such as trilobites, which frequented shallow, muddy waters have left many fragments and impressions, and trails left by crawling animals are numerous. These remains show the formation to be of lower Cambrian age.

Weathering.—The surfaces produced by the formation are marked and regular. Weathering makes its way slowly along the numerous bedding planes, and the rock breaks up into small bits and blocks without much internal decay. Ledges of the Rome formation are rare except in the stream cuts, and its ridges are seldom very high. They are especially notable for their even crests and for frequent stream gaps. In some areas this feature is very prominent and regular. The lower beds, on account of their more sandy nature, are most evident in the topography. On the divides the soils are thin and sandy; down the slopes and hollows considerable wash accumulates and the soil is deep and strong. The fine particles of rock and sand render the soil light, and it is rather easily washed unless protected. In the hollows the timber is large and the vegetation strong.

RUTLEDGE LIMESTONE.

The Rutledge formation occurs in four disconnected areas in the ridge belt northwest of Holston River. It occupies the same general region as the Rome formation, but is somewhat more extensive. The formation is named from its fine development in the valley of Rutledge, in Grainger County, Tenn. As a whole, the strata are limestone, but there are many beds of green and yellow calcareous shale toward the base, which form a passage series from the Rome formation. The limestones are massive and fine grained and range in color from blue to dark blue, black, and gray. The thickness of the Rutledge in this area ranges from 400 to 450 feet. The highly calcareous nature of the rock causes it to weather easily and it invariably forms low valleys or slopes along the Rome sandstone ridges.

Underground drainage through sinks is a common feature of this limestone. Deep, red clay covers its areas, and outcrops are few. The soils of the formation are very rich and strong and are among the most valuable of those derived directly from rock in place. Their value is somewhat injured, however, by the rather frequent wash from the Rome sandstone.

ROGERSVILLE SHALE.

This shale, like the preceding limestone, can be distinguished in all of the zones of Cambrian rocks northwest of Holston River. The excellent showing of the formation near Rogersville, Hawkins County, Tenn., gives the formation its name. It consists chiefly of bright-green argillaceous shales, with occasional beds of thin, red, sandy shale. In its eastern area it is divided by a bed of massive blue limestone, and many outcrops contain small beds of shaly limestone. The formation varies in thickness from 200 to 250 feet. Numerous remains of trilobites are found in the shales, which show the formation to be of middle Cambrian age.

Excepting the interbedded limestones, the formation is but slightly soluble. It decays down the numerous partings into thin, green scales and flakes, which are gradually broken up by rain and frost. Outcrops are frequent, but the rock is soft and forms only small knolls in the limestone valleys. Its soils are always thin and full of flakes of shale, and are rapidly drained by the numerous partings of the shale. When carefully protected from washing they are fairly productive.

MARYVILLE LIMESTONE.

This limestone is present in the same belts of Cambrian rocks as the preceding formation. It receives its name from its great development near Maryville, in Blount County, Tenn. The formation consists of massive blue limestone, with few changes in appearance except those due to numerous earthy, siliceous bands and occasional grayish-blue and mottled beds. The top of the limestone is composed of from 20 to 50 feet of a peculiar dark-gray limestone. This is frequently seamed with calcite and weathers into knots or balls, which are noticeably round. These layers are frequently sandy, a fact which appears plainly on the weathered surfaces. They also weather with a very dark or black surface, like many layers in the Shady limestone. In thickness the formation ranges from 750 to 800 feet. Fossils are rare in these beds, but a few trilobites are found.

The limestone decays readily by solution and forms a deep, red clay. From this many ledges of limestone, especially of the upper beds, protrude. Near Rogersville the upper beds of the limestone combine with the base of the Nolichucky shale to make a series of low hills; elsewhere the whole formation lies in valleys. Its soils are clayey and are deep and strong, forming some of the best farming lands in the State.

HONAKER LIMESTONE.

During the deposition of the Rutledge limestone, Rogersville shale, and Maryville limestone in the northwestern portion of this area the strata which were laid down in the southeastern portion were practically all limestones. No beds which have the character of the Rogersville shale can be distinguished south of the basin of the Bays Mountains. It is questionable whether the rocks exposed over most of the Nolichucky plateau are lower than the Maryville limestone at any point. Southeast of Johnson City, in the Roan Mountain quadrangle, adjoining on the east, much lower strata occur, as was stated in the description of the Watauga shale. Above the Watauga, and below the Nolichucky, only massive limestones occur. In the Bristol quadrangle, northeast of this, the gradual disappearance of the Rogersville shale can be readily seen. Without the intervention of this shale it is impossible to separate the limestones above and below it. To the strata which formed during this period the name Honaker is given on account of their development near Honaker, W. Va.

The strata composing the formation are limestones of a general dark-blue or gray color. They have the same characters as the corresponding Maryville and Rutledge limestones, and in general the description of the latter will suffice for these. The beds next below the Nolichucky are usually the same gray limestones that are seen in the Maryville, which weather into lumps with black surfaces. These are not invariably present, however, and in places there is an interbedding of the Nolichucky shales and blue limestones at the top of the Honaker. Northeast of Greeneville blue limestones at the top of the formation are succeeded by alternating blue and white limestones, which in turn are underlain by blue and blue banded limestones. In a few sections, which expose a considerable thickness of the Honaker, a few beds of shaly limestones appear which might represent the Rogersville shale. They occur at about the same interval below the Nolichucky shale, but they have not the distinctive characters and the persistence of the Rogersville. In the region northeast of Greeneville there is in the formation a small development of chert, which is almost never seen in the Maryville or Rutledge limestones. It occurs in large, irregular lumps a foot or two in diameter and rather widely scattered. The formation as exposed on the Nolichucky plateau is 700 feet or more in thickness above the faults. Throughout the Nolichucky plateau the formation lies in valleys between the hills and slopes of Knox dolomite and Nolichucky shale.

NOLICHUCKY SHALE.

This formation is shown in the same belts as the preceding one and also on the Nolichucky plateau, and is the most common of the Cambrian formations. It is named from Nolichucky River, along whose course in the Greeneville region the shale is well exhibited. The formation is composed of calcareous shales and shaly limestones, with beds of massive blue limestone in the upper portion. The included limestones are heaviest northwest of Holston River, being 50 feet thick on Big Creek. When fresh the shales and shaly limestones are bluish gray and gray in color; but they weather readily to various shades of yellow, brown, red, and green. The strata are best preserved in the fresh exposures along Nolichucky River. Over much of this region the formation is nearly uniform in character, and contains only yellow and greenish-yellow shale. Along the belts northeast of Greeneville the shale beds are harder and contain thin sandy layers. The thickness of the formation varies from 450 to 700 feet, being thickest in the belts northwest of Holston River and northeast of Greeneville. East and south of Greeneville the formation diminishes to 450 or 500 feet in thickness.

This formation is the most fossiliferous of the Cambrian rocks, and remains of animals, especially trilobites and lingulæ, are very common.

Solution of the calcareous parts is so rapid that the rock is rarely seen in fresh condition. After removal of the soluble constituents decay is slow, and proceeds by the direct action of frost and rain. Complete weathering produces a stiff yellow clay. Weathered rock is near the surface, and the covering of soil is accordingly thin, unless the formation presents very gentle slopes, where a deep clay results. Northeast of Greeneville the more siliceous shales rise in knobs above the adjoining formations. In most other areas the shale forms steep slopes along the Knox dolomite ridges, the soil is thin and full of shale fragments, and rock outcrops are frequent. The soils are well drained by the frequent partings of the shale, but at their best they are poor and liable to wash.

ORDOVICIAN ROCKS.

KNOX DOLOMITE.

Age.—Although the Knox dolomite does not belong entirely in the Ordovician system, a large part of it is of that age, and as the formation can not be divided it is all described under the above heading. The lower portion contains a few middle Cambrian fossils and the upper portion Ordovician fossils, largely gasteropods; but it is impossible to draw any boundary line between these parts of the formation.

Extent and character.—The Knox dolomite is the most important and most widespread of all the Valley rocks. Its name is derived from Knoxville, Tenn., which is located on one of its areas. The formation consists of a great series of blue, gray, and whitish limestone and dolomite (magnesian limestone), most of which is very fine grained and massive. Many of the beds are banded with thin, brown, siliceous streaks. Interbedded with the dolomite are beds of white calcareous sandstone a few feet thick. Around Greeneville these beds attain a thickness of 30 feet, and they can be traced for long distances northeast of that place. They are made up of fine, rounded sand grains embedded in a calcareous cement. These beds are most noticeable at two positions, one a little above the Nolichucky shale, the other in the middle of the dolomite. In the lower part of the formation there are also numerous white and sandy layers. These are of many lithologic varieties, ranging from slightly siliceous marble to calcareous sandstone. Many of these layers are found over the dolomite areas northwest of Holston River, where they are in places coarsely crystalline. Three miles east of Cedar Creek the topmost layers of the dolomite are formed of a breccia or angular conglomerate of limestone. From this it is inferred that before the Athens shale was laid down the newly formed beds of dolomite were exposed to erosion and somewhat broken.

The amount of earthy matter in the dolomite is very small (from 5 to 15 per cent), the remainder being mainly carbonates of calcium and magnesium. The materials composing the dolomite were deposited very slowly, and deposition must have continued for a very long time in order to have accumulated so great a thickness of rock. The dolomite represents a longer epoch than any other Appalachian sedimentary formation.

Included chert masses.—Included in the beds of limestone and dolomite are nodules and masses of black chert, locally called "flint," and variations in the character and number of these constitute the principal change in the formation. They are most conspicuous northwest of Holston River and least so south of Nolichucky River. The cherts are commonest in the lower part of the formation, and in places, by the addition of sand grains, grade into thin sandstones. The formation varies from 3000 to 3500 feet in thickness, being thickest in the ridge district.

Weathering.—The dolomite weathers rapidly on account of the solubility of its materials, and outcrops are rare at a distance from the stream cuts. The formation is covered to a great depth by red clay, through which are scattered the insoluble cherts. These are slowly concentrated by the solution of the overlying rock, and where they are most plentiful they constitute so large a part of the soil that cultivation is almost impossible. The cherts are white when weathered, and break into sharp, angular fragments. Very cherty areas are always high, broad, rounded ridges, protected by the cover of chert; good instances of this are the ridges north of Holston River. Near Fall Branch the dolomite forms valleys, because its chert is scanty and the Nolichucky shale is harder than usual. The impediment to cultivation is the chert, but when the amount of this is small the soil is very productive. Areas of cherty soil are always subject to drought, on account of the easy drainage caused by the chert, and in such localities underground drainage and sinks prevail. Water is obtainable in such areas only from sinks stopped up with mud, from wells, or, rarely, from springs. Chert ridges are covered by chestnut, hickory, and oak to such an extent that they are often named for those trees.

CHICKAMAUGA LIMESTONE.

Extent and character.—This formation is limited almost entirely to the ridge district. A few areas occur on the south side of Lick Creek Valley, but these are small and are noteworthy only because they represent a formation which is elsewhere important. The name is taken from Chickamauga Creek, in Hamilton County, Tenn. The formation consists of blue and gray massive limestone, shaly and argillaceous limestone, and variegated marble. The beds are, as a rule, very fossiliferous, and in the marble especially fragments of corals, crinoids, brachiopods, and gasteropods are so abundant as to make much of the bulk of the rock.

Variations.—The variation in the Chickamauga in both thickness and appearance is greater than in any other formation of the Valley. In the extreme northwest corner of this quadrangle it is composed almost entirely of red and brown variegated marble. Most of this is massive, but many shaly beds are interstratified. These have a thickness ranging from 300 to 450 feet. Overlying this are the red slabby limestones of the Moccasin formation. Not far northwest of this quadrangle both the marble beds and the Moccasin limestones are replaced by the blue and gray limestones of the Chickamauga formation. The narrow belt of the formation near Holston River consists of massive blue limestone and shaly limestone interbedded, about 200 feet thick. In the vicinity of Blue Springs, south of Lick Creek Valley, the formation is composed of 150 feet of thin, blue and gray shaly limestones and knotty blue limestone, while in other parts of the Nolichucky plateau the formation is absent. During the time occupied in the deposition of this limestone northwest of the Holston there were laid down in the Nolichucky district argillaceous and sandy shales, which compose the Athens, Sevier, and Tellico formations.

Sources of materials.—The explanation of these differences in deposits formed at the same time is that the shore from which the material was largely derived lay toward the east or southeast, and that the formations in that vicinity received more shore material. Thus, the sand in the Tellico, which directly implies a neighboring shore, disappears toward the west in receding from the shore. The same is true of the finer shore materials or muddy sediments forming the shales of the Athens and the Sevier, which extend for a considerable distance farther west than the sand grains because of their greater fineness. Thus, the Chickamauga strata in the northwestern areas represent a much longer period than those of the same kind around Blue Springs. In the Moccasin limestone the limestone beds were modified by the introduction of red coloring matter, probably when the Tellico sandstone was formed. This is so striking in appearance as to merit separate representation on the map.

Weathering and soils.—The Chickamauga limestone always occupies low ground, as would be expected from the amount of lime that it contains. Decomposition proceeds by solution, but it varies greatly in rate and in results in the different varieties of the rock. The marbles and purer limestones weather deeply into a dark-red clay, through which occasional outcrops of the original rock appear. Many of the massive blue limestones invariably make ledges that form a characteristic feature of the surface of the formation. Over the shaly varieties the soil is not so deep or strong and many lumps and slabs of rock remain. These slabs occur in great numbers in areas lying near Holston River. Natural growths of cedar usually cover the limestone portions of this formation. The soil of the marble and heavy limestones is deep and fertile and forms some of the best lands of the Great Valley. That derived from the shaly limestone is also very rich wherever it attains any depth, but it needs careful tillage to prevent washing and is apt to be poorly watered. Underground drainage is a conspicuous feature of the formation in this region. Its areas are dotted with sink holes whose basins are from 50 to 200 feet in diameter.

Holston marble member.—That portion of the Chickamauga formation in the vicinity of the Devils Nose (in the Morristown quadrangle) is composed entirely of marble. The beds are usually coarsely crystalline, but include also layers of shaly marble and shale. On account of their distinctive appearance and economic importance these strata are shown on the map under the name of "Holston marble." These beds are from 300 to 450 feet thick in this area and thicken toward the southwest. They also become more massive in the same direction. The marble differs from most of the rocks of the formation in being coarsely crystalline. It may have been altered after its formation by the passage of water through the rock, which dissolved and recrystallized the carbonate of lime, or it may have been deposited in its present form. The shaly parts, containing less lime, are not crystalline. The forms of the fossils inclosed in the marble are plainly visible, although wholly recrystallized. The marble varies little in color, most of the rock being of a variegated reddish brown or chocolate color. Of these two varieties the latter, or reddish marble, is considerably more common. It is extensively quarried for ornamental stone, some of the oldest marble quarries being in this vicinity.

MOCCASIN LIMESTONE.

Areas and general features.—This formation is represented on the map only in the vicinity of the Devils Nose, in a belt adjacent to the Holston marble. This is the southern upturned edge of the Clinch syncline, along whose northern side extends the principal belt of the formation. In areas farther north and west the strata of this formation are so interbedded with limestones of the Chickamauga that it is impracticable to separate them. Lower down on Holston River, in the Maynardville and other quadrangles, they do not appear at all, their place being occupied by the Tellico sandstone. In this quadrangle a similar change takes place between the Nolichucky plateau and the ridge district. It is therefore probable that the Moccasin limestone and Tellico sandstone represent deposits that were formed at the same time under different conditions. The marked red color in both formations, due to iron oxide developed by weathering, distinguishes them from the adjacent formations. Some of the layers of the Moccasin contain sand and resemble the Tellico strongly, the usual difference between the two being the presence in the Moccasin of argillaceous matter, instead of the sandy matter which characterizes the Tellico. This difference is probably due to the greater distance of the Moccasin from the shore, and is of the same class as other differences in the sediments of that time.

Character and thickness.—The formation is so named because of its occurrence along Moccasin Creek in Scott County, Va. It consists of red, green, blue, and gray flaggy limestones in alternation, and contains a little red, yellow, and gray calcareous shale. The red beds are the most numerous and are made conspicuous by their color, which forms the chief distinction between this formation and the Chickamauga. The shaly beds can not be distinguished from those of the Sevier formation. Some of the red layers contain a considerable amount of sand, becoming in places argillaceous sandstone. These are, however, comparatively uncommon. No good measures of the thickness are obtainable here. In the adjoining regions it ranges from 450 to 500 feet.

Weathering.—The Moccasin formation is affected by weathering much as is the blue Chickamauga limestone, and it does not occupy high ground. Small, irregular ridges and conical knobs cover its areas. The red limestones especially weather out in large slabs, and numerous bare ledges are seen. The soil of the Moccasin is yellow, red, or purplish clay, rarely deep, and is strewn with unweathered fragments. On account of its thinness it is subject to washing and drought, but is fertile in the hollows.

ATHENS SHALE.

Extent and character.—The Athens shale occupies wide belts in the Holston River and Lick Creek valleys and numerous narrow strips in the Nolichucky basin. The shale is named from Athens, McMinn County, Tenn., where it is conspicuously exposed. Throughout this region it is composed of black and bluish-black shales which show little variation from one area to another. The shales are all calcareous and, especially at the bottom, are carbonaceous and full of remains of graptolites. Near Limestone Springs the upper portion contains slightly sandy beds and a thin layer of limestone conglomerate. With these exceptions the strata are very fine grained and thin bedded, and sedimentary banding is seldom visible. On account of the obscurity of the bedding planes and the prominence of cleavage lines in the formation its thickness is difficult to measure, but it is probably not far from 1000 feet. In one locality east of Limestone Springs the shale disappears abruptly between Tellico sandstone and Knox dolomite, a change probably due to local erosion after its deposition. The contact of the Athens shale with the underlying Chickamauga or Knox dolomite is sharp in all places and indicates a sudden change in the relations of land and sea at that time. This is comparable in magnitude and extent with that which immediately preceded the Shady limestone.

Weathering.—The rock weathers rapidly because of solution of the calcium carbonate it contains, so that ledges are found only near stream cuts. The lumps and flakes of argillaceous matter left behind decompose and crumble very slowly and turn yellow only after long exposure. Soils on this formation are thin on account of the insolubility of most of the rock and the steep slopes on which it lies in places. In the valley of Lick Creek they are mingled with sandy wash from the adjacent formations, so that they are lighter and more fertile. The formation causes sharp, steep knobs of no great height. Where the areas widen the knobs are less conspicuous, but in the narrow belts of the formation on the Nolichucky plateau the knobs follow very distinct lines, rising above the Knox dolomite. The lower slopes of these are occupied by the black and more carbonaceous shale. In areas where the Tellico appears the latter forms the tops of the knobs and the Athens shale lies on the slopes.

TELLICO SANDSTONE.

Areas and general features.—Outcrops of this formation are limited to a few outlying areas south of Nolichucky River, where it rests upon the Athens shale. Along the southeastern side of Lick Creek Valley, however, the formation is wanting in similar positions on the Athens shale. Many thin beds of sandstone of the same character are interstratified with the lower part of the Sevier shale. These are not of sufficient body or regularity to be shown on the map, but are included in the Sevier shales. The formation is named from Tellico River, in Monroe County, Tenn., where it is well exposed. It consists of calcareous sandstone interbedded with calcareous sandy shale. When fresh these are bluish gray in color, but when weathered they become deep red or brown, the colors being due to the large amount of iron oxide in the rock.

Thickness and relations.—The greatest thickness of the formation is 200 feet, and this measure includes only what is left by erosion in the synclinal folds south of Nolichucky River. In the Lick Creek areas it varies in thickness from 5 to 50 feet, including several beds with no definite upper limit. At the time these sandy strata were laid down near shore the ferruginous Moccasin limestones were deposited in more distant waters, in a relation similar to that of the Athens shale and Chickamauga limestone. North and east of Whig the Athens shale and the Tellico sandstone are interbedded for a few feet. Immediately south of Whig, however, as has been already stated, the Athens shale disappears for a short distance and the sandstone is deposited directly upon the Knox dolomite. This relation extends over a distance of 2 miles along one contact, and is due to a period of local erosion after the Athens shale was deposited.

Weathering.—By solution of the calcium carbonate which it contains the rock is readily reduced to a porous, sandy skeleton. This, however, is rather firm and causes elevations of 200 to 500 feet above the adjacent Athens shale. Its soils are moderately deep, but are too sandy and too rapidly drained to be of value. The large proportion of insoluble matter in the soil renders it sterile and it is little cultivated.

SEVIER SHALE.

Extent and character.—This formation appears in the ridge district northwest of Holston River, also a small area near Graysburg, and in a very large body surrounding the Bays Mountains. It derives its name from Sevier County, Tenn., where it is notably developed in the continuation of the Bays Mountain area. As a whole, the formation consists of argillaceous and calcareous shales, most of them thick bedded and slabby. These are gray, bluish gray, and brown when fresh and weather to dull yellow, greenish yellow, or gray colors. The lower portion of the formation, as already stated, contains many small beds of reddish sandstone representing the Tellico sandstone. Above these are thin beds of limestone, ranging in thickness from a few inches to a few feet, which weather out in slabs or square blocks. The upper shales are rather sandy and contain beds of calcareous sandstone. Thus the whole series shows a progression from the older limestones to the Bays sandstone, a change best shown in the southwest part of the Bays Mountains. In the ridge district this formation is more calcareous and less sandy and may thus be better discriminated from the Bays sandstone.

Thickness.—Owing to the great amount of folding in these beds considerable cleavage is developed, which obscures the bedding. The layers are also uniform for considerable thicknesses, and this uniformity combines with the close folding to render measurements of thickness uncertain. In the southwest part of the Bays Mountains the formation is about 1300 feet thick. In the central and northeastern parts the thickness is greater and may be as much as 2500 feet. Around the Devils Nose the thickness shown is less than that seen at any other place, but the strata are so folded that the measurement is of little value.

Weathering.—The calcareous parts of the formation dissolve readily, leaving the argillaceous matter sufficiently firm to form slabs and flakes of shale, which strew the surface. The shale maintains considerable elevations in round knobs and irregular ridges, between which is a network of deep and narrow valleys. On complete weathering the strata form a thin, yellow clay. This is readily washed down slopes such as the shale usually occupies, leaving much bare rock. Such soils are thin, cold, and subject to drought, and are of no great value. In the lower Lick Creek basin and the areas bordering the Holston, where the surface is well worn down, the soils of this formation accumulate to greater depth and are more mingled with the sandy wash from the rocks of the mountains. These soils are therefore lighter and more fertile, but are not well watered, so that the region is liable to drought. In the coves and hollows receiving the wash from the knobs the soils are deep and rich and they support good crops and a heavy growth of timber. The waters coming from this formation are scanty and much mineral impurity is suspended and dissolved in them.

SILURIAN ROCKS.

BAYS SANDSTONE.

The strata of the Bays sandstone are found in great abundance in the Bays Mountains, from which the formation is named. It is everywhere an argillaceous and calcareous sandstone, and shows very little change in its appearance from place to place. Its color is always red or brown, even on the freshest outcrops. In some places its layers are thin and shaly, but as a rule they are massive. At the northeast end of the Bays Mountains and in Chimney Top the formation is scarcely over 50 feet thick. In other parts of the mountains it becomes 300 or 400 feet thick. In the Devils Nose, outside of this area, in the Morristown quadrangle, and north of Holston River, the formation is 300 feet thick. In the southwest end of the Bays Mountains the Bays sandstone is more or less interbedded with the white Clinch sandstones, but usually the formations are sharply separated. Silurian brachiopods are found in these strata.

Except in a few places, this sandstone occurs with the Clinch sandstone, which makes the crests of the mountains. Accordingly, slopes of the Bays sandstone are usually steep and its outcrop is narrow. A few knobs and high ridges are maintained by the Bays in synclinal folds from which the Clinch sandstone has been recently eroded. Decay is never deep, but the sandy residue is loose and crumbling and does not resist wear. The rock weathers into rounded ledges and lumps. Little soil results from its decay, so that it forms practically no arable land.

CLINCH SANDSTONE.

Like the sandstone just described, this formation is common in the Bays Mountains. It also forms a few small areas near Stone Mountain, in the northwest corner of the quadrangle. Its name is derived from Clinch Mountain, in which it is especially prominent. As a rule, it consists of massive white sandstone formed of rounded quartz grains of even size and fine or medium grain. In this are included, in the southwest part of the Bays Mountains, a few beds of red sandstone of the same nature as the Bays. Very rarely seams of fine conglomerate occur. Some of the layers contain scolithus borings, and occasionally cross-bedded and ripple-marked strata are found. Its thickness ranges from 300 to 500 feet, and there is no apparent system in the changes.

Solution affects it but little, owing to its highly siliceous composition, so that it invariably makes conspicuous ridges. To its hardness and frequent repetition by folds the Bays Mountains owe their existence. When its beds are much tilted they cause mountains with steep flanks and narrow, regular crests, like most of the Bays Mountains. Its flat-lying beds produce table-topped summits, such as Stony Lump; Fodder Stack and Chimney Top are such tables nearly worn away. Many cliffs and ledges are produced by this formation, and its fragments strew the surrounding slopes and choke up the streams. Its soils are sandy and sterile and support a scanty vegetation.

ROCKWOOD FORMATION.

Extent and character.—Strata of the Rockwood formation are found in two areas in the Bays Mountains. The formation derives its name from its outcrops at Rockwood, Roane County, Tenn. In this quadrangle it consists entirely of shales, usually calcareous and slightly sandy. Their colors are bright green, red, and yellow, and endure until the shales are extremely weathered. The shales are usually thin bedded and are always fine grained, even in the sandy layers. As it occurs here only in synclines, its upper layers are not seen.

Thickness and relations.—The thickness remaining from erosion is 700 feet. The formations which follow it in the Bays Mountains are not known. North of Holston River the Rockwood is absent entirely and the formations above and below it come together, the Chattanooga shale of the Devonian resting immediately on the Clinch sandstone. In the Bays Mountains there is practically no interbedding of the Clinch and Rockwood formations, the white sandstones of the Clinch passing almost immediately into the sandy shales of the Rockwood. The formation contains numerous fossils, chiefly brachiopods, which show it to be of Silurian age.

Weathering and soils.—Under the attacks of weather the formation readily loses its calcareous matter and forms rolling valleys between the high Clinch sandstone mountains. Outcrops are common but inconspicuous. By decay it makes sandy clay soils of no great depth. The natural fertility of these is impaired by the sandstone wash from the mountains. They are, however, well situated, well drained, and fairly productive.

DEVONIAN ROCKS.

CHATTANOOGA SHALE.

This formation is found in a small area in the northwest corner of the quadrangle, where it forms a portion of a larger belt that lies at the foot of Stone Mountain, in the Morristown quadrangle. Here it consists of fine, black, carbonaceous shale, which is its characteristic form throughout this region. It is deposited directly upon the beds of the Clinch sandstone, and this contact has been determined in adjacent regions to be due to unconformable deposition after erosion. A few feet of the upper layers of the formation are interbedded with the overlying Grainger shale. Small rounded lumps and nodules of iron ore occur in some layers of the shale. Frequently also the surfaces of the shale are covered with yellowish-red crusts of iron ore, due to the decomposition of pyrite and hematite in the body of the rock.

On account of its fine grain and softness the formation lies in deep valleys or on steep slopes protected from removal by Clinch sandstone. Its valleys are cold and narrow and are shut in between high ridges. Decay is rapid in this rock, so that outcrops are very rare. The residual yellow clay is dense and deep and so much covered with sandstone wash that it is of little agricultural value. Sulphur and chalybeate springs, derived from the decomposition of the iron oxide and sulphides, everywhere accompany the formation.

GRAINGER SHALE.

One area of this formation occurs in the northwest portion of the quadrangle, next to the Chattanooga shale. It is exposed in many places in Grainger County, Tenn., from which it is named. The formation comprises sandy shales and shaly and flaggy sandstone, the latter being more numerous in the upper layers. All the beds are bluish gray when fresh and weather green and greenish gray. In the bottom flags are many impressions of the supposed seaweed *Spirophyton cauda-galli*. The thickness of the formation in this region is almost 1200 feet. Decay proceeds slowly in the argillaceous materials of this rock, and the sandy layers remain unaffected. Its areas stand up in ridges, but only for 400 or 500 feet above the valleys on either side, because the rock gradually crumbles under the wear of rain and frost. These ridges are very regular in height and are gapped by numerous streams from the valleys of Chattanooga shale. In all respects they resemble closely the Rome sandstone ridges. The soils are sandy and full of bits of rock and lie at high angles, so that they are sterile and nearly valueless for agriculture.

CARBONIFEROUS ROCKS.

NEWMAN LIMESTONE.

This is the youngest formation that occurs in the quadrangle. It occupies a single area next to the Devonian formations. It is named from Newman Ridge, Hancock County, Tenn., where it is well exposed. Massive and shaly limestones make up the entire formation. A masssive bed 100 feet thick lies at its base and is overlain by thin and shaly limestones with a few heavy beds. The full thickness of the formation is not represented by the 1400 feet which have been left by erosion in the synclinal basin, but is probably not much greater than is here shown. All of the limestones are blue or grayish blue when fresh, and the shaly layers weather out greenish yellow. The lower massive limestones contain many layers and nodules of black chert. These and the limestone itself are full of fossil crinoids, corals, and brachiopods. The chert weathers white, like the chert in the Knox dolomite, but can be distinguished from this by the fossils that it contains. It does not affect the topography like the Knox dolomite chert, for it breaks into small fragments and is relatively small in amount.

The massive limestone at the base weathers readily and forms low ground; the upper shaly beds resist erosion to a considerable degree and form broad, rounded knobs and hills as high as the Grainger shale. This upland position keeps the soils well drained and they are fairly deep. They are filled with flakes of shale and slabs of limestone, but are productive and strong. Deep, rich clays are formed by most of the beds, especially the lower. Frequent ledges also mark the course of the lower, massive limestones.

STRUCTURE.

INTRODUCTION.

Those rocks of the Greeneville quadrangle that were deposited upon the sea bottom must originally have extended in nearly horizontal layers. At present, however, the beds or strata are seldom horizontal, but are inclined at various angles, their edges appearing at the surface. Folds and faults of great magnitude occur in the Appalachian region, their dimensions being measured by miles, but they also occur on a very small, even a microscopic, scale. Many typical Appalachian folds and faults are to be seen in the Greeneville region. In the folds the rocks have changed their forms mainly by adjustment and motion on planes of bedding and schistosity. There are also countless planes of dislocation independent of the original layers of the rocks. These are best developed in rocks of an originally massive structure and are usually much nearer together and smaller than the planes on which the deformation of the stratified rocks proceeded. In these more minute dislocations the individual particles of the rocks were bent, broken, and slipped past one another or were recrystallized.

Explanation of structure sections.—The sections on the structure-section sheet represent the strata as they would appear in the sides of a deep trench cut across the country. Their position with reference to the map is on the line at the upper edge of the blank space. The vertical and horizontal scales are the same, so that the actual form and slope of the land and the actual dips of the layers are shown. These sections represent the structure as it is inferred from the position of the layers observed at the surface. On the scale of the map they can not represent the minute details of structure, and they are therefore somewhat generalized from the dips observed in a belt a few miles in width along the line of the section. Faults are represented on the map by a heavy solid or broken line, and in the section by a line whose inclination shows the probable dip of the fault plane, the arrows indicating the direction in which the strata have been moved on its opposite sides.

GENERAL STRUCTURE OF THE APPALACHIAN PROVINCE.

Types of structure.—Three distinct kinds of structure occur in the Appalachian province, each one prevailing in a separate area corresponding to one of the three geographic divisions. In the Plateau region and the region farther west the rock layers are generally flat and retain their original composition. In the Valley the strata have been steeply tilted, bent into folds, broken by faults, and to some extent altered into slates. In the Mountain district faults and folds are important features of the structure, but cleavage and metamorphism are equally conspicuous.

Folds.—The folds and faults of the Valley region are about parallel to one another and to the northwestern shore of the ancient continent. They extend from northeast to southwest, and single structures may be very long. Faults 300 miles long are known, and folds of even greater length occur. The crests of most folds continue at the same height for great distances, so that they present the same formations. Often adjacent folds are nearly equal in height, and the same beds appear and reappear at the surface. Most of the beds dip at angles greater than 10°; frequently the sides of the folds are compressed until they are parallel. Generally the folds are smallest, most numerous, and most closely squeezed in thin-bedded rocks, such as shale and shaly limestone. Perhaps the most striking feature of the folding is the prevalence of southeastward dips. In some sections across the southern portion of the Appalachian Valley scarcely a bed can be found which dips toward the northwest.

Faults.—Faulting took place along the northwestern sides of anticlines, varying in extent and frequency with the changes in the strata. Almost every fault plane dips toward the southeast and is approximately parallel to the beds of the upthrust mass. The fractures extend across beds many thousand feet thick, and sometimes the upper strata are pushed over the lower as far as 10 or 15 miles. There is a progressive change from northeast to southwest, in the results of deformation and different ones prevail in different places. In southern New York folds and faults are rare and small. Through Pennsylvania toward Virginia folds become more numerous and steeper. In Virginia they are more and more closely compressed and often closed, while occasional faults appear. Through Virginia into Tennessee the folds are more and more broken by faults. In the central part of the valley of Tennessee folds are generally so obscured by faults that the strata form a series of narrow overlapping blocks of beds dipping southeastward. Thence the structure remains nearly the same southward into Alabama; the faults become fewer in number, however, and their horizontal displacement is much greater, while the remaining folds are somewhat more open.

Metamorphism.—In the Appalachian Mountains the southeastward dips, close folds, and faults that characterize the Great Valley are repeated. The strata are also traversed by the minute breaks of cleavage and metamorphosed by the growth of new minerals. The cleavage planes dip to the east at from 20° to 90°, usually about 60°. This phase of alteration is somewhat developed in the Valley as slaty cleavage, but in the Mountains it becomes important and frequently obscures all other structures. All rocks were subjected to this process, and the final products of metamorphism of very different rocks are often indistinguishable from one another. Throughout the southeastern part of the Appalachian province there is a great increase of metamorphism toward the southeast, until the resultant schistosity becomes the most prominent of the Mountain structures. Formations there whose original condition is unchanged are extremely rare, and frequently the alteration has obliterated all the original textures of the rock. Many beds scarcely altered at the border of the Valley can be traced southeastward through greater and greater changes, until every original feature is lost.

In most of the sedimentary rocks the bedding planes have been destroyed by the metamorphic action, and even where they are distinct they are usually less prominent than the schistosity. In the igneous rocks planes of fracture and motion were developed, which, in a measure, made easier the deformation of the rocks. Along these planes or zones of localized motion the original texture of the rock was largely destroyed by the fractures and by the growth of the new minerals, and in many cases this alteration extends through the entire mass of the rock. The extreme development of this process is seen in the mica-schists and mica-gneisses, the original textures of which have been entirely replaced by the schistose structure and parallel flakes of new minerals. The secondary structure planes are inclined toward the southeast through most of the Mountains, although in certain belts, chiefly among the southeastern and southern portions, northwesterly dips prevail. The range of the southeasterly dips is from 10° to 90°; that of the northwesterly dips, from 30° to 90°.

Earth movements. — The structures above described are chiefly the result of compression which acted most effectively in a northwest-southeast direction, at right angles to the general trend of the folds and of the schistose planes. Compression was also exerted, but to a much less extent, in a direction about at right angles to that of the main force. To this are due the cross folds and faults which appear here and there throughout the Appalachians. The earliest-known period of compression and deformation occurred during Archean time, and resulted in much of the metamorphism of the present Carolina gneiss. It is possible that later movements took place in Archean time, producing a portion of the metamorphism which appears in the other Archean rocks. In the course of time, early in the Paleozoic era, compression became effective again, and a series of movements took place that culminated soon after the close of the Carboniferous period. The latest of this series was probably the greatest, and to it are chiefly due the well-known Appalachian folding and metamorphism. This force was exerted at two distinct periods, the first deformation producing great overthrust faults and some metamorphism, the second extending farther northwest and deforming previous structures as well as the unfolded rocks. The various deformations combined have greatly changed the aspects of the rocks—so much so, in fact, that the original nature of some of the oldest formations can be at present only surmised.

In addition to the force which acted in a horizontal direction, this region has been affected by other forces which acted vertically, and repeatedly raised or depressed the surface. The compressive forces were tremendous, but were limited in effect to a relatively narrow zone. Less intense at any point, but broader in their results, the vertical movements extended throughout this and other provinces. It is likely that these two kinds of movement were combined during the same epochs of deformation. In most cases the movements have resulted in a warping of the surface as well as in uplift. One result of this appears in overlaps and unconformities of the sedimentary formations.

As was stated under the heading "General geologic record" (p. 2), depression of this kind took place at the beginning of the Paleozoic, with several repetitions later in the same era. They alternated with uplifts of varying importance, the last of which closed Paleozoic deposition. Since Paleozoic time there have been at least four, and probably more, periods of decided uplift. How many minor uplifts or depressions have taken place can not be ascertained from this region.

STRUCTURE OF THE GREENEVILLE QUADRANGLE.

Larger features.—The rocks of this quadrangle have undergone many alterations since they were formed, having been bent, broken, and metamorphosed to a high degree. The structures which resulted from these changes trend in general northeast and southwest, with a regularity even greater than is usual in the Appalachians. This is conspicuously shown in the parallel folds of the Bays Mountains.

The structures in the sedimentary rocks are readily deciphered. In the igneous and metamorphic rocks, however, though it is easy to see that they have been greatly disturbed and though the details of the smaller structures are apparent, yet it is difficult to discover the larger features of their deformation. One reason for this is that the original shape of most of the rock masses is unknown because they are intrusive and consequently irregular. Another reason is that the masses of one kind of rock are so great, and distinctive beds are so rare, that structures of large size can not be detected.

In a broad way, the structure of the rocks of the Greeneville quadrangle exhibits two synclinal basins where sedimentary rocks appear and three areas of uplift, two exposing sedimentary and one exposing igneous rocks. The synclinal areas are the Bays and the Bald Mountain districts; the anticlinal areas include the ridge district northwest of Holston River, the Nolichucky plateau, and the area of granitic rocks in the southeast corner of the quadrangle. Each of these main folds contains minor folds in great numbers. Faults are developed chiefly in the anticlinal areas. Each of the synclinal areas of this quadrangle is a part of a belt of similar structures reaching for many miles along the strike in each direction.

Bald Mountain syncline.—In the Bald Mountain basin the rocks are all Cambrian. In its extension toward the southwest the basin continues to be occupied by rocks of practically the same age. Toward the northeast, however, in the adjoining Roan Mountain quadrangle, the strata involved include Ordovician strata as well as the Cambrian series. Considered by itself the Bald Mountain basin is plainly synclinal, but it is also an area of uplift in comparison with the folds of the Nolichucky plateau. The Cambrian rocks of the Bald Mountains are all older than the Ordovician and Cambrian rocks of the plateau and are separated from the latter by a great fault. Motion along the plane of this fault was very great and is to be measured by many miles. After the fault was formed and the strata were overthrust along its plane both overlying and underlying rocks were folded, and thus the present synclinal structure of the range was produced. The fault is to be seen along the northwest foot of the Bald Mountains, and it also intersects the surface southeast of them and just east of the border of this quadrangle. This same fault can be traced many miles to the northeast and southwest, into Virginia and Georgia, and in many places shows similar subsequent folding.

In the Bald Mountain basin such folds as appear are broad and comparatively open. The chief yielding to compression was along the great thrust fault at the northwestern foot of the mountains and along a number of similar but lesser faults parallel to the great one. On the northwest side of the syncline the dips are practically all toward the southeast, ranging from 30° to 70°, while on the southeast side they vary from vertical to horizontal. In the Asheville quadrangle, adjoining on the south, these faults and folds incline both to the northwest and to the southeast, thus forming a fan structure, which is also seen at considerable intervals toward the southwest and northeast.

Bays Mountain syncline.—In the Bays synclinal area the formations are Ordovician and Silurian, and practically the same beds are involved throughout its entire extent. The folds of this basin are seldom inclined. The few axial planes which are not upright are overturned toward the northwest. The rocks involved are for the most part thin-bedded shales and similar rocks, and the folds into which they were compressed are usually small. The Clinch and Bays sandstones are usually seen in broad and open flexures, while the various shales exhibit countless crumples and little folds. Practically no faults are to be seen.

Ridge uplift.—The anticlinal area in the ridge district forms part of the extensive belt of faulted strata that lies along the west side of the Great Valley. It is characterized by a notable development of thrust faults. These are carried so far that in most cases the anticlines from which they were developed have been shoved far over on the synclines and eroded. In many places portions of the synclinal axes are exposed. The dips range from flat to vertical, and thence to 50° overturned. The average fold dips 45° on its southeastern side and from 60° to 90° on its northwestern side, most of the axes of the folds being overturned toward the northwest. The faults of the ridge district are among the longest in the Valley and bring into contact formations which were originally widely separated. The fault which brings the Rogersville shale and Holston marble together on Caney Creek (section C–C) passes through Tennessee into Virginia and Alabama. In some places on this fault Carboniferous and Cambrian rocks are brought into contact.

Nolichucky uplift.—The anticlinal area of the Nolickucky plateau is notable for the closeness and the regularity of its folds. A single formation, the Knox dolomite, rises and falls on the anticlines and synclines and occupies nearly the whole of the area. In the synclines narrow belts of the overlying Athens shale are inclosed, and on the anticlines equally narrow strips of the underlying Nolichucky shale and Maryville limestone appear. Such is the regularity of the folds that no other formation than these appears on the plateau. The axial planes of the folds are usually almost upright and are seldom inclined like those of the ridge district. They are also closely compressed, and vertical dips on both sides of an axis are very common. The force of compression seems to have been so controlled as to produce few structures except folds. There are many faults, but they are of no great length and are not of sufficient throw to involve any formations except those close to the Knox dolomite. They range in length from 5 to 15 miles. In many cases the beginning of a fault in a sharp anticline can be seen. One such fault starts near Washington College (section B–B), one near Allenbridge, one south of Greeneville, and one south of Hawes Crossroads. With the exception of those 1 mile and 3 miles northwest of Leesburg (section A–A), the faults are situated on the northwestern sides of the anticlines. The planes of the faults are nearly parallel to the beds on the southeast side of the anticline. With the exception of a fault northwest of Newmansville, which was folded after it was formed, the fault planes dip to the southeast at angles ranging from 25° to 60°, the dip of most of them being about 50°. Breaks just beginning are seen east of Hawes Crossroads (section A–A) and southeast of Greeneville (section D–D). Faults with a throw of half a mile appear at Allenbridge (section E–E), of 2 miles northwest of Greeneville (section D–D), and of upward of 4 miles near Gilenwater (section C–C).

Archean uplift.—The third anticlinal area is occupied by the Archean granites. It is marked more by its position with reference to the syncline than by any structures which can be deciphered in the granite itself. The granites are the oldest rocks in the region and the sediments were deposited on them. Consequently, areas now occupied by the granites are areas of uplift in comparison with those occupied by the sediments. In closely adjoining regions a number of small synclines are defined by sediments folded in with the granite. A few faults are to be seen near the sediments, but for lack of distinctive or regular beds they can not be determined in the main body of the granite.

Metamorphism.—By far the greatest discoverable effect of the deformation is metamorphism. Its processes were carried on in general along the following lines: The mineral particles were changed in position and broken during the folding of the rock. As the folding went on they were fractured more and more. Simultaneously new minerals, especially quartz and mica, grew out of the fragments of the old minerals. The new minerals were arranged at right angles to the greatest force of compression at any particular point. Inasmuch as the compression was about uniform in direction over large areas, there resulted a general parallelism of the longer dimensions of the new minerals. To this is due the schistosity of the rocks. In folding, the differential motion in the sedimentary strata took place to a large extent along bedding planes. As deformation became extreme, however, other planes of motion were formed through the separate layers, just as they were in the massive igneous rocks. In rocks which had already become gneissoid or schistose by previous metamorphism the existent schistose planes served to facilitate flexure, as did the bedding planes of the sediments. In the massive igneous rocks there were no planes already formed, but they were developed by fracture and mashing, and the change of form expressed in folds was less than that seen in the laminated rocks. The schistose partings are in a general way parallel to one another for long distances and over large areas. They sometimes diverge considerably for short distances around harder portions of the rock, which have yielded less under compression, but the influence of these portions is only local. Near the boundaries of formations, also, they are usually about parallel to the general contact of the formations, the yielding to pressure having been directed by the differences in strength between the formations. Thus, while the strike of the different formations may vary considerably in adjoining areas, yet the schistose planes swing gradually from one direction to another, and there is seldom an abrupt change. The planes of schistosity dip to the southeast in this area, with scarcely any exception. The dips are high and vary from 45° to 90°.

Metamorphism is plainly the most important result of deformation in the Archean rocks, although folding and faulting are important. In the Cambrian quartzites and slates of the Bald Mountain basin metamorphism was subordinate to folding and faulting. A few of the coarse conglomeratic beds near the base of the Cambrian series were metamorphosed in the same manner, but not to the same degree, as were the granites. The usual result of the metamorphism was the production of slaty cleavage among the shales and shaly sandstones. Many of these are now entirely transformed to slates. Another result of the metamorphism, equally prominent in the Mountains, is the transformation of fine sandstones into quartzites. That this is wholly the result of metamorphism through deformation can not be definitely stated, since a certain amount of it might be attributed to the passage of circulating waters through the rocks without any exceptional pressure.

Periods of deformation.—Just how much of the metamorphism proceeds from the period of deformation commonly termed the "Appalachian" is doubtful, for it is certain that some of the Archean rocks had attained considerable metamorphism during previous epochs. The amount of schistosity and folding received substantial additions in this period. Deformation was not, however, completed during one process. From the facts observed in adjoining areas it is clear that some of the great irregular faults were the first results of this deformation. At a somewhat later time these were themselves folded, as deformation took a different form of expression. The great fault passing along the northwest foot of the Bald Mountains is of this class. In like manner there were folded vast masses of igneous rocks, and their existent schistose structures were deformed.

Vertical movement.—The latest form in which yielding to pressure is displayed in this region is vertical uplift or depression. Evidence can be found that such movement occurred at various intervals during the deposition of the sediments, as at the beginning and the end of the periods of deposition of the Knox dolomite, the Athens shale, the Clinch sandstone, and the Newman limestone. In post-Carboniferous time, after the great period of Appalachian folding just described, such uplifts took place again and are recorded in surface forms.

Various peneplains.—While the land stood at one altitude for a long time, most of the rocks were worn down to a nearly level surface, or peneplain. Over most of this region one such surface was extensively developed. Its more or less worn remnants are now seen in a few small plateaus of the Mountain district, at altitudes of 2300 to 2400 feet, and in a number of the even-topped ridges of the Bays Mountains that stand at altitudes between 2100 and 2200 feet. Extensive remnants of this plateau still exist in the quadrangles lying south and east of this area.

A similar surface was developed over practically the same region at a considerably later date. Over the soluble formations of the Valley this second surface entirely replaced the older one. In the harder formations of the Mountains, however, it made less progress than the first, and erosion succeeded only in cutting canyons into the older surface. This second surface is now seen in nearly its original form between the bold front of the Bald Mountains and Nolichucky River. It consists of a gently undulating plain bearing a few small knobs that rise slightly above its level. On its surface are sand and quartzite fragments that were deposited by streams issuing from the mountains. This portion of the ancient plain slopes from 1600 to 1800 feet along the foot of the mountains down to 1500 or 1600 feet near the river. Remnants of this plain form the plateau which lies north of Nolichucky River and extends over into the basins of Lick Creek and Holston River. Fragments of the same plateau that stand at similar heights, 1500 to 1600 feet, are to be seen in the lower ridges of the Bays Mountains and the various summits of the ridge district northwest of Holston River. In general, there is a slight rise of the plateau remnants toward the northeast. Since its formation uplift of the land has given the streams greater fall and greater power to wear. They have accordingly cut down into the old surface to varying depths, according to their size and power, and have produced the present deep, narrow stream valleys, like the canyon of the lower Nolichucky River. As they are still wearing their channels downward and but little from side to side they have not reached the grade to which the old plain was worn. The amount of elevation was, therefore, much more than the depths of the present stream cuts—probably as much as 500 or 600 feet.

In the valley of Lick Creek, and also at places near the course of Holston River, where the rocks encountered are weak and soft, a third period of erosion has produced small plains and terraces that stand at elevations averaging about 1100 feet. As these are followed down the river valleys they broaden out, at elevations a little over 1000 feet, into extensive plains, of precisely the same character as the 1600-foot plain which they are replacing. Of the various other movements of uplift which can be traced in adjoining regions no record is to be seen here. Nor does any record remain of such movements as depression, although they undoubtedly occurred in this region.

MINERAL RESOURCES.

The rocks of this region are of use in the natural state, as marble, slate, building stone, and road material, and in the materials developed from them, such as iron, zinc, lime, and clay. Through their soils they are of value for timber and for crops, and in the grades which they occasion on the streams they cause abundant water power.

Marble.—Marble is found in great quantity in that belt of the Chickamauga limestone which passes through the extreme northwest portion of the quadrangle. The part of this belt lying farther southwest contains many notable quarries. In the other belts of the Chickamauga limestone, lying farther southeast, the formation is much thinner and no marble occurs. The distribution of the marble and of the quarries is shown on the sheet of "Economic Geology." The marble in this occurrence represents practically the whole of the Chickamauga limestone and lies between the Knox dolomite and the Moccasin limestone. The total thickness of the marble beds, which is in places as great as 350 feet, is by no means available for commercial use. The rocks must be of desirable color, must quarry in large blocks that are free from cracks or impure layers, and must be of fine, close texture. The variations in most of these characters are due to differences in the sediments at the time of their deposition. Carbonate of lime, iron oxide or hydrate, and clay were deposited together with calcareous shells of animals. The firmness of the rock is due to its large content of lime, and its rich, dark colors are produced by oxide of iron; but when clay is present in the rock in large proportions it becomes a worthless shale.

In color the marble varies from white to cream, yellow, brown, chocolate, red, pink, and gray, in endless variety. Absence of iron oxide results in gray, grayish white, and white. The colors are either scattered uniformly through the rock or are grouped into separate crystals or patches of crystals. The fossils it contains are usually of pure white calcite. The curious and fantastic arrangement of the colors is one of the chief beauties of this marble. Most of the marble in this region has a distinct reddish or chocolate color.

Like the shaly matter, the iron oxide is an impurity, and the two are apt to accompany each other. The most prized rock, therefore, is a mean between the pure and impure carbonate of lime, and slight changes in the form of the components result in deterioration or improvement in quality. Such changes are common in most sediments and must be expected in quarrying the marble. Not only may a good bed become poor, but a poor bed may develop into good marble. Workable bodies are rarely as thick as 50 feet, and usually in that thickness there is a combination of several varieties. Quarries separated from one another have distinct series of beds, and each quarry has its special varieties. All of the marble is free from siliceous impurity and, when otherwise reasonably pure, takes a good polish and is not affected by weather.

Available localities for quarrying are limited in part by the dip of the marble beds. The dip is usually steep in this region, so that the amount of earth to be stripped is not great. On account of the recent cutting of the streams, the marble is usually at some distance above the water level. Drainage of the quarry is sometimes an important problem, even in areas well above drainage level, when springs and underground streams are encountered, and they frequently are.

Owing to the soluble nature of the pure marble, it is either completely unaltered and fresh or entirely reduced to red clay. The best marbles, therefore, are nearly as solid at the surface as at great depths. Marbles which are shaly at the surface become less weathered below it and appear solid; but when these are sawed and exposed to the weather, their inferiority appears in splits along the argillaceous seams and in cracks that extend through the thicker masses. Solution of the pure beds has produced holes and caves down to the adjacent stream levels. Through these openings the quarrymen attack the rock more easily, but much valuable stone has been lost by solution.

Under tests the better grades of marble absorb little water and the rock is well fitted to withstand the weather. The crushing strength of marble from the purer layers is also very great. Tests of a number of samples gave an average strength of 16,000 pounds per square inch.

Building stone.—Many formations in this region besides the Holston marble contain strata suitable for building material, but few of them have been used. Some, such as the Knox dolomite, the Chickamauga limestone, the Maryville limestone, the Clinch sandstone, the various Cambrian quartzites, and the Cranberry granite, have been utilized for chimneys, foundations, and bridge piers, the loose rock being used in nearly the natural state. Stone suitable for resisting heat is found in the lower Cambrian quartzites. Material for flagstones of poor quality is abundant in the Sevier shale.

Probably the best and the most widely distributed of the building materials is the Knox dolomite. Its outcrops are numerous near any stream of considerable size; the stone is readily opened by partings along the bedding planes, and the beds procured vary from 6 inches to 3 feet in thickness. The most available localities for quarrying the Knox dolomite are along the various stream courses northwest of Holston River near the Nolichucky canyon, and along the border of the Nolichucky plateau and the Lick Creek Valley. The stone resists frost and heat very well and is sufficiently hard. Its firm, fine texture enables it to endure great strain. The massive blue limestones of the Chickamauga formation are occasionally used for building material, and in this use have the same characteristics as the Knox dolomite. The Clinch sandstone and the Cambrian quartzites in large part make building stone of great strength and durability, but these lack variety and beauty of color. Fresh rock can be easily obtained, and the formations can be readily opened along their bedding planes in layers ranging from 1 to 5 feet in thickness. The brown calcareous Sevier sandstone in Bays Mountains affords an admirable building stone. Its layers are from 2 to 6 feet thick and it is readily opened and worked into any shape. Massive ledges indicate its resistance to weather, and its brown, red, and bluish colors are very pleasing. Quarry sites for both the Clinch and the Sevier strata are available along the various gaps in the Bays Mountains. At all the stream gaps in the Bald Mountain region also there are suitable quarry sites for the various Cambrian quartzites.

Road material.—Material for building roads is found in all the limestone formations of the region, in the sandstone and quartzite beds, and in some of the shales. The limestones are most available because of their wide distribution. The ease with which they are broken and their power of recementation make them the best road material in the region. The Rome and Rogersville shales, which are argillaceous and sandy, make smooth roadways that afford excellent drainage, although the material is not especially durable. Outcrops of the Rogersville shale are commonly used as a road location. One of the best road materials is the chert or "flint" of the Knox dolomite, and on the more cherty ridges it forms natural roadbeds. It is used for road making in the northeastern part of the Nolichucky plateau. The chert fragments are sharp, pack together firmly, and are nearly indestructible, and the open structure resulting from its use keeps the roadbed well drained and firm, even in the wettest weather.

Iron.—Ores of iron occur in this region in only one form of importance—as deposits in the residual clays of the limestone formations. Another form of occurrence of iron, which can scarcely be be called an ore, is seen in some of the layers of the Cambrian quartzites in the Bald Mountain region. They consist of red and brown sandstones and quartzites in which the spaces between the sand grains are filled with red and brown hematite. In a few places banks of lean ore are concentrated from these in the residual soils. They have been opened only in prospecting and are of little importance.

Another form in which iron ore occurs consists of deposits of limonite in the shales of the lower Cambrian rocks. They are most noticeable in the shale layers in the upper part of the quartzite series and near the Shady limestone. Typical deposits of these ores occur on Meadow Creek Mountain and in the ridges around the lower part of Clark Creek. They consist of thin crusts and seams of limonite in the shales and are of no special importance.

The chief deposits of iron ore are the brown hematite and limonite which occur in the residual clays of the Knox dolomite and the Shady limestone. In both cases the ore is distributed through the residual clay in lumps of varying sizes up to 2 feet in diameter, most of them being much smaller. The ores connected with the Knox dolomite clays are irregular in distribution, but seem to be associated with the upper part of the limestone. The banks are comparatively small and none are now worked in this quadrangle. The principal ores of the region are those associated with the Shady limestone. Deposited with them here and there are manganese oxide and hydrate, in places sufficient to constitute an ore of that metal. Two areas of this formation are included within this quadrangle, each being part of a more extensive area. That which lies south of Haysville contains few ore banks of importance, although iron ore in small quantities is widely distributed throughout the region underlain by the limestone. Near Haysville considerable ore was taken out and smelted in the old furnace at that place, but operations there were long ago discontinued. In the extension of this area toward the southwest the bodies of ore become larger. The second area of this formation lies at the head of Bumpass Cove, the upper end of which is included in this quadrangle. Mining operations there have been carried on intermittently for many years, and a large amount of ore has been taken out. The limestone there occupies a synclinal fold on the Cambrian quartzites, a structural relation which develops the most ore in this formation. The ore banks are numerous and extensive, and the ore is distributed through the residual clay down to the surface of the eroded limestone. This ore has long been known for its good quality, is free from sulphur and phosphorus, and makes excellent iron. The ore appears to be, in part, at least, due to downward concentration in the bottom of the synclinal basin.

Zinc.—Ores of this metal occur in one place in the quadrangle—2 miles northeast of Fall Branch, in Sullivan County. The deposit there consists of calamine and blende, and lies in a vein, about 5 feet thick, that is associated with brecciated Knox dolomite. The vein dips toward the south at an angle of 45° and has been but little developed. It lies near one of the principal faults of the region, but has no apparent connection with it.

Lime.—Many beds in the Knox dolomite, the Chickamauga limestone (especially the marble), and the Cambrian limestones furnish excellent material for lime. These formations are widely distributed and are burned for local use when needed. The lime is of excellent quality, but the demand for it is small. Thus far its only use has been for building; it is never used as a fertilizer in this region.

Brick clay.—Suitable clays for brick making are found in great abundance in this region. They are derived from the wash of the residual clays, chiefly the Knox dolomite and the Athens and Sevier shales. They collect in depressions of the surface near or upon these formations, and are very widely distributed. The suitability of the material is largely determined by the slopes of the surface. The finer, purer deposits are found in basins that are surrounded by very gentle slopes. On the low ground of Lick Creek and Holston Valley, where the grades are very slight, good clays are widespread and deep. Only local use has been made of these clays, and bricks have been burnt in the immediate neighborhood of the buildings to be erected.

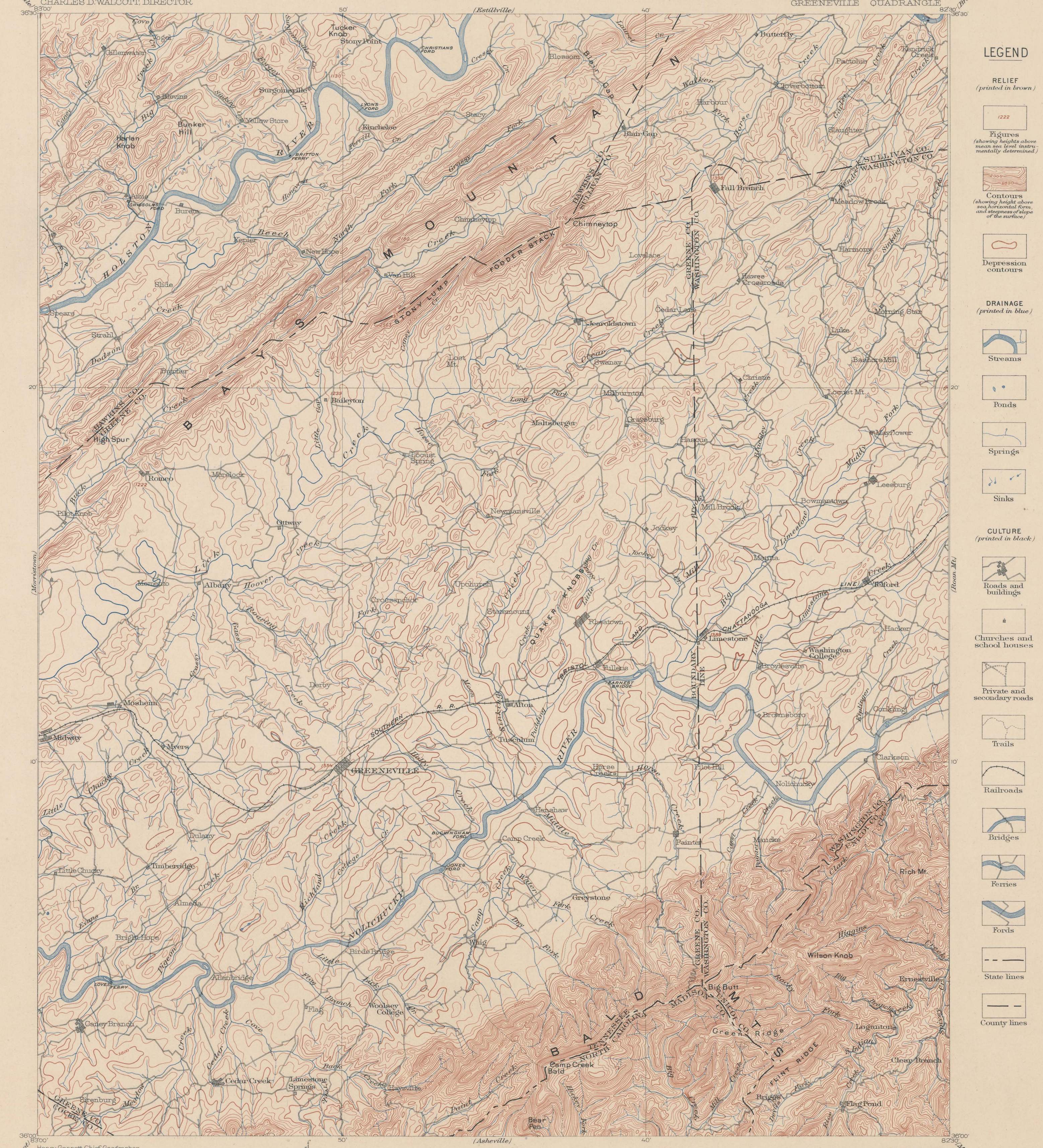
Water power.—A great natural resource of this region, and one but little used as yet, is its water power. The supply of water in most of the streams is abundant and fairly constant. The stream grades are usually heavy, and the fall is frequently concentrated within narrow limits. Along four belts this is particularly the case, these being the Bald Mountain district, the basin of the Nolichucky for 4 or 5 miles on each side of the stream, a belt about 2 miles wide where the Knox dolomite rises above Lick Creek Valley, and a belt lying northwest of the Holston and extending for a few miles along that stream. Along all these lines high grades are maintained by the harder rocks against the wear of the streams. From the northeast part of this quadrangle to the vicinity of Greeneville the difference in hardness between the Athens shale and the Knox dolomite along the border of Lick Creek Valley produces many falls of considerable height. In the Bald Mountains the hardness of the quartzites causes heavy grades, and near the large rivers grades are steepened by the canyon cutting of the streams. This great power is used only here and there in gristmills and still more rarely sawmills. In the future the fall of the streams will no doubt be utilized for manufactures and for power plants of great value.

June, 1903.

U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

TOPOGRAPHY

TENNESSEE - NORTH CAROLINA
GREENEVILLE QUADRANGLE



Henry Gannett, Chief Geographer.
Gilbert Thompson, Geographer in charge.
Triangulation by W. C. Kerr, S. S. Gannett, and F. M. Pearson.
Topography by R. O. Gordon and R. L. Longstreet.
Surveyed in 1883-84, 1888 and 1891.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

Edition of Sept. 1904.

U.S. GEOLOGICAL SURVEY
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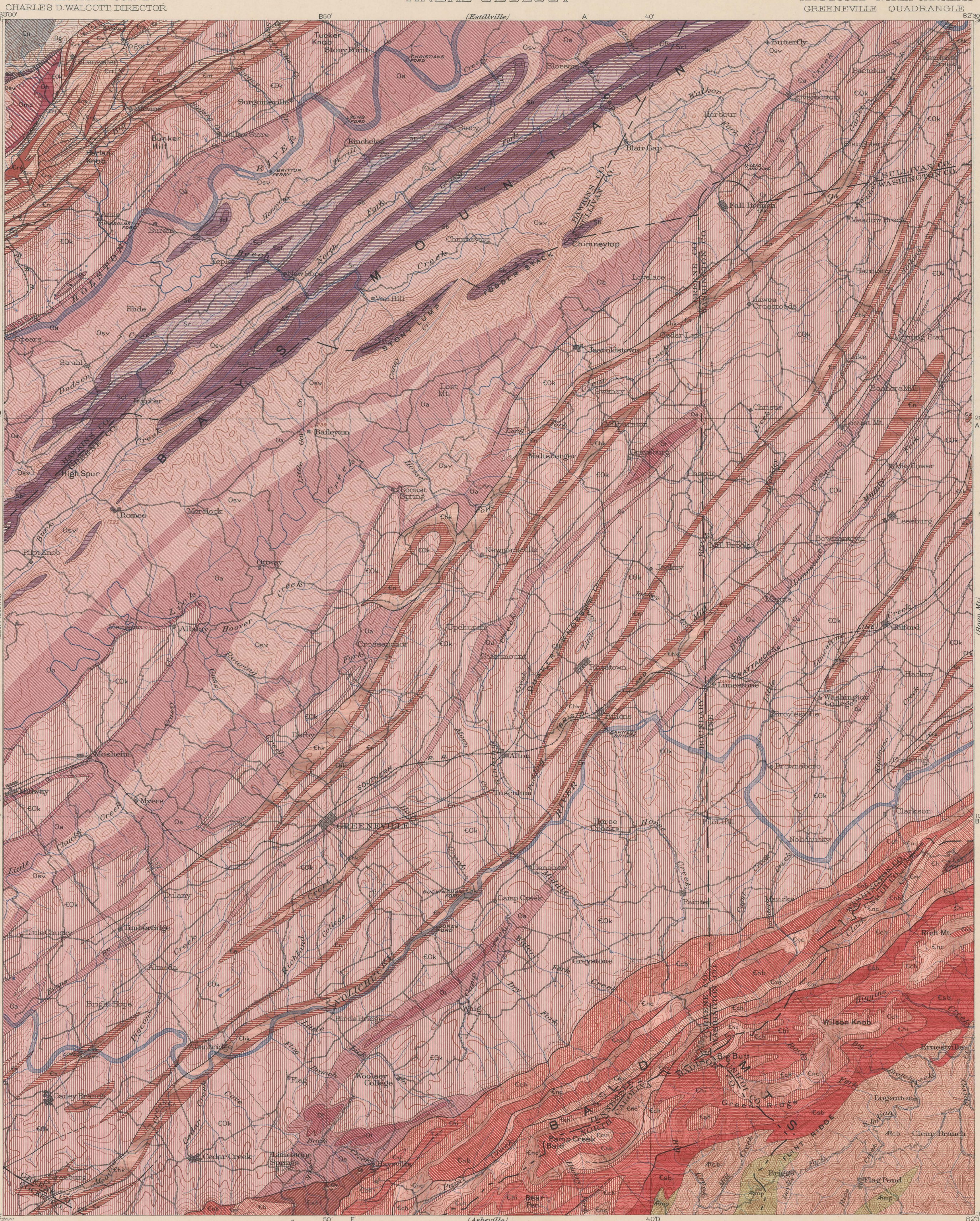
AREAL GEOLOGY

TENNESSEE – NORTH CAROLINA
GREENEVILLE QUADRANGLE



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MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

Edition of Nov. 1904

Geology by Arthur Keith, assisted by A. C. Lane.
Surveyed in 1888-1891, 1900, and 1901.

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines)

CARBONIFEROUS

- Cn — Newman limestone *(bluish shaly and massive limestones)*

DEVONIAN

- Dg — Grainger shale *(grayish sandstone and sandy shale)*
- Dc — Chattanooga shale *(carbonaceous black shale)*

UNCONFORMITY

SILURIAN

- Sr — Rockwood formation *(variegated sandy and calcareous shales)*
- Scl — Clinch sandstone *(massive white sandstone)*
- Sb — Bays sandstone *(red calcareous and argillaceous sandstone)*

ORDOVICIAN

- Osv — Sevier shale *(calcareous sandstone, sandy shale, calcareous shale, and limestone)*
- Omc — Moccasin limestone *(red and green argillaceous limestone)*
- Ot — Tellico sandstone *(red and gray calcareous sandstone)*
- Oh, Oc — Chickamauga limestone and Holston marble lentil *(reddish variegated marble)*
- Oa — Athens shale *(blue and black calcareous shale)*

CAMBRIAN

- €Ok — Knox dolomite *(magnesian limestone, massive and cherty)*
- €n — Nolichucky shale *(variegated calcareous shale and thin limestones)*
- €m — Maryville limestone *(massive blue limestone)*
- €rg — Rogersville shale *(greenish clay shale with limestone layers)*
- €rt — Rutledge limestone *(massive dark-blue limestone)*
- €hk — Honaker limestone *(massive blue and gray limestones)*
- €r, €rs — Rome formation including sandstone lentil at base *(red, green, and brown sandy shale and sandstone)*

SEQUENCE BROKEN

- €sh — Shady limestone *(grayish limestone with chert)*
- €h — Hesse quartzite *(massive white quartzite)*
- €mr — Murray slate *(bluish and gray slate)*
- €nb — Nebo quartzite *(massive white quartzite)*
- €nc — Nichols slate *(bluish and gray slate)*
- €ch — Cochran conglomerate *(white sandstone, quartzite, and conglomerate)*
- €hi — Hiwassee slate *(chiefly dark, banded slate with sandy beds and layers of limestone)*
- €sb — Snowbird formation *(chiefly light-colored quartzite and sandstone; includes beds of slate, conglomerate, and arkose)*

Legend is continued on the left margin.

LEGEND
(continued)

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

ARCHEAN

- Ʀmp — Max Patch granite *(coarse or porphyritic granite, whitish to red in color)*
- Ʀcb — Cranberry granite *(chiefly granite and granite-gneiss)*

Faults

Sections

⚒ *Lead and zinc mine*
× *Iron prospects*

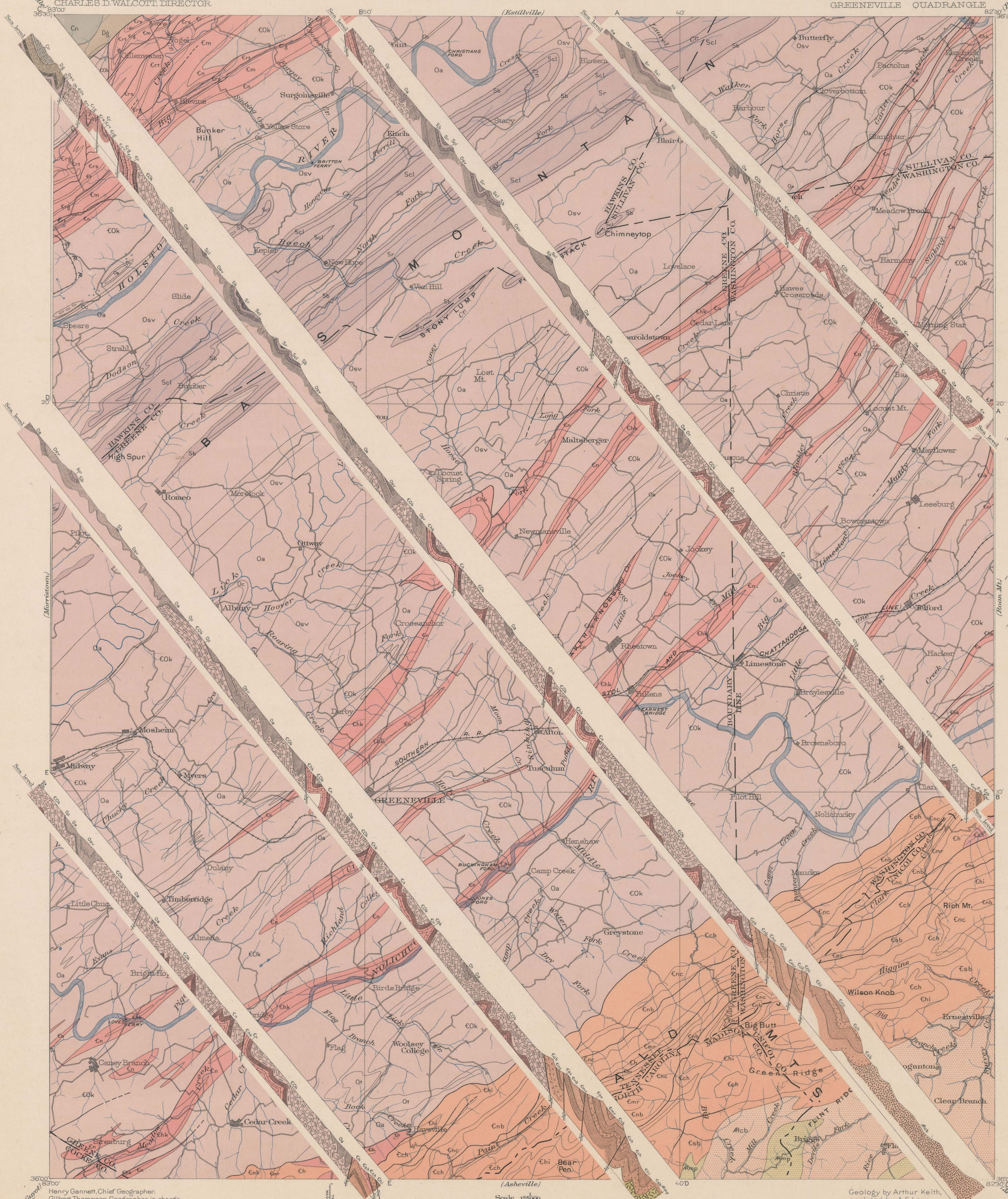
Known productive formations

- *Marble*
- *Brown hematite (residual clay of Shady limestone contains irregular deposits of limonite or brown hematite)*

U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STRUCTURE SECTIONS

TENNESSEE - NORTH CAROLINA
GREENEVILLE QUADRANGLE



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LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

CARBONIFEROUS

- Cn — Newman limestone (bluish shaly and massive limestone)

DEVONIAN

- Dg — Grainger shale (grayish sandstone and sandy shale)
- Dc — Chattanooga shale (carbonaceous black shale)

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- Oh, Oc — Chickamauga limestone and Holston marble lentil (reddish variegated marble)
- Oa — Athens shale (blue and black calcareous shale)
- Є0k — Knox dolomite (magnesian limestone, massive and cherty)

CAMBRIAN

- Єn — Nolichucky shale (variegated calcareous shale and thin limestones)
- Єm — Maryville limestone (massive blue limestone)
- Єrg — Rogersville shale (greenish clay shale with limestone layers)
- Єrt — Rutledge limestone (massive dark-blue limestone)
- Єhk — Honaker limestone (massive blue and gray limestone)
- Єr, Єrs — Rome formation including sandstone lentil at base (red, green, and brown sandy shale and sandstone)

SEQUENCE BROKEN

- Єsh — Shady limestone (grayish limestone with chert)
- Єh — Hesse quartzite (massive white quartzite)
- Єmr — Murray slate (bluish and gray slate)
- Єnb — Nebo quartzite (massive white quartzite)
- Єnc — Nichols slate (bluish and gray slate)
- Єch — Cochran conglomerate (white sandstone, quartzite, and conglomerate)
- Єhi — Hiwassee slate (chiefly dark, banded slate, with sandy beds and layers of limestone)
- Єsb — Snowbird formation (chiefly light-colored quartzite and sandstone; includes beds of slate, conglomerate, and arkose)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

ARCHEAN

- Æmp — Max Patch granite (coarse or porphyritic granite, whitish to red in color)
- Æcb — Cranberry granite (chiefly granite and granite-gneiss)

Faults

COLUMNAR SECTIONS

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS IN THE EXTREME NORTHWEST CORNER OF THE GREENEVILLE QUADRANGLE.

SCALE: 1 INCH=1000 FEET.

System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Soils and Surface.
CARBONIFEROUS	Newman limestone.	Cn		1600+	Blue and gray shaly limestone. Massive blue limestone with cherty layers.	Broad, rounded knobs and hills. Narrow depressions.
DEVONIAN	Grainger shale.	Dg		1150–1200	Bluish-gray sandy shale and thin sandstone.	Straight, even ridges with round tops and many gaps. Thin, sandy and rocky soil.
	Chattanooga shale.	Dc		400	Fine black carbonaceous shale.	Deep, narrow valleys. Thin, yellow clay soil.
	UNCONFORMITY					
SILURIAN	Clinch sandstone.	Scl		300–500	Massive white sandstone.	Sharp, high ridges and mountains. Scanty, sandy soil.

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS IN THE GREAT VALLEY, GREENEVILLE QUADRANGLE.

SCALE: 1 INCH=1000 FEET.

System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Soils and Surface.
SILURIAN	Rockwood formation.	Sr		700+	Green, red, and yellow, sandy and calcareous shale.	Open, rolling valleys. Thin, rather sandy soil.
	Clinch sandstone.	Scl		300–500	Massive white sandstone.	Sharp, high ridges and mountains. Scanty, sandy soil.
	Bays sandstone.	Sb		50–400	Massive and shaly red sandstone.	High, rounded ridges and steep slopes. Thin, red, sandy soil.
ORDOVICIAN	Sevier shale.	Osv		1300–1800	Calcareous sandstones and shales. Bluish, gray, and yellow calcareous shale and shaly limestone.	High, rounded knobs and ridges. Irregular knobs and ridges and rolling valleys. Thin, yellow clay soil.
	Tellico sandstone.	Ot		2–200	Red and gray calcareous sandstone.	Round knobs. Light sandy soil.
	Athens shale.	Oa		1000±	Black and bluish-black calcareous shale.	Sharp, steep knobs in upper portion; low, narrow valleys in lower portion. Thin, yellow clay soil.
	Moccasin limestone.	Omc		450–500	Red, blue, gray, and drab, massive and shaly limestone.	Valleys and areas of low knobs. Deep, red and yellow clay soil.
	Holston marble lentil. Chickamauga limestone.	Oh Oc		0–450	Blue and gray limestone, shaly in part, and variegated marble.	Valleys and low ground. Deep, red and brown clay soil.
?	Knox dolomite.	ꞒOk		3000–3500	Magnesian limestone; light- and dark-blue, white, and gray, with nodules and layers of chert and a few beds of calcareous sandstone.	Broad ridges and irregular rounded hills. Deep, red clay soil mingled with chert.
CAMBRIAN	Nolichucky shale.	Ꞓn		500–750	Yellow, green, and brown calcareous shale with limestone beds.	Steep slopes or narrow sharp ridges. Thin, yellow clay soil.
	Honaker limestone, Ꞓhk: Maryville limestone.	Ꞓm		700–950	Massive dark-blue and dark-gray limestone.	Open valleys and slopes of knobs. Deep, red clay soil.
	Honaker limestone, Ꞓhk: Rogersville shale.	Ꞓrg		180–200	Bright-green clay shales with thin limestone beds.	Lines of low knobs. Thin, red and yellow clay soil.
	Honaker limestone, Ꞓhk: Rutledge limestone.	Ꞓrt		400–450	Massive dark-blue limestone with shale beds at bottom.	Open valleys. Deep, red clay soil.
	Rome formation. Sandstone lentil.	Ꞓr Ꞓrs		200± 400±	Red, green, and brown shale and sandy shale. Red, white, and brown sandstone and sandy shale.	Slopes of sandstone ridges. Light, sandy soil. Sharp ridges with notches and gaps.

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS IN THE BALD MOUNTAINS, GREENEVILLE QUADRANGLE.

SCALE: 1 INCH=1000 FEET.

System.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Soils and Surface.
CAMBRIAN	Shady limestone.	Ꞓsh		1000±	Gray, bluish-gray, mottled-gray, and white limestone with nodules and masses of chert.	Valleys and low hills. Deep clay soil, dark red and cherty.
	Hesse quartzite.	Ꞓh		700–800	Massive white quartzite and sandstone.	High, sharp mountains and ridges. Thin, sandy and rocky soil.
	Murray slate.	Ꞓmr		300–400	Bluish-gray to gray, argillaceous and sandy shale and slate, with thin sandstone seams.	Depressions and slopes of quartzite mountains. Light, sandy soil.
	Nebo quartzite.	Ꞓnb		200–900	Massive white quartzite and sandstone, coarse and fine, with a few layers of sandy shale and reddish sandstone.	High, sharp mountains, with cliffs. Thin, sandy and rocky soil.
	Nichols slate.	Ꞓnc		400–700	Bluish-gray to gray, argillaceous and sandy shale and slate, with thin sandstone layers.	Depressions between quartzite crests. Light, sandy soils.
	Cochran conglomerate.	Ꞓch		200–1600	Massive quartz conglomerate and quartzite, light- and dark-gray, with seams of dark slate.	High butts and mountains. Thin, rocky and sandy soil.
	Hiwassee slate.	Ꞓhi		1200–1500	Blue, gray, black, and banded slate, with a little fine mica-schist. Includes layers of sandstone and conglomerate and beds of calcareous sandstone.	Slopes of quartzite mountains, or low hilly ground. Thin, clayey or sandy soil.
	Snowbird formation.	Ꞓsb		700–2000	Gray and white feldspathic quartzite and sandstone with dark slate beds. Locally becomes conglomerate and dark purplish sandstone. Coarse and fine quartz conglomerate and arkose.	High, irregular mountains and butts, with round summits. Thin, sandy soil.
	UNCONFORMITY					
ARCHEAN	Granites.				Descriptions given in table below.	Descriptions given in table below.

GENERALIZED TABLE OF THE IGNEOUS ROCKS, ARRANGED IN ORDER OF AGE, IN THE GREENEVILLE QUADRANGLE.

System.	Formation Name.	Symbol.	Lithologic Pattern.	Character of Rocks.	Character of Soils and Surface.
ARCHEAN	Max Patch granite.	Æmp		Very coarse biotite-granite, usually massive, but in places porphyritic and altered to augen-gneiss. Colors unusually light gray in the eastern areas and reddish in the western.	High, irregular mountains with steep slopes and broad, round summits. Red and brown clayey soils, with many ledges.
	Cranberry granite.	Æcb		Biotite-granite and granite-gneiss, coarse and fine; colors, light gray, dark gray, and white. Includes dikes of schistose and unaltered diabase, fragments of hornblende-gneiss, and dikes of unaltered, fine biotite-granite.	High, irregular mountains, peaks, and spurs, with round summits. Red and brown clayey soils, with many ledges.

NAMES OF FORMATIONS.

System.	Arthur Keith, Knoxville Folio, U. S. Geological Survey, 1895.	Arthur Keith, Asheville Folio, U. S. Geological Survey, 1905.	Names and Symbols used in This Folio.		M. R. Campbell, Estillville Folio, U. S. Geological Survey, 1894.
Carb.	Newman limestone.		Newman limestone.	Cn	Newman limestone.
Devonian	Grainger shale.		Grainger shale.	Dg	Grainger shale.
	Chattanooga shale.		Chattanooga shale.	Dc	Chattanooga shale.
Silurian			Rockwood formation.	Sr	Rockwood formation.
			Clinch sandstone.	Scl	Clinch sandstone.
	Bays sandstone.		Bays sandstone.	Sb	Bays sandstone.
Ordovician	Sevier shale.		Sevier shale.	Osv	Sevier shale.
	Tellico sandstone.		Tellico sandstone.	Ot	
	Athens shale.	Athens shale.	Athens shale.	Oa	
			Moccasin limestone.	Omc	Moccasin limestone.
	Holston marble lentil.		Holston marble lentil.	Oh	
	Chickamauga limestone.		Chickamauga limestone.	Oc	Chickamauga limestone.
	Knox dolomite.	Knox dolomite.	Knox dolomite.	ꞒOk	Knox dolomite.
? Cambrian	Nolichucky shale.	Nolichucky shale.	Nolichucky shale.	Ꞓn	Nolichucky shale.
	Maryville limestone.	Honaker limestone.	Honaker limestone: Maryville limestone.	Ꞓm	Maryville limestone.
	Rogersville shale.		Honaker limestone: Rogersville shale.	Ꞓrg	Rogersville shale.
	Rutledge limestone.		Honaker limestone: Rutledge limestone.	Ꞓrt	Rutledge limestone.
	Rome formation. Beaver limestone. Apison shale.	Watauga shale.	Rome formation.	Ꞓr	Russell formation.
		Shady limestone.	Shady limestone.	Ꞓsh	
	Hesse sandstone.	Hesse quartzite.	Hesse quartzite.	Ꞓh	
	Murray shale.	Murray slate.	Murray slate.	Ꞓmr	
	Nebo sandstone.	Nebo quartzite.	Nebo quartzite.	Ꞓnb	
	Nichols shale.	Nichols slate.	Nichols slate.	Ꞓnc	
	Cochran conglomerate.	Cochran conglomerate.	Cochran conglomerate.	Ꞓch	
	Sandsuck shale.	Hiwassee slate.	Hiwassee slate.	Ꞓhi	
		Snowbird formation.	Snowbird formation.	Ꞓsb	
Archean		Max Patch granite.	Max Patch granite.	Æmp	
		Cranberry granite.	Cranberry granite.	Æcb	

ARTHUR KEITH,

Geologist.

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