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STATE OF OHIO
MICHAEL V. DISALLE, Governor
DEPARTMENT OF NATURAL RESOURCES
HERBERT B. EAGON, Director
DIVISION OF GEOLOGICAL SURVEY
RALPH J. BERNHAGEN, Chief

REPORT OF INVESTIGATIONS NO. 45

SUB-TRENTON ROCKS FROM LEE COUNTY, VIRGINIA, TO FAYETTE COUNTY, OHIO

By

WARREN L. CALVERT

COLUMBUS

1962

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Ralph J. Bernhagen
Chief

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ABSTRACT

The sub-Trenton formations which crop out in Lee County, Va., continue northward in the subsurface to Fayette County, Ohio, and beyond. The formations thin considerably northward and are progressively truncated below the Knox unconformity, but they maintain their lithologic character to a high degree. The unconformity at the top of the Knox Dolomite Supergroup is the result of a major erosional period, spanning a long unit of geologic time, and represents the boundary between quite different depositional environments. Stratigraphically the unconformity appears to be the practical boundary between Cambrian and Ordovician rocks. Appalachian Valley nomenclature fits the sub-Trenton formations of southern Ohio better than do the Upper Mississippi Valley names so commonly used.

The name "Knox Clastic Group" is proposed for the clastic unit between the Shady Dolomite below and the Knox Dolomite Supergroup above. The name "Lee Valley Group" is proposed for the relatively pure dolomite unit of the Knox Dolomite Supergroup which underlies the Beekmantown Group. The formational name "Lambs Chapel Dolomite" is proposed for the rock-stratigraphic unit heretofore referred to by the term "Longview-Kingsport-Mascot Dolomite, undifferentiated."

INTRODUCTION

THE SUB-TRENTON PROBLEM IN OHIO

Ohio is located in the north-central part of eastern United States, where Cambrian and Lower Ordovician rocks do not crop out but are present in the subsurface. These rocks appear at the surface in the Adirondack region of New York; in the Upper Mississippi Valley area of Iowa, Minnesota, and Wisconsin; in the Ozark region of southeastern Missouri; and in the Appalachian Valley. For the past 130 years the outcrops have been studied independently by numerous geologists and by various state geological surveys, each using local names and each applying different criteria for subdivision and correlation. As a result, a vast complex of Cambrian and Lower Ordovician nomenclature has become part of the geologic literature of eastern United States, with most names ending or beginning at state boundaries. The problem in Ohio is to determine which of the outcrop names and descriptions best fit the subsurface lithologic units found in the sub-Trenton rocks of the State.

SUB-TRENTON NOMENCLATURE IN OHIO AND EASTERN UNITED STATES

NAMES IN COMMON USE

The sub-Trenton formations of Ohio generally have been referred to by geologists as follows (ascending): Precambrian complex; Mt. Simon Sandstone, Eau Claire Dolomite, Franconia Sandstone, Dresbach Sandstone, and Trempealeau Dolomite for Cambrian rocks; Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite for Lower Ordovician rocks; and St. Peter Sandstone, Glenwood Shale, Black River Limestone, and Trenton Limestone for Middle Ordovician rocks (see table 3). In eastern Kentucky, these rocks (ascending) have been called (Thomas, 1960, p. 17) basal sandstone, Tomstown Dolomite, Rome Formation, Conasauga Formation, Knox Dolomite, Wells Creek Dolomite, Black River Limestone, Tyrone-Oregon Limestone, and Lexington Limestone. In Indiana the sub-Trenton rocks have been divided (Gutstadt, 1958, p. 13) (Dawson, 1960) into (ascending) Mt. Simon Sandstone, Eau Claire Formation, Knox Dolomite, Chazyan Series, Black River Limestone, and Trenton Limestone. To the east, the sub-Trenton terminology of Pennsylvania (Wagner, 1961, p. 3) is (ascending) Warrior Formation and Gatesburg Formation for Upper Cambrian rocks; Stonehenge Limestone, Nittany Dolomite, Axemann Limestone, and Bellefonte Dolomite for Lower Ordovician or Beekmantown rocks; and Loysburg Formation, Hatter Limestone, Benner Limestone, Nealmont Limestone, Salona Limestone, and Coburn Limestone for Middle Ordovician rocks. Below these beds, there are in southern Pennsylvania (ascending) the Antietam Sandstone, Vintage Formation, Kinzers Shale, Ledger Dolomite, Waynesboro Formation, and Pleasant Hill Formation, all believed to be of Early and Middle Cambrian (Howell, 1944). To the north, the latest terminology used in Michigan (personal communication, G. D. Ells, 1961) is (ascending) Jacobsville Sandstone, Munising Formation (composed of Mt. Simon, Eau Claire, Dresbach, and Franconia Members), and Trempealeau Formation (composed of St. Lawrence, Lodi, and Jordan Members) for Cambrian rocks; Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite for Lower Ordovician strata; and St. Peter Sandstone, Black River Formation, and Trenton Formation for Middle Ordovician rocks.

The above names are those commonly used in Ohio and adjacent states. In areas more distant, but still in eastern United States, other nomenclature has been applied to Cambrian and Ordovician rocks. In New York State, south and west of the Adirondack Mountains, the geologic units in the section above the basement rocks have been named (ascending) Potsdam Sandstone, Theresa Formation, and Little Falls Formation for Cambrian rocks; Tribes Hill Dolomite for Lower Ordovician strata; and Pamelia Limestone, Lowville Limestone, Chaumont Formation, Rockland Limestone, Kirkfield Limestone, Sherman Fall Limestone, and Coburg Limestone for Middle Ordovician rocks (Wagner, 1961, p. 3). In Wisconsin, the strata above the basement rocks have been called (ascending) Mt. Simon Sandstone, Eau Claire Sandstone, Galesville Sandstone, Franconia Sandstone, and St. Lawrence Dolomite for Cambrian rocks; Jordan Sandstone, Oneota Dolomite, New Richmond Sandstone, and Shakopee Dolomite for Lower Ordovician strata; and St. Peter Sandstone, Platteville Limestone, Decorah Shale, and Galena Limestone for Middle Ordovician beds (personal communication, M. E. Ostrom, 1961). In Illinois the terminology is much the same as in Wisconsin, except for the addition of the Ironton Sandstone above the Galesville Sandstone, the addition of the Gunter Formation below the Oneota Dolomite, the substitution of the term "Trempealeau" for "St. Lawrence" (with the inclusion of the Jordan Sandstone as a member) (personal communication, H. B. Willman, 1962), the change of Glenwood to Dutchtown Limestone and the insertion of the Joachim Dolomite above the St. Peter Sandstone (Bell, 1961, p. 68). The adjoining State of Missouri has an entirely different set of names for the rocks which rest on the basement complex (Howell, 1944) (Twenhofel, 1954). These are (ascending) Lamotte Sandstone, Bonneterre Dolomite, Elvins Group, Potosi Dolomite, and Eminence Dolomite for the Cambrian rocks; Gasconade Dolomite, Roubidoux Formation, Jefferson City Group, Cotter Dolomite, and Powell Formation for Lower Ordovician strata; and Everton Formation, St. Peter Sandstone, Dutchtown Limestone, Joachim Limestone, Plattin Group, Decorah Shale, and Kimmswick Limestone for Middle Ordovician rocks. To this long list of names for Cambrian and Ordovician rock units can be added those of Maryland, Virginia, West Virginia, Tennessee, North Carolina, Georgia, and Alabama. Most of these formation names from adjacent or nearby states have been introduced into Ohio at one time or another in connection with the subsurface rocks, but Upper Mississippi Valley names have been most commonly applied. However, in the opinion of the writer, never has any conclusive evidence been offered to show that the lithic units of Ohio to which these names of Cambrian and Ordovician rocks have been applied are lithologically the same as the outcrop units to which the names were originally given, especially the Upper Mississippi Valley names so commonly used.

HISTORY OF OHIO SUB-TRENTON NOMENCLATURE

In order to understand how the present sub-Trenton nomenclature has come to be used in Ohio, it is necessary to know where, when, and by whom it was introduced, and upon what basis correlations were made and geologic names assigned. The publications of the Ohio Geological Survey have been searched for this purpose, as well as the publications of various geological societies and other surveys.

The first well drilled to the sub-Trenton rocks of Ohio was known as the State House well, located on the grounds of the State Capitol Building in Columbus. It was commenced November 4, 1857, in an attempt to find artesian water by cable tool drilling, and when it was abandoned at a total depth of 2775 feet on October 1, 1860, it was the deepest well ever drilled in Ohio. Samples were saved during the drilling, and a report of progress was made by W. W. Mather (1859, p. 276), the first State geologist, to the State House Commissioners, when the depth of the well was 1850 feet. Mather's report includes a supplement which lists 73 "Artesian and Other Wells Bored in Ohio." The depths of these wells ranged from 50 feet in Trumbull County to 1458 feet in Lucas County; therefore, none was deep enough to have reached sub-Trenton rocks. A prior report of the known "borings" in Ohio had been published (Hildreth, 1838, p. 54-63), which included many shallow wells that had been drilled for salt and other minerals, but none of these had a total depth sufficient to penetrate the dolomites below the top of the Trenton Limestone.

The first correlation of sub-Trenton rocks in Ohio by the Ohio Geological Survey was published by J. S. Newberry (1869, pt. 1, p. 14), the second State geologist, in connection with the State House well, as follows:

> "However unsuccessful as regards the purpose for which it was bored, this well gave us interesting evidence of the nature of the strata underlying those which are exposed to sight in our state. These were plainly the Calciferous sand rock[1] (here containing much more lime and magnesia and less silica than in New York) and the Potsdam sandstone[1], which had not been passed through when the work was arrested."

Newberry in the same report (1869, p. 13) earlier described the Cambrian and Lower Ordovician outcrops of the Adirondacks of New York (then a part of the Lower Silurian System of rocks) as follows:

> "Here the series is complete; the lowest and that resting on the crystalline rocks being a sandstone named the Potsdam sandstone. Above this occurs the formation composed for the most part of a mixture of lime, sand, and clay, called from this fact the Calciferous sand rock. Over this again lies the great group of limestones, of which the Trenton limestone is the most conspicuous, and therefore called the Trenton group, which includes the Blue limestone, the lowest stratum exposed in the state of Ohio."

---

1. Sub-Trenton formation names are underlined in the present report where reference is made to the first usage in Ohio literature.

These then were the first geological names applied to the subsurface part of the Ohio geological column (decending):

Trenton Limestone Group
Calciferous Sandrock
Potsdam Sandstone
Crystalline rocks

It is evident that the correlations were based on two assumptions: first, on lithologic similarity, and second, on the law of superposition. However, it is now known that the rocks correlated with the Calciferous Sandrock (Beekmantown) do not occur in the State House well, and that only the upper 316 feet of what is thought to be Cambrian dolomite had been penetrated, so that the basal sandstone (Potsdam) which rests on the crystalline basement rocks of New York was not reached by the drill in the State House well. With all due respect to Dr. Newberry, and with the recognition of the lack of information from the area between the well in question and the outcrop section in New York State, his correlation was not correct.

Newberry (1873, p. 89) shows a stratigraphic section in which the Potsdam Sandstone is at the base of the column, followed in ascending order by Calciferous Sandrock, Mt. Pleasant Beds, Eden Shales, and Lebanon Beds. These units represented that portion of the Ohio geological column then called Lower Silurian but now commonly assigned to the Cambrian and Ordovician Systems. In the same report Newberry (1873, p. 114) shows the "Geological Section of the Strata Penetrated by the State House Well" as follows:

No.	Thickness [feet]	Character of rocks	Their probable geological equivalents	[Depth to top, in feet]
1	123	Clay, sand & gravel	Drift	[0]
2	15	Blackish shale	Huron shale (Portage and Genessee shales) base only	[123]
3	138	Gray limestone with bands of chert	Corniferous limestone	[138]
4	2	Very gritty rock	Oriskany sandstone	[276]
5	486	Limestone, light colored and sandy above, darker and argillaceous below	Helderberg, Niagara and Clinton limestones	[278]
6	162	Red, brown, and gray shales and marls	Clinton, Medina and upper part of Cincinnati Group	[764]
7	1058	Blue and green calcareous shales and limestones	Cincinnati group, with perhaps Black River, Birdseye and Chazy limestones	[926]
8	475	Light drab, sandy, Magnesian limestones	Calciferous sandrock of N. Y. Magnesian limestone group of Missouri	[1984]
9	316	White sandstone (calcareous)	Potsdam sandstone	[2459]
		[Total Depth]		[2775]

This is the first sample description published by the Ohio Geological Survey. New terms introduced for sub-Trenton rocks are Black River, Birdseye, and Chazy Limestones, and Magnesian Limestone of Missouri. Dr. Newberry, being from New York, used mostly New York terms to designate Ohio formations.

The next reference in Survey publications to the sub-Trenton rocks of Ohio is by Edward Orton, Sr., third State geologist, who mentions, in addition to the State House well and wells near Cincinnati (Orton, 1888, p. 108), the sub-Trenton wells listed below:

Page No. in Orton (1888)	Location	Total depth (feet)	Penetration below top of Trenton (feet)
284	Eaton	1607	575±
193	Fostoria	1775	522
202	Upper Sandusky	1790	472
273	Piqua	1673	488
286	Dayton	2440	1600
291	Washington Court House	1880	530
294	Oxford	1365	535
295	Middletown	1060	430
295	Lebanon	1300+	600±
297	Hillsboro	1750	550
298	Cincinnati	2007	1700±

As of May 1, 1962, approximately 400 sub-Trenton wells had been drilled in Ohio, compared with about 14 wells in 1888. A discussion of sub-Trenton rocks appears in the report by Orton (1888, p. 7) as follows:

> "While the Trenton limestone in its uppermost beds is thus seen to make the lowest rocks which rise to the surface in Ohio, it is still true that the drill is revealing to us the composition of the underlying series for many hundreds of feet below it. The thickness of the Trenton limestone proper can only be judged by a study of the formation as it appears in outcrop to the southward. Mr. W. M. Linney, of the Kentucky Geological Survey, in a paper on the rocks of central Kentucky, published in 1882, gives the thickness of the Trenton limestone in Kentucky as 175 feet. The Bird's-eye [sic] limestone which directly underlies it, he finds to be 130 feet in thickness, and the Chazy next below 300 feet in thickness; the entire series being thus about 600 feet in thickness. It is altogether probable that these three limestones constitute the solid mass which the drill has so often penetrated in Ohio within the last few years to a depth of five or six hundred feet. The formations which the geologist separates when they rise to the surface, are counted by the driller as a single limestone, for which he needs no other name than Trenton. The several divisions, however, are found to vary somewhat in grain, in color, and in chemical composition. Below this great limestone, a sandstone, more or less calcareous is reported in many of our wells. This is probably the horizon of the St. Peter's sandstone of the northwest and very likely deserves to be called by this name. It is charged with the rank salt and sulphur water, which is known as Blue Lick water, though water of the same grade is sometimes found in or between the limestones above named. Still deeper, impure magnesian limestones again occur for the next 1000 feet,

> as shown in the deep wells at Springfield and Dayton. These beds must be referred to the Calciferous period of the general scale."

Edward Orton, Sr., not being steeped in New York geology alone, turns to Kentucky and to the northwest for terminology.

In the First Annual Report of the Third Organization of the Ohio Geological Survey (Orton, 1890, p. 13), the above sub-Trenton discussion is repeated practically word for word. However, Orton stated (1890, p. 9):

> "The granite of Plymouth Rock underlies the continent. But the drill has never yet hewed its way down to these firm and massive beds within our boundaries."

So the records indicate that up to that time no wells drilled in Ohio had reached the basement complex.

Orton used the terms "Trenton limestone," "St. Peter's sandstone," and "Calciferous sandrock" (Orton, 1893, p. 6), and these terms continued to be used by the Survey until 1910, when J. A. Bownocker, fifth State geologist, in Bulletin 12 (Bownocker, 1910, p. 48) substituted the term "Lower Magnesian" for "Calciferous" in connection with the rocks immediately underlying the St. Peter's sandstone.

The following year Bassler (1911, p. 19-44) in the American Journal of Science gave a description and correlation of sub-Trenton rocks which was arrived at by a study of the samples of a deep well drilled at Waverly, in Pike County, Ohio. There is serious doubt as to the accuracy and reliability of the samples, but Bassler found Lowville, Stones River, St. Peter, and Canadian (Beekmantown) rocks to be present in the sub-Trenton part of the well.

Two years later Condit (1913, p. 123-130) in the American Journal of Science presented a sample description and correlation in connection with the first well to penetrate the crystalline basement rocks of Ohio. This well was the No. 1 D. L. Norris, located in sec. 3, Marion Township, Hancock County, which reached a total depth of 2,980 feet. Condit reported (descending) Trenton or Galena, Black River, Stones River, St. Peter sandstone and limestone, Upper Cambrian dolomitic limestone and sandstone, and Precambrian granite.

A radical change in Ohio sub-Trenton terminology was introduced by Isabel Wasson in 1932. She described the samples from a well (No. 1 Friend) which penetrated the basement complex in Clark County, Ohio. In her article (Wasson, 1932, p. 673-687) a generalized cross section is shown which starts at a well in northern Illinois and extends to wells in north-central Ohio and to wells in south-central Ohio. In the above article the rocks underlying the Trenton-Black River strata are divided (descending) as described below. At the top is the Lower Magnesian Dolomite of Chazy and Beekmantown age, described as a uniform, finely crystalline, white dolomite, 800 feet thick. The next unit (764 feet) is called Upper Cambrian and is said to consist mostly of sandstone. The next underlying unit (420 feet) is said to be either Cambrian or Upper Keweenawan gray dolomite, with some sandstone and arkose. The lowest division (807 feet) is described as black, carbonaceous limestone, probably Precambrian. With the help of F. T. Thwaites, the correlations for the Friend well were tied in with the Wisconsin terminology. Certain sections were given names such as Jordan, Trempealeau, Mazomanie, Dresbach, Red Clastics, and Upper Keweenawan, and certain parts were said to correlate with the Prairie du Chien, Madison, Eau Claire, and Mt. Simon Formations, but the sample descriptions in the article are not conclusive enough to permit a standard definition of formations for use in general subsurface differentiation. Therefore, having received help from a

Wisconsin geologist, Mrs. Wasson (1932) introduced names from Wisconsin for formations in Ohio. These names were later adopted by many geologists, including Wilbur Stout, sixth State geologist of Ohio.

The next addition to sub-Trenton terminology was made the same year by the Ohio Geological Survey in Bulletin 37 (Stout, 1932, p. 27) when the "Trenton of the driller" was said to include two formations, the Lexington and the Highbridge (with eight members) between the Utica Shale and the St. Peter Sandstone. In Bulletin 37 these formations are reported to have an average thickness of about 650 feet. The "Trenton" is defined as limestone carrying only small quantities of magnesium carbonate, but it is said to change locally, either laterally or vertically, to a rather pure dolomite, grainy in texture and open or even cavernous in structure. Production of oil, gas, or brines is from the latter type of rock. It is stated that "the St. Peter Sandstone is widely distributed in Ohio but very poorly developed. The horizon appears to be represented by local lenses of sandstone, by sandy matter in dolomite, and by only a plane of disconformity." In Bulletin 37 (Stout, 1932, p. 28) the rocks assigned to the Cambrian System of Ohio are described as follows:

> "Where penetrated these rocks appear to be thin or absent in northwestern Ohio but to be approximately 1,300 feet in thickness in the southwestern part. The strata are mainly massive sandstones with smaller quantities of dolomite, limestone and shale."

Mrs. Wasson's Wisconsin names are mentioned in the literature of the Ohio Geological Survey for the first time in Bulletin 42 (Stout, 1941, p. 21), where it is noted that "In Ohio, the Pre-Cambrian or basement rocks, crystalline in character and igneous or metamorphic in origin" had been reached by seven wells prior to 1940. These rocks are reported to be "gneisses and schists made up largely of the common minerals quartz, feldspar, muscovite, biotite, hornblende, rutile, and apatite, with minor quantities of accessory minerals." The Cambrian system is said (Stout, 1941, p. 22) to be "made up of dolomites, sandstones, and dolomitic shales" and "throughout much of the system sandstones make up about 50 per cent of the total." The statement is made that "the common deposit of Cambrian time is dolomite, laid down in comparatively quiet shallow waters but locally in the Appalachian trough accumulated to great thickness." A brief description of the Cambrian rocks in general is given and is terminated by the following statement (Stout, 1941, p. 23):

> "In Ohio the Cambrian rocks have not (1940) been divided into various formations, but farther west names that commonly appear for the formations are Madison, Jordan, St. Lawrence, Franconia, Dresbach, Eau Claire, and Mt. Simon."

In describing the Ordovician System Stout (1941, p. 25) explains that the term "Lower Magnesian" has been applied loosely to that group of rocks lying below the St. Peter Sandstone and above the Cambrian strata, which the early Surveys called Calciferous. He says that these correlate, at least in part, with the Beekmantown of the New York Geological Survey. He describes them as true dolomites with lenticular masses of sandstone in the upper part. The St. Peter Sandstone "is represented by only local lenses of sandstone. In its absence the horizon is marked by an apparent unconformity, or by a sharp break from limestone to dolomite, and by the presence of green shale at or close to the base of the Trenton group." Stout gives this green shale the name "Glenwood Member" and treats it as a member of the Black River Group.

Stout's final generalized column for the Ordovician and Cambrian rocks of Ohio according to Ohio Geological Survey Bulletin 42 (Stout, 1941, opp. p. 46) is as follows:

System	Series or group	Formation
	Richmond	Whitewater Liberty Waynesville Arnheim
	Maysville	McMillan Fairview
	Eden	Latonia
	Utica	Fulton
Ordovician	Trenton	Point Pleasant __________
	Black River	__________ Glenwood
	St. Peter	
	L. Magnesian	
Cambrian		
Precambrian		

The above terminology was used by the Ohio Geological Survey in 1941, and it is the same as that used in Bulletin 44 (Stout, 1943, p. 109-110) except that the Glenwood is moved into the "Series or group" column between the Black River and the St. Peter. The generalized section of Stout from Bulletin 44 was also used by R. L. Alkire (1948, and 1951, p. 52).

In a subsequent report of the Ohio Geological Survey, (Lamborn, 1952, p. 9) a sample study of the Vance well of Delaware County, Ohio, is quoted from Stout and Lamey (1940, p. 672-692), which shows "sandstone, light, hard, Jordan 3450-3510" and "sandstone, hard, very pure, Dresbach 3710-3845." A sample study (Lamborn, 1952, p. 30) of a well in Wood County, Ohio, shows 369 feet of dolomite below the "St. Peter horizon" as Knox.

On the Oil and Gas Fields Map of Ohio, (Alkire, 1953) a generalized section of rocks of Ohio is shown, which includes some terminology used for the first time by the Survey, as follows:

System	Group	Formation
Ordovician	Trenton Black River Prairie du Chien	 Shakopee Dol. New Richmond Ss. Oneota
Cambrian		Trempealeau Ss. and Dol. Franconia Ss. Dresbach Ss. Eau Claire Ss., Dol., and Sh. Mt. Simon Ss.

However, as late as 1954, Lamborn (1954, p. 214) states that "the exact stratigraphic correlation of this [Cambrian] series [in Ohio] is also in doubt."

An Ohio Geological Survey report (Shearrow, 1957) describes samples (reported as being of Cambrian age) from four wells in northwestern Ohio. Only one of these wells was drilled into the basement complex; the other three penetrated 383 feet, 20 feet, and 36 feet, respectively, below the "Lower Ordovician" unconformity. It is stated (1957, p. 4) that the Prairie du Chien Group is absent in these wells. Upper Mississippi Valley terminology is used, but the descriptions of the formations are not definitive, and appear to be based more on insoluble residues than on lithologic character. No direct correlation with Upper Mississippi Valley outcrops is given to show that these names ought to be applied to the rocks described. In a later publication (Shearrow, 1959) the same terminology is used and again only general descriptions and thicknesses are given.

This completes the story of the introduction and use of the sub-Trenton terminology now commonly used in subsurface work in Ohio. Upper Mississippi Valley nomenclature has been applied to the sub-Trenton rocks of Ohio by geologists making long range correlations with the outcrops in the Upper Mississippi Valley, but these names have been applied more on the strength of tradition than on actual lithologic evidence.

GENERAL CONSIDERATIONS

APPLICATION OF APPALACHIAN VALLEY TERMINOLOGY TO OHIO

It is indeed fortunate for subsurface studies in Ohio that during 1958 and 1959, a series of basement and near-basement tests were drilled by the United Fuel Gas Co. in an almost north-south line across eastern Kentucky, from Carter County on the north, to Bell County on the south. It is fortunate because, for the first time, it made possible a detailed study of samples and gamma ray logs starting at the outcrops in the Appalachian Valley and continuing northward almost directly to a basement test in south-central Ohio. This basement test, the No. 1 Hopkins in Fayette County, Ohio, was drilled in 1957 by the Kewanee Oil Co. From it a complete string of samples from the Silurian into the basement complex has become available for study, in addition to both a gamma ray log and an electrical log. The situation is enhanced by the fact that only 18 miles southeast of the southernmost near-basement test, the No. 1 Knuckles, in Bell County, Ky., there is available an excellent, comprehensive report on the geology of the outcrop section of the Rose Hill district of Lee County, Va. (Miller and Fuller, 1954), which contains a detailed lithologic description of the rock section from Silurian to Lower Cambrian strata. Because all this information is available, it has been possible to construct a cross section from Lee County, Va., to Fayette County, Ohio, to show the lithologic and radioactive characteristics of the sub-Trenton formations, as well as their lateral and vertical continuity northward from the outcrop (see pl. 1).

The outcrops of the Cambrian and Ordovician rocks of the Appalachian Valley are less than half as far from Ohio as those of the Upper Mississippi Valley, or those of the Ozark region of Missouri, or those of the Adirondacks of New York. Furthermore, Ohio is an integral part of the Appalachian geosyncline, being situated on the west flank of the geosyncline. Is it not more logical, therefore, to think that the sub-Trenton sedimentary rocks of Ohio should more closely resemble those of the Appalachian area than those of the far-distant Minnesota-Wisconsin-Iowa district or those of the southern Missouri Ozark region? Is it not probable that one reason stratigraphers have been having so much difficulty in recognizing and defining many formations in the subsurface rocks of Ohio is that they have been trying to apply Upper Mississippi Valley names and definitions to Appalachian Valley formations? These names and definitions do not adequately fit the rocks in Ohio. Since the Pennsylvanian, Mississippian, Devonian, Silurian, and the upper part of the Ordovician Systems of rocks in Ohio have always been closely correlated with the strata of the Appalachian geosyncline, why should not the rest of the strata of the State also be correlated with Appalachian formations? Just as the rocks of the other geologic systems in Ohio thicken southeastward into the Appalachian basin, so do the rocks of the Cambrian System. On all counts, there should be a close relationship between the sub-Trenton rocks of Ohio and those of the Appalachian Valley. A study of the detailed cross section from Lee County, Va., to Fayette County, Ohio, (pl. 1) indicates that this close relationship actually does exist.

DEFINITION OF STRATIGRAPHIC TERMS

Before embarking upon a discussion of a subsurface cross section which is based entirely upon the lithologic and radioactive characteristics of rocks, it might be helpful to discuss briefly the definition of geologic terms. Because it is necessary to use the names of the lithologic units (rock-stratigraphic units) which have been applied to the outcrops to designate the subsurface extensions of these same units, and because there has been some confusion in the past in the use and definition of such terms as "group," "formation," "member," and "bed," the definitions of these terms are emphasized to avoid misunderstanding. The measure of the exactness of a science is generally determined by the relative clarity, accuracy, and applicability of its definitions. The science of geology can become much more exact if geologists will consistently strive to follow the "Code of Stratigraphic Nomenclature" (American Commission on Stratigraphic Nomenclature, 1961) and to eliminate ambiguous, overlapping, unscientific, generally loose, and colloquial terms from geological discussions and reports.

The definitions of terms used for rock-stratigraphic units in this report may be found in the "Code of Stratigraphic Nomenclature." Some of these definitions and the concepts upon which they are based are as follows (American Commission on Stratigraphic Nomenclature, 1961):

> "A rock-stratigraphic unit is a subdivision of the rocks of the earth's crust distinguished and delimited on the basis of lithologic characteristics (p. 649).
>
> Concepts based on inferred geologic history or biologic sequence properly play no part in the definition or differentiation of a rock-stratigraphic unit (p. 649).
>
> Boundaries of rock-stratigraphic units are placed at positions of lithologic change (p. 650).
>
> The formation is the fundamental unit in rock stratigraphic classification. A formation is a body of rock characterized by lithologic homogeneity; it is prevailingly but not necessarily tabular and is mappable at the earth's surface or traceable in the subsurface (p. 650).

A member is a part of a formation; it is not defined by specified shape or extent. A geographically restricted member that terminates on all sides within a formation may be called a lentil. A member that extends outward beyond the main body of a formation may be called a tongue (p. 651).

A bed is the smallest rock-stratigraphic unit recognized in classification (p. 651).

A group is the rock-stratigraphic unit next higher in rank than a formation; a group consists of two or more associated formations (p. 651).

[A] supergroup . . . [is] a formal assemblage of related groups or of formations and groups" (p. 651).

It is clear, then, that the above terms are to be applied solely to lithologic units (stratoliths), and that they should not be applied to faunal zones (bioliths), time-stratigraphic units (chronoliths), or to subdivisions of geologic time (geochrons). Each type of unit is defined and given a separate terminology in the code.

The names of rock-stratigraphic units, according to the code, are binomial, "consisting of a geographic name combined with a descriptive lithologic term or with the appropriate rank term alone."

"A formation name consists of the geographic name followed by a lithologic designation or by the word 'formation.' Examples: Dakota Sandstone, Mitchell Mesa Rhyolite, Monmouth Formation, Fort Covington Till" (p. 652).

In addition to rock-stratigraphic terms defined in the "Code of Stratigraphic Nomenclature," the practical rock-stratigraphic term "sequence" is used in this report. Sequence was introduced by Sloss and others (1949, p. 110-111) to designate rock units which are assemblages of formations and groups. Sequences are separated by objective, recognizable horizons (generally major regional unconformities) and are without specific time significance, since their limits do not necessarily coincide with time lines and may include rocks of different ages in various areas. Sloss and others (1949, p. 110-111) stated that names for sequences are necessary because, as rock units, they cannot be defined in terms of time and they extend beyond the geographic limits of units with formational names which might be given as bounding formations in local areas. Sloss and others have assigned Indian names to the sequences which they have defined.

TRANSGRESSIVE RELATIONSHIPS OF SUB-TRENTON ROCKS

The purpose of the above review of definitions for rock-stratigraphic units is to make crystal clear the meaning of the terms used in discussing sub-Trenton rocks from Lee County, Va., to Fayette County, Ohio. A formation name applied in the cross section (pl. 1) is strictly a rock-stratigraphic designation for a lithologic unit which can be traced vertically and laterally from the outcrop into the subsurface by means of sample descriptions and radioactive or electrical properties. The formations referred to in the cross section carry names with no time significance whatsoever, except on the outcrop. Let it not be said that the term "Erwin Sandstone" cannot be used in Ohio because the Erwin Sandstone is part of the Lower Cambrian while all the Cambrian rocks of Ohio belong to the Upper Cambrian! The Erwin

Sandstone is known to exist in Ohio, because it has been traced by means of subsurface cross sections into Ohio from outcrops in the Appalachian Valley, where it is known to be of Early Cambrian age. In addition, it has been traced farther northwestward from Ohio into Wisconsin, where it is known to be of Late Cambrian age and where it is called the Mt. Simon Sandstone. It is one, continuous sandstone formation, the basal sandstone throughout the area (Freeman, 1953, p. 18-19; and Wheeler, 1960, p. 50), and it is a mappable, traceable lithologic unit which has been given separate formational names at widely separated outcrops. Different names for this formation were assigned, first, because the sandstone was not known to be a continuous lithologic unit when the names were applied, and second, because of fossil content the outcrops were known to belong to two different time-stratigraphic units. This formation might well be called the Erwin-Antietam-Potsdam-Mt. Simon-Lamotte-Reagan-Hickory Sandstone.

A study of the subsurface rocks in the Appalachian area indicates that many of the sub-Trenton formations in eastern United States are probably time-transgressing rock-stratigraphic units similar to the Erwin-Mt. Simon Sandstone. Figure 1, from a paper given by the writer at the Cincinnati Meeting of the Geological Society of America in November 1961 (Calvert, 1962, p. 144-145), illustrates the theory of continuous transgression during Cambrian time in eastern United States.

METHOD OF PROCEDURE

CONSTRUCTION OF CROSS SECTION

In the construction of a sub-Trenton cross section from Lee County, Va., to Fayette County, Ohio (pl. 1), the outcrop section in Lee County, Va., was first put into a vertical geologic column, using the excellent, detailed lithologic descriptions and average thicknesses given by Miller and Fuller (1954). The top of the Trenton Limestone was used as a datum, but the section for 400 feet above the Trenton was shown in order to present the overlying rocks and to establish the validity of the indicated top of the Trenton Limestone. In the original cross section (pl. 1) a vertical scale of 1 inch to 100 feet was selected to provide space for brief lithologic descriptions. Depths are indicated in hundreds of feet. A horizontal scale of 1 inch to 6 miles allowed the entire original cross section to be constructed on paper 42 inches wide. The result of these scales is a vertical exaggeration of approximately 317 to 1 in the cross section. Some of the monotonous Rome Formation section is omitted in the two deepest wells to keep the cross section from having an excessive vertical dimension.

Gamma ray curves are shown in conjunction with brief sample descriptions for each well in the cross section, except in the upper part of the No. 1 Adams well, where it was necessary to use a self-potential curve (no gamma ray log is available). In addition, the neutron curve is shown for the No. 1 Hopkins well. Detailed sample descriptions were employed in this study but could not be shown on the cross section due to lack of space.

The symbols and formation names used on the cross section (pl. 1) indicate rock units only and carry no age connotations whatsoever except on the outcrop section.

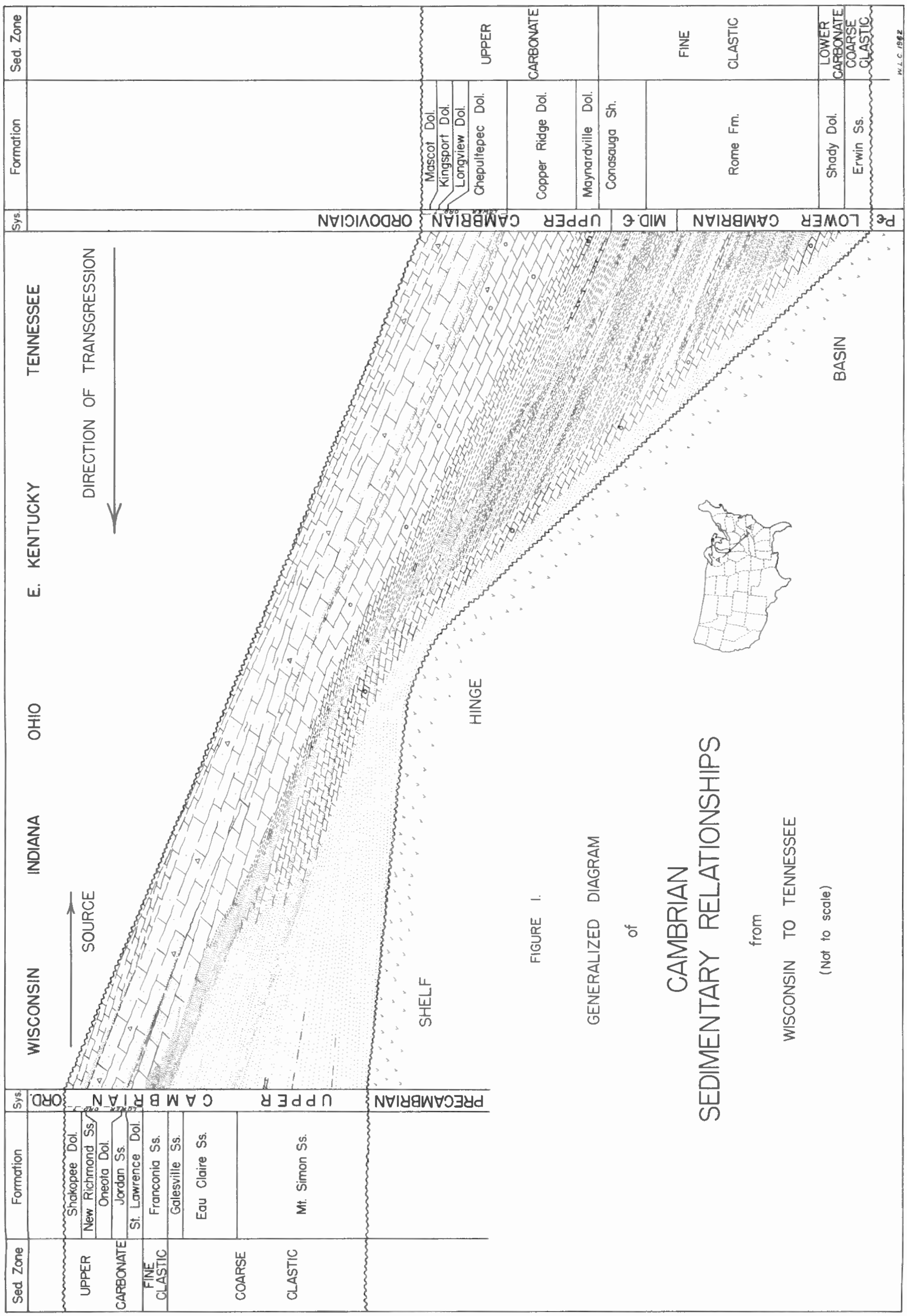

FIGURE I.

GENERALIZED DIAGRAM of CAMBRIAN SEDIMENTARY RELATIONSHIPS from WISCONSIN TO TENNESSEE

(Not to scale)

ORGANIZATION OF DESCRIPTIONS

Much of this report is necessarily devoted to a discussion of Appalachian Valley stratigraphy. In the interest of completeness, the entire outcrop section is described, although a few of the formations are not recognized in the subsurface of Ohio. Each formation of the outcrop section is briefly described under the following subheadings:

(1) Name and type section
(2) Definition and lithologic character
(3) Thickness and stratigraphic relations
(4) Radioactivity.

The characteristics of the outcrop formations which are recognizable in the subsurface northward to Ohio are pointed out. The formation names for lithologic units used by Miller and Fuller (1954) are adhered to as closely as possible, except in a few instances where practical considerations dictate a slightly different terminology in the subsurface. In describing radioactivity characteristics a general scale of average gamma radiation is used as follows (see fig. 2):

Very high - highest gamma radiation shown on log
High - almost the highest gamma radiation shown
Medium high - between medium and high radiation
Medium - half way between low and high radiation
Medium low - between medium and low radiation
Low - almost the lowest gamma radiation shown
Very low - lowest gamma radiation shown on log.

DESCRIPTION OF ROCKS

BASEMENT ROCKS

The name "Precambrian" is applied to all rocks believed to be older than Cambrian. In Ohio and eastern Kentucky the Paleozoic sedimentary rock section rests upon crystalline metamorphic or igneous rocks where the entire stratigraphic section has been penetrated by drilling. These crystalline rocks are commonly referred to as Precambrian metamorphic rocks or basement complex. The basement rocks in Ohio are composed chiefly of gneiss, schist, marble, hornfels, amphibolite, pegmatite, granite, syenite, latite, trachyte, and rhyolite. West of a line from Sandusky Bay to Clermont County, Ohio, the principal rock types in the basement complex are granite, syenite, latite, trachyte, and biotite schist, but east of this line the principal rock types are marble, hornfels and amphibolite, granite gneiss, and pegmatite (McCormick, 1961, p. 56). This line is called the Grenville line because the basement rocks east of it in Ohio are believed to belong to the Grenville Series. Dr. Manuel Bass has placed the age of the Grenville-type rocks in Ohio at 920 to 980 million years by means of the rubidium - strontium content of the muscovite and biotite present in the rocks (McCormick, 1961, p. 55).

In well cuttings, basement rocks are recognized by the presence of angular grains of quartz, feldspar, biotite, hornblende, and other minerals which show no rounding or evidence of transportation. Some quartz grains derived from metamorphic rocks may show some indication of rounding acquired previous to metamorphism. In many areas, the Grenville rocks are so coarsely crystalline that they are drilled as rapidly as the overlying sandstones and dolomites. All basement rocks in the area of the present report are of Grenville type.

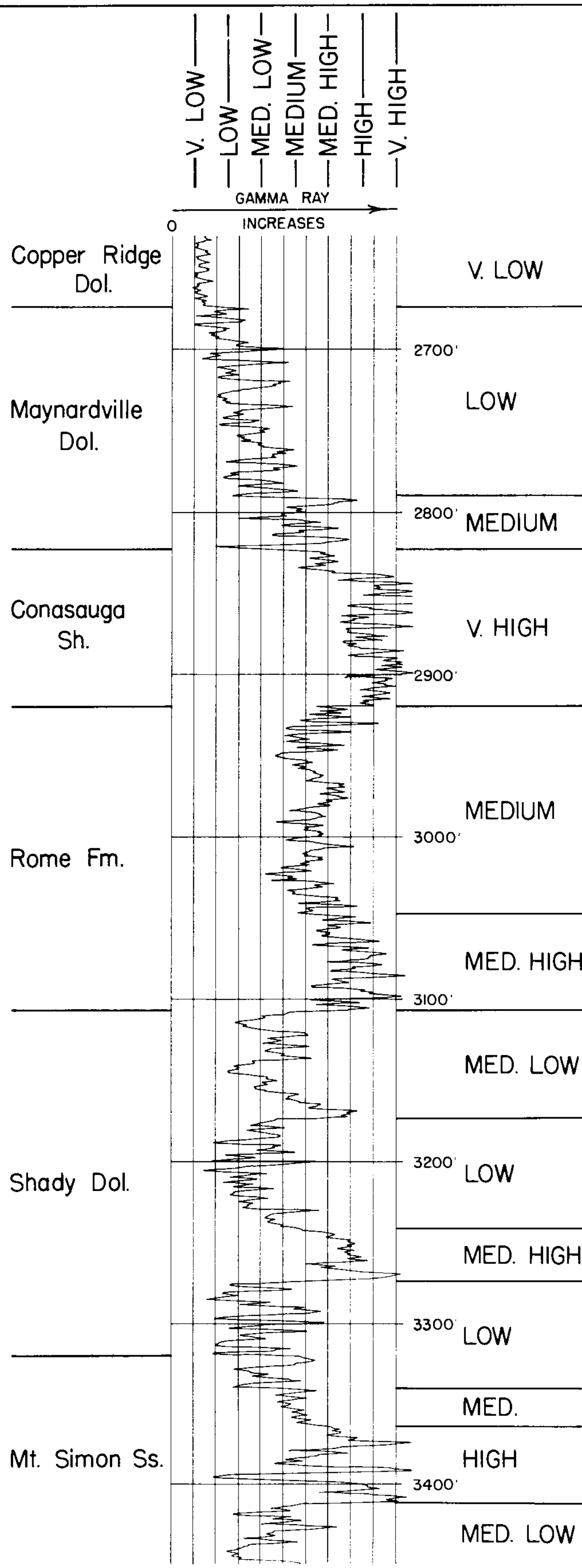

FIGURE 2.

Part of Gamma Ray Log

from

Kewanee- #1 Hopkins

Fayette Co., Ohio

showing

QUALITATIVE CLASSIFICATION

of

GAMMA RADIATION CURVES

W.L.C. 1962

On gamma ray logs, the basement rocks generally show low to very low radioactivity, although a few thin zones show as much as medium radioactivity. The radioactivity is well demonstrated on the log of the No. 1 Hopkins well, in Fayette County, Ohio (see pl. 1). The well penetrated 1, 160 feet of Precambrian metamorphosed and intruded sedimentary rocks.

In Ohio and eastern Kentucky the base of the sedimentary rock section rests with marked unconformity upon the crystalline basement. This unconformity represents a long erosional period (Lipalian interval) preceded by much folding, faulting, and vulcanism in most places. The basement unconformity is thought to be at the surface of an ancient peneplain marked by the presence of scattered monadnocks.

SAUK SEQUENCE

The term "Sauk Sequence" was proposed by Sloss and others (1949, p. 111). The name is taken from Sauk County, in the Driftless Area of southern Wisconsin, where the Sauk Sequence is well exposed and where it consists of all the strata above the basement complex and below the contact between the St. Peter Sandstone and the Oneota Dolomite. This contact represents the first major regional unconformity (see Knox Unconformity, p. 34) above the basement unconformity.

The Cambrian System as originally defined in Wales by Lapworth (1879) included all the strata which overlie the basement rocks and which underlie the top of the Tremadoc Slate (Wilmarth, 1925, p. 83). The top of the Tremadoc Slate is marked by a major regional unconformity. Tremadoc beds are accepted as being of the same age as the Beekmantown beds of North America, and the top of the Beekmantown Group, like the top of the Tremadoc Slate, is marked by the first major regional unconformity above the basement rocks. Therefore, it appears that the rocks of the Sauk Sequence and the rocks of the original Cambrian System are equivalent (see Cambrian-Ordovician Boundary, p. 41). The relationship of the post-Beekmantown unconformity to the post-Tremadoc unconformity is shown in figure 4.

In Ohio and eastern Kentucky the Sauk Sequence includes all formations which hitherto have been classed as Cambrian and Early Ordovician in age. In the central and southern Appalachian area the Sauk Sequence includes all the beds from the top of the crystalline basement rocks (including the Chilhowee Group) to the top of the Beekmantown Group. It thus includes in its lower part some of "the clastic sequence basal to the Cambrian System in the central and southern Appalachians" of Rodgers (1956, p. 410), although Rodgers used the term "sequence" in a general rather than a formal sense, and included some of the highly metamorphosed rocks of the basement complex.

The symbol used in this report to designate the sequence to which a formation belongs is the capitalized first letter of the sequence name followed by the symbol for the geologic system to which the formation is assigned on the outcrop. Thus, the symbol for Sauk Sequence as used in the cross section (pl. 1) is S€.

CHILHOWEE GROUP

A basal group of coarsely clastic rocks overlies the basement complex in the Appalachian Valley. As far south as the Great Smoky Mountains these clastic rocks are commonly called the Chilhowee Group, but in the Great Smokies and southward a similar clastic succession is thought by some geologists to be composed of sediments laid down prior to the deposition of the Chilhowee beds. These latter beds have been called the Ocoee Group, but since they are unfossiliferous it is difficult to determine their age. In this report the Chilhowee Group is defined as all the sedimentary rocks below the Shady-Tomstown Dolomite and above the basement complex, including the beds assigned to the Ocoee Group.

The Chilhowee sandstones and shales were named by Safford (1856, p. 149, 152-153) from Chilhowee Mountain in Sevier and Blount Counties, Tenn. These were mapped in 1895 by Arthur Keith, who divided them into (descending) Hesse Sandstone, Murray Shale, Nebo Sandstone, Nichols Shale, Cochran Conglomerate, and Sandsuck Shale (Keith, 1895). The lowest zone in which fossils have been found is the Murray Shale, which contains brachiopods and also trilobites of the genus Olenellus. The Chilhowee Group consists largely of sandstones and quartzites (total thickness 2,000 to 5,000 feet) which were deposited upon the weathered surface of the basement complex. The Chilhowee Group has been subdivided by Charles Butts (1940, p. 26-27) into the following formations (ascending): Unicoi Formation, Hampton Shale, and Erwin Quartzite (see table 2). None of these formations crop out along the west side of the Appalachian Valley, and only the uppermost formation, the Erwin Sandstone, is known to be present in the subsurface northward from the Rose Hill district of Lee County, Va.

Basal Arkose

In the subsurface of Ohio and eastern Kentucky there is commonly a zone just above the basement complex which is characterized by angular fragments and pebbles of the underlying metamorphic or igneous rock enclosed in a matrix of medium and coarse subrounded quartz grains. This zone is a basal conglomerate or arkose which rests upon a thin zone containing chlorite and other minerals indicative of weathering. The two zones are difficult to distinquish from each other in well cuttings or on gamma radiation logs and generally have a total thickness of 15 to 40 feet. On the cross section (pl. 1) these zones are designated as one unit which has medium-high to very high radioactivity.

Unicoi Formation

Name and type section. - The Unicoi Formation was named (Campbell, 1899, p. 3) for Unicoi County, Tenn., where the type locality occurs. The lower part of the formation is not exposed at the type locality, but an excellent exposure of the entire formation occurs about $1\frac{1}{2}$ miles northeast of Konnarock, Va. (Butts, 1940, p. 30). Other names which have been applied to these rocks, in whole or in part, are Loudoun Formation, Weverton Formation, Chilhowee Sandstone, Snowbird Sandstone, Sandsuck Shale, Cochran Conglomerate, Hiwassee Slate, Murray Shale, Nebo Sandstone, Nichols Shale, Great Smoky Conglomerate, and Ocoee Group.

Definition and lithologic character. - The Unicoi Formation is defined as that body of rocks which conformably underlies the Hampton Shale and unconformably overlies Precambrian gneisses and granites. It consists of gray, white, pink, and red, coarse-grained, feldspathic sandstone or quartzite, partly conglomeratic, with a few beds of gray or red, silty shale throughout the formation. The shale beds are commonly 5 to 10 feet thick. The conglomerates have thicknesses of up to 50 feet and are composed of small quartz pebbles in a matrix of quartz grains and pink feldspar grains. Interbedded with, and conformable with, the beds above and below are several beds of greenish basalt containing pink spherical inclusions called amygdules. One of these amygdaloids is 200 feet thick, and two others are each 50 feet thick.

Thickness and stratigraphic relations. - The maximum thickness of the Unicoi Formation occurs in southern Virginia, where the formation is about 2,600 feet thick. The formation thins to about 800 feet in northern Virginia and Maryland. It crops out only along the east side of the Appalachian Valley, where it rests unconformably on the basement complex and where it is conformably overlain by the Hampton Shale. It has not been recognized in the subsurface of eastern Kentucky or southern Ohio.

Radioactivity. - No gamma ray logs are available from which to determine the character of the gamma radiation curve for this formation.

Hampton Shale

Name and type locality. - The Hampton Shale was named (Campbell, 1899, p. 3) for Hampton, in Carter County, Tenn., near where the type section is located. It is the same formation which was named the Harpers Shale by A. Keith (Williams and Clark, 1893, p. 44) for Harpers Ferry, Md. Although the name "Harpers" has priority, it has been little used in the southern part of the Appalachian Valley. The Hampton Shale forms most of the front of Holston Mountain.

Definition and lithologic character. - The Hampton Shale includes all the beds between the top of the varicolored, thick-bedded sandstone of the Unicoi Formation below, and the base of the thick-bedded, white Erwin Sandstone above. It is typically composed of gray, sandy shale containing a few thin beds of gray, medium-grained sandstone. The Hampton Shale is unfossiliferous, as is the Unicoi Formation.

Thickness and stratigraphic relations. - In Tennessee the Hampton Shale is about 2,000 feet thick. It thins to about 1,200 feet at Harpers Ferry, Md., but thickens northward again to more than 2,700 feet in southern Pennsylvania. It crops out along the western margin of the Blue Ridge Mountains for almost the entire length of the Appalachian Valley. The Hampton Shale is conformable with the Unicoi Formation below and with the Erwin Sandstone above. It has not been recognized in the subsurface strata from Lee County, Va., to Fayette County, Ohio, nor does it crop out along the west side of the Appalachian Valley.

Radioactivity. - No gamma ray logs are available for studying the radiation curve for this formation.

Mt. Simon (Erwin) Sandstone

Name and type section. - The Erwin Sandstone or Quartzite (depending upon the degree of cementation) was named (Keith, 1903, p. 5) for the town of Erwin, in Unicoi County, Tenn., where the type section is located. It is the same formation as the Antietam Sandstone (fig. 3), which was named by Keith, (Williams and Clark, 1893, p. 44) for Antietam Creek, in Washington County, Md. It is also the same formation as the Hesse Sandstone of eastern Tennessee (Keith, 1895, p. 3) and the Weisner Quartzite of Alabama (Smith, 1890, p. 149). It is called the Mt. Simon Sandstone in Ohio. The name "Mt. Simon Sandstone" was formally introduced

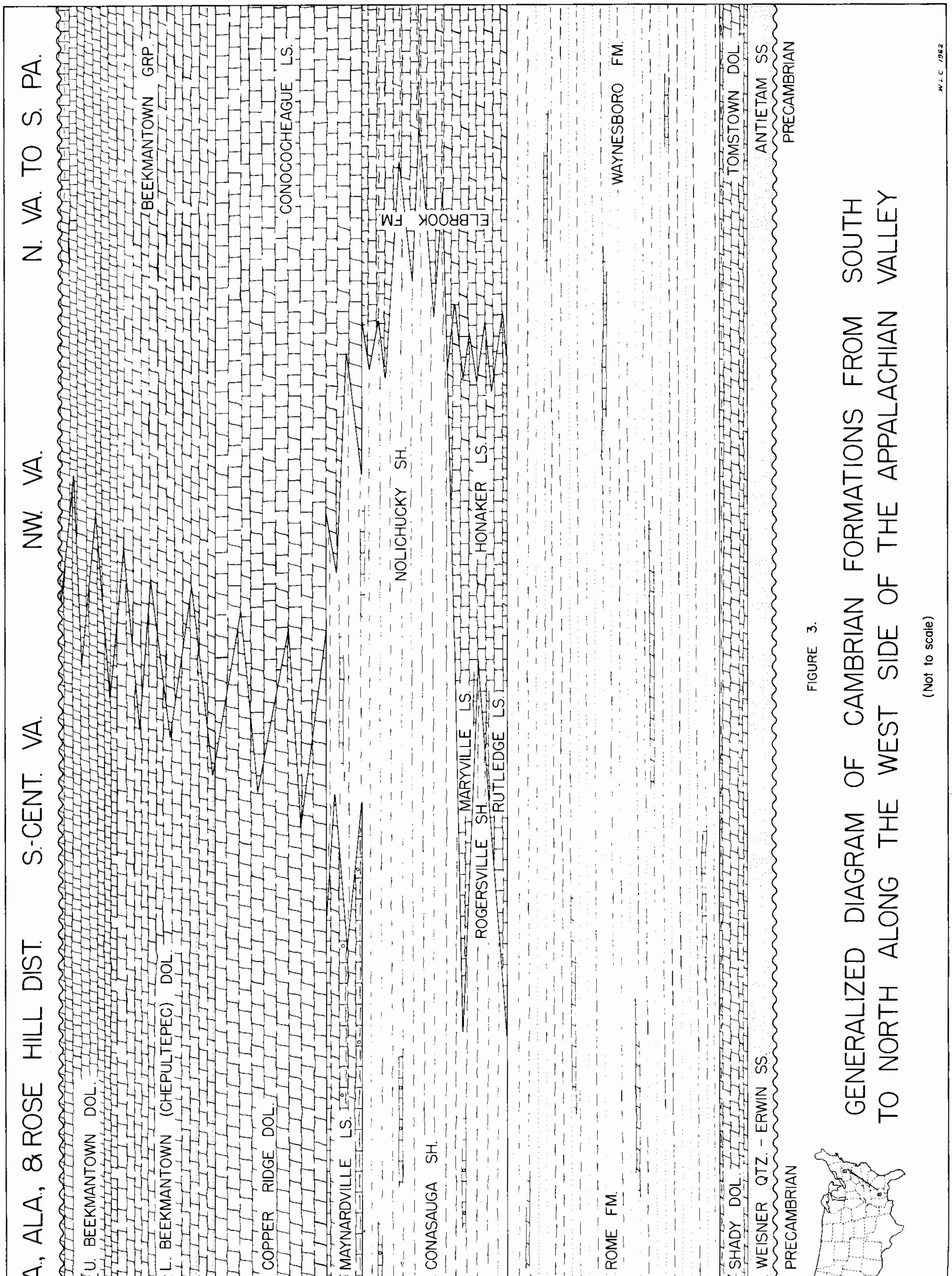

FIGURE 3.

GENERALIZED DIAGRAM OF CAMBRIAN FORMATIONS FROM SOUTH TO NORTH ALONG THE WEST SIDE OF THE APPALACHIAN VALLEY

(Not to scale)

by Walcott (1914, p. 354), but it had been first used in one of Ulrich's manuscripts. At the type section, which is in a hill named Mt. Simon at Eau Claire, Wis., it consists of about 225 feet of coarse- to medium-grained white sandstone with no upper or lower boundaries. It is known to be the basal sandstone of the sedimentary section which rests upon the basement complex in that area.

Definition and lithologic character. - The Erwin Sandstone is that rock-stratigraphic unit which conformably overlies the Hampton Shale and underlies the Shady Dolomite along the east side of the Appalachian Valley. In areas where the Hampton Shale and the Unicoi Formation were not deposited, the Erwin (Mt. Simon) Sandstone is the basal Paleozoic sandstone, which rests unconformably upon metamorphosed basement rocks. No such condition has been observed at the outcrops of the Erwin Sandstone along the east side of the Appalachian Valley, because in this area the Hampton Shale is always present. The Erwin Sandstone does not crop out along the west side of the Appalachian Valley, but wells of sufficient depth near this area and in the subsurface to the north and west generally reach a basal sandstone (Mt. Simon) which has the lithologic character and stratigraphic position of the Erwin Sandstone and which rests unconformably upon a basal arkose or upon metamorphic rocks.

The Mt. Simon (Erwin) Sandstone is a white to gray, coarse- to medium-grained, thoroughly sorted silica sandstone, cemented with secondary silica. It appears to have been a clean white beach sand. On the outcrop, the layers are very massive and show very few shale partings. Scolithus borings are common. The upper part is more thinly bedded and contains small blotches of iron oxide. A few thin shale beds occur throughout the formation. No glauconite has been observed.

Thickness and stratigraphic relations. - In the subsurface from Lee County, Va., to Fayette County, Ohio, the Mt. Simon Sandstone is conformably overlain by the Shady Dolomite. Where traced in the subsurface the Erwin Sandstone is apparently continuous with the Mt. Simon Sandstone of Wisconsin, the Lamotte Sandstone of Missouri, and the Potsdam Sandstone of New York. The Mt. Simon, Lamotte, and Potsdam Sandstones contain a sparse Late Cambrian fauna, but the Erwin Sandstone contains a sparse Early Cambrian fauna, which indicates that this basal sandstone is a time-transgressing rock-stratigraphic unit. On the outcrop in southern Virginia the Erwin Sandstone is about 1,500 feet thick. It is reported to be from 500 to 800 feet thick in Maryland and Pennsylvania and 800 to 1,100 feet thick in Tennessee. In these places it is known to rest conformably on the Hampton Shale. In the subsurface, its thickness ranges from 0 to 250 feet, depending upon the configuration of the surface of the basement rocks upon which it was deposited. It is absent or thin on the top of ancient monadnocks and old topographic ridges.

Radioactivity. - The gamma ray log of the Mt. Simon (Erwin) Sandstone usually shows medium gamma radiation. A few zones may cause a break sharply to the right on the log, indicating high radiation, but these are not common.

SHADY DOLOMITE

Name and type section. - The Shady Dolomite was named (Keith, 1903, p. 5) for the community of Shady Valley, in Johnson County, Tenn., where the type section of the formation is composed of limestone. The same stratigraphic unit was named the Tomstown Limestone by Stose (1906, p. 208) for Tomstown, Franklin County, Pa. On the outcrop in Virginia and in the subsurface, the formation is principally a dolomite. Since the name "Shady" has priority, and since the unit is a dolomite in the subsurface from Virginia to Ohio, the name "Shady Dolomite" is used in this report.

Definition and lithologic character. - At the type locality, the Shady Dolomite is composed of massive beds of gray, mottled, magnesian limestone which occur above the Erwin Sandstone and below the Wautauga (Rome) Shale. In the subsurface of eastern Kentucky it is a white, gray, or light brown, finely crystalline or sucrose, partly sandy, partly oolitic dolomite. Thin, fine-grained, dolomitic sandstone beds occur sparingly, particularly in the lower part, and thin beds and partings of reddish, sandy shale are present, especially in the upper part of the formation.

Thickness and stratigraphic relations. - At the type locality, the Shady Dolomite is about 800 feet thick. At Tomstown, where it occurs between the white Antietam Sandstone and the red Waynesboro Formation, it is also about 800 feet thick. The maximum thickness of the Shady Dolomite is apparently reached along the Blue Ridge in Virginia, where it is approximately 1,800 feet (Butts, 1940, p. 53). In the subsurface from Leslie County, Ky., to Fayette County, Ohio, the Shady Dolomite is about 200 feet thick. It was thought that this formation was absent in the No. 2 Knuckles well, (Bell County, Ky., see Thomas, 1960, p. 26), but it now appears that the well stopped in a sandy zone of the Rome Formation and did not reach the position of the Shady Dolomite.

The Shady Dolomite is a carbonate rock-stratigraphic unit which occurs between the relatively coarse clastic section of the Chilhowee Group below and the finely clastic section of the Knox Clastic Group above (table 2). It is everywhere conformable with the Erwin (Mt. Simon) Sandstone below and the Rome Formation above. In some localities it is markedly transitional. However, it is easily distinguished from the white, medium- to coarse-grained, silica-cemented Erwin (Mt. Simon) Sandstone below and the fine-grained, micaceous, glauconitic sandstone, glauconitic dolomite and limestone, and red shale of the Rome Formation above. The Shady Dolomite is very sparingly fossiliferous on the outcrop and is known to be Early Cambrian in age.

Radioactivity. - The gamma ray log of the Shady Dolomite generally shows medium-low to low radiation, but the part of the log for several exceptionally sandy zones near the middle or upper part shows medium-high radiation.

KNOX CLASTIC GROUP

According to Wilmarth (1938, p. 1,114), J. M. Safford defined the Knox Group as those beds which underlie the Stones River (Chazy) Limestone and overlie the Chilhowee (Erwin) Sandstone (Safford, 1869, p. 151, 158-159, 204-226). This group he divided into (descending) Knox Dolomite (4,000 feet), Knox Shale (1,500 to 2,000 feet), and Knox Sandstone (800 to 1,000 feet). The name "Knox Sandstone" has been replaced by the term "Rome Formation," and the name "Knox Shale" has been replaced by the term "Conasauga Shale." The name "Knox Dolomite" is still acceptable for those beds underlying the Stones River (Chazy) Limestone and resting on the Conasauga Shale, but since it is now divided into groups and formations the Knox Dolomite is considered a supergroup in the present report (table 2).

The lower two units of Safford's original Knox Group form a finely clastic sedimentary unit which occurs between the Shady Dolomite below and the Knox Dolomite Supergroup above (table 2). This sedimentary unit, composed of the Conasauga Shale and Rome Formation, should have a name of group rank for easy reference, and rather than introduce a new name the author of the present report will refer to the unit as the Knox Clastic Group.

Rome Formation

Name and type section. - The name "Rome" was assigned (Hayes, 1891, p. 143) to the formation underlying the town of Rome, in Floyd County, Ga. The type locality is south of this town. The name "Waynesboro Formation" (Stose, 1906, p. 209) is still used for this unit in the Appalachian Valley north of Roanoke, Va., although the name "Rome" has priority (fig. 3).

Definition and lithologic character. - Hayes (1902, p. 2) defined the Rome Formation as being composed of red, purple, green, gray, yellow, and white, thin-bedded, fine-grained sandstones and sandy shales, overlying the Beaver Limestone (Shady Dolomite, which rests upon the Weisner Quartzite) and underlying the Conasauga Shale. In the Rose Hill, Va., area some thin beds of limestone and dolomite are present in the formation (Miller and Fuller, 1954, p. 24), and the lithologic character is as described below.

The sandstones are white, gray, and pink (some are brown where weathered), micaceous, glauconitic, and either calcareous or dolomitic. Locally they contain sizable flakes of white or bronze-colored mica, and numerous grains and nodules of glauconite. The sandstones are composed of fine- to medium-sized, rounded quartz grains, some of which are frosted. On the outcrop, ripple marks are common.

The shales are commonly brilliantly colored, fissile and smooth, and contain much mica. Where weathered, they contain sericite and chlorite from decomposed mica flakes.

Thin beds of limestone and dolomite are dispersed throughout the formation. These are finely crystalline, glauconitic, partly oolitic, locally sandy beds which contain some rounded, frosted quartz grains.

Thickness and stratigraphic relations. - At the type locality the Rome Formation is 700 to 1,200 feet thick. It is reported (Butts, 1940, p. 63) to be about 2,000 feet thick in Virginia and 1,000 feet thick in Franklin County, Pa. (Stose, 1909, p. 5). In the subsurface north of the Rose Hill, Va., district, 1,478 feet of Rome Formation is present in the No. 1 Fordson well (Leslie County, Ky.), but 3,745 feet of Rome Formation is present in the No. 1 Williams well (Breathitt County, Ky.). This latter thickness may be due to faulting, but it is probably the result of deposition in a local basin, because the No. 1 James well (Martin County, Ky.) was drilled 4,558 feet into the Rome Formation without reaching the base of the formation (Thomas, 1960, p. 11). The Rome Formation thins rapidly northward to 72 feet in the No. 1 Stamper well (Carter County, Ky.), but it is 188 feet thick in the No. 1 Hopkins well (Fayette County, Ohio). Where observed on the outcrop or in well cuttings, the contact of the Rome Formation with the overlying and underlying beds appears to be conformable. The Rome Formation is apparently transitional with the Shady Dolomite below and the Conasauga Shale above. The base of the formation is placed at the horizon above which the beds are predominantly red shale and sandstone. The top of the Rome Formation is arbitrarily placed at the base of the lowest bed of coarsely crystalline, oolitic limestone typical of the Conasauga Shale, or at the top of the highest thick sandstone of the Rome Formation. On the outcrop, the Rome Formation is sparingly fossiliferous and is of Early and Middle Cambrian age (Miller and Fuller, 1954, p. 27-28).

Radioactivity. - The gamma ray log of the Rome Formation generally shows medium to medium-high radiation. The Rome Formation is characteristically less radioactive than the Conasauga Shale above and more radioactive than the Shady Dolomite below. The sandstones and shales are shown by a rather uniform curve on the log, but the thin dolomite and limestone beds give sharp breaks toward lower radiation on the gamma ray log. These latter beds seem to decrease in number northward in the subsurface.

Conasauga Shale

Name and type section. - The Conasauga Shale was named (Hayes, 1891, p. 143-148) for the Conasauga Valley of Whitfield and Murray Counties in northwest Georgia. The type section is along the Conasauga River in the Dalton quadrangle. Table 1 shows the various names which have been applied to parts or all of the Conasauga Shale in different parts of the Appalachian Valley (see fig. 3).

Table 1. - NOMENCLATURE OF BEDS ABOVE THE ROME FORMATION AND BELOW THE KNOX DOLOMITE IN THE APPALACHIAN VALLEY

Georgia, Alabama, and Rose Hill, Va., district	South-central Virginia	Northwestern Virginia	Northern Virginia to southern Pennsylvania
Conasauga Sh. (Knox Sh.)	Nolichucky Sh.	Nolichucky Sh.	Elbrook Dol. (Fm.)
	Maryville Ls.		
	Rogersville Sh.	Honaker Dol. (Ls.)	
	Rutledge Ls.		

Definition and lithologic character. - The Conasauga Shale was defined by Hayes as consisting of alternating beds of limestone and calcareous shale which underlie the Knox Dolomite and overlie the Rome Sandstone. The limestones are typically thin, gray, crystalline, magnesian, partly oolitic, and glauconitic in the Rose Hill, Va., area. Some are dense, silty limestones with local edgewise conglomerates. Much of the limestone of the Conasauga Shale is crisscrossed by white calcite veinlets. About 80 percent of the formation is composed of gray, green, red, and brown, smooth, fissile, micaceous shale, similar to that of the Rome Formation. Interbedded with the shales are thin beds of gray, glauconitic, micaceous siltstone containing large, bronze-colored mica flakes.

Thickness and stratigraphic relations. - At the type locality the Conasauga Shale reaches its maximum thickness of about 2,000 feet, but in the Rose Hill, Va., district it is slightly less than 600 feet thick. In the subsurface, the formation thins northward from 286 feet in Bell County, Ky., to 87 feet in Fayette County, Ohio. The Conasauga Shale is everywhere conformable, and its upper limit is placed at the base of the lowest massive bed of finely crystalline limestone (Maynardville) or dolomite of the Knox Supergroup. The Conasauga Shale is sparingly fossiliferous; in the outcrop it is thought to be Middle and Late Cambrian in age.

Radioactivity. - The gamma radiation of the Conasauga Shale commonly is the very highest gamma radiation shown on most gamma ray logs, although in some localities the shale beds of the overlying Maynardville Limestone show similar high gamma radiation. This formation is generally slightly more radioactive than the underlying Rome Formation.

KNOX DOLOMITE SUPERGROUP

The Knox Dolomite was named (Safford, 1869) for Knox County, Tenn., where the type exposures occur around Knoxville. It was defined as consisting of beds of dolomite and limestone, chiefly dolomite, which underlie the Stones River (Chazy) Limestone and overlie the Knox (Conasauga) Shale (see p. 21). This is a major rock-stratigraphic unit composed of beds of similar lithologic character, overlain and underlain by beds quite different lithologically. It deserves the rank of supergroup because it can be subdivided into lesser recognizable units such as groups, formations, and members. The rock-stratigraphic units recognized in the subsurface and discussed in this report are shown in table 2. Their differences from the units of Miller and Fuller (1954) and Charles Butts (1940) are also shown in the table. The reasons for these differences, where they occur in the present report, are presented with the discussion of each formation as it is described. The original Knox Dolomite of Safford is considered as a supergroup and includes the Lee Valley Group and the Beekmantown Group.

The Knox Dolomite Supergroup can be divided logically into a lower unit of rather pure, partly oolitic dolomite with some oolitic limestone at the base (Lee Valley Group) and an upper unit of sandy and argillaceous, very cherty dolomite (Beekmantown Group). The Lee Valley Group is composed of the Maynardville Limestone and the Copper Ridge Dolomite, and the Beekmantown Group includes the Chepultepec Dolomite and the Lambs Chapel Dolomite (Longview-Kingsport-Mascot Dolomite, undifferentiated).

LEE VALLEY GROUP (NEW NAME)

The term "Lee Valley Group" is here proposed as the formal name for that part of the Knox Dolomite Supergroup which is distinct from the Beekmantown Group. The name is taken from Lee Valley Post Office, in Hawkins County, Tenn., which is located on State Route 66 between Sneedville and Rogersville. A stratigraphic section northward along State Route 66, beginning 2.4 miles north of Lee Valley Post Office, has been published by Rodgers and Kent (1948), and units 69 through 162 of this section describe the beds which constitute the Lee Valley Group. This is proposed as the type locality. The Lee Valley Group is defined as that body of generally pure, partly oolitic, partly cherty dolomite and some limestone which composes the Maynardville Limestone and the Copper Ridge Dolomite Formations (see table 2). It is overlain by the sandy and argillaceous beds of the Chepultepec Dolomite and is underlain by the varicolored shales and thin limestone beds of the Nolichucky (Conasauga) Shale.

It is unfortunate that Rogers and Kent (1948, p. 12) treated the Maynardville Limestone (units 69 through 85 of the Lee Valley section) as a member of the Nolichucky Shale. The principal reason for their decision seems to be based on faunal rather than lithologic evidence. The Maynardville Limestone is quite different lithologically from the Nolichucky (Conasauga) Shale but quite similar to the Copper Ridge Dolomite, into which it grades. The Maynardville Limestone is considered to be a separate formation by Oder (1934), Miller and Fuller (1954), and by the author of the present report.

A comparison of the principal characteristics which distinguish the Lee Valley Group from the overlying Beekmantown Group is shown below:

Lee Valley Group	Beekmantown Group
Sandstone beds, rare, present only in upper part of group	Sandstone beds, numerous
Chert, sparse, opaque; some white oolitic chert in upper part of group	Chert, very abundant, mostly light colored; much white oolitic chert

TABLE 2

GENERALIZED GEOLOGIC COLUMN FOR SUB-TRENTON ROCKS FROM LEE CO., VA., TO FAYETTE CO., OHIO

OUTCROP - W. SIDE APPALACHIAN VALLEY: BUTTS, 1940, V. G. S. BULL. 52

SYS.	GRP.	FORMATION
ORDOVICIAN		TRENTON LS.
	BLACK RIVER	EGGLESTON LS.
		MOCCASIN - LOWVILLE LS.
	STONES RIVER	LENOIR LS.
		MOSHEIM LS.
		MURFREESBORO LS.
	BEEKMAN TOWN	BELLEFONTE DOL.
		NITTANY DOL.
		STONEHENGE DOL.
		CHEPULTEPEC DOL.
CAMBRIAN		COPPER RIDGE DOL.
		NOLICHUCKY SH.
		MARYVILLE LS.
		ROGERSVILLE SH.
		RUTLEDGE LS.
		ROME FM.
		SHADY DOL.
	CHILHOWEE	ERWIN SS.
		HAMPTON SH.
		UNICOI FM.
PRECAMBRIAN		

OUTCROP - ROSE HILL DISTRICT, VIRGINIA: MILLER AND FULLER, 1954, V. G. S. BULL. 71

SYS.	GRP.	FORMATION	MEMBER
ORDOVICIAN		TRENTON LS.	
		EGGLESTON LS.	
		MOCCASIN LS.	Hardy Creek Ls.
			Lower Arg. Ls.
		LOWVILLE LS.	Platy Ls.
			Redbed Ls.
		LENOIR LS.	
		MOSHEIM LS.	
		MURFREESBORO LS.	Upper Cherty
			Middle Ls.
			Lower Dol.
	KNOX		
	KNOX	MASCOT DOL.	
		KINGSPORT DOL.	
		LONGVIEW DOL.	
		CHEPULTEPEC DOL.	Upper Arg.
			Lower Sandy
CAMBRIAN		COPPER RIDGE DOL.	Upper Light Dol.
			Lower Dark Dol.
		MAYNARDSVILLE LS.	Chances Branch Dol.
			Low Hollow Ls.
		CONASAUGA SH.	
		ROME FM.	
		UNEXPOSED	

SUBSURFACE - EASTERN KENTUCKY AND SOUTHERN OHIO: CALVERT, 1962, O. G. S. REPT. INV. 45 (PRESENT REPORT)

SEQ.	SUPER GROUP	GRP.	FORMATION	MEMBER
TIPPECANOE	OTTAWA LIMESTONE		TRENTON LS.	
		BLACK RIVER	EGGLESTON LS.	
			MOCCASIN LS.	Upper Ls.
				Lower Arg. Ls.
			LOWVILLE LS.	
			CHAZY LS.	Upper Arg.
				Middle Ls.
				Lower Dol.
UNCONFORMITY				
SAUK	KNOX DOLOMITE	BEEKMAN-TOWN	LAMBS CHAPEL DOL.[1]	
			CHEPULTEPEC DOL.	Upper Arg.
				Lower Sandy
		LEE VALLEY	COPPER RIDGE DOL.	Upper Light Dol.
				Lower Dark Dol.
			MAYNARDVILLE DOL.	
		KNOX CLASTIC	CONASAUGA SH.	
			ROME FM.	
			SHADY DOL.	
		CHIL-HOWEE	MT. SIMON SS.(ERWIN)	
BASEMENT UNCONFORMITY				
BASEMENT COMPLEX				

1. New name replacing "Longview-Kingsport-Mascot Dolomite, undifferentiated."

Lee Valley Group (con.)	Beekmantown Group (con.)
Dolomite, commonly oolitic and pelletal	Dolomite, rarely oolitic; commonly contains scattered sand grains
Shale partings, sparse, gray or brown	Shale partings, abundant, green
Radioactivity, very low; shown by rather smooth curve on log.	Radioactivity, slightly higher than in underlying beds; shown by moderately rough curve on log.

The contrast in lithologic character between the limestone and dolomite beds of the Lee Valley Group and the underlying red and green, micaceous shales and siltstones of the Knox Clastic Group is very striking.

The Lee Valley Group has a thickness of approximately 1,100 feet in the Lee Valley section and a similar thickness in the Rose Hill district of Lee County, Va. It is apparently conformable and transitional with the Conasauga Shale below and with the Chepultepec Dolomite above. On the outcrop, the Lee Valley Group is thought to be Late Cambrian in age.

Maynardville Dolomite

Name and type section. - The name of the Maynardville Limestone was taken from the town of Maynardville, in Union County, Tenn. The type section was $5\frac{1}{2}$ miles northeast of Maynardville along State Route 33, but this section is now covered by water behind Norris Dam. The section was described and the name proposed by C. R. L. Oder (1934, p. 475-476) as a new formation to be included in the Knox Dolomite Group. A new type section has been described by Bridge (1956, p. 13). Another excellent section of the Maynardville Limestone described by Hall and Amick (1934, units 136 through 202) crops out north of Thorn Hill along U. S. Route 25E between Morristown and Tazewell, Tenn. In the Rose Hill district of Lee County, Va., and in the subsurface northward the formation is predominantly dolomite, and it is therefore called a dolomite in this report.

Definition and lithologic character. - The Maynardville Dolomite may be defined as a transitional formation which occurs between the Conasauga Shale (or the Nolichucky Shale) and the Copper Ridge Dolomite. It has been divided by Miller and Fuller (1954, p. 34) into two members, the Low Hollow Limestone Member below, and the Chances Branch Dolomite Member above (see descriptions on p. 27).

Thickness and stratigraphic relations. - The Maynardville Dolomite is about 250 feet thick in the Appalachian Valley. It thins northward in the subsurface from Lee County, Va., to about 160 feet in Fayette County, Ohio. In the No. 1 Hopkins well (Fayette County, Ohio), the Maynardville Dolomite is composed mainly of light brown, finely crystalline, sandy dolomite with interbedded white, fine-grained sandstone and gray shale stringers. In this well the exact top of the Maynardville Dolomite is difficult to recognize because the lower part of the Copper Ridge Dolomite may include sandstone stringers assigned to the Maynardville Dolomite on the cross section (pl. 1). The Maynardville Dolomite section in the No. 1 Hopkins well has been called the Franconia Sandstone by some geologists and the upper part of the Eau Claire Formation by other geologists.

The Maynardville Dolomite is conformable in all respects and is transitional with units both above and below. Northward, in the subsurface the upper member apparently merges into the Copper Ridge Dolomite, but the lower member, with its shale and silty zones, seems to carry through, although it becomes more dolomitic.

Radioactivity. - The curve for the Maynardville Dolomite shown on a gamma ray log is generally sharply irregular. It fluctuates from medium-high to medium in the lower part and shows progressively lower radiation upward until at the upper limit of the formation it generally reaches the lowest radioactivity shown on the log. Apparently the shaly and silty streaks cause the fluctuating character of the curve.

Low Hollow Limestone Member

The Low Hollow Limestone Member is predominantly fine-grained limestone interbedded with shale. On the outcrop, three lithologic units are recognized: a basal unit of medium gray, finely crystalline limestone in beds about 1 inch thick, interbedded with dark gray, medium crystalline silty limestone layers about half an inch thick, with some beds of gray shale and shaly limestone up to several feet in thickness at irregular intervals; a middle unit of mottled gray or tan, finely crystalline, partly silty limestone beds several feet thick; and an upper unit similar to the middle unit but with thin beds of gray, finely crystalline, laminated dolomite. Some of the limestone beds in all three units are oolitic, and some of the silty limestones contain edgewise conglomerates. The fine-grained limestones of the Maynardville contrast sharply with the coarsely crystalline, veined limestones of the Conasauga Shale below.

Chances Branch Dolomite Member

The upper half of the Maynardville Dolomite is composed mainly of light gray, finely crystalline, partly oolitic dolomite and dolomitic limestone in beds up to 3 feet in thickness. Shale is much less common than in the lower member and decreases in amount upward. In the upper part, beds of dark gray, medium crystalline dolomite of the Copper Ridge type are present and increase in number toward the top. The upper boundary of the member (and of the formation) is arbitrarily placed at the horizon above which the dark gray, medium crystalline dolomite of the Copper Ridge Dolomite is more abundant than the light gray, finely crystalline dolomite of the Chances Branch Member.

Copper Ridge Dolomite

Name and type section. - The Copper Ridge Dolomite was named by E. O. Ulrich (1911, p. 548, 635-636) as the Copper Ridge Chert, for Copper Ridge, a prominent mountain in eastern Tennessee and western Virginia, located northeast of Knoxville, Tenn. The type section is along Forked Deer Creek, where it passes through Copper Ridge at Thorn Hill, in Grainger County, Tenn. (Rodgers, 1948, p. 14).

Definition and lithologic character. - In the type section and at Rose Hill, Va., the Copper Ridge Dolomite is defined to include all the beds above the Maynardville Dolomite and below the Chepultepec Dolomite (table 2). It is divisible into two members, the lower dark member and the upper light member, which can be recognized over a wide area (see descriptions on p. 28).

Thickness and stratigraphic relations. - On the outcrop in the Rose Hill, Va., district the Copper Ridge Dolomite is about 800 feet thick. It thins slightly to the north in the subsurface and has a thickness of 574 feet in the No. 1 Hopkins well (Fayette County, Ohio). In this well, a distinctly silty dolomite zone appears at the base of the upper member, and the two members have about equal thickness. The formation is conformable and transitional with both the underlying Maynardville Dolomite and the overlying Chepultepec Dolomite. The lower boundary of the Copper Ridge is arbitrarily defined as the horizon above which the dark brown "stinkstone" dolomite makes up more than 50 percent of the strata. The upper limit is placed at the bottom of the lowest relatively thick sandstone bed which occurs below the conspicuous white, oolitic chert beds and above the commonly oolitic dolomite.

Radioactivity. - The Copper Ridge Dolomite consistently has very low gamma radiation. The lower dark member, or "stinkstone," commonly has a slightly lower average radiation than the upper member, thus causing a slight shoulder at the contact between the two members as shown on most gamma ray curves. Generally the lower member of the Copper Ridge Dolomite has the lowest radiation (along with the Black River Group) of any part of the dolomite section.

Lower Dark Member

The lower dark member of the Copper Ridge Dolomite consists mainly of dark gray or brown, medium to coarsely crystalline, partly oolitic dolomite which is known as "stinkstone" because it has a petroliferous odor when freshly broken. Near the base, light gray, dense dolomite similar to that of the Maynardville Dolomite is interbedded with the "stinkstone." This member is the Morristown Dolomite member of Oder (1934, p. 476-478).

Upper Light Member

The upper light member of the Copper Ridge Dolomite is composed of white, light gray, or light brown, fine to coarsely crystalline, partly sandy, partly oolitic dolomite. The sandy lenses increase in frequency near the top, but they are much less common and much thinner than in the overlying Chepultepec Dolomite, commonly being only an inch or two thick. Rounded, frosted, fine- and medium-sized sand grains are embedded in the dolomite of the upper member. The grains are scattered throughout the member but are more numerous in certain zones. This is the Bloomingdale Dolomite member of Oder (1934, p. 478-479).

Both members of the Copper Ridge Dolomite contain numerous beds of oolitic dolomite, in contrast with the overlying Chepultepec Dolomite, which contains very few. The oolitic beds of the Copper Ridge Dolomite are more common in the lower member. Both members contain beds and lenses of white, oolitic chert, but these are more numerous in the upper member. Some dark gray and black opaque chert is also present, mostly in the lower member. Vugs lined with dolomite or quartz crystals are common throughout the formation.

BEEKMANTOWN GROUP

E. Brainerd and H. M. Seely (1890, p. 501-516) divided the "Calciferous" of the Champlain Valley at East Shoreham, Vt., into five lithologic zones, which occur below the Chazy Limestone and above the basal (Potsdam) sandstone. This became the type section for the Beekmantown Limestone of J. M. Clarke and C. Schuchert (1899, p. 874-878), but they proposed the name "Beekmantown" to replace the name "Calciferous" for Beekmantown, N. Y., where a much thinner but similar section of rocks occurs. In the type section, most of the beds of the Cambrian System are missing because of onlap, and therefore, the Beekmantown Limestone rests unconformably on the basal (Cambrian) sandstone and the true lower limit of the formation has not been defined. The upper boundary of the formation also has not been clearly delineated in the type section because it is also at an unconformity (below the Chazy Limestone). It is necessary, therefore, to present a careful definition when the term "Beekmantown Group" is used. Since Ulrich correlated part of the Beekmantown Limestone by lithologic similarity and fossils with the Chepultepec Dolomite of Alabama (Wilmarth, 1938, p. 147), and since its original upper boundary is the base of the Chazy Limestone, it seems logical to include all the strata in the Rose Hill, Va., district from the base of the Chepultepec Dolomite to the base of the Chazy (Murfreesboro) Limestone in the Beekmantown Group. It is part of a larger unit of carbonates, the Knox Dolomite Supergroup. The term "Beekmantown Group" is widely used in eastern United States, where it embraces a recognizable body of strata having a definite lithologic character. In the present report the Beekmantown Group is divided into two formations (ascending): the Chepultepec Dolomite, and the Lambs Chapel Dolomite (Longview-Kingsport-Mascot Dolomite, undifferentiated).

Chepultepec Dolomite

Name and type section. - E. O. Ulrich (1911, p. 549, 638-640) proposed the name "Chepultepec Dolomite" for a section of dolomite about 1000 feet thick, which is characterized by abundant soft, mealy chert, and which occurs at the town of Chepultepec (now Algood), in Blount County, Ala. This is still the type section.

Definition and lithologic character. - Ulrich originally defined the Chepultepec Dolomite as those dolomite beds which occur "between the top of the typical Knox and the overlying Canadian (Beekmantown) limestone and dolomite" (Ulrich, 1911, p. 549), but the Chepultepec was later correlated with the lower part of the Beekmantown (Wilmarth, 1938, p. 148). The accepted definition of the Chepultepec Dolomite was established by Charles Butts (1926), who defined the formation as those beds which rest upon the Copper Ridge Dolomite and which are in turn overlain by the Longview Dolomite. In the Rose Hill, Va., district, Miller and Fuller (1954, p. 49) recognized and described two lithologic members of the Chepultepec Dolomite, the lower sandy member and the upper argillaceous member (see descriptions on p. 30).

Thickness and stratigraphic relations. - In the type locality the Chepultepec Dolomite is about 1,000 feet thick, but the formation thins northward to about 700 feet in the Rose Hill, Va., area. Here the lower sandy member is about 270 feet thick and the upper argillaceous member is about 430 feet thick. The Chepultepec normally thins northward until it is only 378 feet thick in the No. 1 Stamper well (Carter County, Ky.). North of this well, part of the upper member has been removed by erosion in the No. 1 Adams well (Lewis County, Ky.), and only 180 feet of the Lower Chepultepec Dolomite remains in the No. 1 Hopkins well (Fayette County, Ohio). It is evident, then, that the Chepultepec Dolomite is conformable and transitional with the Copper Ridge Dolomite below and the Lambs Chapel Dolomite (Longview-Kingsport-Mascot Dolomite, undifferentiated) above, in the Rose Hill, Va., district, but that because of truncation northward the Lambs Chapel Dolomite is absent and the Chazy Limestone rests unconformably upon the Chepultepec Dolomite in southern Ohio and northern Kentucky (see pl. 1).

Radioactivity. - The curve on the gamma ray log for the Chepultepec Dolomite shows a more irregular and slightly higher average radiation than that for the underlying Copper Ridge Dolomite. The gamma radiation curve for the lower sandy member is more irregular (with stronger scattered breaks showing higher radiation) than the curve for the upper argillaceous member.

Lower Sandy Member

The lower sandy member of the Chepultepec Dolomite consists of interbedded dolomitic sandstones, sucrose dolomites, and argillaceous dolomites. The sandstones are white, fine- and medium-grained, dolomite-cemented, quartz sandstones which contain about 20 percent subangular feldspar grains. The dolomites are light brown, sucrose or light gray, argillaceous dolomites, characterized by scattered grains of rounded, frosted, quartz and numerous lenses or nodules of white or gray oolitic chert. Thin, gray, green, and brown shale partings are sparingly present. Some of the sandstones are ripple marked on the outcrop.

Upper Argillaceous Member

The upper argillaceous member is similar to the lower sandy member except that it contains more argillaceous dolomite and less chert. Sandstone beds are present toward the bottom of the upper argillaceous member and are thinner and less persistent than in the lower sandy member. Green shale partings are more numerous in the upper argillaceous member. Some of the chert is less oolitic, and some opaque, structureless chert nodules are present. A few thin interbedded sandstones also occur near the top of this member.

The upper boundary of the formation is placed at the top of the argillaceous, partly silty dolomite beds of the upper member, which are commonly darker than the overlying white and cream-colored beds of the Lambs Chapel Dolomite (Longview-Kingsport-Mascot Dolomite, undifferentiated).

UPPER BEEKMANTOWN TERMINOLOGY

The section lying above the Chepultepec Dolomite and below the Knox unconformity has been referred to as the Beekmantown Group or as the upper part of the Beekmantown Group. It is composed of light-colored, finely to coarsely crystalline, partly sandy dolomite which contains white opaque and white oolitic chert. This section is a lithologic unit which has been subdivided locally; it is known as the Longview-Kingsport-Mascot section or as the Longview-Newala section. In order to get a clear picture of the state of present terminology it is necessary to review briefly the origin of, and basis for, the nomenclature commonly in use.

Present names and type sections. - The Longview Dolomite was named by E. O. Ulrich in 1924 for the town of Longview, in Shelby County, Ala., (Gordon, 1924, p. 34), near where the type section is located. The Kingsport Dolomite was named by John Rodgers (1943) for the town of Kingsport, in Sullivan County, Tenn., which is the type locality. In the same report Rodgers also named the Mascot Dolomite for the town of Mascot, in Knox County, Tenn. The type locality is in the Mascot zinc district. The Newala Dolomite was named by Charles Butts (1926, p. 95) as the

Newala Limestone for Newala Post Office, in Shelby County, Ala. The best exposures are about half a mile northwest of Pelham, Ala.

Basis of past subdivision. - Charles Butts (1940, p. 102) considered all the strata in Virginia below limestones "of Chazyan age" and above the Chepultepec Dolomite as the Beekmantown Group. He noted that in central Pennsylvania the Beekmantown has been divided into four formations (ascending): the Stonehenge Limestone, Nittany Dolomite, Axemann Limestone, and Bellefonte Dolomite. He further states:

> "As these beds are traced southward across Maryland and into Virginia, the four formations become difficult to distinguish and map separately . . . ."

He discusses his Beekmantown Group as a unit but in a generalized section (1940, p. 23) he lists (ascending) Stonehenge Limestone, Nittany Dolomite and Limestone, and Bellefonte Limestone and Dolomite as formations of the Beekmantown Group. The U. S. Geological Survey (Wilmarth, 1938, p. 145-148, 413-414) includes the Chepultepec Dolomite in the Beekmantown Group.

Hall and Amick (1934, p. 160) divided their Knox Dolomite in the Thorn Hill section, in Grainger County, Tenn., into four parts (ascending): the Copper Ridge Dolomite, Nittany Dolomite, Forked Deer Limestone, and Thorn Hill Formation. The vagueness and uncertainty with which the formation boundaries were selected is evidenced by the following quotations (Hall and Amick, 1934):

> "The finding of a typical Chepultepec cephalopod at bed 394 may indicate the presence of the Chepultepec limestone and somewhere between beds 394 and 450 the boundary between the Chepultepec and Nittany may eventually be established. (p. 160)
>
> The base of the section [Thorn Hill Formation] as here drawn is marked by a sandy dolomite which is very inconspicuous in fresh unweathered material [well cuttings or fresh outcrops] but which weathers to a porous, rusty sandstone." (p. 161)

Lithologic descriptions of the rocks above and below the proposed formational contacts are strikingly similar, and criteria for distinguishing formations appear to be based upon local variations such as thick or thin bedding, coloration, abundance of chert, weathering phenomena, or upon fossil content.

Oder (1934, p. 474) divided his Knox Dolomite into seven formations (ascending): Maynardville Limestone, Conococheague-Copper Ridge Formation, and Chepultepec Formation for the Lower Knox or Ozarkian Series of the Cambrian System; and Stonehenge Limestone, Nittany Dolomite, Jefferson City Formation, and Cotter-Powell Beds for the Upper Knox or Canadian (Beekmantown) Series of the Ordovician System. From the discussion it appears that the author was principally concerned with the correlation of time-stratigraphic rather than rock-stratigraphic units and that the formations assigned to the Beekmantown Group are more nearly faunal zones than regional lithologic entities. In a later paper (Oder and Miller, 1945, p. 224) their Knox Dolomite was divided into (ascending): Conococheague-Copper Ridge, Chepultepec, Longview (Nittany), Kingsport (Jefferson City), and Mascot (Cotter-Powell). The Kingsport is the only zone discussed in detail. It is divided into four local divisions, but the lithologic boundaries postulated are not definitive for other areas.

Rodgers and Kent (1948) adequately described the rocks of the Lee Valley section, in Hawkins County, Tenn., but divided the Beekmantown Group above the Chepultepec Dolomite into (ascending): Longview Dolomite, Kingsport Dolomite, and Mascot

Dolomite. The divisions are again arbitrary and much reliance is placed on fossil content. In defining the Longview Dolomite it is stated (1948, p. 22):

> "The formation as defined in Alabama includes the Lecanospira zone and excludes the overlying Ceratopea zones, and this usage has been extended to Tennessee (Oder and Miller, 1945; other recent papers, abstracts, and maps). The Lecanospira zone had previously been called Nittany in Tennessee, but the Nittany dolomite in Centre County, Pennsylvania, the region in which it was first described, appears to include a large part of the Ceratopea zones as well and it is not strictly correlative with the beds in question in Tennessee.
>
> The top of the Longview dolomite is drawn at Thorn Hill at the top of unit 458, above the highest occurrence of Lecanospira . . . but below the thick zone of limestone (units 459 to 470) that carries a Kingsport fauna."

In defining the Kingsport Limestone (Dolomite) in the Lee Valley and Thorn Hill sections, Rodgers and Kent (1948, p. 25) indicate that the identification of the formation is made chiefly on the basis of fossils, as shown below:

> "The basal contact of the Kingsport is taken just below a thick bed of limestone (unit 241 of this Lee Valley section, units 459 and 470 of the Thorn Hill section), because at Thorn Hill this contact separates the limestone carrying Orospira and other Kingsport gastropods from the limestone carrying Lecanospira . . . ."

One lithologic boundary is indicated (1948, p. 26) by the following: "The top of the Kingsport is marked by the chert-matrix sandstone taken as the base of the overlying Mascot . . . ." but the validity of this boundary is immediately put in question by the following statement (1948, p. 28) concerning the Mascot Dolomite:

> "In Copper Ridge there are three or four beds of chert-matrix sandstone, the lowest of which most closely resembles that at Mascot and has been taken as the base of the Mascot formation."

This study seems to show that no reliable regional lithic boundaries can be recognized between the top of the Chepultepec Dolomite and the Knox unconformity.

Miller and Brosgé (1954, p. 23-30) discuss the Longview Dolomite, Kingsport Dolomite, and Mascot Dolomite in the Jonesville district, Lee County, Va., and give the following lithologic descriptions:

Formation	Description
Longview Dolomite	"Mainly light-gray to nearly white dolomite, some of which is medium crystalline and some finely crystalline."
Kingsport Dolomite	"Light-colored to white, massive-bedded, medium to coarse-crystalline, saccharoidal dolomite."
Mascot Dolomite	"Consists predominantly of light-colored to nearly white dolomite. In the lower part of the formation most of the dolomite is medium to coarse-crystalline and is saccharoidal, but in the upper part the dolomite is almost all fine crystalline."

This shows how lithologically similar the entire section is, as further emphasized by the following statements (Miller and Brosgē, 1954):

> "In most of the Jonesville district it [Longview Dolomite] was not mapped separately but was included with the overlying Kingsport and Mascot dolomites. (p. 23)
>
> The senior author spent considerable time trying to discover lithologic criteria for distinguishing chert float derived from the Longview from that derived from the Mascot, but the only thoroughly reliable criterion was the presence of *Lecanospira*, which indicates Longview, or the presence of small, high-spired gastropods *Hormotoma*, *Coelocaulus*, etc., which indicate Mascot." (p. 29)

From the discussion in this article it seems that these authors also placed more reliance upon faunal content and local stratigraphic variations than upon regional lithologic formational characteristics to divide the Beekmantown Group.

Finally, Miller and Fuller (1954, p. 54-62) discuss the Beekmantown Group and show it as an undifferentiated unit on their geologic map of the Rose Hill, Va., district. Although they select contacts for the Longview, Kingsport, and Mascot Dolomites, the general lithologic unity of the three so-called formations is shown by the following statements (Miller and Fuller, 1954):

> "The Kingsport dolomite of the Rose Hill district is similar in character to the Longview dolomite. (p. 57)
>
> The Mascot dolomite contains rock types similar to those of the Longview and Kingsport dolomites . . . ." (p. 59)

For both surface and subsurface work it does not seem practical to subdivide the Longview-Kingsport-Mascot Dolomite section into rock-stratigraphic units except in possibly very local areas. However, there is a definite need for a name to use in referring to this unit rather than "Longview-Kingsport-Mascot Dolomite, undifferentiated." The term "Upper Beekmantown Dolomite" is also not acceptable because of different concepts of the range of the "Beekmantown" in various areas. Therefore, it is proposed to substitute the name "Lambs Chapel Dolomite" for the rock stratigraphic unit heretofore called "Longview-Kingsport-Mascot Dolomite, undifferentiated."

Lambs Chapel Dolomite (New Name)

Name and type section. - The name "Lambs Chapel Dolomite" is taken from Lambs Chapel, along Hardy Creek, 1 mile north-northwest of the mouth of Hardy Creek, Lee County, Va. The type section is at this locality and has been excellently described by Miller and Fuller (1954, p. 172-175). It includes a full exposure of the rocks designated as Longview, Kingsport, and Mascot. The unit here named the Lambs Chapel Dolomite extends downward from the base of the Murfreesboro (Chazy) Limestone to the top of the Chepultepec Dolomite. The thickness of the Lambs Chapel Dolomite in this section is 915 feet. This section is designated as geologic section 5, or the Lambs Chapel section, in the report on the Rose Hill, Va., district (Miller and Fuller, 1954, p. 172 and pl. 13).

Definition and lithologic character. - As defined above, the Lambs Chapel Dolomite consists of all the strata above the top of the upper argillaceous member of the Chepultepec Dolomite and below the top of the Knox Dolomite Supergroup (Knox unconformity). These beds are composed of white and light-colored, fine to coarsely crystalline, partly saccharoidal dolomite containing beds and lenses of light-gray banded chert, white oolitic chert, sand-centered oolitic chert, and thin, chert-matrix sandstones. Thin green shale partings are common. Minor unconformities and intraformational conglomerates which contain rounded, frosted quartz grains are present, as are zones of scattered embedded quartz grains.

Thickness and stratigraphic relations. - On the outcrop in Lee County, Va., the Lambs Chapel Dolomite is about 900 feet thick. Its total thickness is determined by the erosional unconformity at the top of the unit. The base of the unit is conformable to and transitional with the underlying Chepultepec Dolomite. The Lambs Chapel Dolomite is truncated northward in the subsurface until it appears to be absent before the No. 1 Adams well in Lewis County, Ky., is reached. In all probability, this unit is not present in the subsurface of Ohio, unless it should extend into the southeastern or southwestern corners of the State.

Radioactivity. - The gamma ray log for the Lambs Chapel Dolomite has a characteristic curve which shows slightly lower radiation than that of the upper argillaceous member of the Chepultepec Dolomite. The gamma ray curve is moderately irregular, due to thin sandy and argillaceous strata, but the breaks are not so extreme as those exhibited by the lower sandy member of the Chepultepec Dolomite.

KNOX UNCONFORMITY

In the Rose Hill, Va., area and in the subsurface northward, there is a major erosional unconformity at the top of Knox Supergroup which has as much as 400 feet of local relief (Miller and Fuller, 1954, p. 67). This is a widespread stratigraphic break throughout eastern United States and in many other parts of the world (Patterson, 1961, and Bushbach, 1961). It is the result of one of the most significant erosional periods of the Paleozoic Era. In the writer's opinion, the significance and magnitude of this unconformity has never been properly emphasized. The erosion was preceded in the central Appalachian area by regional southward tilting, the evidence for which is the continued northward truncation of stratigraphically lower beds. Local folding is also indicated by the truncation of beds in Ohio over the southward-plunging pre-Chazy central Ohio arch. This one unconformity has been called the post-Knox, post-Arbuckle, post-Ellenberger unconformity (Freeman, 1953, p. 14), but for the sake of brevity it is referred to in the present report as simply the Knox unconformity. A major regional unconformity may be designated by the name of one of the major rock-stratigraphic units above which it occurs. Minor unconformities are present within the Knox Dolomite Supergroup, but the Knox unconformity is the first major regional unconformity above the basement unconformity in eastern United States.

ORDOVICIAN NOMENCLATURE

It is necessary in any subsurface study to keep in mind that faunal zones properly play no part in defining formations. The Ordovician System of rocks has probably been subject to more confusion than any of the other geologic systems occurring in eastern United States because some generally homogeneous lithologic units have been divided into formations on the basis of fossils. It might have been better if these biostratigraphic units had been called faunal zones instead of formations. Before the terms "Stones River," "Chazy," "Murfreesboro," "Black River," and "Trenton" are used, their origins and defintions should be analyzed to ensure that their connotations are clearly understood.

The Trenton Limestone was named by Vanuxem (1838, p. 257, 276, 283) for Trenton Falls, in Oneida County, N. Y. It was defined as consisting of about 100 feet of light gray, crystalline, fossiliferous limestone which is overlain by shale (in this case the Utica Shale) and which is underlain by compact birdseye limestone. This definition of the Trenton Limestone is just as good today as it was in 1838.

The Black River Limestone was defined by Vanuxem (1842, p. 38-45) as that body of limestone which underlies the Trenton Limestone and overlies the Calciferous Sandrock (Beekmantown). Vanuxem subdivided the Black River Limestone into four members (descending): the (1) Mohawk Limestone, (2) gray limestone, (3) birdseye limestone, and (4) Chazy Limestone. Cushing (1911, p. 135-144) defined the Black River Group as all the rocks between the Trenton Limestone above and the Chazy Limestone below, and this is the presently accepted definition.

In the Rose Hill, Va., district the following lithologic units (descending) have been recognized above the Knox unconformity (Miller and Fuller, 1954):

Trenton Limestone
Eggleston Limestone
Moccasin Limestone
Lowville Limestone
Murfreesboro (Chazy) Limestone
(unconformity)

These formations, with the exception of the Murfreesboro (Chazy) Limestone, are lithologically similar to the beds in the type localities and are stratigraphically at the proper place in the section. It seems proper to place the Eggleston Limestone, Moccasin Limestone, and Lowville Limestone in the Black River Group, because they form a lithic entity and satisfy Cushing's definition.

The Chazy Limestone was named by Emmons (1842, p. 107, 315, 429) for the town of Chazy, in Clinton County, N. Y. It was defined as 150 feet of partly cherty limestone which underlies the "Birdseye limestone" (Lowville) and overlies the "Calciferous sandrock" (Beekmantown). It will be seen from the discussion of the Chazy (Murfreesboro) Limestone in the present report (p. 36) that this definition closely fits the description of the lithologic character and stratigraphic position of the Murfreesboro Limestone of Butts (1940, p. 119) in the Appalachian Valley. Another definition which also fits this sedimentary unit, at least in the Rose Hill, Va., outcrops and in the subsurface of New York, Pennsylvania, Ohio, and Kentucky, is one by Cushing (1908, p. 155) in which he named the Pamelia Limestone for the village of Pamelia, in Jefferson County, N. Y., and defined it as follows:

> "Chiefly blue and dove limestone with intercalated magnesian limestone, and in the upper half much whitish, impure limestone and some yellow waterlime; at the base 10 to 20 feet of thin sandstone overlain by greenish shale. Thickness 40 to 150 feet. Probably of Stones River age. Overlain by Lowville limestone and unconformably underlain by Theresa formation [Cambrian]."

In the present report the name "Chazy Limestone" is preferred to the name "Murfreesboro Limestone."

The Stones River Group was named by Safford (1851, p. 353-356) for a river in western Tennessee. The name was applied to a 250-foot zone of fossiliferous limestone beds with no visible lower boundary, which has since been divided into (descending) Lebanon, Ridley, Pierce, and Murfreesboro Limestones, mainly on the basis of fossils. These are, therefore, more nearly faunal zones than formations. It was on the basis of fossils that Butts (1940, p. 120, 135, 146) introduced the name "Stones River Group" into the Appalachian Valley and divided it into the (descending) Lenoir, Mosheim, and Murfreesboro Limestones. These formations were said to be Chazyan in age. It is unfortunate that after an excellent discussion of the problem by Miller and Fuller (1954, p. 62, 71), which clearly shows their disagreement with the terminology used by Butts, they continued to use the nomenclature of Butts in their Rose Hill, Va., report. It would probably be better to drop the name "Murfreesboro Limestone" in the Appalachian area and to use the name "Chazy Limestone," which by definition fits the interval described.

TIPPECANOE SEQUENCE

The term "Tippecanoe Sequence" was proposed by Sloss and others (1949, p. 115) as a rock-stratigraphic term for the section of rocks which occurs from the base of the New Albany Shale to the base of the St. Peter Sandstone. The base of the St. Peter Sandstone is at the Knox unconformity, and the base of the New Albany Shale marks the next higher major regional unconformity. The Ottawa Limestone Supergroup is the only portion of the Tippecanoe Sequence discussed in the present report. The symbol for the Tippecanoe Sequence as used on the cross section (pl. 1) is "TO" (see explanation of sequence symbols on p. 16).

OTTAWA LIMESTONE SUPERGROUP

Swann and Willman (1961, p. 478) proposed the name "Ottawa Limestone Megagroup" and defined it as the entire body of Champlainian (Middle Ordovician) carbonates lying on sandstones, sandy shales, or sandy dolomites usually referred to as the St. Peter, Glenwood, Simpson, or Aylmer, and lying beneath shales of Cincinnatian (Late Ordovician) or of late Champlainian age. These carbonate rocks in areas west of Ohio contain much dolomite as well as limestone, especially in the lower part of the unit. In Ohio and eastern Kentucky the Ottawa Limestone Supergroup includes all the formations above the Knox unconformity and below the top of the Trenton Limestone (see table 2). In accordance with the "Code of Stratigraphic Nomenclature" (American Commission on Stratigraphic Nomenclature, 1961) the term "supergroup" is used in place of "megagroup" in the present report.

CHAZY (MURFREESBORO) LIMESTONE

Name and type section. - The Murfreesboro Limestone was named by Safford and Killebrew (1900, p. 105, 125) for the town of Murfreesboro, in Rutherford County, in western Tennessee. The type locality is in the Nashville Basin. However, in the area covered in the present report the name "Chazy Limestone" seems to be more applicable to this formation (see previous discussion, p. 35).

Definition and lithologic character. - The Murfreesboro Limestone was defined as a light blue, heavy-bedded, commonly cherty limestone, of which 70 feet was exposed in the Nashville Basin of Tennessee, where it was said to be the oldest outcropping formation. It was defined as overlying the Knox Dolomite and underlying the Pierce Limestone and was named the basal formation of the Stones River Group. The definition and lithologic character at the type locality do not fit the rock unit given this name in the Appalachian Valley, where Miller and Fuller (1954, p. 63-67) recognized three distinct lithologic units which occur below the Black River Group and which rest unconformably upon the Beekmantown Dolomite Group. This is the stratigraphic position of the Chazy Limestone (table 2). The three members of this formation in the Rose Hill, Va., area can be recognized easily in well cuttings and on gamma ray logs from wells in Indiana, Ohio, Pennsylvania, New York, Ontario, and Kentucky. The members (lower dolomite; middle limestone; and upper argillaceous, cherty, members) possibly should be raised to formational status and considered as formations of the Chazy Group (see descriptions below and on p. 38).

Thickness and stratigraphic relations. - The Chazy (Murfreesboro) Limestone of Lee County, Va., ranges in thickness from 100 to 300 feet. This thickness variation is caused not only by the irregularity of the surface upon which the formation was deposited, but also by normal thinning to the northwest away from the center of the Appalachian trough. The lower dolomite member ranges from 0 to 120 feet in thickness, and appears to have been deposited in basins or low places on the old erosion surface. Where an ancient dolomite hill projected above the waters of the early Chazyan sea, the lower dolomite member was not deposited, therefore, the member is absent in the stratigraphic section. The thickness of the middle limestone member ranges from 50 to 120 feet, and of the upper cherty member from 40 to 120 feet. The upper boundary of the formation is conformable with the overlying massive birdseye limestone beds of the Lowville Limestone.

Radioactivity. - As would be expected in a transitional zone, the gamma radiation curve for the Chazy (Murfreesboro) Limestone is rather variable. However, it generally has a recognizable threefold character. The lower dolomite member and the upper cherty member have more gamma radiation than the middle limestone member. The three characteristic curves on gamma ray logs might be described (ascending) as roughly showing medium radiation, low radiation, and medium-low radiation, respectively, and these three zones can generally be detected in gamma ray logs from wells over a wide area. The upper unit is commonly much thinner but more persistent than the other two units of the Chazy (Murfreesboro) Limestone.

Lower Dolomite Member

A conglomerate composed of subangular dolomite pebbles and cobbles in a gray, argillaceous, dolomite matrix is the basal unit of the lower dolomite member of the Chazy (Murfreesboro) Limestone. The matrix of this conglomerate contains scattered, rounded, and frosted quartz grains and lenses of medium- and coarse-grained sandstone up to 5 feet in thickness in the Rose Hill, Va., district. Some pebbles of white and gray, chalcedonic chert occur in the conglomerate. Above this basal conglomerate is a finer grained conglomeratic zone composed of greenish-gray dolomite which commonly contains white, angular chert pebbles and is marked by thin interbeds of green and gray shale. The main part of the dolomite member lies above the conglomeratic zones; it is characterized by beds of gray or light brown, dense to finely crystalline, argillaceous dolomite, interbedded with thin beds of green shale and a few argillaceous limestones. The limestones increase in number toward the top of the member. In Ohio, this unit is commonly called "Glenwood Shale" and the sand lenses, "St. Peter Sandstone." In Ontario the lower dolomite member is designated as the Shadow Lake Formation.

Middle Limestone Member

The middle limestone member of the Chazy section is composed principally of gray or light brown, lithographic limestone beds, some of which contain scattered calcite crystals designated by the term "birdseyes." The thickest birdseye limestone bed is the top bed of the member (4 to 10 feet thick, known as the No. 1 birdseye zone). The base of the member is defined arbitrarily as the horizon above which the lithographic limestone is dominant over the dolomite. The lower dolomite member and the middle limestone members compose the Dot Limestone Formation of Miller and Brosgē (1954, p. 34-37).

Upper Argillaceous (Cherty) Member

The upper argillaceous (cherty) member consists of chert-bearing, gray to brown, dense limestone strata with some argillaceous limestone, dolomitic limestone, and argillaceous dolomite beds. The chert, which occurs in irregular nodules, is commonly dark gray to black, opaque, and structureless. The argillaceous limestones are locally very shaly and silty, and are separated by green shale partings. The upper argillaceous (cherty) member is the Poteet Limestone of Miller and Brosgē (1954, p. 37-39).

BLACK RIVER GROUP

The Black River Group is composed of the following formations (ascending): Lowville Limestone, Moccasin Limestone, and Eggleston Limestone (table 2). It is characterized by much dense or lithographic limestone, a considerable portion of which contains isolated calcite crystals (birdseyes). A few thin bentonite beds occur in this section, especially in the Eggleston Formation, and a few thin dolomite stringers and beds are locally present, particularly in the lower part of the group. These carbonates are generally quite pure and are easily distinguished from the crystalline Trenton Limestone above and the silty, argillaceous limestone and dolomite of the Chazy Limestone below.

Lowville Limestone

The Mosheim Limestone, Lenoir Limestone, and Lowville Limestones were described separately on the outcrop, but it is exceedingly difficult if not impossible to distinguish them from each other in well cuttings or on gamma ray logs. They all are composed largely of dense, lithographic, partly birdseye limestone and are distinguished on the outcrop principally by bedding and weathering phenomena and by fossil content. It is probably best to consider the Lenoir Limestone and Mosheim Limestone as local phases of the Lowville Limestone, and the Lowville Limestone as all the strata above the Chazy (Murfreesboro) Limestone and below the Moccasin Limestone.

Name and type section. - The Mosheim Limestone was named by E. O. Ulrich (1911, p. 413) for Mosheim Station, in Greene County, Tenn. The type section is in a railroad cut, 0. 8 mile east of the town. The Lenoir Limestone was named by Safford and Killebrew (1876, p. 108) for Lenoir Station, in Loudon County, Tenn. The name "Lowville Limestone" was substituted for Birdseye Limestone by J. M. Clarke and C. Schuchert (1899, p. 874-878). The name is taken from the town of Lowville, in Lewis County, N. Y., where excellent exposures make up the type section. Miller and Brosgē (1954, p. 39-56) have called the Mosheim the Rob Camp, the Lenoir the Martin Creek, and the Lowville the Hurricane Bridge (red bed member) and Woodway (platy member) Limestones.

Definition and lithologic character. - The separation of the Mosheim, Lenoir, and Lowville Limestones in the Appalachian Valley is based principally upon differences in bedding and fossil content. Because differences between the units to which these names have been applied cannot be recognized in subsurface work, these names are not applicable. It seems better to treat the Mosheim, Lenoir, and Lowville strata as one rock-stratigraphic unit between the Moccasin Limestone and Chazy Limestone, and to refer to it as the Lowville Limestone. It occupies the interval below the base of the lower argillaceous limestone member of the Moccasin Limestone and above the top of the upper argillaceous member of the Chazy (Murfreesboro) Limestone (table 2).

The Lowville Limestone is typically composed of light brown or light gray lithographic limestone with interbeds of birdseye limestone and finely crystalline, fossiliferous limestone. Layers of argillaceous limestone occur locally in a few zones. Some beds contain nodules of dark gray, opaque chert, and other beds are locally somewhat oolitic. There are also a few intraformational conglomerates and a few very thin bentonitic or silty shales.

Thickness and stratigraphic relations. - The Lowville Limestone is conformable with the Chazy (Murfreesboro) Limestone below and with the Moccasin Limestone above. Its thickness (including the Mosheim and Lenoir Limestones of Miller and Fuller, 1954, p. 73-102) is approximately 780 feet in the Rose Hill, Va., district, but the formation thins northward and is about 150 feet thick in the No. 1 Hopkins well (Fayette County, Ohio).

Radioactivity. - The Lowville Limestone generally has very low gamma radiation, except for a few thin, argillaceous zones which cause breaks toward medium-low on the gamma ray log.

Moccasin Limestone

Name and type locality. - The Moccasin Limestone was named by Campbell (1894) for the red color of the formation after it has been weathered. The type locality is at Gate City, in Scott County, Va., 40 miles east of the Rose Hill, Va., district.

Definition and lithologic character. - The upper and lower boundaries of the Moccasin Limestone were not well defined at the type locality, and Butts (1940, p. 179) considered it to be a facies of the Lowville Limestone. Miller and Fuller (1954, p. 103) rightly considered it to be a separate formation and described a lower, argillaceous member which they did not name, and an upper limestone member which they named the Hardy Creek Member. Miller and Brosgē (1954, p. 56-58) refer to the lower member as the Ben Hur Limestone and raise the Hardy Creek Limestone member to formational status. In the subsurface the lower boundary of the Moccasin Limestone is placed at the base of a thin shaly or silty zone which normally can be recognized in the samples and which can be observed on gamma ray logs. The upper boundary is placed at the base of a silty, bentonitic zone which forms the lower member of the Eggleston Limestone.

On the outcrop in the Rose Hill, Va., district, the lower member of the Moccasin Limestone is a light brown or gray, argillaceous limestone with abundant mud cracks and some intraformational conglomerates. Some green or gray, silty pyritic shale partings are commonly present, and some of the argillaceous limestone beds are fossiliferous. No birdseye limestone or chert was found in the lower member on the outcrop. The Hardy Creek Member consists of beds of light brown or light gray, lithographic and finely crystalline, pure or siliceous limestone which contain scattered rhombs of clear calcite. A few beds contain nodules of zoned, chalcedonic chert, and some zones of birdseye limestone are present.

Thickness and stratigraphic relations. - On the outcrop in the Rose Hill, Va., district the Moccasin Limestone is about 280 feet thick. Like most of the other formations, it thins northward and is only 128 feet thick in the No. 1 Hopkins well (Fayette County, Ohio). It is conformable with the strata above and below.

Radioactivity. - The Moccasin Limestone has low gamma radiation except for a thin unit (argillaceous member) at the base, which has a medium-low reading on the gamma ray log. In eastern Kentucky, an argillaceous zone occurs a short distance below the top of the Moccasin Limestone, as picked from the gamma ray logs in the cross section (pl. 1). This may actually be the lower argillaceous member of the Eggleston Limestone, but this zone disappears northward before the No. 1 Stamper well (Carter County, Ky.) is reached.

Eggleston Limestone

Name and type section. - The Eggleston Limestone was named by A. A. L. Mathews (1934, p. 11) for the town of Eggleston, in Giles County, Va. The type section is 1 mile north of Narrows, Va.

Definition and lithologic character. - The Eggleston Limestone was defined by Mathews (1934) as consisting of thin- to thick-bedded, fine-grained, argillaceous, dark buff to light brown limestones which contain many thin beds and a few thick beds of bentonite, and which overlie the Moccasin Limestone and underlie the Trenton Limestone (table 2). It fractures into peculiar, cuneiform blocks, probably due to the bentonitic material included in the limestone.

Miller and Fuller (1954, p. 110) divided the Eggleston Limestone into three members in the Rose Hill, Va., district. The lower member (36 feet thick) was described as a gray, calcareous mudstone with no bedding and with small birdseyes; the middle member (57 feet thick) as gray and brown, thin-bedded, crystalline, fossiliferous or lithographic birdseye limestone with thin shale partings; and the upper member (55 feet thick) as a combination of the lower and middle members, with the addition of two relatively thick bentonite beds. The lower bed, with a thickness of 2 feet 2 inches, is just above the base of the upper member in the section at Hagan, Va., and is underlain by a 2-inch bed of gray chert. The upper bed occurs 9 feet below the top of the formation in the Hagan section, where it has a thickness of 3 feet 4 inches. This bentonite bed is underlain by a 2-inch bed of brownish-black chert.

Thickness and stratigraphic relations. - The Eggleston Limestone in the Rose Hill, Va., district is about 150 feet thick, the same thickness as at the type locality, 1 mile north of Narrows, Va. It thins northward until it is about 66 feet thick in the No. 1 Hopkins well (Fayette County, Ohio). It appears to be conformable with the Moccasin Limestone below and the Trenton Limestone above. In the cross section (pl. 1), the base of the Eggleston Limestone is picked at the base of the lowest bentonite bed; some beds assigned to the Moccasin Limestone may be part of the Eggleston Limestone.

Radioactivity. - On a gamma ray log, the bentonite beds of the Eggleston Limestone are easily located because they create sharp breaks from low gamma radiation readings to medium or medium-high readings. In general, the Eggleston has a slightly higher gamma radiation than the Moccasin Limestone, but locally the Eggleston and Moccasin Limestones may have about the same radioactivity, both having slightly higher radiation than the Lowville Limestone below.

TRENTON LIMESTONE

Name and type section. - The origin of the name of the Trenton Limestone and the type section for the formation may be found in the discussion of Ordovician nomenclature on page 35.

Definition and lithologic character. - The original definition of the Trenton Limestone has been given previously. In the Rose Hill, Va., district the Trenton Limestone includes all the strata which occur below the Reedsville Shale and above the Eggleston Limestone. The top of the formation is placed at the horizon above which the shales of the Cincinnati Group predominate over the limestone beds, and the base is placed at the top of the dense, lithographic limestone beds of the Eggleston Limestone, which are generally associated with bentonite.

The Trenton Limestone is composed of gray or light brown, medium to coarsely crystalline, fossiliferous limestone. The middle part is somewhat less crystalline, and the lower and middle parts characteristically contain lenses of gray and white, granular chert. Partings of gray shale are abundant. Some shale beds as much as 2 feet in thickness are present.

Thickness and stratigraphic relations. - The Trenton Limestone is conformable with the beds above and below. Its thickness decreases northward from about 550 feet in Lee County, Va., to only 62 feet in Fayette County, Ohio.

Radioactivity. - Depending upon the percentage of shale present, the Trenton Limestone generally has slightly higher radioactivity than the underlying Eggleston Limestone, especially toward the top of the formation. However, this is not true in areas where the Eggleston Limestone is extremely bentonitic. The general intensity of gamma radiation for the Trenton Limestone may be described as low to medium-low.

CAMBRIAN - ORDOVICIAN BOUNDARY

In their report on the Rose Hill district of Lee County, Va., Miller and Fuller (1954) discuss the paleontology, age, and correlation of each formation which crops out in the area. In their generalized columnar section (1954, opp. p. 24) they show most of the Rome Formation to be of Early Cambrian age. The section which consists of the upper part of the Rome Formation and most of the Conasauga Shale is assigned a Middle Cambrian age. The upper part of the Conasauga Shale, the Maynardville Limestone, and the Copper Ridge Dolomite are shown to be Late Cambrian in age. Early Ordovician age is assigned to the Chepultepec Dolomite, Longview Dolomite, Kingsport Dolomite, Mascot Dolomite, Murfreesboro (Chazy) Limestone, Mosheim Limestone, and Lenoir Limestone. Middle Ordovician age is assigned to the Lowville Limetone, Moccasin Limestone, Eggleston Limestone, and Trenton Limestone (see table 2). By this interpretation a major regional unconformity (the Knox unconformity) lies not at the top of the Lower Ordovician but down in the Lower Ordovician. This means that a considerable thickness of rocks was deposited in Early Ordovician time, and then after an apparently tremendous interval of time, probably millions of years, during which most of the North American continent emerged from the sea and was subjected to prolonged erosion, the sea returned and more rocks were laid down in Ordovician time. Does this seem logical?

It is a striking circumstance that below the Knox unconformity the Knox Dolomite Supergroup is composed predominantly of dolomite, but above this unconformity the Ottawa Limestone Supergroup is predominantly limestone. The Knox unconformity marks the end of an extensive period of time during which predominantly dolomitic rocks were formed; when deposition finally reoccurred in the area, mostly limestone was deposited. This coincidence takes on added importance when it is noted that the top of the Knox Dolomite Supergroup is marked by a major erosional unconformity which exhibits regional tilting, truncation, and extreme relief. Here is a major lithologic change at an unconformity which represents an extremely long interval of time consumed in emergence, regional tilting, possible folding, erosion, and resubmergence on a wide scale. Is not the Knox unconformity, which divides rocks characterized by great faunal change (according to Schuchert and other geologists) as well as by distinct sedimentary differences, a better place to draw a systemic boundary than an arbitrary horizon which most generally cannot be located either on the outcrop or in the subsurface?

Much can be found in geologic literature to support placing the boundary between the Cambrian and the Ordovician Systems at the top of the Sauk Sequence. Schuchert (1924, p. 235-237) noticed the sedimentary as well as the faunal change when he wrote:

> "In all the known areas of North America west of Appalachis and Acadis, there is a marked change in sedimentation between the Lower Champlainian [Beekmantown] and the succeeding strata of Middle Champlainian time. The older formations are dolomites, while the younger ones are thin-bedded limestones. Furthermore, the Middle Champlainian [Middle Ordovician] seas transgressed more widely and their faunas were totally different from those of the earlier epoch. This change is a striking illustration of the fact that the apparently insignificant break--the contact is every where a disconformable one--between the Lower and Middle Champlainian is of much time import in that greatly altered faunas have undergone a long evolutional change. In other words, the break in deposition represents a loss of record long enough for the earlier faunas to have evolved into those so characteristic of Middle Champlainian time. This change is seen best in a completely different series of graptolites; a far greater prevalence of brachiopods, molluscs, and ostracods; the first crinids and fishes; and for the first time an abundance of bryozoans."

Can such evidence be marshalled to support drawing the top of the Cambrian at the base of the Beekmantown Group, where in most areas there is no great faunal change or even a stratigraphic break? Subsequent work has shown that the stratigraphic break referred to by Schuchert is more significant than he thought. When the Beekmantown Group was placed in the Ordovician System the recent extensive subsurface work in eastern and central United States had not been done and the stratigraphic importance of the Knox unconformity had not been recognized.

Another textbook at hand gives a similar picture (Dunbar, 1949, p. 165), as follows:

> "Nowhere in North America is there any evidence of transition strata from the Canadian [Beekmantown] into the Champlainian [Ordovician]. There is a complete break here, which means that the whole continent was dry land for a long time. How long can not be told, but the marked difference between the faunas of the Canadian [Beekmantown] and the Champlainian [Ordovician] indicates a considerable lapse of time. It is for this reason that some stratigraphers are inclined to regard the Canadian as a distinct period." [Ulrich and others].

Subsequently, Dunbar wrote an excellent discussion on the boundaries of the Ordovician System (Twenhofel, 1954, p. 251-253) in which he pointed out that at the type locality in Wales,

> "there are places . . . where the Arenig [Chazy] rests unconformably on the Tremadocian [Beekmantown] and oversteps westward onto various older formations, even to the Precambrian. This is the obvious and natural place to draw the Cambro-Ordovician boundary in this area, and this is the reason it was selected by Lapworth."

Lapworth's original definition of the Ordovician System (discussed on p. 16 of the present report) is discussed by Wilmarth (1925, p. 83-84), who stated:

> "This original definition of Ordovician includes in the Cambrian the Tremadoc slate, which according to Ulrich's 1914 classification is of Beekmantown age."

Walcott's 1914 classification also included Canadian and Ozarkian rocks in the Cambrian (1914, p. 354) and most British geologists have steadfastly included the Tremadocian in the Cambrian System.

Some recent workers concerned with the subsurface stratigraphy of Cambrian and Ordovician rocks have independently come to the same conclusions as has the author concerning the boundary between the two systems. Louise Freeman (1953, p. 13-14) considers the entire Knox stratigraphic sequence to be Cambrian in age and places the Cambrian-Ordovician contact at the post-Knox, post-Ellenburger, post-Arbuckle unconformity. Patterson (1961, p. 1364-1365) gives an excellent faunal and sedimentary analysis of the problem and presents evidence as follows:

> "Under such faunal circumstances it is impossible for any part of the Beekmantown of Glenogle to be anything but Cambrian. Furthermore, the local stratigraphy at Glenogle suggests that the Glenogle slates (post-Tremadoc) rest unconformably on the Beekmantown limestones."

Figure 4 diagrammatically shows Patterson's comparison of the Cambrian-Ordovician boundary in Wales and in Canada.

There seems to be, therefore, a preponderance of evidence in North America which indicates that the Beekmantown Group of rocks stratigraphically belongs in the Cambrian System. If this is so, it seems that American geologists would do well to join many of their British cousins in using this classification, thus eliminating the cumbersome term "Cambro-Ordovician" and the need to adhere to an indefinite, arbitrary systemic boundary.

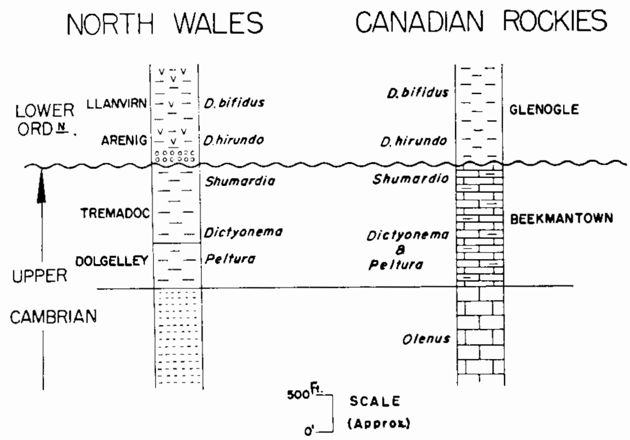

Figure 4. - Comparison of Cambrian-Ordovician boundary in North Wales and in the Canadian Rockies (after Patterson, 1961, p. 1365).

CONCLUSIONS

The following conclusions have resulted from the present subsurface study:

1. The sub-Trenton formations which crop out in Lee County, Va., (and other parts of the Appalachian Valley) continue northward in the subsurface to Fayette County, Ohio, and beyond.
2. The formations thin considerably northward but maintain their lithologic character to a high degree.
3. The pre-Tippecanoe beds are progressively truncated northward below the Knox unconformity.
4. The sub-Trenton formations can be recognized in well cuttings and on radioactivity and electrical logs.
5. The unconformity at the top of the Knox Dolomite Supergroup is the result of a major erosional period, spanning a long unit of geologic time, and represents the boundary between quite different depositional environments. The strata above and below this unconformity are totally unlike, indicating that the unconformity is worthy of being the boundary between major rock-stratigraphic units. It seems logical to use this unconformity as the Cambrian-Ordovician boundary.
6. The Appalachian Valley terminology fits the sub-Trenton rock-stratigraphic units of southern Ohio, which appear to be lithologically more similar to Appalachian Valley formations than to the Upper Mississippi Valley formations. Suggested nomenclature for sub-Trenton rocks in southern Ohio is shown in table 3.

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This study was made possible by the combined courtesy of Mr. Mike Henderson of the Appalachian Log Service, Pittsburgh, Pa., and of Mr. Pat Sasser of the Geological Sample Log Service of Farmington, N. Mex., who furnished logs and sample descriptions for the cross section (pl. 1). Suggestions from Mr. Ralph J. Bernhagen, Dr. Walter Sweet, Dr. George Cohee, and Mr. Jesse Upperco are deeply appreciated, and thanks are due to Mr. John Ulteig, who lettered the figures in this report.

TABLE 3
COMPARISON OF RECENT SUB-TRENTON TERMINOLOGY USED IN OHIO

DRILLER'S TERMS	PRESENT NOMENCLATURE GROUP	PRESENT NOMENCLATURE FORMATION	SUGGESTED NOMENCLATURE GROUP	SUGGESTED NOMENCLATURE FORMATION
TRENTON		TRENTON LS.		TRENTON LS.
	BLACK RIVER		BLACK RIVER	EGGLESTON LS.
				MOCCASIN LS.
				LOWVILLE LS.
				CHAZY LS. Upper
				CHAZY LS. Middle
		GLENWOOD FM.		CHAZY LS. Lower
ST. PETER SS.		ST. PETER SS.		ST. PETER SS.
			KNOX UNCONFORMITY	
LOWER MAGNESIAN OR CALCIFEROUS	PRAIRIE DU CHIEN	SHAKOPEE DOL.	BEEKMAN-TOWN	LAMBS CHAPEL DOL.[1]
		NEW RICHMOND SS.		
		ONEOTA DOL.		CHEPULTEPEC DOL.
		TREMPEALEAU DOL.	LEE VALLEY	COPPER RIDGE DOL.
		FRANCONIA - DRESBACH		MAYNARDVILLE DOL.
			KNOX CLASTIC	CONASAUGA SH.
		EAU CLAIRE FM.		ROME FM.
				SHADY DOL.
SAND		MT. SIMON SS.		MT. SIMON SS.
			BASEMENT UNCONFORMITY	
GRANITE	PRECAMBRIAN		BASEMENT COMPLEX	

1. New name replacing "Longview-Kingsport-Mascot Dolomite, undifferentiated."

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APPENDIX--ABBREVIATIONS USED ON CROSS SECTION (PLATE 1)[1]

A

ang - angular
arg - argillaceous
arkic - arkosic

B

bent - bentonite(ic)
bio - biotite(ic)
blk - black(ish)
brach - brachiopod
brec - breccia(ated)
brn - brown(ish)

C

c - coarse(ly)
calc - calcareous
calci - calcite
carb - carbonaceous
chlor - chlorite
cht - chert
chty - cherty
clr - clear
crin - crinoid(al)

D

dk - dark(er)
dns - dense(er)
dol - dolomite
dolic - dolomitic

E

E - east
elev - elevation

F

f - fine
feld - feldspar
fm - formation
foss - fossil(iferous)
fr - fair(ly)
frac - fracture(ed)
frag - fragment(al)

G

glauc - glauconite(ic)
gr - gray(ish)
gran - granule(ar)
grn - green(ish)

H

horn - hornblende

I

int - inter(prefix)
intr - intrusion(ive)

K

KB - kelly bushing

L

lith - lithographic
ls - limestone
lt - light(er)

M

m - medium
memb - member
meta - metamorphic
mic - micaceous, mica
mot - mottled

N

nod - nodular

O

ool - oolite(ic)
op - opaque
or - orange

P

pel - pellet(al)
pk - pink

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1. Plural formed by adding "s" to abbreviations given.

P (con.)

plag - plagioclase
por - porous, porosity
ptly - partly
ptg - parting
pur - purple
pyr - pyrite(ic)

Q

qtz - quartz

R

r - round
rd - rounded
RFQ - rounded frosted quartz grains

S

s or ss - sandstone
sbr - subround(ed)
scat - scattered
sdy - sandy
sed - sediment(ary)
sft - soft
sh - shale
sli - slight
slst - siltstone
srt - sorted
strg - stringer
strk - streak(ed
suc - sucrose(ic)

T

tr - trace
trip - tripoli(tic)

U

U - upper or unknown

V

v - very, volume(book)
vert - vertical
vug - vug(gy) (ular)

W

W - west
w/ - with
wh - white
wxy - waxy

X

xln - crystalline(ity)

INDEX

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DETAILED CROSS SECTION NO. 1

A CROSS SECTION OF SUB-TRENTON ROCKS FROM LEE COUNTY, VA., TO FAYETTE COUNTY, OHIO

DATUM, TOP OF TRENTON LIMESTONE

WARREN L. CALVERT, GEOLOGIST
MAY 1962

NOTE

The formation names on this cross section carry no age connotations whatsoever except on the outcrop section. Abbreviations explained in appendix.

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PLATE I