

DESCRIPTION OF THE COLUMBIA QUADRANGLE.

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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 bowl-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 cyclorid 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 *Stromatocentrum 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 *Stromatocentrum* 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 *Stromatocentrum* 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 *Lepidodonta* and *Ischilina*, 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*, *Homotrypa nodosa*, and *Strophomena planiconvexa* (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 fossiliferous 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.

Columbia.

Above these heavy layers come the more characteristic St. Louis fossils, like *Melonites* and *Lonsdaleia*, or as the latter is generally called, *Lithostrocion 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 warplings. 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 Cin-

cinnatian. 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 Niagara 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 warplings, 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 tuffaceous 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 tuffaceous 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

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 overlapped 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

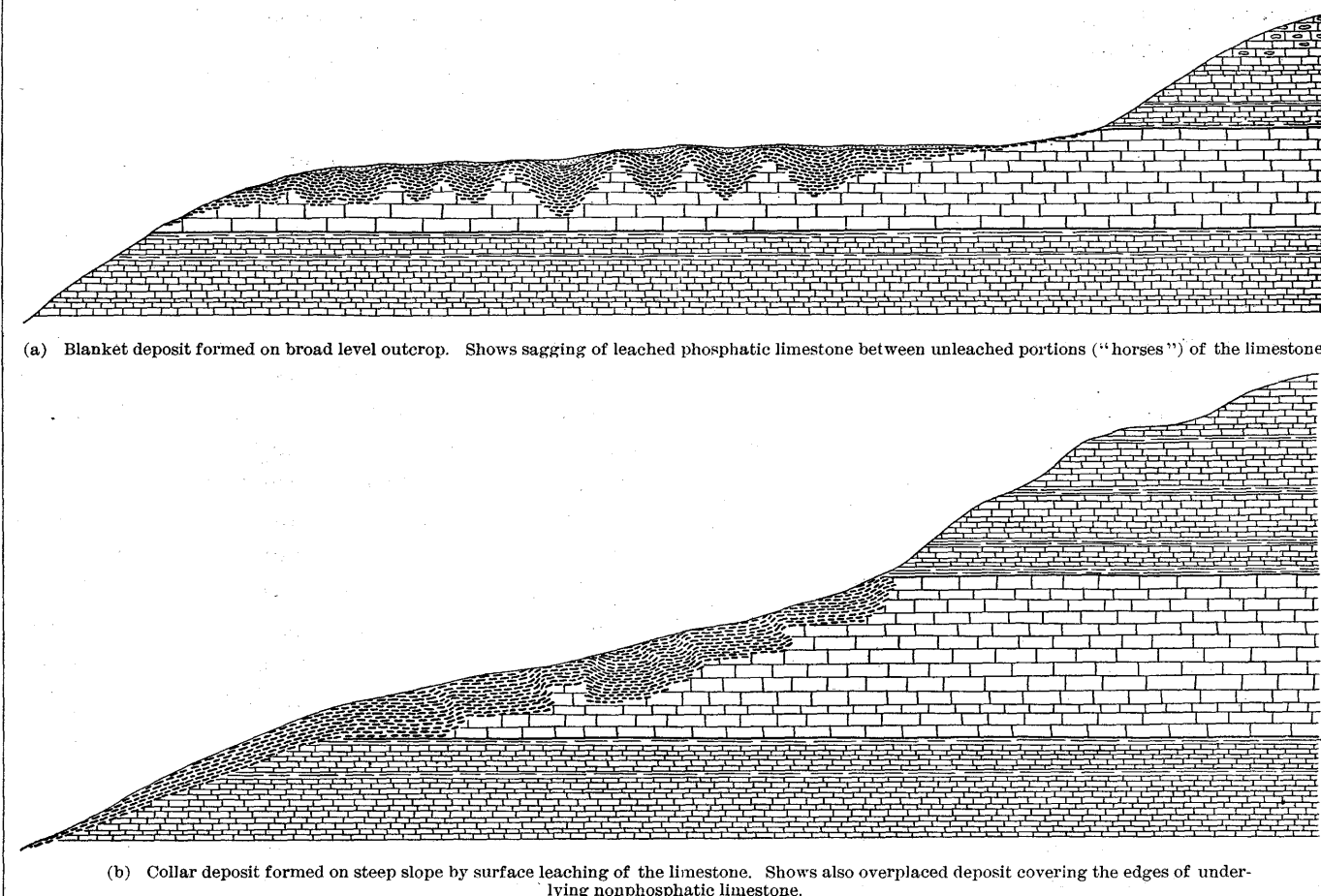


FIG. 1.—Sketch sections, showing the relations of the brown residual phosphate beds to the limestones from which they were derived.

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.

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

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 rhythmically 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.

Columbia.

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 River Valley 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 south 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 surficial.

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 lime-

stone 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 myxinoïd 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 suspen-

sion 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 Nunnely. 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 Nunnely 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 Nunnely, 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 Nunnely 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 necessarily remains. The Nunnely 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 disintegrate 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 boulders. 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.