DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

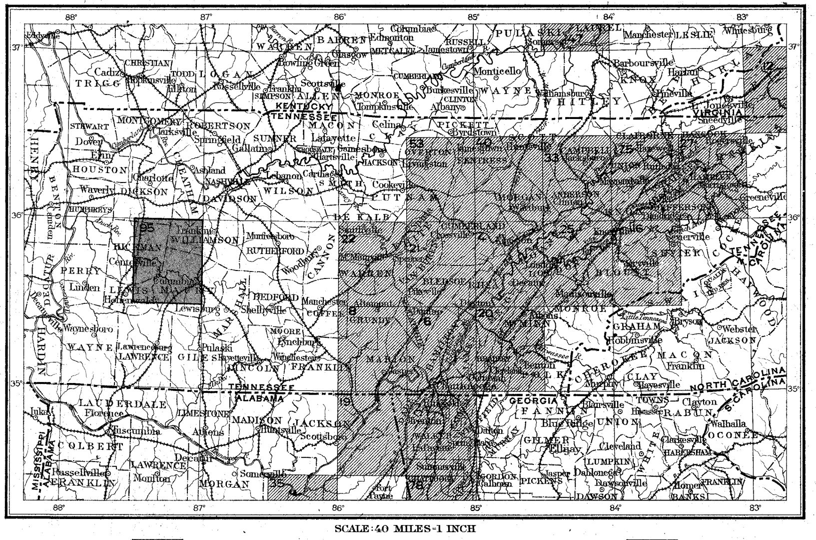
OF THE

UNITED STATES

COLUMBIA FOLIO

TENNESSEE

INDEX MAP



SCALE: 40 MILES=1 INCH

AREA OF THE COLUMBIA FOLIO

AREA OF OTHER PUBLISHED FOLIOS

CONTENTS

LIBRARY EDITION

COLUMBIA FOLIO
NO. 95

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
1903

EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical 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:

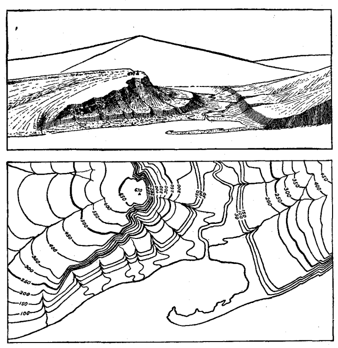


Fig. 1.—Ideal sketch and corresponding contour map.

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 in a precipice. Contrasted with this precipice is the gentle descent of the slope at 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 approximately a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all 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 nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The 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 vertical 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 used 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.—Water courses are indicated by blue lines. If the streams flow the year round 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, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be 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 of "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

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 and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,000}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory 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-quarter of a square degree; each sheet on a 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, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or 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 sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it may consolidate in cracks or fissures crossing the bedding planes, thus forming dikes, or spread out between the strata in large bodies, called sheets or laccoliths, or form large irregular cross-cutting masses, called stocks. Such rocks are called *intrusive*. Within their rock inclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock it is younger than that rock, and when a sedimentary rock is deposited over it the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive 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 over wide expanses, and as it rises or subsides the shore lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

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

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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 formations are remote one from the 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 rocks of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions and groups of the periods, frequently used in geologic writings, are bracketed against the appropriate period names.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the one at the top of the column (Pleistocene) and the one at the bottom (Archean). The sedimentary formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint is printed evenly over the whole surface representing the period; a dark tint brings out the different patterns representing formations. Each formation is furthermore given

Period.		Symbol.	Color.
Cenozoic	Pleistocene	P	Any colors.
	Neocene { Pliocene / Miocene }	N	Buffs.
	Eocene, including Oligocene	E	Olive-browns.
Mesozoic	Cretaceous	K	Olive-greens.
	Juratrias { Jurassic / Triassic }	J	Blue-greens.
Paleozoic	Carboniferous, including Permian	C	Blues.
	Devonian	D	Blue-purples.
	Silurian, including Ordovician	S	Red-purples.
	Cambrian	Є	Pinks.
	Algonkian	A	Orange-browns.
	Archean	Æ	Any colors.

a letter-symbol composed of the period letter combined with small letters standing for the formation name. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations, chiefly Pleistocene, render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the metamorphic rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology sheet.—This sheet 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 particular colored pattern and its letter-symbol on the map 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet 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 symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

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 name 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 the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting 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:

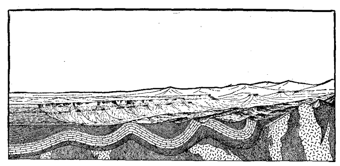


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane, so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section 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:

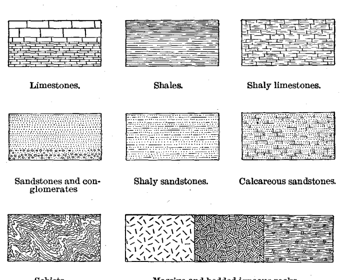


Fig. 3.—Symbols used to represent different kinds of rock.

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 beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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*.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. 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 regarded as proof that forces exist which 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 slipped past one another. Such breaks are termed *faults*.

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

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the 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 swelled upward 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 strata thus rest upon an eroded surface of older strata 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 this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration 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, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond 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 rock formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thicknesses of the formations, and the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given in figures which state the least and greatest measurements. The average thickness of each formation 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 is placed at the bottom of the column, the youngest at the top, and igneous rocks or surficial deposits, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

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

CHARLES D. WALCOTT,
Director.

Revised January, 1902.

DESCRIPTION OF THE COLUMBIA QUADRANGLE.

By C. Willard Hayes and Edward O. Ulrich.

GENERAL RELATIONS.

The Columbia quadrangle embraces 969 square miles, lying wholly within the State of Tennessee and extending from latitude 35° 30′ on the south to 36° on the north and longitude 87° on the east to 87° 30′ on the west. The name is derived from Columbia, the county seat of Maury County. About two-thirds of the area is embraced in Maury and Hickman counties, but it includes also portions of the adjoining counties of Lewis, Dickson, Williamson, and Davidson.

The quadrangle lies within the Ohio Basin, which forms the westernmost division of the Appalachian province. The Ohio Basin embraces the greater part of the Cumberland Plateau, the Allegheny Mountains, and the lowlands of middle and western Tennessee, Kentucky, and Ohio. Its northwestern boundary is indefinite, but may be regarded as extending from the Mississippi River at Cairo in a northeasterly direction across the States of Illinois, Indiana, and Ohio to the western end of Lake Erie.

When contrasted with the profoundly folded strata of the Appalachian Valley, the rocks of this region may be classed as horizontal, but, strictly speaking, they are rarely in this position, the beds being generally more or less inclined in varying directions.

The most important structural feature of the Ohio Basin is a broad fold in the strata known as the Cincinnati arch or geanticline. The northern end of this arch has two branches which diverge in western Ohio, one extending northwestward toward Chicago, the other northward through Toledo. These two branches of the Cincinnati arch are of great economic importance, since they afford conditions favorable for the accumulation of gas and oil in western Ohio and central Indiana. From Cincinnati the arch extends southward through Lexington and Danville, Ky., and thence southwestward through the Central Basin of Tennessee. This portion of the arch south of Cincinnati is divided into two dome-like uplifts, of which the northern has its greatest development between Lexington and Danville, Ky., and the southern near the center of Bedford County, Tenn. In both cases the dip of the strata from the summits of the domes is steeper toward the south than toward the north. The Cincinnati arch divides the Ohio Basin into two broad, shallow structural basins, both of which contain coal measures. The Appalachian coal field lies on the east and the Eastern Interior coal field on the west. In addition to these broad structural features the strata of the Ohio Basin exhibit almost everywhere more gentle folds, and in places they have been broken by faults. Faults, however, are not common, nor are they very large, the displacement rarely exceeding 500 feet.

TOPOGRAPHY OF THE OHIO BASIN.

The altitude of this division is greatest along its southeastern margin, where the mountainous belt, including the escarpments of the Cumberland Plateau and the Cumberland and Allegheny Mountains, rises from 500 feet at its southwestern extremity in Alabama to 2000 feet at Chattanooga, 3500 feet in the vicinity of Cumberland Gap, and from 2000 to 4000 feet in eastern Kentucky and West Virginia. From this line of maximum elevation the surface descends toward the west to less than 500 feet along the western border. This descent is effected mainly by a series of steps or escarpments marking the extent of particularly resistant beds of rock. The highest and most pronounced of these escarpments is along the western margin of the Appalachian coal field. In Kentucky, this escarpment separates the interior plain from the higher and more hilly region of the coal field, and in Tennessee forms a division line between the eastern Highland Rim and the Cumberland Plateau. In Tennessee the escarpment is steep and regular and the plateau is very perfectly preserved, but in Kentucky the rocks were not hard enough to protect the plain after it was uplifted, and as a consequence it has been deeply dissected by the numerous streams which drain its surface, producing a hilly region in place of a plateau, and an irregular margin instead of an escarpment.

The interior plain of Kentucky is continuous with both the eastern and western highlands of Tennessee, and also with much of the highest land in Ohio and Indiana. Its general elevation along the western margin of the Appalachian coal field is about 1000 feet above sea level, but toward the west it descends to somewhat lower levels.

The principal streams draining the Ohio Basin have cut deep channels below the surface of the plain, producing in their immediate vicinity a rugged topography in place of the original gently undulating surface. In central Tennessee the erosion has been especially active, and since the rocks exposed to the action of the streams are soft, the highland surface has been entirely removed and a second plain formed at a lower level. This lower plain is particularly well developed in the vicinity of Nashville, and is known as the Central Basin of Tennessee.

Since the formation of the lowland which occupies the Central Basin, the land has been again elevated and the streams have cut deep channels in its surface and have deepened their old valleys in the surrounding highland region.

TOPOGRAPHY OF THE COLUMBIA QUADRANGLE.

The Central Basin of Tennessee has a gently undulating surface whose altitude is about 600 feet. It is entirely surrounded by a more or less deeply dissected plateau known as the Highland Rim, the surface of which is about 1000 feet above sea level. The outline of the basin is extremely irregular. Outliers from the surrounding plateau extend far out into the basin in the form of spurs and isolated hills. The Columbia quadrangle is located upon the western margin of the basin, somewhat over three-fourths of its surface being occupied by the highlands which bound the basin on the west. The character of the Central Basin is represented by the gently undulating lowlands which extend from Columbia to Mount Pleasant. The hills south of Columbia are more or less completely isolated outliers of the highlands of the west.

The larger part of the quadrangle lies within the drainage basin of Duck River, which crosses it from southeast to northwest a little south of its center. A small area in the northeastern portion of the quadrangle is drained by the headwaters of Harpeth Creek. Numerous tributaries enter Duck River from either side, the largest being Big Bigby, Hampshire, and Swan creeks on the south, and Piney River and Lick, Leipers, and Snow creeks on the north. These streams, with their tributaries, have deeply dissected the central and southern portions of the quadrangle. They are characterized by rather narrow, level valleys, with steep slopes to the intervening ridges. In the northern portion of the quadrangle the surface is less dissected, and considerable areas are found with comparatively level surfaces, the higher portions of which rise to nearly 1000 feet above sea level.

A careful study of the topography of this region shows clearly that the present surface is the result of the dissection of a level or gently undulating plain, which, if restored, would have an altitude of between 900 and 1000 feet. This restored plain, extended eastward, would coincide with the summits of the hills and spurs about the margin of the Central Basin and with the surface of the Highland Rim at its eastern edge. Such a continuous plain doubtless at one time existed over this region. It was probably produced by the slow process of subaerial erosion, and, when formed, it occupied a position near sea level. Throughout its entire extent, so far as it was developed within the limits of Tennessee, its surface was probably occupied by the basal cherty member of the Lower Carboniferous. This cherty member, however, was very much thinner in the region now occupied by the Central Basin, since the beds had there been lifted by the doming of the Cincinnati arch and largely removed. When, therefore, the region was again uplifted, and the streams began to cut their channels, the limestone which underlies the Carboniferous chert was first encountered by these streams upon the summit of this dome. The limestones are much more easily eroded than the cherts, and hence the lowering of the surface went on most rapidly where the protecting cover of the cherts was thinnest. In this way the Central Basin of Tennessee was developed by Duck River and other streams which now head upon the lowlands of this basin and flow westward through narrow valleys, cutting down into the more resistant cherts. The elevation of the region to its present altitude was not continuous, but occurred at several periods, separated by intervals of repose. The downward cutting of the streams was correspondingly interrupted. Thus Duck River cut a rather broad valley down to about 400 feet below the surface of the old plain, and, when the region was again uplifted, cut a much narrower valley within this broad one. The remnants of the broader valley are now found as terraces at various points along Duck River, their surfaces showing a gradual descent downstream from about 600 feet in the vicinity of Columbia to 550 feet at Centerville.

At some time near the period when the formation of the older plain above described was practically completed, the region appears to have been depressed slightly, and its streams made considerable deposits of coarse gravel. These are most abundant along the western edge of the quadrangle, and the streams by which they were deposited do not appear to have coincided with the main drainage lines as at present developed. The gravels are thoroughly waterworn, and are composed in part of chert and in part of vein quartz. The origin of the vein quartz is difficult to explain, as no rock of this character now occurs in the drainage basin of Duck River. These gravels are probably to be correlated with similar deposits which extend around the margin of the Appalachian province from southern Illinois to New Jersey, and may represent deposits made by streams upon their flood plains at or slightly above sea level.

GEOLOGY.

DESCRIPTION OF FORMATIONS.

The formations occurring in the Columbia quadrangle are represented in the generalized columnar sections, and their age relative to corresponding beds in adjacent portions of the Ohio Basin is indicated in the Correlation Table. The rocks are all of sedimentary origin, and represent deposition extending through portions of the Silurian, Devonian, and Carboniferous periods.

SILURIAN SYSTEM.

ORDOVICIAN.

Lebanon limestone.—This formation consists of thin-bedded, compact limestones and thin seams of shale, yellow, light gray, dove colored, or bluish, and often very fossiliferous. In the quadrangle it has an average thickness of about 125 feet, but none of its outcrops, all of which occur in the southeastern quarter of the quadrangle, expose the basal part. Ordinarily its presence is indicated by bare rocky surfaces and dense growths of cedars. Where covered by the massive Carters limestone and subjected to rapid stream erosion, as along Duck River at Columbia, it forms bold cliffs. It is the formation with which the red cedar glades of middle Tennessee are most commonly associated, and in Safford's Geology of Tennessee (1869), it is called "Glade limestone."

The type locality for the limestone is Lebanon, Tenn. It and the overlying Carters limestone belong to Safford's original Stones River group. The three other members of this group, in descending order, are the Ridley limestone, the Pierce limestone, and the Murfreesboro limestone. None of these outcrop within the quadrangle.

Carters limestone.—This, the uppermost division of the Stones River group, is composed of whitish-gray or light-blue, compact, heavy-bedded limestone, varying between 50 and 60 feet in thickness. It takes its name from Carters Creek, a stream draining a considerable area near the eastern border of the quadrangle. Along the lower end of the valley of this stream the formation is well exposed. Equally good or better exposures occur in the bluffs of Rutherford Creek and Duck River, and in them it often presents a castellated appearance, with striking turret-like projections. In ordinary surface exposures it is distinguished at once from other Ordovician formations by the eroded bowlder-like white masses sticking out of the red clay soil which it forms on decomposition. Most of the outcrops of Carters limestone in this quadrangle are portions of a large area on which the greater part of the town of Columbia is situated. There are besides a number of other areas, generally of limited extent, where the rock has been brought up by local uplifts. A number of these occur near the southeast corner of the quadrangle, and two others just south of its center, in the banks of Duck River. Finally, Hampshire is in part situated on one and Sawdust Valley on another, while a third occurs on Snow Creek near Santa Fe, on the south side of a small east-west fault.

As stated above, the average thickness of the formation is from 50 to 60 feet, but in some of the areas mentioned it is less than 40 feet, while the maximum thickness for middle Tennessee falls little, if any, short of 100 feet. These differences are not wholly due to variation in amount originally deposited. On the contrary, it appears that the thickness was originally much more uniform and that the greater part of the differences noted is the result of erosion and denudation prior to the deposition of the succeeding formation. In the northern and northeastern portions of the Central Basin of Tennessee the Carters limestone has generally 10 to 20 feet of shaly, thin-bedded limestone at the top, resembling the Lebanon limestone both in appearance and fauna. This bed is followed by arenaceous shale of the Hermitage formation, which, like the top member of the Carters limestone, is wholly wanting in other localities. Other evidence of erosion unconformity is presented by a thin bed of ferruginous conglomerate which often occurs at the base of the Hermitage. The wide and even distribution of the Stones River group, which includes the Carters and Lebanon limestones, as shown in the Correlation Table, and the erosion unconformity at its top clearly indicate that the Cincinnati geanticline was elevated above sea level, probably for the first time, at the close of the Stones River epoch.

The fauna of the Carters limestone, though very characteristic, is not a large one, and, excepting a few species, the forms found are generally rare. The fossils freed from the rock by natural means are always silicified.

Hermitage formation.—This formation consists of thin-bedded to medium-bedded, fine-grained to granular limestone and shale, with a fairly constant thickness throughout the quadrangle of 40 to 70 feet. The basal portion as here developed is usually made up of 12 to 20 feet of thin, even-bedded, argillaceous and siliceous blue limestone layers, separated by seams of gray or bluish shale. These are followed by heavier-bedded, siliceous, subgranular limestones, which occasionally include a little shale, and are commonly more or less charged with phosphatic matter. Many of the layers are filled with *Orthis* (*Dalmanella*) *testudinaria* (see figs. 42 and 43 on Illustration sheet), the shells of which are generally silicified. The formation may be recognized at once by these shells, even without exposure, the light-red subsoil, where washed, being profusely speckled with their white fragments.

In other parts of the Central Basin of Tennessee, especially toward its northern and eastern borders, the formation weathers into fine-grained, earthy, yellowish or brown sandstone and shale, and the sandstone is often phosphatic.

The name "Hermitage" is derived from the station of that name, situated near the old home of President Jackson, on the Tennessee Central Railroad, where a good section was secured.

Bigby limestone.—In the Columbia quadrangle this formation consists of a nearly uniform series of semi-oolitic or granular, crystalline, laminated, phosphatic limestones, gray or bluish in color, and 30 to 100 feet in thickness, the minimum original thickness (i. e., where it has not suffered from Paleozoic erosion) being about 50 feet. At the base there may be a few feet of shaly layers; also at the top, but there the shales are commonly arenaceous. Throughout the quadrangle the formation is sufficiently homogeneous and characteristic to be always readily recognized, but northward toward Nashville and thence eastward to Hartsville it gradually loses more and more of its granular structure and phosphatic contents, until at Hartsville there is only an insignificant remnant of high-grade phosphatic rock. In this northeast direction the water in which the formation was deposited seems to have deepened, causing the deposits to assume a different character, and to increase very materially in thickness.

Between Hartsville and Carthage, for instance, the strata equivalent to the Bigby limestone of the Columbia quadrangle aggregate a thickness of from 120 to 150 feet. A considerable part of the limestone here is still more or less laminated in structure, but only a very small proportion has the granular composition characterizing the phosphatic beds. Besides, more than half of the limestone layers are compact, and of light-blue or gray ("dove") color, while most of the other layers contain a much greater proportion of subcrystalline matter than does the typical Bigby limestone. The most striking difference, however, is that presented in the fauna. Aside from the minute cycloid and other molluscan shells which are common to all of the Tennessee phosphate horizons and *Rafinesquina alternata*, which is often very abundant, fossils are comparatively rare in the lower fourth of the Bigby limestone of this quadrangle. In the upper part Bryozoa, especially three species of *Constellaria* (see figs. 30 and 31), and *Eridotrypa briareus* are sometimes extremely abundant. At Columbia, for instance, about 4 feet of shale and limestone are filled with them. The other fossils are confined to local thin shaly layers or to small, almost purely calcareous lenses. In Trousdale and Smith counties, on the other hand, nearly all the layers are profusely fossiliferous, the series, moreover, affording a large and varied fauna, in which the mollusca are strongly represented and the typical Bigby Bryozoa and Brachiopoda are rare or are absent altogether. The formation takes its name from Big Bigby Creek, along which, and its tributaries, it is well exposed. Because of the presence in it of large deposits of phosphate of lime this formation is one of the most important that is exposed within the quadrangle.

Catheys formation.—This series of highly fossiliferous, knotty, and fine-grained earthy limestones and shales has been named from Catheys Creek, a tributary of Duck River. In the quadrangle the formation is generally not difficult to distinguish from the underlying Bigby limestone, but the knotty and shaly beds, which make up the greater part of it, are often so much like portions of the overlying Leipers formation that, unless one is thoroughly familiar with the fossils, confusion between them is very likely to occur. The minimum original thickness was probably not much less than 50 feet, the maximum 100 feet or more. South of Duck River the thickness often falls to less than 50 feet. This is due to Paleozoic erosion which took place either in Utica time or later. At some places the formation was removed entirely, as at a point one mile east of Hunter Ford, where the cherty St. Louis limestone rests directly upon eroded Bigby limestone.

The Catheys formation varies considerably in its lower members. At Columbia, where the finely granular siliceous top of the Bigby limestone is extensively quarried, the Catheys formation begins with a rather massive, coarsely crystalline limestone, holding many large masses (3 inches to 3 feet in diameter) of *Stromatocerium pustulosum* (see figs. 23 and 24). Following these are shaly, thin-bedded, and often rough limestones, full of brachiopods and of Bryozoa highly characteristic of this horizon. *Cyclonema varicosum* probably deserves to rank as the most characteristic fossil. It is also a common one, especially in the lower beds of the formation. Farther north, about Jameson, for instance, the *Stromatocerium* bed is replaced, in part at least, by siliceous shales full of basalia of sponges (*Pattersonia aurita*) and corals of the genus *Columnaria*. In other places again, as at points a few miles north and west of Mount Pleasant, the *Stromatocerium* bed, which in these cases is not well marked, is preceded by shaly beds simply crowded with monticuliporoid Bryozoa. Finally, the basal part of the formation may look like a continuation of Bigby limestone, being, as is so commonly the case with that formation, full of *Rafinesquina alternata*, though always in association with characteristic Catheys Bryozoa like *Heterotrypa parvulipora* (see fig. 26).

As a rule the upper half of the formation consists of compact, impure, blue limestones, in layers varying from a few inches to 4 feet in thickness. Between these are thin layers of calcareous shale. Generally the fossils belong almost wholly to brachiopodan, molluscan, and crustacean types, but occasionally, especially toward the north, a small bryozoan bed may be encountered. Several large Ostracoda, of the genera *Leperditia* and *Isochilina*, are highly characteristic of these upper beds. They are restricted to fine-grained impure limestones and with these increase in abundance northward from this area. On account of the erosion mentioned above, part or all of the upper half is usually wanting in the vicinity of Mount Pleasant and on Nelson Hill.

Leipers formation.—This formation consists of granular limestone, quite uniform in the western portion of the quadrangle, but changing toward the east to a knotty, earthy limestone overlying certain shaly and fossiliferous beds. In thickness the formation varies from nothing to 100 feet. A complete section is nowhere to be seen, the top being cut away in some places and the lower portion never having been deposited in others.

In the eastern half of the quadrangle a complete section, beginning below, would be as follows: (1) Shales and thin limestones, with a maximum observed thickness of 10 feet, usually containing fossils indicating early Lorraine. An undetermined species of *Bucania* or *Salpingostoma* is characteristic for this region. (2) A series of more or less coarsely crystalline speckled limestone, up to 20 feet thick, containing shells of *Ctenodonta*, a large branching *Escharopora*, and a small ramose bryozoan (*Bythopora*). This and the preceding bed were observed between Williamsport and Kettle Mills, and in McClanahan Branch west of Hampshire. (3) Thin-bedded, shaly, and very fossiliferous layers 6 to 14 feet thick. Among the fossils, a long hinged form of *Platystrophia laticosta*, a *Hindia*, varying from a half inch to over one inch in diameter, and several undescribed Bryozoa, are characteristic. At Columbia, Mount Pleasant, and Negro Hill (just south of Greenfield Bend on Duck River) this bed forms the base of the formation. (4) Granular crystalline, occasionally arenaceous, grayish limestones, sparingly fossiliferous and slightly phosphatic. This bed may reach a thickness of over 40 feet. (5) Knotty impure limestones and shales, blue and gray, full of fossils; monticuliporoid Bryozoa extremely abundant; 5 to 12 feet thick. Of over fifty species of fossils, perhaps the most characteristic of this horizon are *Amplexopora columbiana*, *Homotrypella nodosa*, and *Strophomena planoconvexa* (see figs. 11, 12, 14, 15, 18, and 19). The best exposure is found in the excavation for the Columbia waterworks reservoir on Mount Parnassus. (6) Next comes a rather widely distributed bed of earthy limestone and calcareous shale, not over 7 feet thick, holding *Orthorhynchula linneyi* and *Tetradium fibratum* and resembling very greatly several beds in the Catheys formation that afford the same species. (7) A thin bed of soft, calcareous, light-blue shale, rarely seen. This is the horizon of *Bythopora gracilis* (Nicholson), a slender, branching bryozoan, described from the strata at Cincinnati where it occurs in great abundance near the top of the hills. (8) Finally, the top of the formation is usually formed by an earthy blue limestone, weathering knotty, but appearing solid in fresh exposures. This evidently was current formed, the valves of a large *Platystrophia* (see figs. 21 and 22), the only common fossil contained in it, being, as a rule, more or less waterworn.

Westward, in Hickman County, these eight beds are no longer distinguishable, the whole series becoming more and more uniform in composition, and fossils, good ones at least, comparatively rare. In the region embracing the lower part of Swan Creek and the streams emptying into Duck River from the north, below Anderson Bend, the formation consists almost entirely of granular (oolitic) or granular crystalline, laminated phosphatic limestones, the phosphate, especially toward the top, being so abundant in places that on leaching an excellent grade of light-brown phosphate rock is produced. The fossils found near or at the top of the formation in this region prove that the *Platystrophia* bed (No. 8 of the foregoing paragraph) is everywhere absent. Nos. 5, 6, and 7 are often represented, but it is clear that the bulk of the 60 to 90 feet or more of phosphatic limestones here representing the Leipers formation is the equivalent of beds 1 to 4, and chiefly of the last.

The absence of the upper bed indicates elevation and then erosion during a long period, beginning apparently very soon after, if not before, the close of Lorraine time; it is a significant that those parts of the area which remained above water till the general subsidence which took place in the Devonian are precisely those which have the strongest development of the Devonian black phosphate. These stratigraphic unconformities are well illustrated by the detailed sections on the Columnar Section sheet. As will be noted from the descriptions given, the formation is more variable even than the Catheys, which it greatly resembles in both physical and faunal characters. It is named from Leipers Creek, along which it has a good average development.

Fernvale formation.—The Fernvale formation consists mainly of soft chocolate and green shales. Commonly the shales include one or more layers of coarsely crystalline, occasionally flesh-colored, limestones, usually with greenish specks. Not infrequently the lower of these layers is conglomeratic and highly phosphatic. In the valley of South Harpeth Creek, south of Fernvale, and on both sides of Duck River, in Tottys Bend and Morgan and Haley creeks, the lower part of the formation is made up of 5 or 6 feet of strongly ferruginous, often vermilion-red limestone. Where the formation is thin, as along the borders and more particularly the heads of the bays in which it was deposited, the shales only are developed. In thickness the formation varies from nothing to 40 feet, the average being less than 20 feet.

As more fully explained later, the Fernvale formation and the next following, Clifton limestone, were deposited in shallow troughs and embayments along the western border of the middle Tennessee dome. These are well shown, and their mode of formation unmistakably indicated, in the valleys and branches of Leipers, Lick, and South Harpeth creeks, which, in a general way, still follow these ancient depressions.

UPPER SILURIAN.

Clifton limestone.—In the Columbia quadrangle the Clifton limestone is composed of compact, light-gray or light bluish-gray, and more or less thick, even-bedded limestones. Some of the layers are crinoidal, many contain green points, and others have thin layers of chert. In the western part, portions may be thin bedded, and, in the lower half, even shaly. The latter character increases westward beyond this quadrangle. At the top there is often a heavy, yellow, argillaceous layer. It is easily distinguished from the preceding formations.

This formation was named by Safford from Clifton, a town in Wayne County, Tenn., where the formation has a thickness of nearly 200 feet. In the Columbia quadrangle the formation is represented only by deposits in embayments along the ancient coast line, and ranges in thickness from nothing to about 60 feet, the mass increasing in a general way from east to west by the addition of new layers at the bottom. The subsidence of the middle Tennessee dome thereby indicated ceased at the close of Niagara time, when the land was elevated again, the sea being pushed westward beyond this quadrangle. The emergence of the dome probably continued through Cayugan and Helderbergian time, the rocks of those groups being found but little east of the Tennessee River.

In view of the extremely fossiliferous character of the formation, as well as the varied character of its fauna, along the Tennessee River, fossils must be counted rare in the Clifton limestone exposures within this quadrangle. No sponges at all were seen, and extremely few brachiopods, and of crinoids only a single specimen of the small *Haplocrinus hemisphericus*, which was found at Centerville. Corals alone are fairly abundant, but even these grow rare toward the heads of the bays.

DEVONIAN SYSTEM.

Chattanooga shale.—Excepting the bottom and top, which will be described separately, the mass of this formation is a nearly black, rather tough, bituminous shale, splitting generally into thin plates. It is the well-known and sharply defined formation so often called the Black shale. The formation as a whole is remarkably persistent in its distribution, being found nearly everywhere in Tennessee and adjoining States to the south, west, and north, where its proper horizon is exposed. Its occasional absence is due either to nondeposition or to erosion preceding Carboniferous deposition. Generally throughout middle Tennessee there is at the base of the formation a thin bed which is entirely different in character from the black shale above. In the western part of the Columbia quadrangle, particularly in the valley of Swan Creek, this bed consists largely of calcium phosphate and forms the source of the Tennessee black phosphate. Its appearance varies somewhat from place to place, as well as its chemical composition. It may be gray, bluish-black, or black in color, and it may be composed of grains large enough to be seen by the naked eye, or may have a dense fine-grained structure. When examined with the glass small oval grains are generally found to be more or less abundant, sometimes making up the mass of the rock. These have polished surfaces and a brown or amber color. In many cases they are the casts of minute coiled shells. The phosphate bed passes by gradations laterally into a bed of coarse sandstone or conglomerate containing varying amounts of phosphate. The grains are in part phosphatic ovules and in part quartz, with less abundant waterworn fragments of other rocks, and fish bones.

The phosphate bed is also replaced, particularly toward the southwest, in Hardin, Wayne, and Perry counties, by a fine-grained gray or black sandstone, which reaches a maximum thickness of 12 feet in Hardin County, where it has been called the Hardin sandstone by Safford. It may consist of a single massive bed or may have a shaly structure, and is generally more or less phosphatic.

It is evident that the black phosphate, the conglomerate, and the fine sandstone are merely three phases of the same member of the Chattanooga formation, and represent deposition during approximately the same time, their difference in composition being due to differences in the sources from which their materials were derived. Occasionally, and this is particularly true of areas in which the Chattanooga formation rests on the Clifton and Fernvale formations, the conglomeratic phosphate layer is replaced or represented by black shale like that making up the body of the formation. Except in these cases the basal bed everywhere follows a more or less easily determined erosion unconformity, and was deposited over a nearly submerged land surface. This subsidence began in the Oriskany, and, continuing through the Onondaga and Hamilton ages, resulted finally in the submergence of the whole of the middle Tennessee dome. This submergence occurred in the Portage and continued through the Chemung, these late Devonian ages being represented by the typical Chattanooga shale.

At the top of the formation there is very generally a thin stratum of greenish shale and earthy sandstone, which has recently received the designation "Maury green shale" from Professor Safford. He says it ranges "from a few inches to 4 or 5 feet in thickness;" but so far as our observation is concerned, it does not exceed 2 feet in this area, and usually varies between 12 and 18 inches. Nearly always this green shale has embedded in it smooth dark nodules or concretions of lime phosphate. The nodules vary greatly in size, shape, and relative abundance. Some are spherical, and from a half inch to several inches in diameter; others are flattened or irregular ellipsoids, sometimes as much as 2 feet in length and over 6 inches thick; and they may be loosely disposed in the shale, or closely packed. The green color is due to the presence of glauconite or greensand, a silicate of iron and potash. Rarely, as in the upper part of East Fork of South Harpeth Creek, the green shale is absent or not distinguishable, and in these cases the black shale seems to pass very gradually into overlying green shale, which constitutes the base of the full Tullahoma section.

Fossils are almost if not entirely restricted to the lower member of the Chattanooga formation. In the dark-gray variety of phosphate rock, which is really a conglomerate, casts of minute coiled and bivalve molluscan shells, washed out of the Ordovician rocks forming the surface of the land that was being gradually submerged, are very abundant. Waterworn bones of large fishes not infrequently occur with them. In the basal shale and fine-grained sandstone a species of *Lingula*, probably *L. spatulata*, is frequently seen, while the shiny teeth, jaws, and cephalic plates of conodonts, supposed to be small fishes related to myxinoids, are often found, sometimes in great numbers.

CARBONIFEROUS SYSTEM.

Tullahoma formation.—This formation consists chiefly of siliceous shales and limestones, but the lowest member is a calcareous shale, generally a grayish green or pale blue, but occasionally dark, varying from nothing to perhaps 30 feet in thickness. As this member is not often seen in the Columbia quadrangle, it may be well to mention that a good exposure, and the most fossilliferous seen, occurs on the first hill west of Mount Pleasant. It is significant that all the known exposures occur within or in prolongations of the Fernvale and Clifton embayments shown on the Embayment sheet. The fossils, though chiefly of undescribed species of Ostracoda, indicate very early Mississippian age. Fossils collected apparently from an equivalent shale by Safford, and reported by Alexander Winchell many years ago, were believed to indicate the age of the Marshall or Kinderhook.

A strongly siliceous and argillaceous limestone that weathers into a cherty, shale-like material occurs stratigraphically above the calcareous shale, but usually constitutes the ordinary base of the formation. Similar strata, in one place more shaly, in another more calcareous, and generally with heavier chert, continue to the top of the formation, which has a maximum thickness of about 250 feet. Usually it is much less, especially in the southeastern quarter of the quadrangle. The decomposed siliceous shales and limestones, especially those of the lower third of the formation, often afford an excellent road material.

Excepting in the basal shales, specifically recognizable fossils are extremely few in this formation. Here and there the heavier chert blocks contain large crinoid stems in abundance, and occasionally a brachiopod cast, indicating the Burlington or Keokuk horizon of Iowa and Illinois.

St. Louis limestone.—This, the latest or youngest formation exposed in the quadrangle, consists in the main of a thick bed of limestone, gray to blue in color, and associated with considerable chert. The limestone is rarely exposed away from stream beds, and as the formation occupies only the highlands, it is known mainly from its aspect after decomposition. With chert-bearing formations decomposing as deeply as the St. Louis and Tullahoma do in this area, exposures showing contact are extremely rare. The two are, accordingly, separated on the map by a more or less arbitrarily drawn line. For convenience, certain heavy and often cellular chert layers have been taken for the base of the St. Louis. These layers reach a thickness of over 2 feet, and on this account alone frequently constitute a conspicuous guide. They are further distinguished from the preceding cherts by their highly fossiliferous character. The fossils are mostly small, and consist mainly of Bryozoa and brachiopods more or less characteristic of the "Warsaw horizons" of Illinois, Indiana, and Kentucky, which have been referred to various ages. Above these heavy layers come the more characteristic St. Louis fossils, like *Melonites* and *Lonsdaleia*, or as the latter is generally called, *Lithostrotion canadense* (see fig. 2). The St. Louis may also be distinguished from the Tullahoma formation beneath it by changes in the character of the topography, that of the latter abounding in steep, rocky slopes, while the St. Louis forms more rolling lands, with a red, instead of a yellow, and a much more fertile soil. The St. Louis chert, aside from its fossiliferous character, occurs in large, angular masses, is less abundant, less porous, and contains much less clay. Where the St. Louis limestone attains considerable thickness, the areas of its outcrop are further distinguished by sink holes, underground streams, and caves. These are due to the purer and more soluble character of its limestones. The iron-ore banks of middle Tennessee and western Kentucky are almost entirely restricted to this formation. They mark the location of old bogs, in which the mineral, derived from decomposing limestones, was deposited.

GENERAL SEDIMENTARY RECORD.

All the rocks appearing at the surface in the Columbia quadrangle are of sedimentary origin—that is, they were deposited by water. They consist chiefly of various kinds of limestone, often separated by rather thin beds of shale and occasionally sandstone, the total exposed section having a maximum thickness of about 1100 feet. The materials of which they are composed were originally mud, sand, and gravel, derived from the waste of older rocks, and from the remains of animals and plants that lived in the seas when the strata were laid down. The limestones, especially, were largely formed of the shells and other remains of sea animals, and these remains are not only interesting relics of bygone ages, but are of the first importance as aids in the identification of the various formations.

The rocks of this portion of the Ohio Basin afford a record, here and there incomplete, of sedimentation from middle Ordovician to early Carboniferous time. They also present evidence concerning the depth of the water in which they were deposited and the condition of the land areas which furnished more or less of the material of which they are composed. Judging from the character, distribution, and varying thickness of the deposits and their fossil contents, we may determine with considerable certainty the physical conditions of the region contributing to, or in other ways concerned in their formation.

The sea in which the Paleozoic sediments in the interior of the continent were laid down probably came into existence during the latter half of Cambrian time, and at one time or another covered most of the region now drained by the Mississippi River. Its outline probably varied greatly from time to time, the floor of its basin having suffered many broad fluctuations and local warpings. Several times before the final emergence of this region the basin was almost entirely drained, but, as a rule, the elevations or depressions were relatively local. In two limited areas, one embracing the northern part of central Kentucky, and the other middle Tennessee, the oscillations of level seem to have been exceptionally frequent, and, in some cases at least, the two areas were alternately elevated and depressed.

The Knox dolomite and equivalent beds of limestone were deposited without serious interruption in a sea extending from the present Appalachian Mountains westward beyond the Mississippi and northward into Canada. The Stones River group, made up of mainly fine-grained, alternating massive and thin-bedded limestones, was then laid down apparently as an unbroken sheet from Alabama northeastward into Canada, and westward to and perhaps across the Mississippi. In eastern Tennessee, however, the formations resting upon the Knox dolomite—like the Lenoir limestone, Athens shale, Tellico sandstone, and Sevier shale—differ sufficiently in lithologic and faunal characteristics to justify the assumption that they were deposited in a narrow trough or bay separated from the larger sea by a narrow land barrier. The main Stones River sea evidently encroached northeastwardly upon a land area, since in New York and Canada only the closing deposits of the age are present in the Birdseye or Lowville limestone of that region. On the west it seems to have been bounded by a large land area lying in Missouri and Arkansas.

At the close of the Stones River epoch, subsidence of the land areas in the northeast was increased, while the bottom of the sea became at the same time somewhat unstable, the result of the movement being the formation of gentle folds and a slight accentuation of previously existing anticlines. These changes had little effect at first beyond allowing the influx of a considerable portion of siliceous muddy sediment, but in time they resulted in great faunal changes. This was the beginning of the elevation which resulted in the Cincinnati arch or geanticline. Its two highest points were between Lexington and Danville in Kentucky, and between Murfreesboro and Shelbyville in Tennessee. The higher portions of these two dome-like elevations received very little of the deposits of the Hermitage formation; those in Tennessee perhaps none. At the close of the Hermitage the folds were again somewhat emphasized, and the summit of the Kentucky dome shifted to Cincinnati, where it probably remained till the close of the Trenton age. At the same time the central Kentucky portion of the axis was submerged to receive the upper three-fourths of the Lexington limestone, while the Tennessee end received the Bigby limestone. Both of these nearly equivalent limestones are strongly phosphatic, and to this fact is to be ascribed the extreme fertility of the areas where they now form the surface. This, however, can not be said of the strata representing the same time interval at such intermediate localities as Hartsville and Carthage, on the Cumberland River, the percentage of the phosphatic ingredient growing gradually less as the equivalent beds are followed northeastward from Columbia and Nashville.

During most of the time occupied by the deposition of the Catheys formation, the Cincinnati end of the axis was a land area and was denuded of what Catheys it may have received and of nearly all of the underlying Bigby. At the close of the Catheys deposition—that is, at the end of Trenton time—the summit of the northern dome was shifted back to central Kentucky. Almost immediately the Cincinnati end of the axis began to sink, allowing first the Utica and then the Frankfort sea and deposits to cover more and more of the eroded land surface. South of the Kentucky River, however, there is no evidence of the presence of deposits of either age, the invading Utica barely crossing the Ohio at Cincinnati, and the Frankfort shale reaching only a point a few miles south of Lexington. It is quite certain that they are wanting in northern Tennessee, where they might be expected if the Utica sea covered the depression between the Kentucky and Tennessee domes.

What was going on in middle Tennessee in Utica times is an interesting problem. One might suspect that the upper part of the Catheys limestone represented deposition during that time if it were not known that the equivalent beds in Kentucky are followed by Utica deposits. In view of this fact it seems necessary to assume that the Utica and Frankfort divisions of the time scale were not represented by deposits in middle Tennessee—in other words, that land conditions then prevailed. Furthermore, the frequent absence of more or less of the lower part of the deposits belonging to the Lorraine age shows that this interval of non-deposition lasted longer than Utica time, which alone sufficed in some places to make a deposit of shale over 500 feet thick. And yet there is extremely little evidence of unconformity between the top of the Trenton and the members of the Lorraine resting upon it. When unmistakable evidence of erosion of a Trenton surface is found, the following formation is not the Lorraine, but one of the two lower Carboniferous formations. Two good examples of this relation occur within the Columbia quadrangle. The first is the uplift of Tottys Bend of Duck River, where the Tullahoma formation rests on the eroded top of the Catheys formation; the other is about one mile east of Hunter Ford, where the St. Louis limestone rests on the Bigby limestone. On the other hand, it must be admitted that the uppermost beds of the Catheys formation do not by any means always have the same character, and this variation may be regarded as evidence of erosion that took place during the first half of the Cincinnatian. Still, the visible evidence of this erosion is so faint, and the passage from the Trenton into the Lorraine often apparently so gradual, that the elevation of the land surface above sea level during the Utica interval must have been extremely slight.

With the gradual submergence of this low land the Lorraine deposits covered more and more of the Tennessee dome and the whole of the Kentucky dome. The closing member (*Platystrophia* bed) of the Leipers formation, which represents the entire Tennessee equivalent of Lorraine deposits, is commonly present, yet not infrequently in part or wholly absent. Here again we have the lapse of a time interval without deposition indicated by the total absence south of Nashville of the greater part of the Richmond formation. Of this age only the closing fauna, which is a very distinctive one, lived in the bays that indented the western shore line of the Tennessee island and in which the Fernvale formation was laid down. This same fauna alone represents the Richmond also in northern Illinois, Wisconsin and Minnesota, where it rests upon strata of late Utica age; also in Manitoba, Wyoming, Colorado, Indian Territory, western Texas and Nevada, in which regions the strata containing it rest on rocks generally older than Lorraine.

On comparing the shaly and often ferruginous and phosphatic conglomerate deposits of the Fernvale formation with the comparatively even-bedded and uniformly fine-grained limestones of the Niagaran in these embayments, it is evident, even without taking into account the great disparity in time represented by the Fernvale formation and Clifton limestone, that the Fernvale sea received much muddy sediment and the formation was therefore laid down rapidly, and that the Clifton sea received very little of such sediment, which consequently accumulated more slowly and under more uniform and longer established conditions.

At the close of the Niagara epoch, during which the Clifton limestone was deposited, the land area was increased until it embraced nearly the whole continent, and in middle Tennessee the Devonian submergence did not become effective till the advent of the Chattanooga shale, which is believed to be equivalent to the upper part of the Genesee and later Devonian sediments of New York. This remarkably uniform, and, considering its small volume, widely and evenly distributed formation, extended well over the submerged flanks of the middle Tennessee dome. If it did not entirely cover the summit, it at least encircled it, which certainly was not the case with respect to the later Silurian and the early and middle Devonian formations. It paved the way, though with a comparatively brief emergence and erosion interval, corresponding to latest Devonian and perhaps earliest Carboniferous time, for the sediments composing the Tullahoma formation which extended as a gradually thinning sheet over the summit of the dome. This was probably the last formation to wholly cover the dome, the St. Louis limestone being deposited in a retreating sea. The Cincinnati island was rising at the same time, but the sea occupying the space intervening between it and the middle Tennessee dome remained open and may have been deepening, allowing deposits during St. Louis and Chester times. The great number of breaks in the stratigraphic column above described are clearly brought out in the detailed columnar sections on the Columnar Section sheet and in the Correlation Table.

The view has been held that the Appalachian and Interior Coal Measure deposits originally extended as an uninterrupted sheet across the space now separating them. It appears more probable, however, that these deposits never extended over either the Cincinnati uplift or the middle Tennessee dome. In other words, it appears that when in St. Louis and Chester times these areas emerged from the seas, they did so never again to be entirely covered by water.

STRUCTURE.

As stated in a previous paragraph, the Columbia quadrangle lies in a region of practically horizontal strata, but the beds are probably nowhere absolutely horizontal for a great distance. Lying upon the western flank of the Cincinnati arch, the strata have a general westerly dip, but they have been affected by the uplift of the dome which occupied the central basin, and now form numerous gentle but irregular flexures. The sections represented on the Structure Section sheet show the character of these flexures. It will be noted that the vertical scale has been greatly exaggerated, so that the profiles do not show the true slopes at the surface, nor the actual dips of the strata. The folds are so slight, however, that this vertical exaggeration is necessary in order to render them apparent. The position of the sections with reference to the map is indicated by the lines on the embayment sheet. The unconformity at the base of the Tullahoma formation and the embayment deposits of the Fernvale and Clifton are clearly illustrated. The sections have been drawn chiefly to illustrate the structure in the southeast portion of the quadrangle, where it has a very direct and important bearing on the economic problems connected with the phosphates. In general the strata of this region are free from fractures, but a few small faults have been observed. The most striking of these is in the Nebo Hill region, where a block of strata appears to be bounded by rectangular faults and to have dropped vertically a distance of 300 or 400 feet.

The undulations in the strata of this region date in part from early Ordovician time. The doming which has resulted in the Cincinnati arch probably did not attain the degree required to effect its first elevation above sea level before the conclusion of the period marked by the deposition of the Carters limestone. From that time until nearly the close of the Devonian middle Tennessee was subjected to repeated slight warpings, and in part or whole to successive submergences and emergences, receiving deposits when under water and suffering subaerial erosion when above it. As shown in the Correlation Table and the detailed sections on the Columnar Section sheet, there are at least five breaks in the continuity of deposition, and these were all accompanied by more or less marine and subaerial erosion. Two of the formations mapped, namely the Fernvale formation and the Clifton limestone, were deposited over only a small portion of the quadrangle, apparently in a series of embayments produced by warping of the preexisting surface. That these formations were not deposited continuously over the whole region and subsequently eroded, except in the areas where they are now found, is proved by the fact that the outer edges of the lower beds of the formation are overlapped by the higher beds—a relation which could not result from continuous deposition and subsequent erosion. The Fernvale formation was deposited in a rather broad embayment at the northeast corner of the quadrangle and in a second extremely irregular embayment which extended nearly across the north-central portion of the quadrangle, and probably opened to the sea toward the north. None of this formation appears ever to have been deposited in the southern half of the quadrangle. The later embayments in which the Clifton limestone was deposited appear to have coincided in a general way with those of the earlier Fernvale. A much less extensive area of this formation was deposited in the extreme northeast corner of the quadrangle. Another bay extended across its north-central portion, coinciding somewhat closely with the earlier one of Fernvale time, but probably having its connection with the sea to the west instead of to the north. Two other long and narrow embayments occurred in the southwest quarter of the quadrangle, also probably opening into the sea toward the west. The regions occupied by these embayments are shown on the Embayment sheet. The lines there drawn are in part actually determined and in part, by reason of the lack of exposures, are conjectural.

A curious relation is observed through this region between the present drainage lines and the undulations in the strata. In a great majority of cases in ascending one of the larger tributaries of Duck River the strata are found to rise from the mouth of the stream toward its head, a particular bed thus retaining a practical parallelism with the bottom of the valley. Further, the same relation is often observed upon the side tributaries of the main creeks, which thus appear to be located in many cases in gentle synclines. The number of cases in which this relation was observed suggests that the structure of the strata has exercised some control upon the location of the minor drainage basins.

MINERAL RESOURCES.

The most important mineral resources occurring in the Columbia quadrangle are rock phosphates and iron ore. Of less importance are building stone, limestone for flux and lime, and a variety of rock suitable for road metal.

PHOSPHATE.

Excepting the Clifton limestone and probably the Fernvale formation, phosphate deposits occur in all of the formations from the top of the Carters limestone to the base of the Tullahoma formation. Of the five phosphate-bearing formations four are Ordovician and one, the uppermost, is Devonian in age. Two of the formations contain each three or four separable beds, so that no fewer than ten phosphate horizons are distinguishable within the Columbia quadrangle.

ORDOVICIAN (BROWN RESIDUAL) PHOSPHATES.

Hermitage phosphate.—This bed occurs in the upper half of the Hermitage formation. Its presence is usually indicated by secondary tufaceous deposits covering the hill slopes at or slightly below the outcrops of the formation. Such deposits are so generally associated with this bed and so rarely with any of the other Ordovician horizons that they may be accepted as a fairly reliable indication of this particular horizon. Sometimes, as on the farm of T. D. Simmons, several miles beyond the eastern margin of this quadrangle, between Jameson and Spring Hill, the tufaceous deposit forms considerable masses and is abundant enough to be worth mining. Concerning the bed itself from which these secondary deposits are derived, it but rarely forms a continuous sheet of phosphate rock corresponding to a particular stratum. Instead, the phosphate follows the surface of the ground rather than the bed, the limestone being leached to approximately uniform depth beneath the surface. In other words, the Hermitage phosphate usually occurs as a "collar deposit." As many different beds are concerned in the production of this type of phosphate deposit, the product of the mines is extremely variable in quality. The principal cause of this is the varying amount of siliceous material contained in the limestone. In the Columbia quadrangle but little sand occurs in the Hermitage formation, but toward the north and east the amount increases materially until, in Wilson and Smith counties, it sometimes makes up nearly half of the rock mass. In the latter cases the lime phosphate in the leached rock rarely exceeds 50 per cent, though here and there a thin bed may afford 70 per cent phosphate. In Maury and Williamson counties, however, the Hermitage phosphate commonly runs from 65 to 74 per cent, and considerable tracts are found furnishing a fair grade of such domestic rock. Too often, however, the rock is light and contains more silica than is desirable. A possible offset to the unfavorable features of the Hermitage phosphate is its relative solubility, which the frequent secondary deposits indicate to be greater for this bed than for any of the succeeding Ordovician phosphates.

Valuable deposits of this bed occur mainly about Godwin and may be looked for in a northeast direction from that point beyond the limits of the quadrangle. The known occurrences are shown on the Economic Geology map. The American Phosphate Company has opened several promising mines at this horizon about one mile north of Godwin.

Bigby phosphates.—The Bigby limestone embraces at least four phosphatic zones, distinguished and recognized by physical peculiarities, fossils, and position in the formation. Beginning with the lowest, they may be conveniently designated Bigby Nos. 1, 2, 3, and 4. Under favorable circumstances, as at Mount Pleasant, Nos. 1 and 2 are sometimes so closely associated as to form practically a single bed, generally, however, divided near the middle by a dark clay layer, the residue of a more or less shaly limestone, which in its unweathered condition varies in thickness from 1 to perhaps 4 or 5 feet. When the two zones are thus united they are difficult to distinguish, since there is little if any constant difference between the leached phosphate rock of the two zones. When the unchanged limestone rock is compared, some difference may be detected. Recognizable fossils are always rare in the lower bed, the small cyclorids even being broken up. The limestone of No. 2, on the contrary, is often very fossiliferous. The fossils, of course, occur mainly in the easily decomposed, subcrystalline, pure limestone streaks traversing the rock, and this explains why they are so seldom seen in the phosphatic seams which alone remain solid after the leaching of the limestone mass.

Bigby zones Nos. 1 and 2 afford the typical brown or Mount Pleasant phosphate. It is a loosely coherent, porous, rusty-brown rock, disposed in rather thin horizontal plates, which rest directly one upon another or are separated by thin seams of dark clay. It is mined without the use of explosives, and, according to various circumstances, yields from 500 to 800 tons per foot of its thickness for each acre covered by the deposit. As seen in the mines the perpendicular face of the deposit exhibits a series of superposed wavy lines caused by local depressions between the unchanged limestone "horses" (see fig. 1) and the contraction or diminution in volume sustained by the rock during the process of leaching. The amount of lime phosphate varies from about 73 to over 82 per cent. An average analysis is about as follows:

Average analysis of Bigby phosphate.

	Per cent.
Moisture	0.93
Phosphoric acid	36.27
Iron oxide and alumina	3.25
Corresponding to lime phosphate on dry basis	79.06

When the beds are traced from Mount Pleasant to and beyond the borders of this quadrangle the percentage of lime phosphate is found to remain fairly constant in a northeast direction to Spring Hill, and southeast into Giles County. Beyond these points it becomes perceptibly less, as is also the case when the formation is followed northward beyond Williamsport and eastward from Maury into Marshall County.

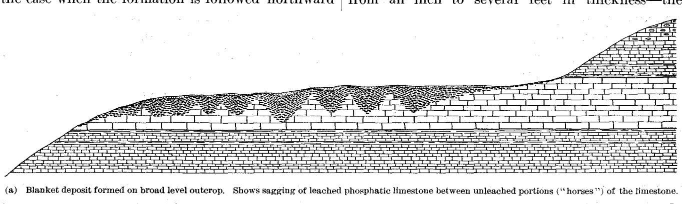
Bigby Nos. 1 and 2 are mined as a single bed on the west side of the creek at Mount Pleasant. East of the creek denudation has removed more or less of No. 2 and in some places only the lower bed remains. At the Tennessee Phosphate Company's mines most of the rock is furnished by the upper bed, the leaching process there having as a rule failed to reach No. 1. Both horizons are abundantly leached along the Columbia and Williamsport Pike between Greens Lick Creek and Mount Nebo, and again between the northern slope of that hill and Parsons Bend of Duck River. Unimportant deposits occur also west of the latter region. Considerable patches of No. 1, and more limited ones of the Hermitage bed, occur in the region south of Wisner Hill and Roberts Bend of Duck River and north of Tea Hill. A few relatively unimportant deposits of No. 1 are to be found also in the vicinity of Godwin and also at intervals between that point and Jameson. Very large deposits, however, occur just east of this quadrangle between Jameson and the Louisville and Nashville Railroad. In the last area, at Carpenter and Wilson's mine, Nos. 1 and 2 are combined into a single bed about 20 feet thick.

In a district lying between 5 and 10 miles east of a line passing from Jameson southwest through Mount Pleasant, the portion of the Bigby limestone corresponding to phosphate zones Nos. 1 and 2 affords a phosphate rock differing in several respects from the Mount Pleasant variety. Nearly all of it is more massive and of a lighter color, and much of it is softer. Some of the bands are almost white. Finally, this lighter-colored rock runs, on an average, higher in lime phosphate and lower in iron and alumina. A considerable proportion of the output of the mines in this eastern tract, which at present is not well supplied with transportation facilities, runs over 80 per cent and in some cases as high as 88 per cent lime phosphate. In the southern part of the district, near its beginning on the north slope of Elk Ridge, the lands holding the bed are usually too steep to permit the formation of true "blanket" deposits. Still, part of the phosphate rock resists decomposition so well after leaching that it often forms sloping sheets several hundred feet wide resting unconformably upon the limestone, or is overplaced on the lower slopes by solution of the underlying beds (see fig. 1). From 3 to 4 miles northeast of Columbia, however, where the topography is less abrupt, larger deposits occur. Good examples of this light-colored Bigby phosphate may be seen at Alexander and Frayer's mine, 4½ miles south of Columbia, on the Pulaski Pike; at the mine of the Southwestern Phosphate Company, situated a little over a mile south of McCains; and at several other points in this vicinity.

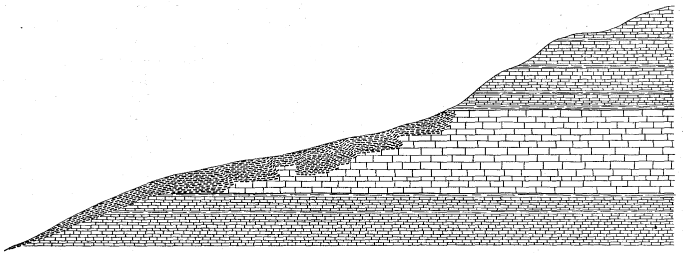
Bigby zone No. 3, where the rock is unleached, is generally to be distinguished at once by the abundant remains of several species of *Constellaria* which it contains (see fig. 31). Bands of the rock from an inch to several feet in thickness—the thicker ones nearly always shaly—are almost made up of the star-covered fragments of this sharply defined type of Bryozoa. Unfortunately, very similar species abound in the shales of the overlying Catheys and Leipers formations, so that the presence of the "star coral" (*Constellaria*) indicates only one of several horizons. Still if *Constellaria* is accompanied by numerous other ramose Bryozoa, and, better still, if the limestones above and beneath are of the granular kind that is usually the mother rock of the phosphates, then the evidence is fairly conclusive that the bed belongs to the upper third of the Bigby limestone.

The only valuable deposit of Bigby phosphate No. 3 known within this quadrangle is in the western of the Wright mines, located about a half mile northeast of Jameson. The eastern mine of this company, lying just off the quadrangle, is in Bigby No. 2, while Nos. 1 and 2 combined are worked in the Wilson mines, a short distance farther east. Excepting that the Bigby No. 3 rock is a trifle lower in grade, there is little difference between the products of the three Bigby beds in the Carters Creek region. In both quality and yield per acre the Carters Creek field is little if any inferior to the Mount Pleasant district.

Bigby No. 3 has not been satisfactorily identified



(a) Blanket deposit formed on broad level outcrop. Shows sagging of leached phosphatic limestone between unleached portions ("horses") of the limestone.



(b) Collar deposit formed on steep slope by surface leaching of the limestone. Shows also overplaced deposit covering the edges of underlying nonphosphatic limestone.

FIG. 1.—Sketch sections, showing the relations of the brown residual phosphate beds to the limestones from which they were derived.

in other parts of the Central Basin of Tennessee. However, it may be accepted as probable that the bed mined in the eastern part of Davidson County, and seen at intervals as far east as Hartsville, is its equivalent. It there furnished a 70 to 74 per cent rock, otherwise much like the bed under discussion.

Bigby phosphate No. 4 is finer-grained and much more siliceous than the preceding Bigby phosphates, and it is doubtful if it anywhere yields a commercial product—certainly none within the Columbia quadrangle. At Cleburne station, about 3½ miles east of Jameson, a considerable deposit was mined in 1899 by Swift and Company, but without satisfactory results. This company is now mining the same bed at Spring Hill, and here it is a little improved in quality. Perhaps it continues to improve in the direction of Franklin, in which case it may very well be the source from which the large secondary or precipitated deposits lying east of that town were derived.

About Hampshire and Mount Pleasant this deposit is, at present prices, quite valueless. In these two regions it is soft, frequently shale-like, and always contains a large percentage of fine sand. It is well shown on the point of land occupied by the shacks of the Tennessee Phosphate Mining Company and lying between their works and the railroad cut. It was formerly mined by the Tennessee Company, but, on account of its low grade and other objectionable features, is not likely to be used again for many years.

The unleached representative of the bed is a fine-grained laminated rock, about 6 feet thick, that is extensively quarried at Columbia for curbing and flagging. It there lies directly beneath a shaly layer holding many large masses of a sponge-like coral called *Stromatocerium pustulosum*. The known occurrences of Bigby phosphate are shown on the Economic Geology sheet.

Catheys phosphates.—The lower part of the Catheys formation frequently presents granular limestones that under favorable conditions might by leaching become a fair quality of phosphate rock. Promising limestone was noticed at several points along Big Bigby Creek and again, more abundantly, in outcrops of the formation for several miles south and west of Jameson. Only in the latter region was any of the rock observed in the leached condition, and nowhere in encouraging quantity. Those cases that might possibly be so considered occurred chiefly on the low ridges between the prongs of Sycamore Branch.

Leipers phosphates.—The Leipers formation contains at least three distinct horizons that at one point or another in the Central Basin of Tennessee are sufficiently phosphatic to furnish a commercial product. As with the Bigby limestone, a large proportion of the limestone of the formation, especially that having a granular structure, is phosphatic, but only in certain areas is the mineral sufficiently concentrated to permit it to maintain coherency as a rock mass after leaching. The three horizons in which this condition often prevails are all in the upper half of the formation, and the two lower beds yield a rock which closely resembles the Mount Pleasant rock in its physical characters, but does not average above 70 or 72 per cent lime phosphate. The lowest of the beds is, so far as known, not being mined, though it occurs in promising quantity in the lower 3 miles of the valley of Lick Creek. This bed is marked by a subglobular bryozoan, recently named *Amplexopora columbiana* (see figs. 11 and 12 on Illustration sheet), varying from a half inch to 2 inches in diameter. This fossil may always be found wherever its proper horizon, which is a little above the middle of the formation, is exposed. When the horizon is not phosphatic, as at the top of Mount Parnassus at Columbia, many other fossils are found associated with it.

Zone No. 2 is marked by the large *ponderosa* variety of *Rafinesquina alternata* (see fig. 20), which is twice as large as the variety that occurs so abundantly in the underlying Catheys formation and Bigby limestone. Another characteristic fossil is *Monticulipora molesta* (see fig. 13), a frondose or palmate bryozoan having the surface studded with rythmically disposed conical elevations. Both of these fossils are represented merely by their moulds in the phosphate rock. The fossils themselves, being calcareous, have been removed by solution. The bed is being mined at Parson Grimes's farm on Camp Branch about 4 miles northwest of Mount Pleasant. Here it lies within a few feet of the top of the formation, and is less than 3 feet thick. Prospect holes have been dug into the bed at several points near Swan Bluff.

Zone No. 3 is in the upper member of the Leipers formation. It is marked by a large brachiopod, *Platystrophia lynx* (see figs. 21 and 22), the particular variety of the species characterizing the horizon being over an inch and sometimes 2 inches in diameter. The bed is often wanting in the Columbia quadrangle, having been removed by erosion, but toward the north, especially in Sumner County, where it contains extensive deposits of phosphate, it has a maximum thickness of at least 30 feet.

The most important of the Leipers phosphatic deposits occur in the valley of Duck River, between the mouth of Swan Creek and Centerville, and along Indian Creek for 2 or 3 miles north of Dean, as shown on the Economic Geology sheet. The deposits occur along the bases of the hills in the creek valley, but being thick, almost without dirt seams, and as a rule wholly leached, they yield, despite their limited horizontal extent, a large quantity of rock. In the wider Duck RiverValley they are more extensive, but having been longer exposed to solution agencies they are softer and therefore liable to greater wastage in mining. In grade these Leipers phosphates compare favorably with the Mount Pleasant product, their content of lime phosphate averaging between 76 and 81 per cent, while the iron and alumina generally average less than in the Bigby phosphates.

The deposits described in the preceding paragraph are equivalent to Nos. 1 and 2, but were deposited under such conditions that they form a single bed. Indeed, in the district lying between Graytown and Dean, the greater part of the Leipers formation is sufficiently phosphatic to yield, under the proper conditions of weathering, a fair to excellent quality of phosphate rock. The distribution of the phosphate, however, is more uniform and more compact in the upper 30 or 40 feet, the unleached limestone frequently carrying as much as 40 to 50 per cent of lime phosphate.

Recent developments near the mouth of Piney Branch of Swan Creek give a good idea of the great thickness of the Leipers phosphate in Hickman County. In the locality mentioned tunnels have been driven along vertical joint planes in the phosphatic limestone, showing that contiguous to these planes the limestone is leached into 74 to 78 per cent phosphate rock to a depth of over 30 feet.

DEVONIAN (BLACK, BLUE, BEDDED) PHOSPHATES.

DISTRIBUTION OF THE CHATTANOOGA PHOSPHATES.

The commercially important deposits of Devonian phosphates in the Columbia quadrangle are, with perhaps a few unimportant exceptions, confined to the areas represented on the Economic Geology map as Chattanooga phosphates. In the practical development of the deposits two factors chiefly determine whether the phosphate can be worked with profit. These are the thickness of the bed and the grade of rock. If it is exceptionally high-grade rock, a bed 12 inches thick can be worked under favorable conditions, while if the rock is below a certain grade it can not now be worked with profit, no matter how thick the bed may be. The map gives information principally concerning the first of these two factors; thoroughly satisfactory information on the second, referring to the grade of the rock, requiring so many chemical analyses that it is beyond the scope of this report.

Excepting the small areas on Leatherwood Creek and its main northern tributary, Gracey Branch, the area just west of Tucker Bend of Duck River, and another on Indian Creek, between 2 and 3 miles south of Centerville, all the workable part of this bed thus far discovered lies along Swan Creek and its tributaries, and principally to the east of the northern half of the creek itself.

VARIETIES OF CHATTANOOGA PHOSPHATES.

These phosphates of this area consist, first, of several varieties of black or blue, bedded phosphate, which usually forms the basal member of the Chattanooga shale, and, second, of nodular phosphate, which occurs usually in a thin bed of greensand shale lying immediately over the black shale and constituting the upper member of the formation. The Devonian phosphates differ from the Ordovician phosphates, which are the result of leaching of a phosphatic limestone, in being simply beds unchanged from their original form and composition excepting such alterations as resulted from the process of consolidation to which all deeply buried sediments have been subjected. They are therefore harder and have a much denser structure than most of the Ordovician phosphates, and are richer in phosphoric acid than the unleached Ordovician phosphatic limestone. They are mined, not like the leached phosphates, by stripping, but like coal, by the much more expensive method of driving tunnels.

The bedded phosphate occurs in intermittent seams varying from 0 to 50 inches in thickness. The percentage of lime phosphate varies from less than 30 to about 85 per cent, while in the better grades such injurious ingredients as iron and alumina usually aggregate less than 3 per cent. Where the bed furnishes high-grade rock it rarely exceeds 20 inches in thickness. When the thickness is much greater the rock is apt to be of inferior quality, being generally too sandy. A notable exception, however, is found in the Tottys Bend mines of the Duck River Phosphate Company, where the bed is at least 40 inches in thickness and all good rock. Considering the conditions under which it was deposited the bed may be expected to vary considerably in both quality and thickness within short distances. In the manufacture of fertilizers, so far as regards consumption of acid, the black, bedded phosphate, or, as it is called commercially, "blue rock," is conceded to be the best rock yet found in the United States.

The phosphatic nodules of the upper greensand member contain about 60 per cent of lime phosphate. The expense of mining them, however, is too great at present to make them of commercial importance. Under unusually favorable circumstances they might be worked in connection with the bed of black phosphate beneath them.

The Devonian bedded phosphates may be subdivided, according to physical peculiarities, into four varieties, viz: oolitic, compact, conglomeratic, and shaly.

Oolitic phosphate.—This variety on the weathered outcrop has the appearance of a rusty, porous sandstone, but in a fresh condition its structure is more dense and its color light gray to bluish black, the darker tints being much the more common and due to finely disseminated carbonaceous matter. On close examination the rock proves to be composed chiefly of round or flattened ovules having a glazed surface. These are embedded in a fine-grained or structureless matrix. The ovules do not have a concentric structure, so the rock is not, strictly speaking, an oolite, although it closely resembles one in appearance. The constituent grains or ovules appear to be for the most part the more or less waterworn casts of minute spiral and bivalve shells and of fragments of Bryozoa that lived at a much earlier period and had previously been embedded in an Ordovician phosphatic limestone. The fine-grained matrix in which they are embedded is more easily soluble than the ovules and disappears as the rock weathers, leaving a porous, loosely compacted mass of the less soluble grains.

Compact phosphate.—This variety resembles a homogeneous fine-grained sandstone. It has a dark-gray or bluish-black color, and weathers less freely than the oolitic variety to a compact yellowish sandstone. When examined under the microscope the rock is seen to be made up of very small flattened ovules or grains closely packed together with much less or none of the amorphous or granular groundmass observed in the oolitic rock.

Conglomeratic phosphate. — Closely associated with the oolitic and compact varieties, and often entirely replacing them, are beds of coarse sandstone or conglomerate containing varying amounts of phosphate. They are usually gray or black, and, like the other varieties, weather to rusty sandstone. The constituent grains vary greatly in size, the largest reaching one-fourth of an inch in diameter. They are partly phosphatic ovules, similar to those making up the oolitic rock, and partly quartz. In addition to these smaller grains, the rock often includes flattened pebbles, apparently well waterworn, some of them an inch or more in diameter. These are composed of hard, black phosphate, so fine grained and homogeneous as to resemble black flint. Occasionally the rock contains also waterworn bones and teeth of large fishes.

The shaly phosphates have the appearance of a dark-gray or black fine-grained shaly sandstone. The shaly structure is sometimes pronounced, but in other cases the layers, which usually have a glazed surface, are an inch or more in thickness. Some parts of the bed often resemble very closely the compact phosphate above described, but its appearance is deceptive, as it generally contains much less phosphate, and thin sections, when examined under the microscope, are seen to be largely composed of fine grains of angular quartz. The spiny teeth and jaws of conodonts and a thin spatulate or tongue-shaped phosphatic shell, two perhaps not unimportant sources of the phosphatic constituents of this geologic horizon, occur often abundantly on the bedding planes.

ORIGIN OF THE PHOSPHATES.

Ordovician deposits.— The Ordovician phosphatic limestones were deposited in a very shallow sea, the bottom of which must have been more or less affected by wave action and tidal currents, and in such a manner that it received, or rather retained, but little foreign detrital matter. This sea skirted the southwestern border of the middle Tennessee uplift, which, at the close of Stones River time, had been raised nearly to or a little above sea level. In this shallow sea the deposits were almost wholly of organic origin, consisting in part of the phosphatic shells of small mollusks—which seem to have flourished almost to the exclusion of the more characteristic elements of the Ordovician fauna—and in part of the more common calcium carbonate shells which form ordinary limestone. Some portion of the calcium carbonate was probably redissolved by the sea water while the less soluble phosphatic shells were rolled and polished by wave action and tidal currents, and finally deposited on the sea bottom together with more or less carbonate. The rolled fragments of phosphatic shells were probably enlarged somewhat by coatings of phosphate, derived by precipitation from the water which in turn had received it from the decomposing animal remains. The presence of phosphate in any considerable amount in a limestone can generally be detected by the appearance of small, highly polished oval grains having a brown or amber color. The more abundant these oolitic grains in the limestone the greater is the proportion of phosphate which it contains. With the decrease of its phosphatic content the limestone becomes more crystalline and the volume of the bed greater, indicating that the richer portions are the result of concentration by solution of a part of the originally deposited carbonate. Thus, while the principal phosphate-bearing formation is less than 50 feet thick about Mount Pleasant, it is nearly 70 feet thick about Williamsport and over 80 feet between that point and Water Valley on Leipers Creek, corresponding to a decreasing proportion of phosphate northward from Mount Pleasant.

The brown phosphate of commerce is the result of a process of leaching to which the phosphatic limestones have been and are now being subjected. Originally it constituted what may be called the phosphatic skeleton of the limestone. In the course of the leaching process this skeleton has been increased by additional phosphate derived from other beds or other parts of the same bed and precipitated in the place of other constituents removed. The calcium carbonate has been more or less completely removed by percolating surface waters charged with carbonic and other organic acids, most of the clay and iron, together with the less soluble calcium phosphate, being left behind.

Leaching usually begins in joint planes in the phosphatic limestone. These planes form avenues for the descent of the acidulated surface waters, capillarity being chiefly responsible for the movement of the waters. In wet weather the flow is downward and outward from the joint plane into the bedding planes of the limestone. In consequence of the alternation of wet and dry seasons a system of circulation is established. As more and more of the lime is dissolved and carried away the remaining rock becomes correspondingly more phosphatic, until practically all of the calcium carbonate is removed and nothing remains but brown phosphate rock with varying proportions of residual clay.

By a continuation of the leaching and decomposition process the phosphatic skeleton is itself broken up and the whole mass is finally changed in the ordinary manner into soil. Under certain conditions, however, a valuable body of phosphate rock is formed beneath the soil, which is generally much thinner than when no phosphate bed exists.

The leached deposits of brown phosphates are divisible, according to the conditions under which they occur, into two classes, which may be designated "blanket deposits" and "collar deposits" (see fig. 1, p. 4). By a "blanket deposit" is meant a nearly uniform sheet of phosphate rock extending without interruption over a considerable area, either the crown of a low hill or the surface of a gently sloping terrace, approximately the same strata throughout being concerned in its make-up. In a "collar deposit," on the other hand, only the edges of the strata have been leached, and the deposit encircles a hill without reaching the top, which is composed of later, nonphosphatic beds. Obviously the blanket deposits are the more extensive, and therefore the more valuable, of the two. In Maury, Hickman, and Williamson counties they are confined largely to the Bigby phosphates, but in Sumner County the beds in the Leipers formation often afford good examples of blanket deposits. This class of deposits occurs only when the land slopes are comparatively gentle, and is, therefore, dependent primarily on favorable conditions of erosion.

Certain conditions of underground drainage are particularly favorable to the production of a blanket deposit. The best result is reached when the phosphatic layers are underlain by one of those fine-grained, easily soluble limestones that so commonly give origin to sink-holes and caverns. Ordinary sink-holes are rare in phosphate regions, but this is due to the resistance of the phosphate rock to decomposition. As a rule, the leaching of the phosphatic limestone begins where surface waters gain access to the bed along joints and cracks, from which the process extends outward until the calcium carbonate is removed from the entire mass. Where the process is incomplete unchanged portions of the limestone frequently remain as "horses." During the process of leaching, the purer limestone beds, which occur in alternation with the highly phosphatic layers, decrease in bulk, a foot of limestone being represented in the leached mass by an inch or less of clay. The phosphate layers therefore settle down unequally, and a wavy structure, always noticed in the blanket deposits, is produced (see fig. 1). The high points of the waves usually have an unleached limestone core.

The "collar deposits" are produced where the phosphate bed outcrops on a steep slope. They result chiefly from capillary circulation, the water extending into the beds along the seams from the outcrop. Since the water can not pass through the bed, except to a very limited extent, its effect on the rock is correspondingly small and is confined to the outcropping edges of the bed. The drainage in this case is not underground but superficial.

What might be called a third type or class of brown phosphatic deposits occurs in areas—notably about the mouth of Piney Branch of Swan Creek—where the Leipers formation consists almost entirely of phosphatic limestone. Here, as is the case with nearly all the phosphatic limestones, the leaching process either begins in, or its progress is particularly favored by, vertical joints in the rock mass. On account of the unusual thickness of the phosphatic bed, the leaching of the rock on each side of the joint plane results in vertical, vein-like deposits that at first sight may appear very different from the horizontal deposits. In fact, however, they are merely earlier stages in the development of either a "collar" or a "blanket" deposit, into one or the other of which continued leaching would finally convert them.

The Mount Pleasant field is an example of a region in which the conditions are exceptionally favorable to the production of extensive blanket deposits of phosphate rock. The Bigby limestone here is very phosphatic, and, as shown in the structure sections, the strata south of Ridley and east of Mount Pleasant occupy a low dome dipping away from the center in every direction except the southeast. The general erosion of the land surface has proceeded to such a point that the Bigby limestone occupies the surface over a broad, undulating terrace between Sugar Creek and the hills to the southeast. The stream channels are sufficiently deep to secure perfect drainage of all portions of this terrace. Finally, an easily-decomposed, sometimes cavern-making limestone occurs beneath the phosphatic beds, affording conditions favorable for underground circulation. In all other good Ordovician phosphate regions of middle Tennessee all or most of these conditions are present.

The absence of these favorable conditions is observed north of Ridley, along East Fork, and along Big Bigby to Duck River. The same is true of the district between Canaan, Frierson, and Ashwood. In these districts the Bigby limestone lies either almost flat or in a syncline, and this structure does not favor rapid underground drainage, which is necessary to dissolve and carry away the lime of the phosphatic beds. A further reason why there are few if any good phosphate deposits in the areas mentioned is that the Bigby limestone becomes on the whole purer and the amount of phosphate relatively less as the formation is traced northward from Mount Pleasant.

Devonian deposits.—The conditions that produced the Devonian phosphate rocks were somewhat similar to those prevailing when the Ordovician limestones received their phosphatic matter. In addition, however, to the lime phosphate derived from animals then living, they also obtained a large amount of phosphate from the residual mantle overlying the weathered Ordovician limestones. Their phosphate, in other words, is in part primary, derived from organisms living at the time the rocks were formed, and in part secondary, derived from the waste of a pre-existing rock. It was deposited in a shallower sea, where fewer lime-carbonate secreting animals lived; hence it contains relatively less carbonate and more phosphate, and therefore requires no concentration by leaching to make it almost as rich in phosphoric acid as the leached Ordovician rock. Excepting the nodules, which doubtless were formed by subsequent segregation, the Devonian phosphate was concentrated when originally laid down, the sifting and washing process that carried away the detrital and calcareous matter probably having been, though in more limited areas, even more thorough than in earlier times. Besides, the animals from whose decomposition presumably a part of the phosphates of the Devonian formation was derived were all of kinds secreting more of that material than did the Ordovician types of life. That fishes of large size abounded in the Devonian seas is well known, and, in the case in hand, is evidenced by remains of their skeletons in the phosphate beds. Lingulas also were more abundant, but it is doubtful if they are responsible for any considerable amount of the total, for they are restricted wholly to the relatively unphosphatic shaly beds. Perhaps a more important source of phosphate is supplied by the conodonts. These are small teeth, jaws, and plates of probably myxinoid fishes—a low type of vertebrates related to the sharks. Countless numbers of these conodonts occur in the shales associated with the Swan Creek phosphate bed.

However, the principal source of the phosphate, if not the only one of consequence when we restrict our inquiry to the bed having commercial importance, is the underlying Ordovician limestone of the Leipers formation. This limestone is unusually phosphatic in the southwestern quarter of the quadrangle, to which also the valuable deposits of the Devonian phosphate are almost wholly confined; and it is full of the same minute spiral and other shells that occur so abundantly in the Swan Creek phosphate, especially in the oolitic variety. The latter never forms a valuable deposit where it does not rest directly upon the Leipers formation, being of low grade and generally shaly—never oolitic—where the Clifton limestone and Fernvale formation intervene. That portion of the surface of the Leipers formation not covered by the Clifton limestone and Fernvale formation was exposed as low land to subaerial decomposition, the phosphatic limestone becoming leached and broken up much as it does now. The ovules of the limestone, however, being highly phosphatic, resisted decomposition, and were preserved in the soil, which formed a coating over the ancient land. Finally, when the land was again sunk beneath the shallow Devonian sea, the soil was washed and sifted, the clayey and finely divided phosphatic matter taken into suspension and carried away by the currents, and the coarser ovules and sand were left to form the material composing the present layers of high-grade oolitic phosphate rock. The sorting and distribution of the material depended on gravity and currents, and the different varieties therefore should be expected to grade into one another.

Perhaps the most convincing proof of the conglomeratic origin of the blue Swan Creek phosphate bed is found in the fact that the organic ovules and casts of shells which constitute a large part of its bulk consist solely of more or less waterworn casts of the interior, thin sections of the rock showing not a trace of the outer shell which must have enveloped them when they were formed, and which actually does inclose the casts in the Ordovician limestone of which they originally formed a part.

IRON ORE.

Iron-ore deposits of sufficient size to be commercially important are confined to the northwest corner of the quadrangle. The largest deposit is at Nunnelly. Within an area a mile and a half in length east and west and three-quarters of a mile broad north and south large deposits of limonite, or "brown ore," are found embedded in red clay. Some waterworn pebbles are found at the surface, sometimes cemented into a conglomerate by the iron oxide. It appears probable, therefore, that the region has been covered by alluvial deposits, but that they have been almost entirely removed, and the great depth of clay found associated with the iron is doubtless residual, being derived from the weathering of the St. Louis limestone. Abundant fragments of chert, associated with the clay and iron, are a proof of this origin. The iron occurs in irregular pockets, frequently in the form of geodes which range in size from a few inches to several feet. The workings at Nunnelly have reached a depth of 60 feet, and a shaft put down 60 feet farther is reported to be still in iron-bearing ground. Three other deposits of limonite occur to the northeast of Nunnelly, but these are small and unimportant in comparison with the deposit above described. In the adjacent quadrangle, to the west, very extensive deposits of iron ore occur. These have been worked for many years at Aetna and Mannie. They closely resemble the Nunnelly deposits, and in every case are associated with more or less waterworn gravel. The exact conditions under which these iron ores were segregated are not clearly understood. Evidently conditions at these particular points were favorable for the deposition of the iron, which replaced the limestone removed by solution. Being pocket deposits, it is impossible to tell in advance how much ore they will yield. Even with the most thorough prospecting considerable uncertainty necesssarily remains. The Nunnelly deposit has been worked for a number of years, being in part utilized at the Goodrich furnace and in part shipped to other iron-making districts.

ROAD MATERIAL.

The rocks of this region yield an abundance of material admirably suited for road building. In the southeastern, more thickly populated portion of the region the roads, without macadamizing, become practically impassable in wet weather, owing to the clayey character of the soil. All of the main roads are, therefore, toll pikes. The material most commonly used for road making is the hard blue limestone, which occupies most of the surface in this portion of the quadrangle. Certain portions of the Tullahoma formation consist of very siliceous shaly limestone. This weathers by the removal of the calcium carbonate in solution, leaving a hard, porous chert, which makes a most excellent road material. In its natural state it is ready for use without crushing or other treatment. It packs quickly, and is much more durable and affords less dust than the limestone. This material is very abundant wherever the Tullahoma formation comes to the surface in the northern and western portions of the quadrangle. It also occurs capping many of the hills in the southeastern portion.

CLAY.

All the areas in this region underlain by Silurian and St. Louis limestones are almost entirely covered by a residual red clay soil. This is used for the manufacture of brick. The methods employed are rather crude, and the resulting product is consequently of low grade. The clay generally contains too high a proportion of iron to make first-class building brick, but the quality of the product would doubtless be much improved by proper manipulation.

BUILDING STONE.

Several of the Silurian formations occur in regular, even layers, which can be easily quarried. No quarrying on a large scale, however, has been done in this region. The quarries now open merely meet local demands. Some of the beds contain so large a proportion of lime phosphate that they tend to disentegrate rather rapidly, as is the case with much of the rock used in the construction of the Capitol at Nashville. The purer beds of limestone, however, are very durable, and beds of any desired size for foundations, or other purposes, might be obtained from the Carters limestone.

SOILS.

The soils of this quadrangle are almost entirely the result of the decay and disintegration of the rocks outcropping at the surface. Since such a close relationship exists between the rocks and the soils, the geologic map of the region may become, with proper interpretation, a valuable soil map.

The Lebanon limestone is the characteristic base of the former great red-cedar glades of middle Tennessee. The soil is apt to be shallow and rocky, but is fertile and forms good wheat and grass land where the slopes are gentle.

The Carters limestone, except close to the streams, produces an excellent and generally deep, light-red soil, usually distinguished from that formed from the beds next above and below by the small chert nodules or fragments which it contains. Under cover the rock disintegrates rather rapidly, especially along the joints, so that it outcrops usually in the form of white limestone bowlders. For the same reason, sinks, underground drainage, and large springs are perhaps more frequently associated with outcrops of this formation than with any other coming to the surface within this quadrangle.

The Hermitage formation gives, on the whole, a very good soil. This is true especially of the phosphatic upper portion, which forms the surface over considerable gently rolling tracts in the vicinity of Columbia. Close to the streams, especially near Duck River, it washes rather badly.

The Bigby limestone ranks first as a producer of durable and productive soils, and its large outcrops in the southeastern quarter of this area are counted among the best of the natural blue-grass regions of middle Tennessee. They are highly prized as wheat lands.

Both the Catheys and Leipers formation also produce excellent soils, but, as they usually outcrop on rather steep slopes and wash readily, they are liable rapidly to deteriorate unless great care is exercised in their tillage.

The next three formations, Fernvale, Clifton, and Chattanooga, directly contribute very little material to the soil in this region. They outcrop chiefly in bluffs and steep slopes, and their agricultural value, therefore, is confined to furnishing lime and phosphoric acid to the small tracts of bottom land beneath them.

The poorest soil of this territory is derived from the Tullahoma formation. It occurs nearly always on steep slopes, is flinty, and, when thoroughly leached and light in color, constitutes the "barrens" of the Highland Rim. Occasionally, however, when the under clay is red and tenacious, so that the calcareous matter is not readily leached out, the soil is very good and capable of producing abundant crops of corn and other staple products.

The St. Louis limestone weathers deeply, and, when it forms the surface rock of moderately level land, produces a good red soil. But where the tracts are narrow, as on the summits of the ridges in the southeastern quarter of this quadrangle, the soil is little if any superior to that of the underlying Tullahoma formation.

Narrow strips of bottom lands occur along the large streams, particularly along Duck River. The soil on these is a fine clay loam of great productiveness.

June, 1902.

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

TOPOGRAPHY

TENNESSEE
COLUMBIA QUADRANGLE

LEGEND

RELIEF
(printed in brown)

Figures
(showing heights above mean sea level instrumentally determined)

Contours
(showing height above sea, horizontal form, and steepness of slope of the surface)

Depression contours

DRAINAGE
(printed in blue)

Streams

CULTURE
(printed in black)

Roads and buildings

Private and secondary roads

Trails

Railroads

Tunnels

Bridges

Fords

County lines

B.M.
X
Bench marks

H.M. Wilson, Geographer in charge.
Control by Gilbert Thompson, W.J. Peters, and G.T. Hawkins.
Topography by A.E. Murlin, Hersey Munroe, and Albert Pike.
Surveyed in 1895 and 1899.

Munroe 1899
Pike 1899

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.
Datum is mean sea level.

Edition of Nov. 1902.

U.S. GEOLOGICAL SURVEY
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AREAL GEOLOGY

TENNESSEE
COLUMBIA QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines)

CARBONIFEROUS

Csl — St. Louis limestone *(gray and blue, heavy-bedded, cherty limestone)*

Ct — Tullahoma formation *(extremely cherty shale and limestone, with greenish clay shale at the base in places)*

DEVONIAN

Dc — Chattanooga shale *(carbonaceous black shale)*

SILURIAN

Sct — Clifton limestone *(even-bedded, compact, light-gray or bluish limestone)*

Ordovician

Sf — Fernvale formation *(soft, green or chocolate shale with bands of crystalline limestone)*

Sl — Leipers formation *(knotty, earthy limestone and interbedded shale, or granular crystalline limestone without shale)*

Scy — Catheys formation *(knotty, earthy limestone and shale with heavy bands of impure blue limestone)*

Sby — Bigby limestone *(mainly granular, crystalline, laminated, phosphatic limestone)*

Sht — Hermitage formation *(even-bedded shale with siliceous limestone below and siliceous, granular, phosphatic limestone above)*

Scr — Carters limestone *(massive, compact, white or light-blue, cherty limestone)*

Slb — Lebanon limestone *(thin-bedded, compact, bluish or dove-colored limestone)*

Faults

H.M. Wilson, Geographer in charge.
Control by Gilbert Thompson, W.J. Peters, and G.T. Hawkins.
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Surveyed in 1895 and 1899.

Munroe 1899 | Murlin 1895 | Pike 1899

TRUE NORTH — MAGNETIC NORTH — APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Miles 1 ½ 0 1 2 3 4 5

Kilometers 1 ½ 0 1 2 3 4 5

Contour interval 50 feet.
Datum is mean sea level.
Edition of June 1903.

Geology by C. Willard Hayes and E.O. Ulrich.
Surveyed in 1899-1900.

U.S. GEOLOGICAL SURVEY
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ECONOMIC GEOLOGY

TENNESSEE
COLUMBIA QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines)

CARBONIFEROUS

- Csl — St. Louis limestone *(gray and blue, heavy-bedded, cherty limestone)*
- Ct — Tullahoma formation *(extremely cherty shale and limestone, with greenish clay shale at the base in places)*

DEVONIAN

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- Scr — Carters limestone *(massive, compact, white or light-blue, cherty limestone)*
- Slb — Lebanon limestone *(thin-bedded, compact, bluish or dove-colored limestone)*

Faults

- ⚒ *Phosphate mines*
- ⚒ IRON *Limonite mines*
- × *Phosphate prospects*

Known productive areas

- *Limonite* *(deposits in residual clay of St. Louis limestone)*
- *Chattanooga phosphates* *(original deposits of concentrated phosphates)*
- *Leipers phosphates* *(brown phosphate, the residuum of leached phosphatic limestone)*
- *Bigby phosphates* *(brown phosphate)*
- *Hermitage phosphate* *(brown phosphate)*

H. M. Wilson, Geographer in charge.
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Munroe 1899 | Murlin 1895 | Pike 1899

TRUE NORTH | MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

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Contour interval 50 feet.

Datum is mean sea level.

Edition of June 1903.

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Surveyed in 1899-1900.

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FERNVALE AND CLIFTON EMBAYMENTS

TENNESSEE
COLUMBIA QUADRANGLE

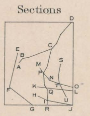
LEGEND

Embayments of the interior Silurian sea on the western border of the middle Tennessee land area.

Clifton embayment (areas in which Clifton limestone was deposited; outcrops are shown by solid color)

Fernvale embayment (areas in which Fernvale formation was deposited; outcrops are shown by solid color)

Sections



Letter symbols and formation boundaries are explained on the Areal Geology map.

H.M.Wilson, Geographer in charge.
Control by Gilbert Thompson, W.J. Peters, and G.T. Hawkins.
Topography by A.E. Murlin, Hersey Munroe, and Albert Pike.
Surveyed in 1895 and 1899.

Munroe 1899 / Murlin 1895 / Pike 1899

TRUE NORTH / MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Miles / Kilometers

Contour interval 50 feet.
Datum is mean sea level.

Edition of May 1903.

Geology by C. Willard Hayes and E.O. Ulrich.
Surveyed in 1899-1900.

U.S. GEOLOGICAL SURVEY
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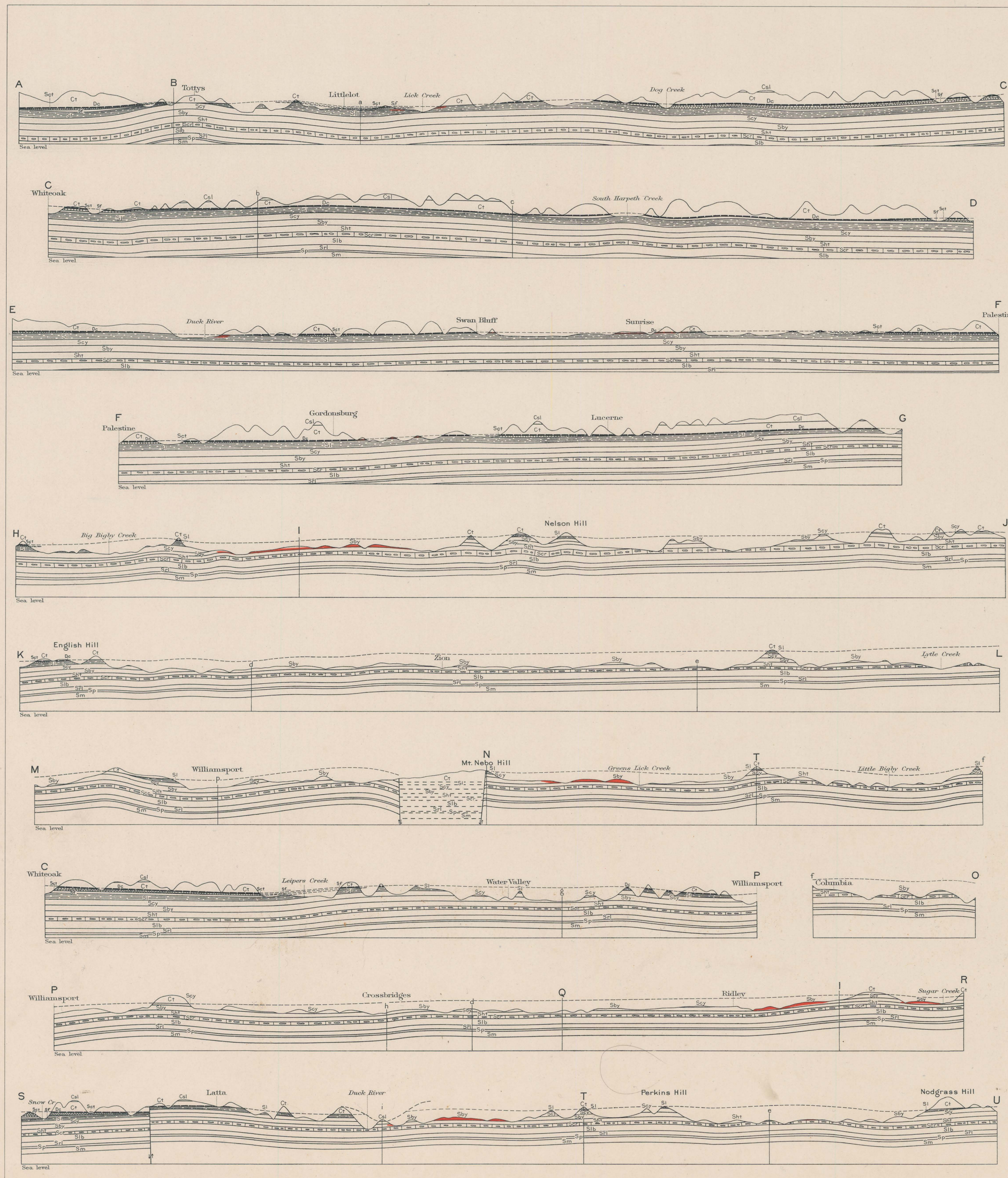
STRUCTURE SECTIONS

TENNESSEE
COLUMBIA QUADRANGLE



LEGEND

CARBONIFEROUS — Mississippian series

Csl — St. Louis limestone

UNCONFORMITY

Ct — Tullahoma formation

UNCONFORMITY

DEVONIAN

Dc — Chattanooga shale

UNCONFORMITY

SILURIAN

Sct — Clifton limestone

UNCONFORMITY

Ordovician series

Sf — Fernvale formation

UNCONFORMITY

Sl — Leipers formation

Scy — Catheys formation

Sby — Bigby limestone

Sht — Hermitage formation

Scr — Carters limestone

Slb — Lebanon limestone

Srl — Ridley limestone

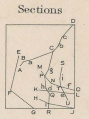
Sp — Pierce limestone

Sm — Murfreesboro limestone

Phosphate deposits

The Ordovician phosphates occur on gentle anticlines which favor the formation of residual phosphate deposits by leaching; the Devonian phosphates are restricted to the areas where the Devonian sediments rest directly on the phosphatic Ordovician limestones.

Sections



Section lines shown on the Fernvale and Clifton embayment map.

Horizontal scale: 1 inch = 1 mile.
Vertical scale: 1 inch = 1000 feet.
Edition of Aug. 1903.

Geology by C. Willard Hayes
and E. O. Ulrich.
Surveyed in 1899-1900.

COLUMNAR SECTIONS

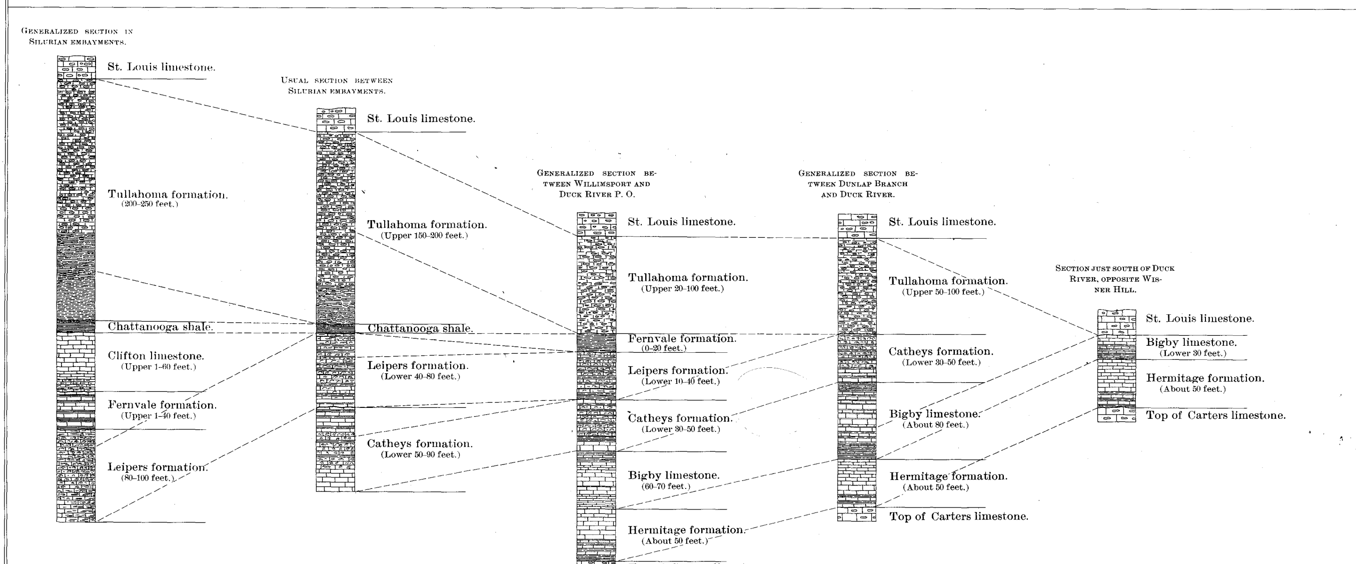
GENERALIZED SECTION OF THE ROCKS OF THE COLUMBIA QUADRANGLE.

SCALE: 1 INCH = 100 FEET.

Period.		Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Topography and Soil.
CARBONIFEROUS	(MISSISSIPPIAN)	St. Louis limestone.	Csl		250	Gray and blue, thick-bedded, fossiliferous limestone, generally very cherty; chert in large pieces and solid except in the basal part, where it is cellular.	Rolling or hilly land, with cliffs along streams. Residual chert of this formation covers nearly all of the northeast quarter of the quadrangle and caps the higher ridges in the northwest and southwest quarters. Soil good where slopes are not too steep.
		UNCONFORMITY					
		Tullahoma formation.	Ct		0–250	Greenish clay shale at the bottom, followed by extremely cherty shale and cherty limestone above; chert clayey and in small pieces.	Hilly lands and very steep slopes. Soil generally very poor.
		UNCONFORMITY					
DEV.		Chattanooga shale.	Dc		0–10	Black carbonaceous shale, generally with a phosphatic band at the base and a glauconitic green shale, containing phosphatic nodules, at the top.	Rarely seen except in cliffs or on steep slopes.
		UNCONFORMITY					
SILURIAN	UPPER SILURIAN	Clifton limestone.	Sct		0–60	Even bedded, dense, light-gray or bluish limestone, often thin-bedded and occasionally shaly in the lower part.	Cliffs and steep slopes. Very little soil.
		UNCONFORMITY					
	ORDOVICIAN	Fernvale formation.	Sf		0–40	Soft, green and chocolate shales, and red, ferruginous, crystalline limestone, often containing greenish specks, and occasionally conglomeratic and phosphatic.	Little effect on topography and soil.
		UNCONFORMITY					
		Leipers formation.	Sl		0–100	In eastern half of quadrangle, knotty, earthy limestone at the top, with similar but more shaly and highly fossiliferous beds below. In western half, nearly uniform granular crystalline limestone, the more granular portions highly phosphatic.	Generally hilly, with steep slopes. Soil very good but inclined to wash.
		UNCONFORMITY					
		Catheys formation.	Scy		0–100	Shales and knotty limestones, usually underlain by heavy-bedded subcrystalline limestone and overlain by fine-grained, blue, and earthy limestones separated by thin seams of shale; all more or less highly fossiliferous. Basal part occasionally includes some granular phosphatic layers.	Rather hilly lands and generally steep slopes. Excellent soil in the larger tracts.
		Bigby limestone.	Sby		30–100	Generally nearly uniform granular, crystalline, laminated, phosphatic limestone; the upper part often shaly or arenaceous, the lower part frequently having beds of shales but never sandy.	Gently undulating surface. Soil durable and highly productive; "blue grass" lands.
		Hermitage formation.	Sht		40–70	Even-bedded, alternating thin layers of argillaceous or siliceous limestone and shale in lower third, and siliceous subgranular limestone more or less strongly phosphatic in the middle and upper parts.	Lower part of formation rather steep slopes and poor soil; upper part, nearly level lands and very good soil.
		UNCONFORMITY					
		Carters limestone.	Scr		40–60	Heavy-bedded, fine-grained, white or light-blue limestone, often containing chert and silicified fossils.	Generally cliffs along streams. Soil good where slopes are not too steep.
		Lebanon limestone.	Slb		70–100	Thin-bedded, often shaly, fine-grained, bluish or dove-colored limestone, frequently weathering yellow.	Along larger streams, steep slopes and bluffs, but elsewhere nearly level lands. Soil rather shallow; good where not too rocky.

SECTIONS SHOWING LOCAL VARIATIONS IN THE SEQUENCE OF THE STRATA.

SCALE: 1 INCH = 100 FEET.



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THE CORRELATION TABLE.

The first column at the left shows the major geologic time divisions, and on the right, the principal and generally accepted geologic subdivisions of the Paleozoic rocks of the region between the Appalachian Mountains and the Mississippi River. The units of the column are believed to represent consecutive periods of time and are distinguished by more or less well-marked breaks in the continuity of the faunal and physical history of the continent.

The second column contains the formations that are distinguished in the Columbia quadrangle and shows their respective positions in the geologic scale. Stratigraphic unconformities, determined chiefly by paleontologic evidence, are indicated by wavy divisional lines. When the wavy line extends only half across the column it indicates that the unconformity is not general throughout the quadrangle. The first unconformity or stratigraphic hiatus occurs between the Carters limestone and the Hermitage formation, the top of the former having been reduced by erosion during the deposition elsewhere of the Black River rocks and the basal portion of the overlapping Hermitage formation. The unconformity between the Bigby and Catheys formations is a local occurrence. The third, fourth, fifth and sixth unconformities, however, seem to be general for the quadrangle. In each case one or more formations known in more complete sections have no stratigraphic representation here. In the third case the Utica and Frankfort shales are absent, in the fourth case the lower three-fourths of the Richmond group seems not to have been deposited, and in the fifth case the Clinton is wanting, while the sixth unconformity represents the long time during which in other areas the formations intervening between the Niagara and the Portage were deposited. Further, the Chattanooga formation, despite its very limited volume here, seems to represent the whole of, and perhaps more than, the upper Devonian deposits of Pennsylvania and New York. Locally a seventh and an eighth unconformity, due like the preceding ones to erosion and non-deposition, occur respectively between the Chattanooga and Tullahoma formations and between the latter and the St. Louis limestone.

In the third column, which is devoted to Safford and Killebrew's section of the rocks of middle Tennessee, the formations and parts of formations wanting in the Columbia quadrangle, but occurring in other parts of the State, are inserted in their proper positions. The Maury green shale they place at the base of the Carboniferous instead of at the top of the Devonian Chattanooga shale, the latter being the position assigned to the bed in this folio. Their Carters limestone embraces higher beds, and the Clifton limestone both lower and higher members that are wanting in this quadrangle. The earlier sections by Safford, given in the fourth and fifth columns, are not so exactly correlated, the principal reason for their insertion here being the wish to show the changes in nomenclature and classification that the formations in middle Tennessee have undergone since 1851.

In the section taken from the Richmond and London (Ky.) folios the Clifton limestone of the Columbia quadrangle represents only a part (probably the middle) of the Panola formation, while the Richmond formation in the Kentucky section does not include the Fernvale formation, but, on the contrary, is made up of lower Richmond deposits wanting in the Columbia quadrangle. The statements that Cayuga, Helderberg, Oriskany, Hamilton, upper Richmond, lower Frankfort, and Utica deposits are absent in this section are inserted by the authors.

In the last column, representing the section in Ohio, the St. Louis limestone is wanting, while the Maxville limestone is correlated with the middle part of the Chester. Further noteworthy features shown in this column are the absence of Oriskany, Helderberg, and upper Trenton deposits in Ohio, the early Trenton age of the Point Pleasant beds, and the lower position of the "Trenton oil horizon" than is generally supposed.

	Generalized time scale for central North America.	Mapable lithologic equivalents in the Columbia quadrangle.	Safford and Killebrew: Elements of the Geology of Tennessee, 1900. Middle Tennessee.	Safford: Geology of Tennessee, 1869. Middle Tennessee.	Safford: American Journal of Science, second series, vol. xii, 1851. Geological reconnaissance, 1856.	Marius R. Campbell: Richmond and London (Ky.) Folios, U. S. Geological Survey, 1898.	Geological Survey of Ohio, 1873-93.
CARBONIFEROUS (MISSISSIPPIAN)	Chester.	*(Not present.)*	Mountain limestone.	Mountain limestone.	Pentremital or Mountain limestone.	Pennington shale.	*(Wanting.)* Maxville limestone.
	St. Louis.	St. Louis limestone.	St. Louis limestone.	Lithostrotion bed or St. Louis limestone.	Cherty limestone.	Newman limestone.	*(Wanting.)*
	Keokuk.			Siliceous group.	Siliceous group.		
	Burlington.	Tullahoma formation.	Tullahoma formation.	Lower or Protean member.	Siliceous beds.	Waverly formation.	Waverly formation.
	Kinderhook.						
DEVONIAN	Chemung.	Chattanooga formation.	Maury green shale. Black shale (Chattanooga shale), Swan Creek phosphate, and Hardin sandstone.				
	Portage. (Including Genesee.)			Black shale.	Black slate.	Chattanooga shale.	Black or Ohio shale (1893). (Including Cleveland shale, Erie shale, and Huron shale.)
	Hamilton.	*(If present, are represented in the phosphatic beds at the base of the Chattanooga formation.)*					Olentangy shale and Delaware limestone. (Hamilton.) Columbus limestone. (Corniferous.)
	Onondaga. (Corniferous.)						
	Oriskany.		Camden chert (Oriskany).				
SILURIAN — UPPER SILURIAN	Helderberg.	*(Wanting.)*	Linden limestone. (Lower Helderberg.)	Lower Helderberg.		Panola formation. *(Cayuga, Helderberg, Oriskany, and Hamilton not represented by sediments in this area.)*	*(Wanting.)*
	Cayuga.				Harpeth and Tennessee River group. (Gray limestone; Dyestone.)		Waterlime. (Lower Helderberg, 1893.)
	Niagara. (Including Guelph.)	Clifton limestone.	Clifton limestone. (Niagara.)	Meniscus limestone. (Niagara group.)			Niagara.
	Clinton.	*(Wanting.)*					Clinton.
SILURIAN — ORDOVICIAN	Richmond.	Fernvale formation. *(Wanting.)*		Upper Nashville.	Upper Nashville.	*(Wanting.)* Richmond formation.	Lebanon beds.
	Lorraine.	Leipers formation.	Hudson (College Hill; Cincinnati). Includes Hudson phosphate.				Hill Quarry beds.
	Frankfort.	*(Wanting.)*				Winchester limestone, including Garrard sandstone lentil. *(Lower Frankfort and Utica wanting in this area.)*	Eden shale. Hudson River series.
	Utica.			Middle Nashville. Nashville.	Lower Nashville. Nashville group.		Utica shale.
	Trenton.	Catheys limestone. Bigby limestone. Hermitage formation.	(*f*) (*g*) Cyrtodonta and Stromatopora beds. (*d*) (*e*) Dove and Ward limestones. (*c*) Capital limestone or Mount Pleasant phosphate. (*b*) Orthis bed. Nashville (Trenton).	Lower Nashville. (Orthis bed.)	Siliceous or sandy limestone.	Flanagan chert. Lexington limestone.	*(Wanting.)* River Quarry and Point Pleasant beds. Trenton ? Cincinnati group.
	Black River.	*(Wanting.)*	*(Not classified.)*	Carters Creek limestone.	Upper Lebanon limestone. Central limestone and shale group.		"Hard cap of Trenton."
	Stones River.	Carters limestone. Lebanon limestone. *(Not exposed.)*	(*a*) Carters limestone. Lebanon limestone. Ridley limestone. Pierce limestone. Murfreesboro limestone. Stones River (Chazy).	Glade limestone. Ridley limestone. Pierce limestone. Central limestone. Trenton or Lebanon.	Lower Lebanon limestone. Stones River beds Stones River group.	High Bridge limestone. *(Not exposed.)*	"Trenton oil horizon." Trenton, Birdseye, and Chazy.

NOTE.—Italics in the last two columns are insertions by the authors

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GENERALIZED FAUNAL CHART.

Only a few of the more striking species of some of the formations exposed within the Columbia quadrangle are figured on the Illustration sheet. There are many other fossils equally characteristic of the formations, and these are listed in the generalized faunal chart opposite, which aims to show their first occurrence and their vertical range by the letters a (signifiying abundant), c (common), or r (rare), in spaces each representing approximately 20 feet of the stratigraphic column. As the chart is intended to serve for the whole of the Central Basin of Tennessee, it includes the species occurring in the Ridley, Pierce, and Murfreesboro limestones, which do not outcrop within this quadrangle.

GENERALIZED FAUNAL CHART

FOR THE WESTERN SIDE OF THE MIDDLE TENNESSEE BASIN

Vertical range of species indicated by horizontal spaces, each representing approximately 20 feet of thickness.

a=abundant; c=common; r=rare.

Formation in which species first appear	Names of species arranged in groups under the formation in which they first appear.	St. Louis limestone.	Tullahoma formation.	Chattanooga.	Clifton limestone.	Fernvale.	Leipers formation.	Catheys formation.
ST. LOUIS FORMATION	Lithostrotion proliferum	c c						
	L. canadense	c c						
	Melonites sp.	c c						
	Cystodictya st. ludovici	c c						
	Worthenopora spinosa	c						
	Hemitrypa proutana	c						
	Fenestella tenax	c						
	Spirifer leidyi	c c c						
	S. tenuicostatus	c c						
	Productus punctatus	r r r						
TULLAHOMA FORMATION	Productella concentrica		r					
	P. (very small species)		c					
	Camarotœchia sageriana		r					
	Lingula subspatulata ?		c					
	Pleurotomaria hickmanensis		r					
	Ctenobolbina loculata and other small Ostracoda		c					
	Columns and plates of many crinoids		c c c r					
CHATTANOOGA	Lingula spatulata ?			a				
	Dinichthys and other fish remains			c				
	Conodonts			a				
	Athyris incrassata							
CLIFTON LIMESTONE	Duncanella borealis ?				c			
	Heliolites interstinctus				c r			
	Thecia minor				c r			
	Halysites catenulatus				c r			
	Favosites favosus				c r			
	F. niagarensis				c r			
	Holocystites sp. undet.				r			
	Haplocrinus hemisphæricus				c			
FERNVALE FORMATION	Bythotrypa epidermata					c		
	Anolotichia ponderosa					c		
	Monotrypella quadrata					c		
	Crepipora hemisphærica					c		
	Pachydictya grandis					c		
	Ptilotrypa obliquata					c		
	Goniotrypa bilateralis					c		
	Leptæna unicostata					c		
	Strophomena planodorsata					c		
	Dalmanella tersa					c		
	Dinorthis subquadrata					c		
	Hebertella insculpta					r		
	Rhynchotrema capax					r		
	Parastrophia divergens					r		
LEIPERS FORMATION	Dystactospongia insolens						c	
	Labechia scabra						c	
	Glyptocrinus decadactylus						r	
	G. subglobosus						r	
	Lepidodiscus cincinnatiensis						r	
	Crepipora simulans						a c	
	Monticulipora mammulata						r	
	M. molesta						c	
	Atactoporella mundula						c	
	Peronopora compressa						a	
	Homotrypella nodosa						a	
	Bythopora minuta ?						c	
	B. gracilis						c c	
	Heterotrypa frondosa						a	
	H. solitaria						a	
	Dekayella grandis						a	
	Callopora dalei						a r c	
	Constellaria florida						a c	
	Amplexopora columbiana						c a	
	Escharopora pavonia						c	
	E. falciformis						r	
	Phylloporina clathrata						r r	
	Crania scabiosa						c	
	Platystrophia laticosta						c a	
	P. lynx						a	
	Hebertella sinuata						c a r	
	Rafinesquina alternata ponderosa						c c	
	Strophomena sinuata						r	
	S. planoconvexa						c	
	Bucania n. sp.						r	
	Cyclonema mediale						c	
	Byssonychia radiata						[illegible]	
	Pterinea cincinnatiensis						c	
	Modiolopsis modiolaris						r	
	Modiolodon truncatus						r r	
	Calymene senaria						r	
	Ceraurus milleranus						r	
	Lichas halli						c	
CATHEYS FORMATION	Pattersonia aurita							r a
	Columnaria alveolata							c c r a
	Stromatocerium pustulosum						rc	c c a r
	Tetradium fibratum						rc	c a r
	T. apertum							c c
	Heterotrypa parvulipora							a c
	H. sp. undescr., nodose							a c
	Escharopora, tuberculated species near pavonia							a c
	Hebertella sinuata, var.						?r	a a c r
	Platystrophia lynx, small var.							a
	P. laticosta, var.							c
	P. n. sp. with bifurcating plications							r
	Orthorhynchula linneyi						c	c a c
	Oxydiscus cristatus							c
	Bucania lindsleyi							r c
	B. frankfortensis							r c
	Cyclonema varicosum							c a
	Leperditia linneyi							c c
	L. n. sp. with ventral spine							c c
	Isochilina saffordi							c c
	I. ampla							c c

Vertical range of species indicated by horizontal spaces, each representing approximately 20 feet of thickness.

a=abundant; c=common; r=rare.

Formation in which species first appear	Names of species arranged in groups under the formation in which they first appear.	Leipers formation.	Catheys formation.	Bigby limestone.	Hermitage.	Carters limestone.	Lebanon limestone.	Ridley limestone.	Pierce.	Murfreesboro limestone.
BIGBY LIMESTONE	Solenopora compacta		a	c		r	r			
	Constellaria teres		c r	a						
	C. florida emaciata		c c	a						
	C. grandis			c						
	Eridotrypa briareus		c r c	c r						
	Escharopora ponderosa			r						
	Lingulops norwoodi			c						
	Dalmanella testudinaria, var.			c						
	Hebertella borealis			c						
	Rafinesquina alternata		c c c r r	r a c r						
	Rhynchotrema inæquivalve			a						
	Ctenodonta subrotunda			a						
	Clidophorus fabula	c c c c c		c a						
	Ctenodonta obliqua	c c c c c		c a						
	Byssonchia intermedia		r	r						
	Archinacella patelliformis			c						
	Cyrtolites retrorsus			c						
	Bellerophon clausus			a						
	Lophospira oweni			a						
	Hormotoma gracilis			c						
	Cyclora minuta	c c c c c	r r r r r	r c a						
	C. parvula	r r r r r		r a						
	Microceras inornatum	c c c c c		a						
	Ormoceras capitolinum			c						
	Cyrtoceras macrostomum		?c	c						
	C. constrictum		c	?c						
	C. n. sp.			c						
HERMITAGE	Prasopora patera				a					
	P. simulatrix				c					
	Leptobolus lepis				c					
	Dalmanella testudinaria, var.				c c c					
	Ctenodonta, small, circular species				a					
	Whiteavesia cincinnatiensis				r					
	Lophospira abnormis				c					
CARTERS	Dystactospongia minor					a r	c			
	Tetradium columnare					a c				
	Columnaria halli					a a		c		
	Rhinidictya nicholsoni					a				
	Phyllodictya frondosa					a				
	Stromatocerium rugosum					r a c				
LEBANON LIMESTONE	Bythotrephis cæspitosa						c c r c			
	Tetradium cellulosum					c	a r			
	Streptelasma profundum					r c r	r r			
	Cliocrinus n. sp.						r c			
	Amygdalocystites n. sp.						r r			
	Rhinidictya trentonensis						c c			
	Escharopora ramosa						c			
	E. libana						c			
	E. briareus						c			
	Helopora spiniformis						c			
	Batostoma libana (Saff.)						a c		?c	
	10 undescribed Bryozoa						c			
	Diplograptus						a			
	Plectambonites n. sp., obliquely wrinkled						c a			
	Orthis deflecta						c c			
	O. tricenaria					r	c c			
	Skenidium halli						c			
	Rhynchotrema minnesotensis						a a			
	Zygospira recurvirostra		c c r c	r	c	a	c			
	Z. (Hallina) saffordi						a			
	Conradella grandis						c			
	Helicotoma planulatoides					c	r			
	Lophospira peracuta						r			
	Subulites						r			
	Pterotheca saffordi					?	c			
	Lituites undatus ?						r			
	Eurychilina subradiata						c			
	Drepanella macra						c			
	Encrinurus excedrinus						c			
	Pterygometopus callicephalus		r			c	r			
	Thaleops ovatus						c			
RIDLEY	Orthis bellarugosa						c	r r a		
	Rhynchotrema ottawaensis ?							a		
	Liospira convexa							c		
PIERCE LIMESTONE	Nicholsonella pulchra								a	
	Phylloporina sublaxa						c c		c	
	Rhinidictya nashvillensis								a	
	Escharopora symmetrica								a	
	20 undescribed Bryozoa								a	
	Rafinesquina minnesotensis						a a	r	c	r c
	Strophomena incurvata					a	a a		c	
	Dalmanella subæquata						a a		c	
	D. stonensis								c	
	Protorhyncha ridleyana							a	r	
	Rhynchotrema n. sp.								c	
MURFREESBORO LIMESTONE	Anthaspidella sp. undet.									r
	Ctenodonta gibberula									c
	C. n. sp.									c
	Orthodesma saffordi									c
	Holopea sp. undet.									r
	Solenospira prisca-extenuata									c
	Helicotoma tennesseensis									a
	H. declivis									a
	Trochonema bellulum									c
	Lophospira perangulata									a
	L. bicincta									c
	L. centralis									c
	L. procera									r
	Liospira abrupta									a
	L. decipiens							c		c
	L. progne						c	c		c
	L. subconcava									c
	L. vitruvia						c	c		c
	Salterella billingsi									a
	Hyolithus baconi									r
	Actinoceras bigsbyi									r
	Cyrtoceras bondi									r
	C. stonense									c
	Leperditia fabulites					c c	c c c	r r	r	a a

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THE ILLUSTRATION SHEET.

On the Illustration sheet are figured some of the more striking species of fossils found in the quadrangle, grouped according to their respective formations, as follows:

ST. LOUIS LIMESTONE.

FIG. 2. Upper surface of *Lonsdaleia* (or *Lithostrotion*) *canadense* (Castlenau), a coral growing, as in the figure, into compact masses reaching a foot in diameter. In the associated *L. prolifera* the individual corallites do not touch each other and therefore are cylindrical instead of prismatic. The latter variety is the more common in this region and probably occurs alone in the lower beds of the formation.

FIGS. 3 and 4. Highly magnified views of the front and back of one of the delicate "lace Bryozoa," the species figured being *Fenestella tenax* Ulrich. The broken remains of these beautiful Bryozoa often cover the heavy layers of chert at the base of the formation.

CLIFTON LIMESTONE.

FIG. 5. Upper surface of *Favosites favosus*, one of the honey-comb corals. Other species of *Favosites*, having much smaller cells, are often found with this.

FIG. 6. One of the varieties of *Halysites catenulatus*—the chain-coral—which in this region is highly characteristic of the Clifton limestone.

FERNVALE FORMATION.

FIGS. 7 and 8. Views of the exterior and interior of the ventral (in this case the flatter) valve of *Dinorthis subquadrata* (Hall).

FIGS. 9 and 10. A group of three specimens of *Monotrypella quadrata* (Rominger), and the surface of one of them magnified five diameters. At the ends of the branches the cells are rhombic in shape.

LEIPERS FORMATION.

FIGS. 11 and 12. A sub-globular bryozoan, *Amplexopora columbiana* Ulrich and Bassler, composed of small radiating prismatic tubes. Fig. 12 shows the openings of these tubes magnified five diameters.

FIG. 13. A frond of the strongly pustulose bryozoan *Monticulipora molesta* Nicholson. This fossil is highly characteristic of the upper middle part of the formation and its empty molds were frequently observed in the phosphate of this horizon in the Swan Creek region. (An outwardly similar but structurally quite different species occurs in the underlying Catheys formation.)

FIGS. 14 and 15. *Homotrypella nodosa* Ulrich and Bassler. A group of three specimens and the surface of a fourth magnified five times. The cells are very small and the walls granulose.

FIG. 16. *Glyptocrinus decadactylus* Hall. This fine crinoid occurs about the middle of the formation. Fragments of the annulated stem or column, which in life was attached to the lower end of the portion shown in the illustration, are common and heads even are not rare where the strata are shaly.

FIG. 17. The dorsal side of *Hebertella sinuata* Hall, a common brachiopod of this and the underlying Catheys formation. In the latter the plications are usually a little coarser than in the Leipers formation variety.

FIGS 18 and 19. *Strophomena planoconvexa* Hall. The first shows the convex or dorsal side of an entire specimen; the second the interior of the flat ventral valve.

FIG. 20. The convex side (ventral valve) of an entire shell of *Rafinesquina alternata* var. *ponderosa*. The opposite valve is concave. This species is even more abundant in the Catheys and Bigby formations, but in those lower horizons it scarcely reaches half the size of the *ponderosa* variety which characterizes the upper middle part of the Leipers formation.

FIGS. 21 and 22. *Platystrophia lynx* Von Buch. Dorsal and cardinal views of two specimens of the large variety of this species which is so abundant in and characteristic of the uppermost bed of the formation.

CATHEYS FORMATION.

FIGS. 23 and 24. *Stromatocerium pustulosum* Safford. Portions of a silicified mass of this common hydro-coralline, the first showing the upper surface, the second the laminar structure of the edge and bottom. Masses of this coral vary from a few inches to 2 or 3 feet in diameter. A variety of the species reappears in the upper part of the Leipers formation, while along the northern margin of the basin it occurs in rocks that are equivalent to the Bigby limestone of this quadrangle. Almost invariably the matrix is an earthy, fine-grained limestone.

FIG. 25. Portion of the weathered upper surface of a mass of *Columnaria alveolata* Goldfuss, showing the strongly septate corallites. This coral and the preceding pustulose *Stromatocerium* are nearly always found associated and generally in company with one or another of the species of *Tetradium*.

FIG. 26. *Heterotrypa parvulipora* Ulrich and Bassler, a frondescent or palmate bryozoan found very abundantly in the shaly lower third or half of the formation. The entire surface is covered with the angular apertures of very small tubes.

FIG. 27. *Oxydiscus cristatus* Safford, a symmetrically involuted, disciform gastropod shell, highly characteristic of the lower part of the formation. The keel is very thin and sharp.

FIGS. 28 and 29. A very large and small specimen of *Cyclonema varicosum* Hall. The species is distinguished by its strong revolving lines, is very common, and restricted to the Catheys formation.

BIGBY LIMESTONE.

FIG. 30. A group of eight specimens of *Constellaria florida* var. *emaciata* Ulrich and Bassler.

FIG. 31. A group of five specimens of *Constellaria teres* Ulrich and Bassler. These two species of *Constellaria* are often extremely abundant in the upper part of the Bigby limestone. In this quadrangle *Constellaria teres* appears to be restricted to the Bigby, but in the vicinity of Nashville it seems to pass over into the Catheys formation. *Constellaria florida* is very common in the shaly parts of the Leipers formation, and the variety *emaciata* is not infrequently found also in the Catheys formation.

FIGS. 32 to 34. Dorsal, lateral and apertural views of two specimens of *Bellerophon clausus* Ulrich. This species is generally associated with another gasteropod, a variety of *Lophospira oweni* Ulrich, and these, together with *Ctenodonta subrotunda* Ulrich, *Hebertella borealis* (Billings), and *Rhynchotrema inæquivalve* (Hall), may be regarded as reliable indications of a horizon lying between the middle of the formation and the *Constellaria* bed at the top—in other words, to the horizon intervening between Bigby phosphates Nos. 2 and 3.

FIG. 35. *Lingulops norwoodi* (James), a small, strongly convex linguloid brachiopod, of the natural size and magnified, found in the unleached limestone horses of Bigby phosphate No. 2.

FIGS. 36 and 37. Opposite view of two specimens of *Hebertella borealis* (Billings).

FIGS. 38 and 39. Opposite views of two specimens of *Rhynchotrema increbescens* (Hall).

FIGS. 40 and 41. Exterior and interior views of a valve of *Ctenodonta subrotunda* Ulrich. A much smaller undescribed species of this type occurs sometimes very abundantly in the Hermitage formation in the region between Mount Pleasant and McCains.

HERMITAGE FORMATION.

FIGS. 42 and 43. Portions of a slab of chert almost made up of silicified valves of a variety of *Orthis* (*Dalmanella*) *testudinaria*.

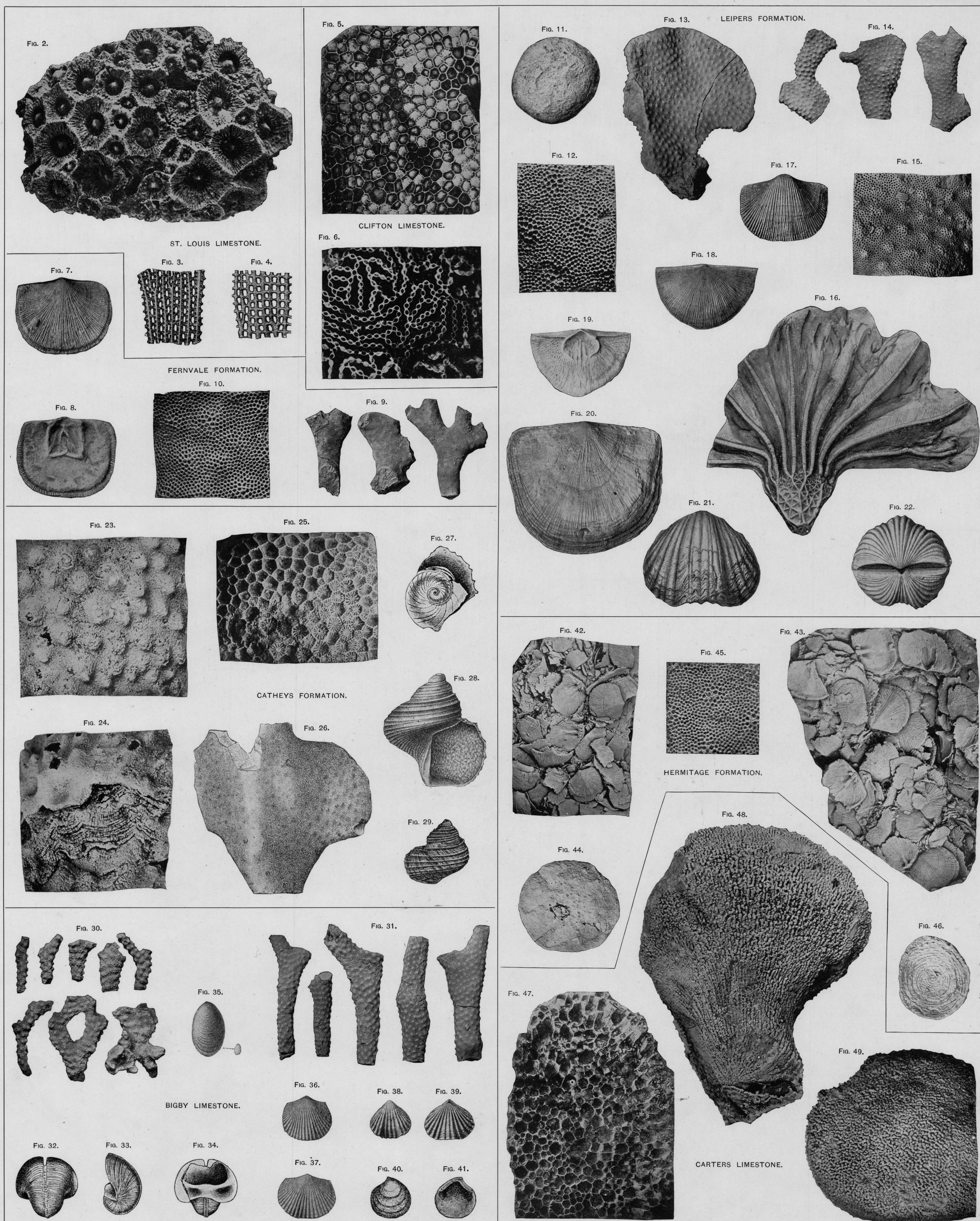
FIGS. 44 to 46. A thin, concavo-convex bryozoan, *Prasopora patera* Ulrich and Bassler. It is common and highly characteristic of the shaly lower third of the formation. Fig. 44 represents the celluliferous upper surface; fig. 45 a portion of same magnified five diameters, and fig. 46 the concentrically striated under surface. Often the cells are more angular and the walls thinner than in fig. 45.

CARTERS LIMESTONE.

FIG. 47. *Columnaria halli* Nicholson. Comparing figs. 47 and 25 it will be noticed that the radiating septa are much shorter in this species than in *C. alveolata* which marks the Catheys and Leipers formations.

FIGS. 48 and 49. Side and top views of two specimens of a fine sponge that is often found in the upper part of the Carters limestone. The specimens are silicified and were freed from the limestone matrix by means of hydrochloric acid. The species is provisionally identified with *Dystactopongia minor* Ulrich. It usually occurs in association with *Columnaria halli* and *Stromatocerium rugosum* Hall, which differs from *Stromatocerium pustulosum* (see figs. 23 and 24) in wanting the regularly disposed pustules on the upper surface.

ILLUSTRATION SHEET



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