STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF GEOLOGY

BULLETIN 58, PART II

Geologic Map of East Tennessee
With Explanatory Text

Compiled by
JOHN RODGERS
Geologist, U. S. Geological Survey
with the Collaboration of Geologists of the
Tennessee Division of Geology
Tennessee Valley Authority
and United States Geological Survey

Prepared under the Joint Auspices of the
United States Geological Survey and the
Tennessee Division of Geology

Nashville, Tennessee
1953
Reprinted 1993

STATE OF TENNESSEE
FRANK G. CLEMENT, *Governor*

DEPARTMENT OF CONSERVATION
Jim McCORD, *Commissioner*

DIVISION OF GEOLOGY
W. D. HARDEMAN, *State Geologist*

1993

STATE OF TENNESSEE
Ned McWherter
Governor

DEPARTMENT OF ENVIRONMENT
AND CONSERVATION
J. W. Luna
Commissioner

DIVISION OF GEOLOGY
Edward T. Luther
State Geologist

CONTENTS

ILLUSTRATIONS

TABLES

Geologic Map of East Tennessee
With Explanatory Text

ABSTRACT

A new geologic map of the Unaka Mountains and the Valley of East Tennessee, compiled from all available sources, is presented herewith. The accompanying text describes the rock units shown on the map.

The oldest rocks present form a pre-Cambrian crystalline complex, part of the southwest end of the Blue Ridge welt of such rocks. These igneous and metamorphic rocks were already crystalline before the end of pre-Cambrian time, but they were again deformed, with the production of thrust faults and accompanying mylonite zones, at the time of deformation of the overlying Paleozoic rocks. Above this basement complex lies the immensely thick Ocoee series (perhaps 5 miles thick), composed of detrital rocks of graywacke type; these were deposited after the formation of the crystalline complex and may be of late pre-Cambrian age or possibly younger. Overlying the Ocoee series is a sequence of somewhat better sorted detrital rocks about a mile thick, called the Chilhowee group and presumed to be of early Cambrian age.

Next are Cambrian and Lower Ordovician rocks, more than a mile thick and dominantly carbonate, though including some detrital material of northwestern provenance. These rocks comprise the Shady dolomite, Rome formation, Conasauga group, and Knox group. Above a disconformity between Lower and Middle Ordovician rocks limestone recurs; the Chickamauga limestone, approximately 2,000 feet thick, represents the Middle Ordovician and a part of the Upper Ordovician series on the northwest side of the Valley of East Tennessee, but it is replaced on the southeast by a great detrital wedge a mile or more thick. The youngest Ordovician rocks form a similar detrital wedge (about 1,000 feet thick in East Tennessee), which extends entirely across the Valley. The two detrital wedges appear to record two pulses of the Taconian orogeny of late Ordovician time.

The Silurian rocks are mostly sandstone and shale and are less than 1,000 feet thick; in this sequence the Clinch sandstone lies below and to the southeast and grades up and northwest into the

shaly Rockwood formation, recording the waning phase of the Taconian orogeny. In Hancock County and vicinity, the upper Silurian and Lower Devonian are represented by a thin formation of carbonate rock, the Hancock limestone. Above a second disconformity lies black shale of Devonian and basal Mississippian age, generally 100 feet thick or less (Chattanooga shale), but thickening northeastward to 900 feet and there including gray shale and sandstone, the feather edge of thick deposits in the states to the northeast, and a record of the Acadian orogeny. Lower Mississippian detrital rocks are followed by limestone, and these again by highest Mississippian detrital rocks, but each subdivision of the Mississippian is more calcareous to the northwest, more coarsely detrital to the southeast. The combined thickness of the Mississippian subdivisions (Grainger formation and Fort Payne chert, Newman limestone, Pennington formation) ranges from about 1,000 feet on the west and northwest to about a mile on the east and southeast. The Pennsylvanian rocks, the youngest Paleozoic rocks in the area, are preserved at only a few places within the valley, and they are not considered at length in this report.

After the deposition of the Pennsylvanian sediments, the entire sequence of sedimentary rocks, 9 or 10 miles thick, was deformed, and many folds and thrust faults were produced. Several small igneous intrusions appear to have accompanied the deformation. The resulting structure is shown by the map and by 10 geological cross sections (pl. 15). Since the deformation, erosion seems to have been dominant in East Tennessee; parts of the Cenozoic history are recorded, however, by a mantle of residual and alluvial material that largely blankets the Paleozoic bedrock formations.

A final section of the text discusses the source material for the map and points out 58 areas still requiring detailed geologic work.

INTRODUCTION

Area covered by present map. - The (political) subdivision East Tennessee includes all that part of Tennessee east of the western boundaries of Scott, Marion, and-intervening counties; it lies within three of the eight main geographic divisions of the State. These are (1) the Unaka Chain, as defined by Safford (1869, p. 21 ff.), including all or part of the counties along the North Carolina line; (2) the Cumberland Plateau, centered in the tier of counties from Scott to Marion but extending into the tiers next east and west; and (3) the Valley of East Tennessee, including all the intervening country. The present geologic map, however, covers only the Unaka Mountains and the Valley, for study of the Pennsylvanian rocks of the Cumberland Plateau has not yet progressed to the point where a new general map can be prepared, and likewise not enough is known of the areal geology of the inliers of pre-Pennsylvanian rocks within the Plateau-Sequatchie Valley and related coves from Marion to Cumberland Counties, and Elk Valley in northern Campbell County-to permit the addition of those areas to the present map. The western boundary of the geologic map therefore follows the eastern escarpment of the Cumberland Plateau (called Cumberland Mountain, Walden Ridge, or Cumberland Escarpment on the map), which sweeps in a great curve, broken only by the offset southwest of Jacksboro, Campbell County, from Cumberland Gap to Chattanooga. The other boundaries follow the State line except where part of North Carolina has been included in order to complete the mapping of the sedimentary rocks above the crystalline complex. The map itself is published in 14 plates, and the index map, figure 1, shows the names and relative positions of these plates. Abbreviations of those names are used in the text to locate places mentioned.

Compilation of the map. - Until the present map was compiled, the only existing general geologic map of East Tennessee had been the one based on the geologic folios, published and unpublished, of the U.S. Geological Survey. The folio mapping, done by Arthur Keith, C. W. Hayes, and H. R. Campbell between 1890 and 1907, was outstanding for its time, especially in view of the inadequate topographic base maps on which it was carried out. During the last 20 years, a large amount of new geologic mapping has been done in East Tennessee, stimulated and immeasurably aided by

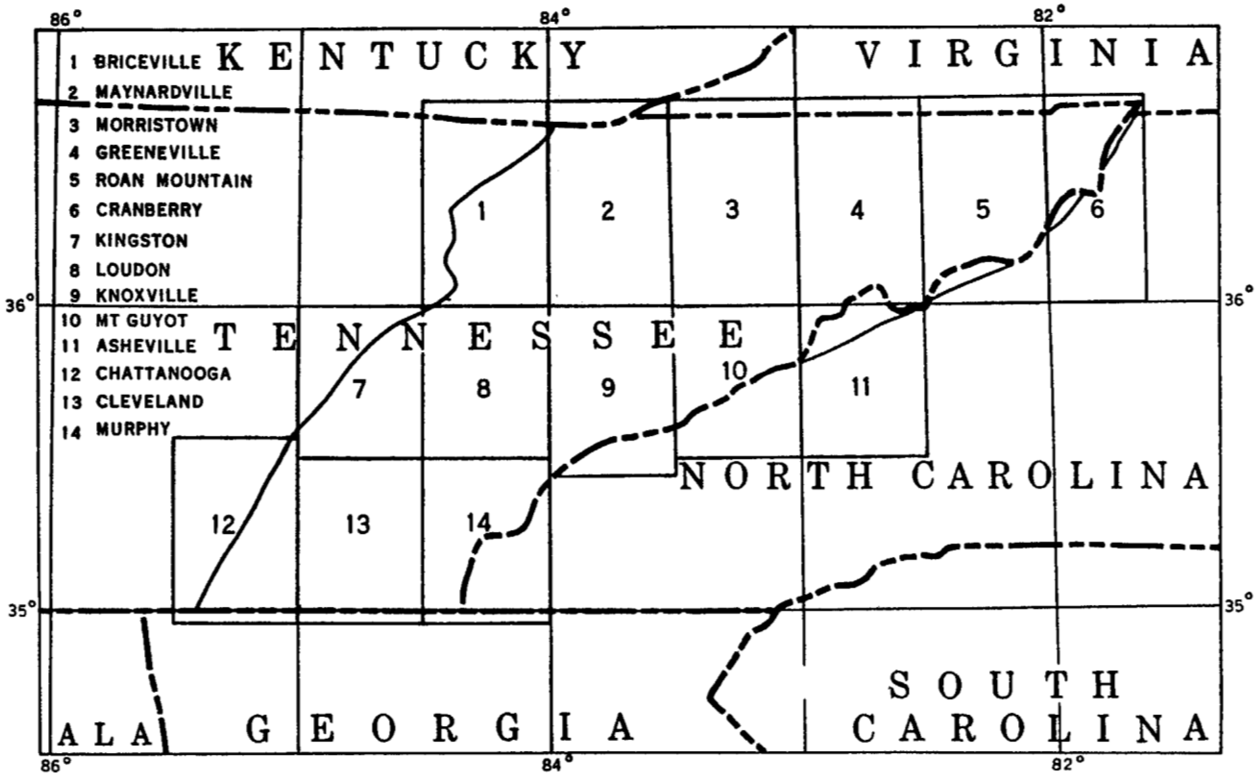


FIGURE 1. Index map to plates of Geologic map of East Eennessee.

the appearance of the excellent new topographic maps published by the Tennessee Valley Authority and the U. S. Geological Survey, which now cover all but a small fraction of the area. The accumulation of these new geologic data and the demand for a general geologic map of East Tennessee based on them are the justification for the present compilation.

The new field work, however, was done by many individuals working on separate assignments for several organizations, and it differs considerably both in scope and in detail. Moreover, it by no means covers all of East Tennessee but consists rather of a small spot here and a larger patch there, tied together, if at all, by general reconnaissance never formally recorded. Some of the new information is published, but much of it is not, and without the cordial cooperation of the several agencies no compilation could have been made. Thanks are especially due the Geologic Branch of the Tennessee Valley Authority and Berlen C. Moneymaker, chief of the branch, for making available a wealth of unpublished information on dam sites and reservoir basins from Bristol to Chattanooga. Much material was gleaned from the files of the Tennessee Division of Geology and of the U. S. Geological Survey, and from personal notes by members of both organizations.

Even so, there remained large gaps between available maps, which had to be filled if the new map was to have value. In filling them, the compiler has drawn on certain kinds of nongeologic evidence as well as on the older maps of Keith and his colleagues. More than half of East Tennessee is covered by recent county soil maps of the U. S. Soil Survey, Department of Agriculture, and in nonglaciated country such as this soil maps offer invaluable clues to the underlying geology. Officials of the Soil Survey kindly made available unpublished soil maps of many counties. The new topographic maps of the area themselves are so expressive of the geology that considerable confidence can be placed in them, at least for the extension of formation contacts along strike from known points. Aerial photographs likewise furnish much information on strike and continuity of formational units.

Finally, many problems that appeared in extrapolating geology from known to unknown have been resolved by field visits. It was not possible, of course, to map with care even a few of the critical localities, and a detailed study of all would be the work of several lifetimes. But what could be learned by rapid road traverses, supplemented by a few on foot, was ascertained, and all the available data, meager though they often were, being considered, one of the several possible interpretations was adopted. The compiler has deliberately made a guess for every part of the map between the crystalline complex and the Pennsylvanian rocks, and he has tried to proceed so that the guesses were consistent, not only with all the facts known to him, but with each other.

The chief danger in such a procedure is, of course, that the resulting map will appear much more accurate than it really is. No one is so well aware of its weak points and imperfections as its compiler, and he wishes to issue a general warning to all not to accept it without caution. This map is not a final summing up of the areal geology of East Tennessee, but a progress report, and in order to indicate the relative reliability of the various parts of the map, a detailed discussion, with index maps, of the source material and of the areas where more work is most needed has been appended to this text. There are enough such areas to keep many geologists busy for a long, time. It is hoped that this enumeration of them will stimulate field workers to tackle them and to uncover and correct the many errors that must be hidden in the present map. The compiler will gladly welcome all such corrections, but would suggest that anyone finding these errors not rest content with that but go on to map the debated areas and establish securely the alternative interpretations, and then publish his results for the benefit of all his colleagues.

Map units. - A geologic map is no better than the units used, and much of the value of a new compilation in East Tennessee results from the finer discrimination of units that recent work has made possible. In view of the spottiness and lack of uniformity of the source material, however, it has not been possible to use the same map units consistently throughout the map. Instead it seemed desirable to devise a scheme that would permit showing detail where detail exists but only generalized units where information is wanting, and the following scheme has been adopted. The entire sedimentary column is divided into major units whose boundaries can be drawn with reasonable accuracy everywhere. These units are not necessarily comparable either in thickness or in the time required for their deposition; they range from barely 100 feet to more than 3 miles in thickness, and some cross system boundaries whereas others include only a fraction of a series. Each of these units is shown on the map by a distinctive color pattern. Where information permits, however, these units are further subdivided, the subdivisions being indicated not by patterns but solely by contact lines and letter symbols. The sequence of minor units differs from one part of the map to another, depending either on change in the units present or on variation in the detail of existing maps. Thus the Knox group, half a mile or more thick and including much of the Upper Cambrian and all of the Lower Ordovician series, is one of the major units; on some parts of the map it is undivided, on others a sequence of two, three, four or five units has been recognized within it. In all, 11 different letter symbols differentiate these units (see table 5, p. 56).

It should be remembered,. however, that the number of subordinate units recognized in a given area is not necessarily a clue to the detail of the maps available for that area. The intrinsic divisibility of the Knox group, for example, varies greatly across the Valley, and, moreover, the compiler has in many places extended such subdivisions well beyond the limits of available detailed maps by attention to topography or to soils or by the help of occasional road traverses. For example, the mapping of the subdivisions of the Knox group on the Mosheim or Big Ridge dome in Greene County (Greene and Morr.) is based on detailed field work, but the mapping on the adjacent dome south of Midway is based only on meager data from a couple of road traverses and on the similarity of the topography to that of the Mosheim dome.

To give the map units meaning, more description, is needed than can be presented in a conventional map explanation, especially because some of the units recognized differ from those previously used on maps of East Tennessee and because in certain parts of the column the whole classification is currently under vigorous debate. A fairly comprehensive text has therefore been prepared, and it presents, for each major map unit, first, a statement of the sources of the names used and of the relation of the present usage to previous usage of those names or of other names for the same units, with a discussion of the contacts where pertinent; second, a general description of the rocks, emphasizing especially stratigraphic sequence within the major and minor units; third, a brief discussion of the soil, the outcrops, and the topographic expression at the surface over the rocks, and of outstanding exposures and sections; and last, a very summary mention of present knowledge of the geologic age. Here and there the compiler has expanded a little on the history of our knowledge, has added general comments on paleogeography and geologic history, or has pointed out stratigraphic problems awaiting study, wherever such material seemed pertinent. For some major units the text is relatively short, but for some it is long and complex, reflecting in general thick and complex units such as the Ocoee series and the Knox group. The reasons for the great length and intricacy of the chapter on the lower and middle parts of the Chickamauga limestone and equivalent rocks are given near the beginning of that chapter. Lastly, the compiler must warn again that the text is not a final summing up of the stratigraphy of East Tennessee but a progress report; for this reason, indeed, he has chosen to adapt already existing names to the units mapped rather than to introduce new ones, for the present publication is based on field work that is not sufficiently comprehensive to warrant a thorough-going revision of nomenclature.

Acknowledgments. - Even in so-called independent field work, every geologist depends on the instruction, assistance, and previous work of his colleagues; how much more in a compilation such as this one! Where possible, the compiler's indebtedness for particular items is noted in the section on source materials, but many have contributed as much or more by general criticism and assistance, not only while the compilation was in progress and while the manuscript was undergoing review but also at earlier times, when the compiler was laying the ground work of his knowledge of East Tennessee geology.

The present map was compiled in 1948, 1949, and 1950 as part of the ground-water investigations of the U. S. Geological Survey in East Tennessee, in cooperation with the Tennessee Division of Geology. Previously the compiler had taken part in several other geological investigations of the U. S. Geological Survey in East Tennessee, many of them also in cooperation with the Tennessee Division of Geology.

First thanks should be given to the four men who in turn have been State Geologist of Tennessee during the compiler's decade of geologic work in the State. Walter F. Pond followed the compiler's work with helpful interest and encouragement, H. B. Burwell commissioned the present compilation and actively supported it, Herman W. Ferguson saw the map to completion, and William D. Hardeman made the final arrangements for publication of the text. The compiler is particularly fortunate to have been often associated with Mr. Ferguson in field work and field excursions in East Tennessee, especially in the Unaka Mountains, and to have had his valuable assistance and advice on both geological and technical problems from the beginning of the compilation until publication.

The geologists of the Tennessee Valley Authority, intimately familiar with the geology of many parts of East Tennessee, have been most helpful. Berlen C. Moneymaker, chief of the Geologic

Branch, and his staff, especially Leland F. Grant and John M. Kellberg, have often discussed East Tennessee geology with the compiler and have made freely available all the material accumulated during many years' study of dam sites and reservoir basins. They have also kindly reviewed the manuscript. Benjamin Gildersleeve and the late H. S. Rankin of the Regional Minerals Section have also been most cordial.

The geologists of the several zinc companies who have interests in East Tennessee have repeatedly tendered courtesies to the compiler and his colleagues during their field work. Charles R. L. Oder, chief geologist of the American Zinc Co. of Tennessee, was especially generous of his time during the early years of the compiler's work in East Tennessee, and, out of his detailed acquaintance with the Knox group, greatly aided the compiler at the time when the latter was beginning his study of the stratigraphy of the rocks of the Valley. E. P. Kaiser, Howard W. Miller, and Johnson Crawford should also be thanked for many friendly discussions of the stratigraphy and structure of the Knox group.

To the late George M. Hall and R. E. Lee Collins, and to Paris B. Stockdale, H. Clyde Amick, Caspar Rappenecker, and Harry J. Klepser of the staff of the Department of Geology and Geography of the University of Tennessee, the compiler is grateful for making available the facilities of the University, and to them and other members of that staff and to students in the department he is grateful for many stimulating discussions on all aspects of East Tennessee geology. To Mr. Stockdale, in particular, the compiler is thankful for guiding him to many points in Rhea and Hamilton Counties. The compiler's own colleagues at Yale University and several graduate students there who have worked in and near East Tennessee have likewise contributed much in thoughtful discussion of the geological problems of the area and in critical comments on the manuscript.

To his colleagues on the U. S. Geological Survey the compiler is very deeply indebted. Unpublished maps of many areas and unpublished text on several parts of the section were his for the asking and have been incorporated into the present map and text. George D. De Buchananne, geologist in charge of the ground-water work in East Tennessee, and the members of his staff, especially Raymond M. Richardson, Stuart W. Maher, and George D. Swingle, have been very helpful on both geological and technical problems of map and text, particularly in the preparation of the base map, which has been largely in their hands. Victor T. Stringfield, Elliott M. Cushing, and Charles B. Hunt, supervisors of the project, have steadily supported it, and the compiler thanks them for their interest and encouragement. The late Josiah Bridge, who first interested the compiler in the southern Appalachians, has again and again given of his time and wide knowledge of Appalachian stratigraphy, from the time when the compiler first began field work in Clinch Valley and Copper Ridge to the time when the present map and text required critical review. In particular, Mr. Bridge made available the manuscript of his report on the Mascot-.Jefferson City zinc dis- trict. Robert A. Laurence, first as geologist in the Geologic Branch of the Tennessee Valley Authority, then as Regional Geologist for the U. S. Geological Survey, has consulted with the compiler many times both in the field and in the office, and during the actual compilation provided office space and facilities and all manner of day-by-day interest, help, and encouragement. He was also the first critic of most of the manuscript. The members of the Survey zinc party during, the Second World War, Charles H. Behre, Jr., John C. Dunlap, Deane F. Kent, Arnold L. Brokaw, and others, have many times helped the compiler during his field work and report writing, and he has leaned heavily on the unpublished results of their field work. The members of the Great Smoky Mountains party, especially Jarvis B. Hadley and Robert B. Neuman, have likewise been stimulating companions in field and office, have made available all the results of their own work, and have read and criticized the manuscript. Finally, the compiler owes his greatest debt to Philip B. King, with whom he has had the privilege of 10 years' association, whose wide knowledge of the Unaka Mountains and of the Appalachians generally was always at the compiler's command, and whose friendly and critical interest in all the compiler's geological work, and especially in the present compilation, has been a continual and valued stimulus to their improvement and completion.

PHYSICAL GEOGRAPHY

The physical geography of Tennessee has been described once for all with clarity and elegance by James M. Safford in his Geology of Tennessee (1869; Part 1, Physical Geography, was first published in 1861). The present discussion consists in large part of direct quotations from Safford (here cited by page only), to which is added a brief discussion of the vexing problem of erosion surfaces as it concerns East Tennessee.

Regional setting. -"Upon examining any good map of the country between the Gulf of Mexico and the Hudson River, we will see a long continuous area or belt, from 50 to 100 miles in width, traversing, the eastern part of Pennsylvania, Maryland, Middle Virginia[1], East Tennessee, and the western part of North Carolina, remarkable for its long, parallel, straight, or gracefully curving, mountains, ridges, and valleys. The general trend of this belt and its ridges is northeast and southwest; its rivers, too, and especially the smaller tributaries, generally conform to the same direction. This is a well-developed portion of the Appalachian, or Alleghany region. The entire region, however, extends much beyond the area designated. It is in fact a long, great *belt*, stretching for more than 1200 miles, from Gaspe, in Canada, through Vermont, the western part of Massachusetts, the eastern part of New York and the States mentioned, to Georgia and Alabama. This great belt throughout, is noted for its peculiar topography, its beautiful scenery, and its geological structure. The parallelism of its numerous valleys and ridges, and the remarkable and singular uniformity they preserve for long distances, both in direction and outline, are its most striking topographical features. (P. 8.)

"The great belt just considered intersects, or rather supplies, the elevated and mountainous [region of East Tennessee]. From it, come, therefore, the parallel ridges and valleys which make up the eastern part of the State; in other words, these are Appalachian features." (P. 9.)

The present map covers most of the Appalachian portion of Tennessee, specifically the two eastern geographic divisions of the State-the Unaka Mountains and the Valley of East Tennessee. These are the Tennessee representatives of the two physiographic provinces that form the geographic core of the southern Appalachian Mountains-the Blue Ridge province and the Valley and Ridge province. These provinces are flanked on the northwest by the Appalachian Plateaus, represented in Tennessee by the Cumberland Plateau, and on the cast and south (outside the State) by the Piedmont Plateau, which lies beyond the Blue Ridge in the Carolinas and Georgia.

Unaka Mountains. -The Blue Ridge province of the southern Appalachians comprises two main chains of mountains, which form its northwest and southeast boundaries. These both begin at Bent Mountain southwest of Roanoke, Va., whence they diverge southwestward, terminating in northern Georgia in Cohutta Mountain east of Chatsworth and Mount Oglethorpe east of Jasper.

---

[1] West Virginia was still a part of Virginia when this was written (compiler's note).

The belt between them consists of a number of high relatively flat-floored basins separated by transverse chains of mountains, some no lower than the boundary chains, which they connect like the rungs of a rope ladder. The southeast boundary chain is the Blue Ridge proper,[2] and it ties well east of Tennessee; the northwest boundary chain is called the Iron Mountains in Virginia and the Unaka Mountains[3] in Tennessee, and it forms in the main the State line between Tennessee and North Carolina. The intervening basins are drained by rivers that "rise upon the northwestern side of the Blue Ridge, and flow, in a northwesterly direction, into the State of Tennessee, passing, without material deflection, the Unaka Chain, in deep and grand mountain-cuts." (P. 4.) These basins lie outside Tennessee except where the southeastern corner of the State includes "as it were, accidentally, a most interesting triangular area-the *Ducktown Region*. This region is, physically, a portion of one of the mountain valleys, or basins of North Carolina and Georgia. (P. 29.)

"Coming out of Virginia, the (Unaka] chain pursues a somewhat serpentine, though, in general, direct southwesterly course, along the Tennessee and North Carolina line, into Georgia. Its length, within the northern and southern limits of Tennessee is about 200 miles; it extends, however, a considerable distance each way beyond these limits. (P. 22.)

"This is a long range of mountains, and the most massive of all the Alleghany, or Appalachian Ranges. . . . As here to be understood, this chain is not a single great ridge, but rather, especially on the Tennessee side, a long belt of parallel ridges, which vary at different points, counted across the chain, from two to four in number. One of these is the main axis; the others are subordinate and more or less broken, but all, in general, trending in the same direction. The range, or its main axis, is continuous lengthwise, excepting, principally, that it is intersected by the deep and rocky cuts of the tributaries of the Holston and Tennessee Rivers that flow out of North Carolina and the northeastern corner of Georgia. These divide it into sections; but the sections, abutting end to end, are merely links of the great chain. (Pp. 21-22.)

"In the northeastern corner of the State,....in Johnson and Carter counties, the Unaka Chain is divided lengthwise into *three* leading ridges or mountains separated by wide and beautiful valleys. These ridges, seen from some points, appear to be parallel, but in reality they converge towards the northeast, the two most westerly [Holston and Iron Mountains] coming together and blending in a common ridge, as they enter Virginia, which also, further to the northeast, unites with the most easterly and remaining one [Stone Mountain]. (pp. 23-24.)

"In Washington County [which then included what is now Unicoi County],

---

[2] The name "Blue Ridge," given by the pioneers advancing west over the Piedmont Plateau to the great mountain front that first barred their way, is best reserved for that front and the mountains upon it, marking the cast margin of the Blue Ridge physiographic province. On the other hand, the term has been used for the subcontinental watershed between the Mississippi drainage basin and the Atlantic and eastern Gulf drainage basin, which coincides more or less with the front in question across the Carolinas and into northern Georgia but deserts it near its southwest end and actually enters Tennessee in southern Polk County at Big Frog Mountain (Cleve.). This use of the term, however, is undesirable.

[3] To quote Safford: "Several prominent portions of the chain, lying in different and distant counties, have the name *Unaka* applied locally to them. As it is desirable for greater convenience and for other reasons, that the entire range should, like the *Blue Ridge*, have a general and distinctive name, I have in this Report, borrowing the one above, denominated it the *Unaka Chain*.

"Haywood, in his 'Natural and Aboriginal History of Tennessee,' (Nashville, 1823), appears to use *Unaka* in the same general sense. He spells it *Unuca*, and says: 'East Tennessee is divided from North Carolina by the Unaca or White Mountains-Unica, in the Cherokee language, segnifying white.' " (P. 22, footnote.)

The name Unicoi is obviously from the same root. Apparently the accent in all these words should be on the first syllable.

the Unaka Mountains consist, in general, of two parallel subordinate beds, which are separated by a long, straight valley, called Greasy Cove. The eastern bed may be designated the *Bald Mountain Range*, . . . the western . . . the *Buffalo and Rich Mountain Range*. . . . Entering Greene County, we find the Unaka, within Tennessee, reduced suddenly to a single massive ridge.... This [the range extending from the Big Butt to Camp Creek Bald] is the conspicuous mountain lying to the southeast of Greeneville, and is in a line with the Buffalo and Rich Mountain Range of Washington. (Pp. 26-27.)

"In the Southern part of Greene [County] two other well marked ranges occur [Paint Mountain and Meadow Creek Mountain, separated by Houston Valley]. . . . After crossing the French Broad, there are in Cocke County, several subordinate ranges, continuations, to some extent, of those in Greene. The range which marks out the State line, is at first, for several miles, poorly defined, being very low and broken. Within six or seven miles, however, it rises rapidly, and soon becomes one of the greatest mountains of the Unakas [Bluff Mountain]. (Pp. 27, 28.)

"Southwest of the Big Pigeon, the Unaka Chain throughout, may be divided generally ... into two parallel but unequal ranges. The *first*, which I will call the *Great Smoky*, is, in much of its extent, the State boundary. It is the greatest bed of mountains in Tennessee, having the highest peaks, and occupying with its high ridges, a large area. The *second* is a range, or chain, of prominent, isolated, and long mountains, all arranged lengthwise, nearly in the same line, and . . . all *outliers* skirting, at intervals, the northwestern base of the Smoky Range. They appear, in most cases, to rise up massively and independently, just within the southeastern edge of the East Tennessee Valley. The whole chain may be named, from one of its principal mountains, the Chilhowee Range. The interval between the ranges is occupied by narrow valleys or coves, and numerous ridges and spurs. The ridges and spurs have, generally, a much lower elevation than the principal ranges; in a few cases, however, they become high and conspicuous mountains." (Pp. 28-29.)

This grouping is well displayed in the Great Smoky Mountains National Park and vicinity (Mt. G. and Knox.). Thus the main range is the Great Smokies proper, with Mt. LeConte and Greenbrier Pinnacle as prominent northern spurs; the outlying mountains are represented by English Mountain north of the east end of the Park and Chilhowee Mountain northwest of its west half; and between is a wide belt of lower foothills (some of it with and some without a pronounced linear grain to the topography) locally enclosing large flat-bottomed coves such as Wear, Tuckaleechee, and Cades Coves.

"As a general thing, the Unaka Ridges are clothed with forests, the high, exposed summits, however, running up from 4000 to more than 6000 feet above tide-water, are frequently destitute of trees. . . . Such places are said to be *bald*, or are called the *balds*. . . . They are treeless domes capping the great mountains.

"These domes are, in some cases, nearly, or quite, a mile in diameter; sometimes a chain or succession of them, occurs along the summit of a ridge, giving, in fact, a more or less continuous bald for several miles. Such is the case upon the Roan.

"Although treeless, the balds are not wanting in verdure; supplied often with a good, though not deep, soil, they abound in grasses, ferns, and small shrubs, several of which belong to a far more northern climate than is found in the valleys below. During the summer, the clouds, in which they are often buried, keep them moist, and supply with water the ice-cold springs which are frequently found around their edges, much to the comfort and relief of the mountain-climbers who visit them. In winter they are, much of the time, covered with snow." (P. 34.)

"Those summits, or crests of considerable elevation, but not high nor exposed enough to be bald, are generally covered with a stunted open growth. Some of the very highest points, in place of being bald, are dark with a heavy balsam and evergreen growth, through which it is sometimes impossible to pass. (P. 37.)

"The balds, in themselves, are interesting, but when the great and magnificent views of the world below and around them are associated, they become in truth, sublime. They must be visited, to be appreciated. There is a fascination about them which cannot be told." (P. 35.)

Valley of East Tennessee.-"The Valley of East Tennessee constitutes the largest and most interesting portion of that part of the Appalachian Region, which lies within Tennessee. It has the Appalachian characteristics well developed. It is closely furrowed with parallel valleys and ridges, all trending to the northeast and southwest. Owing to this character, the surface in a transverse direction, that is to say, from the southeast to the northwest, is remarkably rolling. 'Across the country' is here significant. The luckless traveler, whose route lies ‘across,’ unless happily favored with breaks and gaps in the ridges, prepares for 'wave on wave succeeding.' On the other hand, ‘up,’ or 'down the country,'-to the northeast or southwest - is as equally significant of good level roads." (Pp. 41-42.)

"Such are the relations of this area to the mountains on both sides, that it is well called, collectively, the Valley. . . . It is, in reality, but a part of a long, great and complex trough that extends, at least from the Susquehanna, in Pennsylvania to the Coosa and Black Warrior rivers, in Alabama. . . . This trough, in its southwestern course, enters Tennessee obliquely with reference to its northern boundary, but, in crossing the State, turns with a graceful curve more southward, and passes the southern boundary at a much less acute angle." (Pp. 40, 41.)

"The ridges [in the Valley] are very numerous, and differ more or less in height, sharpness of outline, agricultural and other features; while, at the same time, each one is remarkable for the uniformity of character it preserves from one end to the other-a distance, in some cases, of a hundred miles or more. The differences among them depend, for the most part, . . . upon the differences in geological character. The most important are mentioned below.

"In the first place, several, in the northern part of the Valley, are called *mountains*. Most of these are prominent ridges, which, coming out of Virginia, terminate abruptly, within the borders of Tennessee." (P. 42.) Typical is Clinch Mountain, "the most prominent of all the ranges included in the Valley. After pursuing a long course in Virginia, it crosses the Tennessee boundary and runs continuously for more than fifty-six miles, in a nearly straight line, to within sight of Knoxville, when it breaks off abruptly in a bold end. It has a sharp crest, and well-defined outlines. In height, it will average not much, if any, less than 1000 feet above the level of the Holston." (P. 43.) Parts of the mountain are even-crested, others somewhat comby or marked by fairly deep gaps, but no stream breaks through Clinch Mountain within the State. Other mountains of this type in this part of the Valley are Powell and Bays Mountains; with Clinch Mountain they dominate the topography in the northern part of the Valley between the meridians of Knoxville and Kingsport. Elsewhere the type is represented only by stray ridges like Little Mountain in Blount County (Knox. and Loud.) and Whiteoak Mountain in Bradley and Hamilton Counties (Cleve. and Chatt.) or by much lower ridges resembling somewhat the next class to be mentioned. Mountains of this first type are held up by thick formations of sandstone, preeminently the Clinch sandstone, but also sandstone in the Bays, Rockwood, Grainger, and Pennington formations.

"A second and large class, includes numerous ridges which are steep and sharp-crested. These owe their characteristic forms to the sandstone, and sometimes to the slaty layers which they contain. Though often occurring in groups, yet they more frequently, perhaps, alternate in position with those of the [next type described], and like them extend in length a great number of miles. Sometimes their sharp crests are notched by gaps, at short intervals, affording curious lines of pointed peaks. In such cases, they are frequently denominated *comby 'ridges.'* " (P. 45.) Another common name is Pine Ridge, from the pines that commonly grow on them. Ridges of this type are nearly confined to the northwest half of the Valley. They are held up by thin sandstone layers in the Rome, Rockwood, and Grainger formations.

Contrasted with these sharp narrow ridges, though of about the same average height, is a third type, broad ridges with smoothly rounded contours, rarely less than a mile across and commonly much more. "These are generally limestone ridges, and often of great length. Most of them have a comparatively unbroken outline, others are more or less cut into a succession of dome-like knobs. Many of them are covered, to a greater or less extent, with sharp flinty gravel." (Pp. 44-45.) In certain areas they spread out into wide belts of country characterized by fairly steep-sided valleys and sinks. The Powell River traverses such a belt in Claiborne and Campbell Counties (Mayn. and Brice.); another lies west of the Tennessee River in southern Rhea and northern Hamilton Counties (Chatt. and Cleve.). Ridges of this type are common in all parts of the Valley though generally highest and roughest to the northwest and more subdued or even hardly recognizable east of Newport and Greeneville. Some of those to the northwest can be traced for a hundred miles or more, but those to the southeast are generally short and difficult to trace. Hardwoods rather than pines characterize these ridges, some of which are called Chestnut or Blackoak Ridge, and indeed much of their surface is cultivated or in pasture. They are underlain by the generally cherty rocks of the Knox group.

A fourth type of elevated belt consists of steep knobs, "separated from each other by deep gaps. They have generally a conical shape, sending up their peaks from 200 to 400 feet, and sometimes to a greater altitude, above the general level of the Valley. . . . [In some areas] these curious hills dot out straight or gently curving ranges, remarkable for their length, and for their uniform appearance throughout." (P. 45.) In other areas they "are crowded together without order, and, where most numerous, form wild labyrinths of conical hills, from which a stranger, once off the beaten track, might not easily extricate himself." (P. 46.) "Some of these regions when viewed from high points, look like *mammoth potato patches*, the hills, however, not in very regular rows." (P. 247, footnote.) These knobby belts occur mainly on the southeast side of the Valley, southeast of the Tennessee and Holston Rivers, and are rarely found near ridges of the first two types, excepting Bays

Mountain. They are generally one or two hundred feet higher than adjacent ridges of the third type, which are of less than their average altitude in this part of the Valley. Regular belts of knobs are commonest southwest of Sevier County; typically "the soil upon them has a deep brownish red color," (p. 45) and they are called Red Knobs or Red Hills. The knobs are typically underlain by the sandy layers of the Sevier shale or its equivalents, the Red Knobs generally by the quartzose phase of the Holston formation.

A fifth, less important, type of ridge consists of long, low, narrow hills with smooth semielliptical crestlines, alined end to end and separated by stream gaps at half-mile to mile intervals. These occur in two general areas: one close to the northwest side of the Valley through Roane, Rhea, and Hamilton Counties (over the Fort Payne chert), the other in the southeastern half of Greene County and northeastward through Washington and Sullivan Counties (over the Nolichucky shale and the basal sandstone layers of the Conococheague limestone).

Between the ridges the valleys also have curiously distinctive characteristics, which can be recognized for miles, but the differences are more subtle and less readily described in general terms. These differences strongly affect the fertility of the valleys, however; thus the valleys of one type (generally narrow and overlooked by a mountain or sandwiched between a mountain and a comby ridge) have consistently barren acid soils, derived from noncalcareous shale (the Devonian and basal Mississippian shale units), and are commonly called Poor Valley, where those of another type (commonly wider but in several places occurring on the other side of the same mountain or ridge) are notably fertile and rich, though the underlying Chickamauga limestone crops out widely in many of them. The several wider types of valleys are commonly diversified by subordinate lines of knobs or of long, low swells hardly high enough to be called ridges. To the southwest, however, some of these valleys are remarkably wide and flat-bottomed (especially those over the Conasauga shale).

Cumberland Plateau.- The west wall of the Valley or "the eastern border of the [Cumberland] Table-land is comparatively a nearly direct, or gracefully curving line. The indentations made by the streams, are, upon the map, hardly noticeable." (P. 67.) Southwest of Harriman (Kings.) it is for the most part a steep, cliffed slope a thousand feet high leading up to the nearly flat surface of the Cumberland Plateau. Northeast of Harriman the margin of the Valley is commonly "a steep and roof-like ridge, … entirely detached from the body of the Table-land, being separated from it by a deep and narrow valley, or line of valleys. From the Salt-works [Oliver Springs, Brice.], in Anderson County, northeastward, this ridge [Walden Ridge] is very prominent and characteristic; it runs many miles in a direct course, then curves beautifully around to the northwest, after which it again pursues a direct course until intersected by the valley of Cove Creek.... in Campbell, where it falls away. Here, however, it is very nearly continuous with [a similar ridge which] from Cove Creek to Cumberland Gap may be considered as continuing the line of Walden's Ridge on to Virginia.

"These ridges, from the Emery to Virginia, are among the greatest curiosities of the whole Cumberland Table-land. Sharp, bold, and roof-like, mostly made up of vertical sheets of solid [Pennsylvanian) sandstone, they appear like a vast military work, designed to protect the main mountain from the encroachments of the Lowlanders. There are very few gaps in them. Those that do occur are water-gaps formed by creeks. To get at the foot of the mountain, though it may not be more than half a mile off, it is often necessary to ride half a dozen, to find a passage through these skirting ridges." (Pp. 69-70.) Behind the ridges, the main mass of the Plateau here is not flat but deeply dissected into rough mountainous country.

Set deep in the Cumberland Plateau, like outliers of the main Valley, are Sequatchie Valley (west of the area on the present map), 4 or 5 miles wide and 60 miles long from its north end to the Alabama line, and the much smaller Elk Valley (Brice.), approximately a mile wide and 10 miles long. The two valleys are roughly in line, but they are not connected; between them is the Brushy Mountain area, some of the roughest mountain country in Tennessee.

Erosion surfaces.-The land forms of East Tennessee and the surrounding area were apparently produced during at least two nearly complete cycles of stream erosion accompanied by weathering, solution, and mass wasting, plus a third, the present cycle, still far from complete. The earlier cycles are recorded by widespread erosion surfaces (perhaps peneplains), whose remnants are found in many parts of the area. These land forms have been studied by many observers, most comprehensively perhaps by Wright (1931, 1934, 1936). More recently emphasis has shifted from the land forms to the underlying mantle materials, and new insights have been gained into the history of the area (King, 1949a; Bridge, 1950). The mantle materials and their implications are discussed in a separate section below (pp. 114-121).

The drainage of East Tennessee, especially of the Valley, has in consequence of the linearity of the minor valleys and ridges an over-all trellis pattern, but in detail many of the streams, large and small, show sweeping bends or tight meanders. Except for the Clinch and Powell Rivers above Norris Reservoir, the main rivers in the Valley have considerable areas of flood plain, but almost nowhere is this flood plain as wide or even half as wide as the belt spanned by the bends or meanders. In many areas, however, the remainder of the meander belt shows stepped terraces (underlain by old flood-plain deposits) up to a few hundred feet above the stream, and the meander belt as a whole interrupts the continuity of the minor linear valleys and ridges, otherwise characteristic of the Valley. To what extent these terraces can he grouped into sets recording especially well developed ancient flood plains has not yet been properly investigated.

Away from the main rivers, the Valley ridges of the second and third types described above characteristically rise nearly to a common level, though few flat areas at this level are preserved on them. It is thought that these summits record an important erosion surface, the Valley Floor (or Valley) surface or peneplain, once developed over the whole area of the Valley except for the mountainous ridges of the first type described and perhaps, to a small extent, the knobs of the fourth. To be sure, no single obvious flat surface can be reconstructed from the present topography, for the original surface may not have been flat, or there may have been several surfaces. Thus the accordant summits of the knobs of the fourth type may record a slightly higher surface or merely higher parts of 'the same surface, and the wide minor valleys, some of which are fairly flat bottomed, have been thought by some to record another lower surface, though more probably they are simply areas where more active erosion or chemical solution of limestone has reduced the land evenly below the main erosion surface.

In the wider valleys within the Unaka Mountains, there are evidences of similar surfaces. In northeast Tennessee, -there appears to have been a whole family of such surfaces, now recorded by accordant spur tops or patches of flat ground (underlain by gravel and *not* lithologically controlled), recurring at several levels above stream level in the areas that have been investigated, such as Stony Creek Valley and.Bumpus Cove (Roan M.) (King and others, 1944, pp. 42-48, fig. 7; Rodgers, 1948, pp. 23-24, pl. 4). Perhaps the finest display of an ancient erosion surface in the mountains is in the foothills of the Great Smoky Mountains near Gatlinburg (Knox.), where the summits of the foothills, viewed from a suitable vantage, merge into a broad, even, north sloping surface that bevels different rock types (fig. 2). The modern streams flow in valleys cut hundreds of feet below this surface. This and similar high surfaces in the foothills and mountain valleys probably represent the Valley Floor surface; the lower surfaces which can be recognized in places may correspond to the terraces found along the major streams out in the main Valley or to the lower areas of flat ground in the wider minor valleys there. Iii some places these lower surfaces merge upstream into broad fanlike areas at the foot of steep mountain slopes, on which the present streams still flow not entrenched.

The age of the Valley Floor and associated surfaces is not certain; the relatively small amount of subsequent erosion argues for a late Cenozoic though pre-Pleistocene age, but certain sinkhole deposits found on the Valley Floor surface are thought to be very early Cenozoic (p. 120).

Standing high above the general level of the highest surfaces so far described are such mountain ridges as Clinch Mountain in the Valley and all the ranges of the Unaka Chain. The mountains in the Valley and most of the outer ranges of the Unakas, such as Holston and Chilhowee Mountains, have fairly sharp, narrow, but typically even, crests, whereas the mountains of the main Unaka range along the State line commonly show, on their summits sizable areas of rolling ground of much lower relief than the surrounding slopes. It is on these flatter areas that the balds are commonly developed. It has generally been thought that the even crestlines of the higher ridgelike mountains such as Clinch and Chilhowee record a high erosion surface or peneplain, the Upland (Schooley?) surface, and that this surface is also preserved on the higher shoulders of the main range, whose summits rose as rolling hills above it, perhaps to a still higher "Summit" peneplain. Byron Cooper has shown (1944, pp. 213-214), however, by quantitative study of the debris derived from a ridge like Clinch Mountain in Virginia, that that mountain has been lowered not less than 75 feet and probably several times as much since the development of the Valley Floor surface far below the mountain crest, so that the crest itself certainly does not represent an undisturbed remnant of any higher surface. He believes that the height of such mountains is far more a function of the thickness, resistance, and dip of the underlying rocks than of any preexisting erosion surface, and the same reasoning can well be applied to the linear mountain ridges in the Valley of East Tennessee. An ancient Upland surface cannot therefore be restored with confidence within the Valley, though it may be represented in part by the Cumberland Plateau as well as by parts of the Unaka Chain, for example, the accordant (but not horizontal) summits and spurs of such mountains as Holston and Iron Mountains in northeast Tennessee (King and others, 1944, p. 43, fig. 7). Indeed, it is possible that the rolling surface of the high Unakas is a fair sample of the whole of the

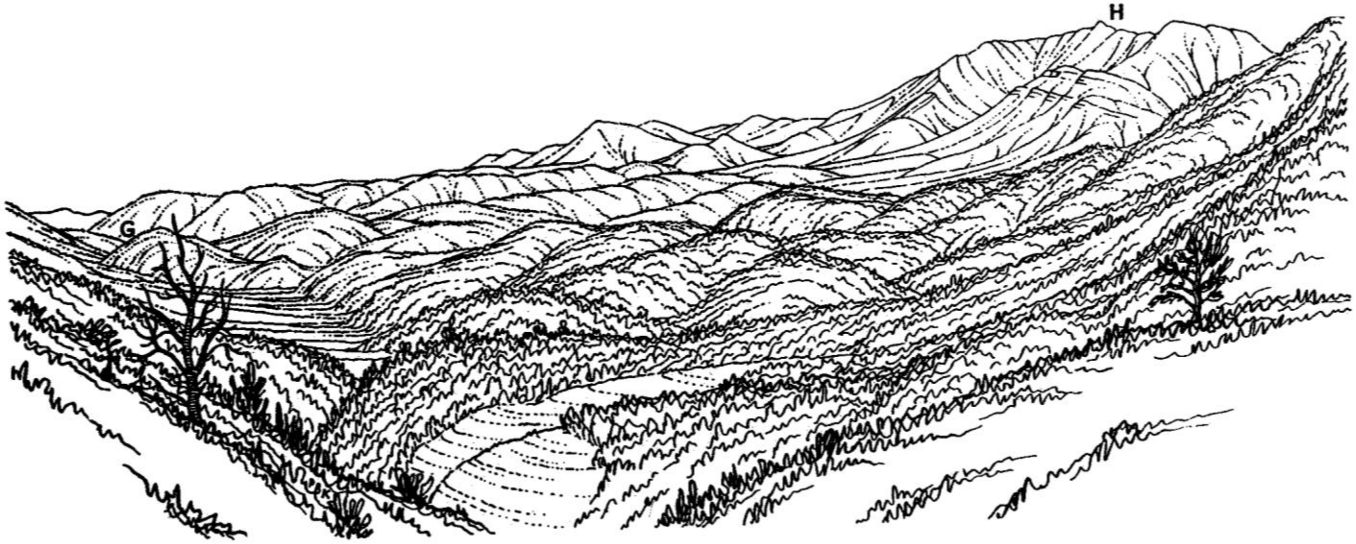


Figure 2. The north face of the Great Smoky Mountains as viewed from Fighting Creek Gap, looking east and southeast toward Gatlinburg (G) and Mount Le Conte (H). Three general levels are shown--the present valleys as at Gatlinburg, the high mountain summits like Mount Le Conte, and a pronounced intermediate level which may correspond to the Valley Floor surface in the main Valley of East Tennessee. (Drawing by P. B. King, from King and Stupka, 1950, fig. 6, p. 35, published by permission of the Scientific Monthly.)

Upland surface in East Tennessee, as it existed when the cycle of erosion that produced it was most nearly complete.

No evidence of the age of the Upland surface can be obtained in East Tennessee and vicinity, but it must be much older than the Valley Floor surface.

DESCRIPTION OF ROCK UNITS

PRE-CAMBRIAN CRYSTALLINE COMPLEX (p∈c)

In northeast Tennessee, along the east edge of the State, a pre-Cambrian basement complex of igneous and relatively high-grade metamorphic rocks underlies unconformably the lowest sedimentary rocks present. The outcrop area of these basement rocks forms the core of the great Blue Ridge anticlinoriurn or welt from the vicinity of the French Broad River in Madison County, N. C., or a little southwest, northeastward roughly along the North Carolina-Tennessee State line and on into Virginia. Keith (1903, Cran. f.; 1904, Ashe. f.; 1905a, Greene. f.; 1905b, Mt. M. f.; 1907b, Roan M. f.) mapped a number of pre-Cambrian units in this part of Tennessee and North Carolina, but these units have not been shown separately on the present map. Safford (1869, pp. 170-174) included them all within his metamorphic group.

According to Keith, these pre-Cambrian units fall into three groups: a group consisting of gneiss and schist, intruded by a group consisting of granite and granite-gneiss, overlain unconformably by a group consisting of relatively low-grade metavolcanic rocks. The granitic group Keith divided into two phases-the older Cranberry granite, generally gneissic, and the younger Beech and Max Patch granites, generally massive, coarse, and porphyritic. The main outcrop belt of this group forms the core of the welt, and, within the area of basement rocks in Tennessee, Keith mapped little else. The gneiss and schist group, mainly of sedimentary and volcanic origin, he divided into the Carolina gneiss (dominantly micaceous) and the Roan gneiss (dominantly hornblendic). In Tennessee these rocks occur chiefly as numerous small lenses and stringers included in the granitic rocks, and Keith did not map these separately. In North Carolina, however, they form a wide belt on the southeast side of the welt, and according to Keith's mapping this belt reaches into Tennessee on and around Roan Mountain in southern Carter County (Roan M.) and on Snake Mountain at the southeast corner of Johnson County (Cran.). King (1950, pp. 648, 650) has suggested that the rocks of this belt may be chiefly the metamorphosed equivalents of the Ocoee series or other rocks younger than the crystalline complex, thus resembling the main body of the Lynchburg gneiss of Virginia (Jonas and Stose, 1939, pp. 589-590). This suggestion may well apply to the bodies of Roan gneiss mapped by Keith on Roan and Snake

Mountains, but not to the gneiss and schist lenses and stringers elsewhere in Tennessee, which are clearly inclusions in the granitic rocks. On the present map, however, all these rocks are included in the pre-Cambrian crystalline complex.

Of the metavolcanic group (metadiabase, metarhyolite), the largest area mapped by Keith (1903, Cran. f.) lies within the Grandfather Mountain window in Watauga, Avery, and Caldwell Counties, N. C., beyond the limits of the present map (see fig. 5). The metavolcanic rocks there are probably equivalent to the Mount Rogers volcanic group, mapped separately on the present map and discussed below. Outside that window, Keith recognized smaller areas of these rocks, mostly too small to map, especially in a belt a little southeast of the southeastern limit of sedimentary rocks from near Hot Springs, North Carolina (Ashe.), to near Mountain City (Cran.). These he considered to be mainly sheets and dikes, probably feeders of the flows. Some of these bodies are certainly metadiabase, presumably younger than the basement rocks, but others, particularly those considered by Keith to be metarhyolite, may be sheets of mylonite along major thrust faults within the crystalline complex (cf. Bayley, 1923, pp. 245-251). These bodies are not shown separately on the present map.

Much further work is needed to separate the different components of the pre-Cambrian crystalline complex and to determine their mutual relations.

The rocks of the crystalline complex weather variably; in some places they form bold cliffs and areas of bare rock, in others they are covered by a deep mantle of decomposed rock with a fairly thick soil layer. The more massive phases of the granite and gneiss resist erosion and form the highest mountains in the area; the other rocks underlie intricately dissected country of moderate relief but steep slopes, covered with a patchwork of farms and woodland plots.

The complex is faulted against younger rocks through much of the area, but in some places it underlies them directly. The immediately overlying rocks belong to the Mount Rogers volcanic group in the extreme northeast corner of Johnson County (Cran.), to the Unicoi formation elsewhere northeast of the Nolichucky River, and to the Ocoee series farther southwest. A fine exposure of the unconformity may be seen along the East Tennessee and Western North Carolina Railroad in the Doe River gorge southeast of Hampton (Roan M.). As the overlying rocks themselves lie well below the lowest rocks containing Lower Cambrian fossils, there is no doubt of the pre-Cambrian age of the complex.

MOUNT ROGERS VOLCANIC GROUP (mr)

The Mount Rogers volcanic group, named by Stose and Stose (1944, pp. 410-411) for Mount Rogers, the highest point in Virginia, underlies a large area in Grayson, Smyth, and Washington Counties, Va., adjacent to the northeast corner of Tennessee, and reaches into both Tennessee and North Carolina. In Tennessee, however, it is of very limited extent. It was included by Safford (1869, p. 172) in his metamorphic group, though he recognized that the rocks are less highly metamorphosed than those of the crystalline complex (p. 21). On Stack Ridge, nearly a mile north of Laurel Bloomery (Cran.), the feather edge of the group is inserted between the crystalline complex and the Unicoi formation. The contact of the Mount Rogers group with the complex is unconformable; that with the Unicoi may be disconformable.

The character of the Mount Rogers volcanic group in the type area in Virginia has been well summarized by Jonas and Stose (1939, pp. 590-591). In Tennessee and North Carolina it consists of purplish and greenish metavolcanic rock, chiefly metarhyolite, and apparently includes both tuffs and flows. Most of the rock shows a strong foliation approaching slaty cleavage and some is good slate, but despite the foliation much of the rock forms massive ledges and blocks. In the more massive rock, the foliation is normally made irregular by small blebby masses of quartz; the slaty rock is commonly spotted with paper-thin lenses of chlorite and epidote. Interbedded with the metavolcanic rocks, especially in Virginia and North Carolina, are layers of conglomerate, graywacke, and nonvolcanic silty shale or slate, not unlike some of the rocks of the overlying Unicoi formation.

The rocks of the group crop out in great ledges or break down to a thin very stony soil. They form high rough mountains such as Fodderstack Mountain, a mile and a half north of Laurel Bloomery, and Pond Mountain, in the extreme northeast corner of the State (Cran.), and also Whitetop and Mount Rogers in Virginia, still farther northeast. They have generally been classed as late pre-Cambrian, and King (1949b, p. 635) has suggested that they may be roughly correlative with the Ocoee series. As the overlying Unicoi formation, generally classed as Lower Cambrian, includes sedimentary rocks like those in the Mount Rogers volcanic group as well as some volcanic rocks, the compiler would prefer to leave the age of the group indefinite. The U. S. Geological Survey classes the Mount Rogers volcanic group as pre-Cambrian (?).

OCOEE SERIES (ocu)

Name, subdivision.-The Ocoee series, which forms the Great Smoky Mountains and the other high ranges southwest along the North Carolina State line, was named the Ocoee conglomerate and slates by Safford (1856, pp. 151-152; 1869, pp. 183-198) for the fine section along the Ocoee River between Parksville (Cleve.) and Ducktown (Mur.). He called it variously the Ocoee group, the Ocoee formation, and the Ocoee conglomerate and slates. Commonly he included in it rocks here referred to the overlying Unicoi formation and Cochran conglomerate. On the other hand, he referred the more highly metamorphosed parts of the series in Monroe and Polk Counties to his metamorphic group, though he stressed the gradual transition from one to the other (1869, pp. 177-178).

Though the Ocoee series is a body of sedimentary rocks several miles thick (about as thick, in fact, as the entire Paleozoic sequence that overlies it), its subdivision has proved very difficult. In the folio mapping it was divided, chiefly by Keith, into a number of named units, which differ considerably from folio to folio (table 1).

Work now in progress by King, Hadley, and others in the Great Smoky Mountains has greatly changed our understanding of the Ocoee series (see King, 1949b, pp. 624-634), and has rendered obsolete Keith's interpretation of the sequence and of its correlation. Sequences have now been worked out in several areas, but the correlation between them remains uncertain. The classification used on the present map is generalized from the new work, but it is only tentative and is subject to correction as that work is carried forward. Because of the revision of the sequence, however, the equivalence of the present subdivisions to the folio units cannot be stated in general terms but only for certain areas. The present classification is shown in table 2; the sequences in the different areas are treated separately below. The base of the group is exposed only northeast of the Pigeon River, where it is clearly unconformable on the crystalline complex. The top, beneath the conglomeratic Unicoi and Cochran formations, is less clear; disconformities have been reported at several places, as on Chilhowee Mountain (Knox.) and close to the Nolichucky River (Roan M.), but it is not certain that the contact elsewhere has been drawn at the same level as at these places.

Northeast of Pigeon River.-Where detailed work has been done northeast of the Pigeon River (Ferguson and Jewell, 1951; Oriel, 1950; Lowry, ms.), the Ocoee series has been subdivided into the Sandsuck shale (ocss) above and the Snowbird formation (ocsb)

TABLE 1.—*Sequences of units used in published folios for the Ocoee series and immediately overlying rocks* (Correlations according to Keith; for present views see table 2)

Keith, 1895, Knox. f. (main belt); 1896a, Loud. f.; Hayes, 1895a, Clev. f. (differs slightly)	Keith, 1907a, Nant. f.; 1904, Ashe. f. (south part); LaForge and Phalen, 1913, Ell. f.	Keith, 1895, Knox. f. (Chilhowee Mtn.); 1896a, Loud. f.; Hayes, 1895a, Cleve. f.	Keith, 1904, Ashe. f. (north part); 1905a; Greene. f.; 1907b, Roan M. f. (west part)	Keith, 1907b, Roan M. f. (east part)
Clingman conglomerate*	(Higher units in North Carolina and Georgia)			
Hazel slate*	Nantahala slate			
Thunderhead conglomerate Cades conglomerate	Great Smoky conglomerate	Cochran conglomerate	Cochran conglomerate	Unicoi formation
Pigeon slate Citico conglomerate Whilhite slate	Hiwassee slate	Sandsuck shale	Hiwassee slate	
			Snowbird formation	

*Keith (1907a, correlation table) correlated both Clingman conglomerate and Hazel slate with part of the Great Smoky conglomerate, but his mapping shows that at that time he considered the Hazel and Nantahala slates to be the same. Presumably he had altered his views on the relative order of these units.

TABLE 2.—*Subdivisions of the Ocoee series used on present map, showing tentative correlations*

Southwest of Pigeon River (especially Sevier County)				Northeast of Pigeon River
Mountain belt		Foothill belt		
(Top missing)	Correlation uncertain	Fine-grained part of Ocoee series (ocf)	Sandsuck shale (ocss)	Sandsuck shale (ocss)
Nantahala slate (ocn)			Pigeon siltstone (ocp)	Snowbird formation (ocsb)
Great Smoky conglomerate (ocgs) Lowest part of Ocoee series (ocl)		(May rest on Great Smoky conglomerate southwest of Little Tennessee River; see text, pp. . .32 33. .)	(Base probably not exposed may rest on rocks like Great Smoky conglomerate or lower part of the Snowbird formation)	(Rests unconformably on crystalline complex)
(Base not exposed)				

below; elsewhere northeast of the Pigeon the present map shows it as Ocoee series, undivided (ocu). The type area of the Sandsuck is southwest of the river and the Sandsuck shale in that area is discussed below. The Sandsuck as mapped northeast of the river corresponds roughly to what Keith mapped as Hiwassee slate in the same area (1904, Ashe. f.; 1907b, Roan M. f.). In its type area along the Hiwassee River (Mur.), however, the Hiwassee slate corresponds roughly to the whole fine-grained part of the Ocoee series (ocf), and its correlation with the units farther northeast is uncertain. The Snowbird formation was named by Keith (1904, Ashe. f., p. 5) for Snowbird Mountain on the State line just east of the Pigeon River (Mt. G.), whence it is continuous into the Del Rio area mapped by Ferguson (Ferguson and Jewell, 1951). In several areas, however, Keith mapped rocks of the Ocoee series as the Cochran conglomerate or the Unicoi formation.

Northeast of the Pigeon River, the Sandsuck shale consists chiefly of dark silty to argillaceous shale commonly showing slaty cleavage. Normally the bedding is clearly shown by fine laminae, alternately more and less silty, but the rock may not break along them. Interbedded in the shale are lenses of fairly fine dark feldspathic conglomerate, normally thin but locally, as near the Nolichucky River (Roan M.), as much as 100 feet thick. Also interbedded in the shale are lenses or beds of dark blue-gray dolomite and limestone, commonly well laminated and silty or sandy; such beds were noted by Keith and separately mapped by him (1904, Ashe. f.) southwest of Wolf Creek, and also around Allenstand, N. C., 7 miles northeast of Hot Springs (Ashe.). They have also been noted in the Sandsuck shale near the Nolichucky River. The Sandsuck in these areas is probably between 500 and 2,000 feet thick, except close to the Nolichucky River, where it appears to be truncated beneath a disconformity (Lowry, ms.).

In the type area and northeast toward the French Broad River (Mt. G.), the Snowbird formation appears to show a sequence of units, though the sequence is not yet certainly established. Each of these units is dominated by one type of rock, but other types are interbedded in considerable abundance in each unit, particularly the rock types dominating the adjacent units. The dominant rock types and the thicknesses of the corresponding units are as follows (in descending order):

Sandstone, light-gray, coarse, quartz grains with dolomitic cement - 1,000 feet

Shale, dark, silty, and sandy siltstone, well and thinly laminated, good slaty cleavage in many beds (some dolomite and limestone occur in this unit)-uncertain, perhaps 1,500 feet.

Siltstone and fine-grained sandstone, massive, uniform, dark-green, bedding obscure; also lighter, slightly coarser sandstone below-5,000 feet
Arkose, massive, light-gray to pink, coarse-grained-5,000 feet
Basal mixed beds, including arkose and arkosic conglomerate, much of it almost unsorted granitic debris, and siltstone and silty shale-2,500 feet

Because of the interbedding of rock types all contacts are graduational. When more work has been done, the Snowbird may well be subdivided into a number of formations, some of them at least equivalent to units southwest of the Pigeon River, as suggested by King (1949b, fig. 8, P. 629).

In the Hot Springs, N. C., area (Ashe.) (Oriel, 1950, pp. 25-30), the Snowbird formation consists of dark graywacke grit and feldspathic sandstone with much siltstone and some shale above; the beds exposed may represent about the upper half of the typical sequence. Farther northeast the Ocoee series thins rapidly, apparently chiefly from the base, and it pinches out near the Nolichucky River, at least on some of the thrust sheets of that area. In that area the Snowbird is lighter in color and the sandstone is more quartzose than to the southwest.

Southwest of Pigeon River, foothill belt.-The belt of Ocoee rocks in Sevier County has been studied in detail by King, Hadley, and Ferguson. It is divided by the Greenbrier fault into a foothill belt to the north and a mountain belt to the south. In the foothill belt, rocks of the mountain belt crop out in several areas, notably Cove Mountain west of Gatlinburg (Knox.) and some patches to the southwest. These areas are interpreted as klippen or down-faulted outliers of the Greenbrier thrust sheet. Similar rocks also form Webb Mountain in eastern Sevier County (Mt. G.) and Hannah Mountain and the surrounding area west of Cades Cove in southern Blount County (Knox.); these may also be klippen or faulted outliers, but detailed work has not yet been done there.

Excluding these areas, the rocks of the foothill belt can be divided in Sevier County into two broad units, which may be called, following King (1949b, pp. 639-640), the Sandsuck shale (ocss) above and the Pigeon siltstone (ocp) below. Further work will undoubtedly subdivide these units. Outside of Sevier County, where less work has been done, even these units cannot everywhere be distinguished, and on the present map they have been grouped as an (upper) fine-grained part of the Ocoee series (ocf). Northwest of the Miller Cove and Sylco Creek faults, however, the rocks appear to belong, entirely to the Sandsuck shale, and they are so mapped.

The Sandsuck shale was named by Keith (1895, p. 3) for Sandsuck Branch of Walden Creek (Knox.) and was mapped by him beneath the Cochran conglomerate both at Sandsuck Branch and on Chilhowee Mountain just to the north. Recently, however, Ferguson (ms. a.; see King, 1949b, p. 634) has discovered a disconformity within the Cochran as mapped by Keith on Chilhowee Mountain and has shown that, although the conglomerate beds above it may form a mappable unit (the Cochran conglomerate of present usage), the conglomerate beds below are lenses within shale or slate typical of the Sandsuck. South of the Miller Cove fault similar slate and conglomerate occur, but here Keith mapped them (1895, Knox. f.) as Wilhite slate and Citico conglomerate (and locally as Pigeon slate). In present usage, therefore, the Wilhite slate, named by Keith (1895, Knox. f., p. 2) for Wilhite Creek, Sevier County (Mt. G.), is considered a synonym of Sandsuck shale, but the Citico conglomerate, named by Keith (1895, Knox. f., p. 2) for Citico Creek, Monroe County (Loud. and Mur.), may be used as a member name for conglomerate beds and lenses within the Sandsuck shale, especially south of the Miller Cove fault.

In the Cleveland folio (1895a, p. 2) Hayes named the Starr conglomerate lentil in the Sandsuck shale for Starr Mountain, Monroe and Polk Counties (Mur. and Cleve.), and stated that it occurs at the north end of Starr Mountain (Mur.) and the south end of Bean Mountain (Cleve.) but is absent in the area between, near the Hiwassee River. Because of the poor base map on which he had to work, however, he had made an error in tracing the units from the Hiwassee River to the Ocoee River; what he mapped as the Nebo sandstone near the Hiwassee River he mapped as the Cochran conglomerate near the Ocoee River, and hence what he mapped as the Cochran conglomerate near the Hiwassee River seemed to be a new unit near the Ocoee River. The Starr conglomerate is therefore a synonym of Cochran conglomerate and should be abandoned. The small area that Hayes mapped as Starr conglomerate on Little Mountain and Sugar Loaf near Parksville (1895a, Cleve. f.), however, is white *Scolithus*-bearing quartzitic sandstone and belongs to either the Nebo or the Hesse sandstone.

Keith (1895, Knox. f., p. 2) named the Pigeon slate for exposures near the West Fork of the Little Pigeon River (not the "Big" Pigeon River); the unit is well displayed along the river for 3 miles north of Gatlinburg (Knox.) but it is rather a siltstone than a slate, and King (1949b, pp. 639-640) has changed the term to Pigeon siltstone.

The compiler suspects that the Sandsuck shale in this area includes a greater stratigraphic interval than northeast of the Pigeon River. Probably the beds mapped as Sandsuck in Sevier County and farther southwest include equivalents of the upper two units of the Snowbird formation and possibly even of the lower part of the Unicoi formation as recognized in the Del Rio area and southward (Mt. G.). Further refinement of the correlation and classification of all these rocks may be expected as work now in progress is carried forward.

The Sandsuck shale (ocss) as mapped southwest of the Pigeon River is much more heterogeneous than to the northeast. Dark well-laminated silty to argillaccous shale, showing prominent slaty cleavage in the more southeastern areas, forms a large part of the formation, but sandstone and conglomerate are much more prominent and form thicker bodies, many of them of mappable proportions, though all appear to be lenticular. These coarser rocks range from medium-grained sandstone to spectacular boulder conglomerate. Most of them are composed of grains of quartz and feldspar in a light-colored commonly dolomitic or ankeritic cement; the rocks are light gray when fresh but commonly weather to a rusty brown. Some of the conglomerate layers, however, include pebbles and slabs of limestone, slate, or calcareous sandstone, some as much as a foot across. The typical Citico conglomerate on Citico Creek (Loud.), here considered part of the Sandsuck, is a medium to coarse pebble conglomerate full of limestone fragments; similar rock is common elsewhere in the belt of Sandsuck shale south of the Miller Cove fault. Limestone pebbles and coarse conglomerate are uncommon north of that fault. The Sandsuck also contains layers of dolomite and limestone, mostly dark blue-gray and fine-grained and silty or sandy, forming lenticular bodies 25 feet or more thick. These are especially prominent in eastern Sevier County, as in Jones Cove and on Wilhite Creek (Mt. G.) but have been seen as far southwest as the Ocoee River above Parksville (Cleve.). The Sandsuck in Sevier County can hardly be less than 4,000 feet thick.

The Pigeon siltstone (ocp) is dominated by uniform massive dark-green siltstone. Bedding is commonly marked only by thin, faint laminae, more conspicuous on weathered than on unweathered surfaces; locally, however, the rock is fairly well bedded. Strong slaty cleavage has developed over much of the area. More argillaceous layers occur but are rare. Slightly coarser beds, approaching fine-grained medium-gray impure quartzite, become common in the lower part of the unit, but coarse sandstone and conglomerate are virtually absent. Locally, in what appears to be the upper part of the unit, the rock contains layers, half an inch or more thick, that are ankeritic and weather brown; otherwise carbonate is rare. In all these characteristics the unit closely resembles the third unit of the typical sequence of the Snowbird formation. The Pigeon siltstone appears to be bounded by faults everywhere in Sevier County; its thickness is estimated as 15,000 feet, of which the more quartzitic part forms the lower third or half.

The rocks mapped as the fine-grained part of the Ocoee series (ocf) include rocks of all the types described for the Sandsuck shale and Pigeon siltstone. Silty shale and siltstone seem to dominate; coarser beds form lenses here and there, especially in the northwestern part of the belt. In the southeastern part of the foothill belt these rocks are metamorphosed to slate or even phyllite. No estimate of thickness is possible. The relation of this unit to the Great Smoky conglomerate southwest of the Little Tennessee River is discussed below.

Southwest of Pigeon River, mountain belt.-The main mass of the Great Smoky Mountains (Knox., Mt. G.) south of the Greenbrier fault consists of the Great Smoky conglomerate (ocgs) overlain by the Nantahala slate (ocn) and underlain by sandstone and slate forming the lowest part of the Ocoee series (ocl). As noted above, similar rocks are present in certain areas north of the main range of the mountains; mostly these consist of conglomerate like the Great Smoky conglomerate but in the Cove Mountain area west of Gatlinburg (Knox.) lower rocks also appear. Of these units only the Great Smoky conglomerate is mapped southwestward beyond the Little Tennessee, but further work may show that the other units are present there also.

The Nantahala slate and Great Smoky conglomerate were named by Keith (1904, Ashe. f., p. 6) for the Nantahala River in Macon and Swain Counties, N. C. (Keith, 1907a, Nant. f., p. 4) and the Great Smoky Mountains (Knox., Mt. G.). In his earlier published map of the Great Smoky Mountains (1895, Knox. f.), he had attempted to divide these rocks into four units (top four units in first column of table 1, p. 25), but the subdivision was based in part on a misapprehension of the structure and could not be carried out. His later classification agrees better with the now available facts and is used on the present map. The lowest part of the Ocoee series was included by Keith partly in. his Cades conglomerate, partly in his Pigeon slate, along with other rocks belonging much higher in the section.

The Nantahala slate (ocn) consists of strongly pigmented, dark-gray to black slate (or phyllite) and siltstone, some of it well laminated. To the south, mainly in North Carolina, it contains beds or tongues of graywacke sandstone and conglomerate like that of the Great Smoky conglomerate, and Hadley (personal communication) believes that it intertongues laterally with the Great Smoky. Thin beds of dolomite have been reported. About 2,000 feet of the slate remains in synclines along the crest of the mountains.

The Great Smoky conglomerate (ocgs) consists of graywacke sandstone and conglomerate in thick graded beds, with partings of slate between many of the layers. Except for occasional slate flakes, the fragments rarely exceed fine-pebble size (8 mm.) and consist chiefly of feldspar and quartz; the matrix contains considerable dark argillaceous material. The thickness of the Great Smoky conglomerate on Mt. Le Conte (Mt. G.), where both top and base are present, is 6,000 feet.

The oldest part of the Ocoee series (ocl) beneath the Great Smoky conglomerate consists of fine- to medium-grained graywacke sandstone with much dark slate. Conglomerate is generally rare, but around Elkmont, 4 miles southwest of Gatlinburg (Knox.), conglomerate like that of the Great Smoky becomes an important constituent. Graded bedding is present but is not as prominent as in the Great Smoky conglomerate. In general, the conditions of deposition of this unit seem to have been like those of the Great Smoky but the material supplied was considerably finer. The base of the unit is nowhere exposed, but its thickness is not less than 2,000 feet in the Cove Mountain area and may be more around Elkmont.

In the area west of the Little Tennessee River and south of the Gatlinburg fault (Mur. and Cleve.), the mountains along the State line and west of Ducktown consist of coarse sediments like, and here mapped as, the Great Smoky conglomerate, and the foothills consist of finer sediments like the Pigeon siltstone and Sandsuck shale and here mapped as the fine-grained part of the Ocoee series. The nature of the contact between these two rock masses is not known, and available evidence is conflicting. According to the folio mapping (Hayes, 1895a, Cleve. f.; Hayes and Keith, ms. maps of the Murphy quadrangle), the Great Smoky conglomerate overlies the foothill rocks in normal succession, but to the compiler it seems more probable that the Great Smoky is older than the fine-grained rocks here as well as to the northeast, whether dipping beneath them or thrust over them. In view of the many faults discovered by the recent work in Sevier County, it is not unlikely that similar faults are present farther southwest, but in the absence of detailed mapping no reasonable guess can yet be made as to their character or distribution. The present map merely indicates the areal distribution of the two rock types without attempting to settle the problem of their mutual relations.

General remarks.-The degree of metamorphism of the Ocoee series is very low to the northwest, even slaty cleavage being lacking in some areas, but it rises steadily to the southeast. Rocks of middle grade lie mostly southeast of the State line in North Carolina, but they just enter Tennessee in southeastern Monroe County and they underlie the Ducktown basin of southeastern Polk County (Mur.). They are not separately shown on the present map.

The coarse-grained rocks of the Great Smoky conglomerate and allied units are resistant to weathering and commonly form rugged mountainous country with large areas of outcrop on the ridges and huge detached blocks, locally called graybacks, choking the streams. The soil is rather thin and stony but it can support a lush forest growth of hardwoods at lower elevations and of conifers, especially balsams, at higher elevations. At the highest elevations, and also in burnt-over or cut-over areas, thickets of rhododendron and mountain laurel are characteristic. The coarse-grained rocks in the Sandsuck shale, on the other hand, because of their prevailing carbonate cement, tend to weather fairly deeply, freeing the pebbles and sand they contain, so that good outcrops are relatively less common; they form lower but still steep linear mountain ridges, mostly rather short and separated by lower ground that is underlain by the main part of the Sandsuck shale. The massive Pigeon siltstone is fairly resistant to mechanical weathering but characteristically decays spheroidally to considerable depth; outcrops are common in the valleys, however. The Pigeon underlies steep hilly country of moderate relief, the ridge crests rising to a common level and the valleys being mostly narrow. Excepting the Nantahala slate, the bodies of shale and slate in the Ocoee series also weather deeply, but the weathered rock is covered by a fairly thin soil full of small shale chips; these rocks underlie low hills or small open valleys. The Nantahala slate is resistant to chemical decay, exhibits many outcrops, underlies sharp serrate ridges and narrow valleys, and forms some of the highest peaks in the area. The soil over the siltstone, slate, and shale (again excepting the Nantahala), though generally acid, is relatively fertile enough to support scattered farms.

Good exposures of the Ocoee series are fairly common, particularly in the gorges of the several rivers that cross the mountain belt from the Pigeon River to the Ocoee River, both of which have cut especially continuous sections. Several of the trails up the north face of the Great Smoky Mountains also traverse good sections. In the foothill belt exposures are abundant along many of the roads and smaller streams, but they are more scattered and, because of the complex folding and faulting, are not readily linked into sequence.

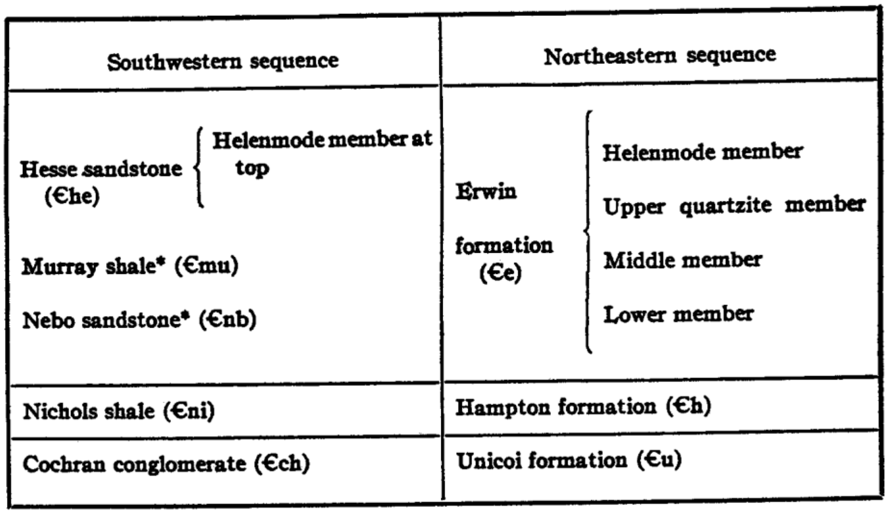
The age of the Ocoee series has long been a matter of dispute (see King, 1949b, table 2, p. 623). It can now be considered established that the series underlies, perhaps disconformably, the Lower Cambrian Chilhowee group. In the absence of further evidence of age and because most of the Ocoee rocks show signs of rapid deposition, the compiler would prefer to leave the age indefinite. The U. S. Geological Survey classes the Ocoee series as pre-Cambrian (?).

The Ocoee series will need much more detailed investigation before its stratigraphy and structure are thoroughly understood. Such work is now in progress in the Great Smoky Mountains National Park and at Ducktown and is planned for the area northeast of the Park, between the Pigeon and French Broad Rivers. A vast area for future study remains between the Park and Ducktown and on into Georgia, but unfortunately that work will be very difficult because of the thick gradational units, the absence of fossils or distinctive key beds, the probably complex faulting, and the inaccessibility of the country.

UNICOI FORMATION (∈u) AND COCHRAN CONGLOMERATE (∈ch)

Overlying the Ocoee series and the Mount Rogers volcanic group, or, where they are absent, the crystalline complex, is the Chilhowee group of detrital rocks, which forms most of the mountains east of the Valley in northeast Tennessee and also several outlying mountains in front of the main ranges farther southwest. Safford (1856, pp. 152-153; 1869, pp. 198-203) named these rocks the Chilhowee sandstone for Chilhowee Mountain (Knox. and Loud.), the outlying mountain in front of the Great Smoky Mountains. Keith later subdivided Safford's Chilhowee sandstone into two correlative sequences of named formations, a southwestern sequence named in the Knoxville folio (1895, p. 3) for localities on Chilhowee Mountain, and a northeastern sequence named in the Cranberry folio (1903) for localities in northeast Tennessee. The formations in these two sequences are now considered to form the Chilhowee group. The group is distinguished from the Ocoee series below by the far greater regularity of its units and to a considerable extent by the higher quartz content of its coarser rocks; there may also be a disconformity at the contact (pp. 27, 29). The upper contact of the group is marked by a sharp change from dominantly detrital rocks below to dominantly carbonate rocks above. On the present map the group is everywhere divided into three major units, described in the present and the two following chapters. Table 3 shows the relation of the formations in the group.

TABLE 3.—*Formations of the Chilhowee group*



Southwestern sequence	Northeastern sequence
Hesse sandstone (€he) { Helenmode member at top Murray shale* (€mu) Nebo sandstone* (€nb)	Erwin formation (€e) { Helenmode member Upper quartzite member Middle member Lower member
Nichols shale (€ni)	Hampton formation (€h)
Cochran conglomerate (€ch)	Unicoi formation (€u)

*The reasons for correlating these formations with the Erwin formation rather than with older formations are given on page 40.

Keith used the southwestern sequence of names as far northeast as the Roan Mountain folio (1907b), but recent workers (King and others, 1944; Ferguson and Jewell, 1951) have found the northeastern sequence more useful and have carried it southwest to the Pigeon River (Mt. G.). On the present map the northeastern set of names is used for the almost continuous belt of outcrops reaching southwest to Cosby, Cocke County (Mt. G.), a few miles west of the Pigeon River, and the southwestern set is used for the outlying ranges from English Mountain (Mt. G.) southwestward. Actually, however, the differences between the rocks of the two sequences are far less than the totally different terminology would suggest. A standard section for the northeastern sequence is provided by the gorge of the Doe River through Iron Mountain just northwest of Hampton (Roan M.) (King and others, 1944, fig. 5, sec. B), and for the southwestern sequence by the gorge of the Little River through Chilhowee Mountain 8 miles east of Maryville (Knox.) (Swingle, ms.).

The Unicoi formation was named (Campbell, 1899, Bris. f., p. 3; Keith, 1903, Cran. f., pp. 4-5) for Unicoi County, Tenn., but when Keith came to map that county (1905, Greene. f.; 1907b, Roan M. f.) he used the name only along the State line near the Nolichucky River and to the northeast. Nevertheless he mentioned (1907b, p. 5) the fine section of the Unicoi, as now understood, along the Nolichucky River 4 miles south of Erwin (Roan M.), and that section may be taken as the type (King and others, 1944, fig.6, sec. G; Lowry, ms.). The Cochran conglomerate he named in the Knoxville folio (1895, p. 3), but he first mentioned the locality in the Asheville folio (1904, p. 5), where he calls it "Cochran Creek, on Chilhowee Mountain, in the Knoxville quadrangle." Wilmarth (1938, p. 478) adds "Sevier Co., Tenn., on S slope of Chilhowee Mtn." The only Cochran Creek shown on maps available to the compiler, however, is on the south side of Chilhowee Mountain in Blount County, just east of the Little Tennessee River (Loud.; see Tallassee 7 1/2-minute quadrangle). The Cochran conglomerate makes the crest of the mountain northwest of the lower course of the creek, and that area may be taken as the type locality.

Keith was not entirely consistent in his mapping of these formations. In several places in the Asheville folio (1904) he mapped beds now assigned to the Unicoi formation as a quartzite lentil in the Nichols slate or even as Nebo quartzite. In the Roan Mountain folio (1907b) he mapped much of the Unicoi as Hiwassee slate and Snowbird formation, as he thought those formations were equivalent to the lower part of the Unicoi, including the beds carrying amygdaloidal basalt. Safford (1869, pp. 195, 201) likewise varied in his usage, placing the beds in the Ocoee where they are obviously conglomeratic, as along Laurel Creek north of Laurel Bloomery (Cran.), but retaining them in the Chilhowee where they are more quartzitic, as along Doe River northwest of Hampton (Roan M.) (cf. his secs., pp. 195-196 and 201). In present usage, the top of the formation is taken at the top of the conglomeratic beds, whether quartzitic or not, beneath a fairly persistent layer of argillaceous shale that has been recognized in most of the areas recently studied.

The Unicoi formation and the Cochran conglomerate have a common lithology, though the Unicoi is more heterogeneous. The upper part of each is dominated by feldspathic coarse sandstone and fine conglomerate, ordinarily strongly indurated by vitreous quartz cement. Shale and siltstone layers, though present, are in minor amount. In the lower part of each, silty shale and feldspathic siltstone become more prominent; highly feldspathic sandstone and conglomerate still prevail but generally they are less well indurated, range from fine sandstone to cobble conglomerate, and show much poorer sorting. In the lower part of the Unicoi some layers have dark argillaceous matrix and approach graywacke; others, chiefly fine-grained, are composed of dark-greenish uniformly massive rock containing a large proportion of ilmenite. These beds somewhat resemble the typical Pigeon siltstone, but commonly they show thin seams of sand and pebbles. Both formations have small amounts of red and purple shale and siltstone, especially in their lower parts. Beds of basalt are present sporadically in the Unicoi formation from the Virginia line to the Nolichucky River. Two zones of such beds appear to be present, one near the middle of the formation and one near the base, but each zone consists of a series of lenses, commonly overlapping, rather than a single layer. The rock is dark green and aphanitic, and typically is amygdaloidal.

In northeast Tennessee the Unicoi formation ranges in thickness from 2,000 feet, as on the Doe River southeast of Hampton (Roan M.), to 5,000 feet, as on the face of Iron Mountain northwest of Laurel Bloomery (Cran.). In these sections both top and base are present, and the variation probably results from deposition on an uneven floor. A similar range has been found in the Del Rio area of Cocke County (Mt. G. and Ashe.). The thickness of the Cochran conglomerate, on the other hand, is less than 2,000 feet and generally closer to 1,000. As noted in the discussion of the Sandsuck shale, it is possible that some beds in the lower part of the Unicoi where the formation is thickest are equivalent to the Sandsuck rather than to the Cochran.

The upper parts of the Unicoi formation and the Cochran conglomerate are very resistant to weathering and crop out as bold cliffs along the crests of the mountains they uphold. The lower parts, however, weather more deeply and outcrops are generally poor; the soil over them is commonly dominated by blocks from the nearby ridges. The Unicoi is well displayed in several sections in northeast Tennessee (King and others, 1944, figs. 5 and 6); there are good sections also along Spring Creek just south of Hot Springs, N. C. (Ashe.), and along the Pigeon River northwest of Hartford (Mt. G.). The Cochran conglomerate is present at the

Little River gorge through Chilhowee Mountain (Knox.), but there it is only partly exposed; better sections can be found on the face of Chilhowee Mountain to the northeast, on the south side of English Mountain (Mt. G.), and on several roads up Bean Mountain (Cleve.).

No fossils have been found in the Unicoi and Cochran but they form an integral part of the Chilhowee group and have generally been classed as Lower Cambrian by workers in Tennessee. The argument for this age assignment is given by King (1949b, pp. 636-638).

HAMPTON FORMATION (∈h) AND NICHOLS SHALE: (∈ni)

The Hampton shale was so named (Campbell, 1899, Bris. f., p. 3; Keith, 1903, Cran. f., p. 5) for Hampton, Carter County (Roan M.), but as it is by no means wholly shale, King and others (1944, p. 28) have called it the Hampton formation. Good sections of the formation are present along the Doe River both northwest and southeast of Hampton; the section to the northwest is more typical (King and others, 1944, fig. 5, sec. B). The Nichols shale (later called Nichols slate by Keith) was named (Keith, 1895, Knox. f., p. 3) for Nichols Branch of Walden Creek at the east end of Chilhowee Mountain (Knox.).

Both the Hampton formation and the Nichols shale include much dark silty and sandy shale and some argillaceous shale, commonly well laminated and containing abundant flakes of detrital mica, but the Hampton is diversified by thick bodies of feldspathic sandstone, some of it well cemented by vitreous quartz and approaching an impure quartzite. The sandstone is normally medium-grained, but some is coarse or even finely conglomeratic; it is generally darker than the purer quartz sandstone of the Erwin formation. Some of these bodies of sandstone are lenticular, but others are persistent, and in some areas a middle quartzite member of the Hampton formation has been mapped (Rodgers, 1948; Ferguson and Jewell, 1951; Oriel, 1950). In the Asheville folio (1904), Keith likewise mapped a quartzite lentil within the Nichols, but he was not entirely consistent in his mapping and sometimes mistook the upper part of the Unicoi formation for this lentil. The Nichols shale southwest of the Pigeon River is much more uniform, but relatively thin beds of similar feldspathic sandstone have been found near the east end of Chilhowee Mountain (Knox.) and on Bean Mountain (Cleve.).

The thickness of the Hampton formation normally ranges between 500 and 1,500 feet, but in a few places reaches 2,500 feet or more. In general the greater thicknesses are in the higher thrust sheets, those that presumably lay farthest southeast before deformation. The thickness of the Nichols shale is 800 to 1,000 feet.

The shale of the two formations weathers deeply, though the soil above it is thin and full of shale chips. Commonly it underlies short strike valleys or sags on transverse ridges and is covered by stony wash from adjacent more resistant units. The sandstone layers of the Hampton formation are more resistant, and some of the quartzitic layers form mountain crests for considerable distances. Outcrops are fairly common, particularly along transverse stream valleys. In addition to those along the Doe River near Hampton, fine sections are exposed along the Watauga (Roan M.), Nolichucky (Roan M.), Pigeon (Mt. G.), and Little (Knox.) Rivers, along roads climbing Starr and Bean Mountains (Mur. and Cleve.), and along U. S. Highway 421 on Holston Mountain and on Iron Mountain, on either side of Shady Valley (Cran.). The section on Holston Mountain is somewhat misleading, however, for the sandstone beds that normally mark the base of the Erwin formation are absent here, though present a few miles away along the strike in either direction, so that the thick shaly section exposed on the highway includes not only the Hampton formation but also more than half the Erwin (see King and others, 1944, p. 33; also fig. 6, sec. L).

The only fossils reported from the Hampton formation are tubes like *Scolithus*, some of which differ from the typical *Scolithus* tubes of the Erwin formation in being smaller, shorter, and irregularly bent. No fossils are reported from the Nichols shale. Like the Unicoi formation and the Cochran conglomerate, the Hampton and Nichols have generally been classed as Lower Cambrian.

ERWIN FORMATION (∈e) AND EQUIVALENT ROCKS

Keith (1903, Cran. f., p. 5) named the Erwin quartzite for Erwin, Unicoi County (Roan M.), but as quartzite, though conspicuous, makes up less than half the formation, King and others (1944, p. 28) have called it the Erwin formation. A good section is exposed along the Nolichucky River 3 miles south of Erwin (King and others, 1944, fig. 6, sec. G; Lowry, ms.). King and others (1944, pp. 31-33) have divided the formation in northeast Tennessee into four members, in ascending order the lower (quartzite) member, the middle (fine-grained) member, the upper quartzite member, and the Helenmode (mainly fine-grained) member, the last named for the Helenmode pyrite mine in Stony Creek Valley northeast of

Elizabethton (Roan M.). Keith (1895, Knox. f., p. 3) described three formations above the Nichols shale on Chilhowee Mountain, namely (in ascending order) the Nebo sandstone (∈nb), the Murray shale (∈mu), and the Hesse sandstone (∈he). (Keith later called them Nebo quartzite, Murray slate, and Hesse quartzite.) The Nebo was named for Mount Nebo Springs on Chilhowee Mountain just west of the Little River gorge (Knox.), where the Nebo sandstone forms the crest of the mountain. According to Keith, and also Wilmarth (1938, p. 1453), the Murray was named for Murray Branch of Walden Creek, presumably at the east end of Chilhowee Mountain, but no branch of that name can be found on available maps. On the other hand, the Murray shale is well exposed in Murray Gap on Chilhowee Mountain above Montvale Springs (Knox.; not the Murray Gap 4 miles east of the Little River gorge), and indeed fossils have been reported from this locality (Keith, 1895, p. 3). The Hesse sandstone was named for Hesse Creek, which cuts the formation at the southwest end of Miller Cove (Knox.).

Keith has indicated two different correlations of the Hesse, Murray, Nebo, and Nichols formations with the Erwin and Hampton formations of northeast Tennessee. In correlation tables in the Asheville (1904), Mount Mitchell (1905b), and Roan Mountain (1907b) folios, and on the map explanation of the last-named, he correlated the Hesse alone with the Erwin and the Murray, Nebo, and Nichols with the Hampton; yet in a similar correlation table in the Cranberry folio (1903), and in the text of the Roan Mountain folio (1907b, pp. 5, 6), the only folio in which both sets of units were mapped and described, he correlated the Hesse, Murray, and Nebo with the Erwin and only the Nichols with the Hampton. Comparison of the sequence on Chilhowee Mountain with that in northeast Tennessee shows clearly that the latter correlation is correct, and as the Helenmode member can be recognized and mapped as a member at the top of the Hesse sandstone on Chilhowee Mountain and around Miller Cove (Knox.) (Ferguson, ms. a; Swingle, ms.; Tucker, ms.), each of the members of the Erwin formation is represented by a mappable unit there. (Correlation of the Nebo sandstone with the upper part of the Unicoi formation [Stose and Stose, 1947,-p. 629; 1949, pp. 299-3001 is quite unjustified and presumably stems from failure to recognize the transverse fault in the Little River gorge [Knox.].)

The Erwin formation and its equivalents consist of thick beds of white vitreous quartz-cemented sandstone (quartzite) interbedded with bodies of dark greenish silty, sandy, and locally argillaceous shale mixed with shaly siltstone and very fine sandstone. The grains in the white sandstone beds are generally of medium-sand size, though they range from fine sand to very fine pebbles (granules), are almost entirely quartz, and commonly are remarkably well rounded. Feldspar is rare, but glauconite is fairly common, especially in the upper part and in the Helenmode member. Tubes of *Scolithus* are very abundant in many of these beds. The fine-grained rocks are generally well laminated and commonly show flakes of detrital mica. Locally the shaly siltstone and sandstone beds approach impure quartzite.

In northeast Tennessee, individual quartzitic beds in the Erwin formation reach thicknesses as great as 50 feet, but even in the quartzitic members they are interbedded with shale and siltstone, and in the fine-grained members they are uncommon, so that in general they form only a small part of the formation. Locally, however, especially within the Mountain City window (Cran. and Roan M.), they form a larger part, and in the Nebo and Hesse sandstones they greatly predominate over the fine-grained rocks. In northeast Tennessee there is a suggestion that the proportion of clear quartz sandstone decreases from lower to higher thrust sheets; hence it may have decreased southeastward across the original basin of deposition.

The thickness of the Erwin formation is generally close to 1,300 feet, but it ranges from 1,000 to 1,500. There is a tendency for it to be thick where the Hampton formation below is thin, but there are also many exceptions. The equivalent formations total about 1,300 feet on Chilhowee Mountain (Knox.) but probably less than 1,000 feet on Starr and Bean Mountains (Mur. and Cleve.). The Helenmode member rarely exceeds 100 feet, so far as known.

The quarzitic sandstone beds of these formations are resistant to weathering and develop no proper soil of their own; they are important ridge-makers and contribute vast numbers of blocks to colluvial and alluvial deposits. The interbedded shale and siltstone are less resistant but produce only a thin chippy soil. The Helenmode member is commonly very deeply leached, presumably because of its position between the thick soluble carbonate rocks of the Shady dolomite and the generally impervious quartzitic beds of the Erwin or Hesse formation. In most places, moreover, it is hidden beneath slope wash from underlying quartzite forming an adjacent ridge and makes no contribution to the soil or the topography. Except for the Helenmode member, the Erwin and its equivalents crop out in many places, especially in transverse stream valleys. Good sections are exposed along the Watauga, Doe, and

Nolichucky Rivers (Roan M.) in northeast Tennessee and also along the Pigeon River (Mt. G.), the Little River section (Knox.) is complicated by faulting, but the units can be seen along Chilhowee Mountain on either side.

Lower Cambrian fossils were found by Walcott and his collectors (Walcott, 1890, pp. 536-537, 570, 626; 1891, pp. 154, 302) in the top beds of the Erwin and Hesse formations, presumably chiefly in the Helenmode member, in Tennessee and Virginia, and also in the Murray shale at Murray Gap (Knox.). Except for *Scolithus* these are the oldest fossils recorded in East Tennessee.

SHADY DOLOMITE (∈s)

The Shady dolomite, which occurs in strips and patches associated with the rocks of the Chilhowee group all along the east side of the State, is the one major unit in Tennessee stratigraphy that Safford failed to recognize, though he mentioned the common occurrence of "jaspery rock in this horizon, especially when in the vicinity of a Chilhowee sandstone mountain" (1869, p. 209). Keith likewise mistook it for the Knox dolomite in the early folio mapping and therefore postulated nonexistent unconformities (Keith, 1892; 1895, Knox. f.). Its existence was finally discovered by Keith in mapping the Stony Creek syncline northeast of Elizabethton (Roan M.), and he named it (1903, Cran. f., p. 5) for Shady Valley (Cran.), a basin on the northeastward extension of that syncline. On the present map it is used as conceived by Keith.

The Shady dolomite is the lowest of the several thick carbonate formations that have formed the Valley of East Tennessee; it is confined, however, to the southeast margin of the Valley. Some of the dolomite is white and pure, some blue gray and slightly silty. Limestone is present locally in the lower part; detrital material is confined to a few sandy layers close to the base and thin but persistent layers of argillaceous shaly dolomite in the upper part, the latter being especially prominent in the southwestern areas such as those in Miller Cove (Knox.) and around Tellico Plains (Mur.). Chert is common in the upper part and occurs below also in some areas.

A consistent sequence of units can be worked out in the Shady dolomite in some areas, notably Stony Creek Valley (Roan M.) (King and others, 1944, pp. 18-21). Here much of the lower third of the formation is prominently "ribboned," the ribbons being the surface expression of thin alternating layers of lighter coarser-grained and darker finer-grained dolomite. In the upper part of the formation is a unit of massive white dolomite overlain by one of the persistent layers of shaly dolomite. In other areas, however, no such sequence can be recognized. No subdivisions of the Shady dolomite are shown on the present map. The thickness of the formation averages about 1,000 feet.

Characteristically, the Shady dolomite weathers very deeply, producing a yellow "buckfat" clay containing little silt. Soil-forming processes convert the surface layer of this clay into a red-brown soil. The yellow clay commonly contains masses of jasperoid (gray to yellow-brown fine-grained silica) and, less commonly, nodules of iron and manganese oxides. (For further details and interpretations, see King and others, 1944, pp. 22-27, 52-59; Kesler, 1950, pp. 47-50, 53-57; Rodgers, 1948, pg. 13-17, 37-42.) The Shady normally underlies foothill ground beside mountains upheld by the Chilhowee group or hills of the Rome formation, but the ground is by no means flat, partly because of bodies of gravel slope wash from the mountains. Exposures of the dolomite are not common, but they do occur along the major streams crossing the outcrop belts, notably along the Watauga River in Johnson and Carter Counties (Cran. and Roan M.), and in lower Stony Creek Valley in Carter County (Roan M.), where a section can be pieced together. The dolomite is also well exposed in Miller Cove in Blount County (Knox.) and around Tellico Plains in Monroe County (Mur.). The Shady has yielded no fossils in Tennessee, but fossils collected in Virginia and Georgia leave no doubt of its Early Cambrian age.

ROME FORMATION (∈r)

The Rome formation is the lowest formation that is exposed widely across the Valley of East Tennessee; it is also almost the highest that occurs within the belt of mountains on the east side of the valley. In only a very few places, therefore, is there a continuous sequence from beds below it to beds above it, the most important being in the Stony Creek syncline northeast of Elizabethton (Roan M.). The formation was named for Rome, Floyd County, Ga. (Hayes, 1891, P. 143; Walcott, 1891, p. 304). As originally defined, it extended downward from the highest of several prominent sandstone beds below the Conasauga shale, the base of the Rome being concealed by faulting. Later, however, Hayes and Keith extended the name to include the layers above the sandstone beds up to the base of the first blue limestone bed, and in general they mapped two portions: "Rome shale" above the top of the sandstone beds in question, and "Rome sandstone" below. In the Estillville (1894a) and Bristol (1899) folios, Campbell called virtually the same beds the Russell formation. In certain belts, Hayes and Keith recognized below the sandstone unit a unit of variegated shale with no sandstone, which they termed the Apison shale, from Apison, Hamilton (formerly James) County (Chatt.; Hayes, 1894a, Ring. f., p. 1); in other areas, however, as in Way Ridge in Hancock County (Morr.), equivalent rocks were included in the Rome formation. For the present map, the compiler has returned to the original usage, considering the Apison shale as a locally mappable member of the Rome formation, but excluding the overlying "Rome shale," which belongs rather to the Conasauga group. In this usage, the Rome formation corresponds to Safford's Knox sandstone (1869, pp. 209-210). On the present map, the Apison member of the Rome formation (∈ra) is mapped separately only in the type belt and closely related belts east of the Whiteoak Mountain fault from the Georgia line north a little past the Hiwassee River (Chatt. and Cleve.); in these areas the remainder of the Rome is called the sandstone-bearing member (∈rs).

The base of the Rome formation is not exposed in the type area or anywhere else away from the mountains along the east side of the Valley. In northeast Tennessee, when Keith recognized the Shady dolomite, he called (Keith, 1903, Cran. f., p. 5) the overlying red shale and dolomite the Watauga shale, for the Watauga River in Johnson and Carter Counties (Cran. and Roan M.). It has since been recognized that his Watauga shale is a phase of the Rome formation, and the older name, Rome formation, is now used. The base of the Rome in this area is ordinarily drawn beneath the lowest red shale, though yellow or black shale interbedded with massive dolomite may occur as much as 100 feet lower.

The Rome formation is a heterogeneous and variegated mixture of sandstone, siltstone, shale, dolomite, and limestone. The proportions vary greatly. To the northwest, shale and siltstone predominate, but there are several prominent sandstone beds and locally one or two fine conglomerate layers; carbonate rocks are present but to a minor extent. To the southeast, on the other hand, especially in northeast Tennessee, dolomite of the "Watauga phase" makes up as much as half the unit, and sandstone is wanting, showing that the main source of detrital material was to the northwest. The distribution of color is likewise variable; red or maroon predominates in the shale and siltstone to the southeast but is subordinate in amount, though still prominent, to the northwest, except in the brightly colored lower part (Apison shale member).

Olive green, light green, purple, and brown also occur, and some of the sandstone beds weather orange or yellow. The carbonate rocks are dark gray to the northwest, generally lighter to the southeast. Keith (1895, Knox. f.) mapped a dolomite bed 300 feet thick on the Bays Mountain south of Knoxville (Knox.) as the Beaver limestone, named from Beaver Ridge northwest of Knoxville (Brice., Mayn.), but he did not map its type area separately from the rest of the Rome, and the name is now abandoned.

In Claiborne, Hancock, and northern Grainger Counties (Mayn. and Morr.) a sequence of units in the Rome formation has been worked out (Rodgers and Kent, 1948, pp. 4-7), but not enough has been done to determine how far southwest or southeast these units can be traced. These subdivisions are not shown on the present map. The stratigraphy of the Rome is one of the major outstanding problems of East Tennessee stratigraphy; its study will be difficult because the Rome occurs chiefly just above major thrust faults and hence is commonly folded and imbricated and shows no base, and because fossils are comparatively scarce. The thickness of the Rome in northeast Tennessee is 1,200 feet or more; elsewhere the base is missing and the thickness is unknown, though it is certainly more than 700 feet in many places.

The different rock types in the Rome formation weather differently, but ordinarily the sandstone and siltstone beds dominate the residuum and soil, which is only a shallow mantle full of rock chips. The carbonate rocks weather more deeply and locally form bodies of yellow generally silty clay with a red-brown soil layer. The Rome forms characteristic knobby or comby ridges, commonly covered with pines (and commonly called Pine Ridge or Comby Ridge), especially to the northwest where sandstone beds are prominent. The Rome is well exposed in many road and railroad cuts through the many water gaps in these ridges; an excellent exposure is that along U. S. Highway 25E where it cuts the end of War Ridge north of Thorn Hill (Morr.). To the southeast the Rome forms knobby hills with less conspicuous alignment. The best section of the southeastern phase is along the Doe River near Valley Forge, Carter County (Roan M.).

Fossils of both Early and Middle Cambrian age are reported from the Rome formation. It is the compiler's belief that the Middle Cambrian fossils come from the "Rome shale" unit of Hayes and Keith and hence should be assigned instead to the Conasauga group, and that most if not all the Rome as here mapped is of Early Cambrian age.

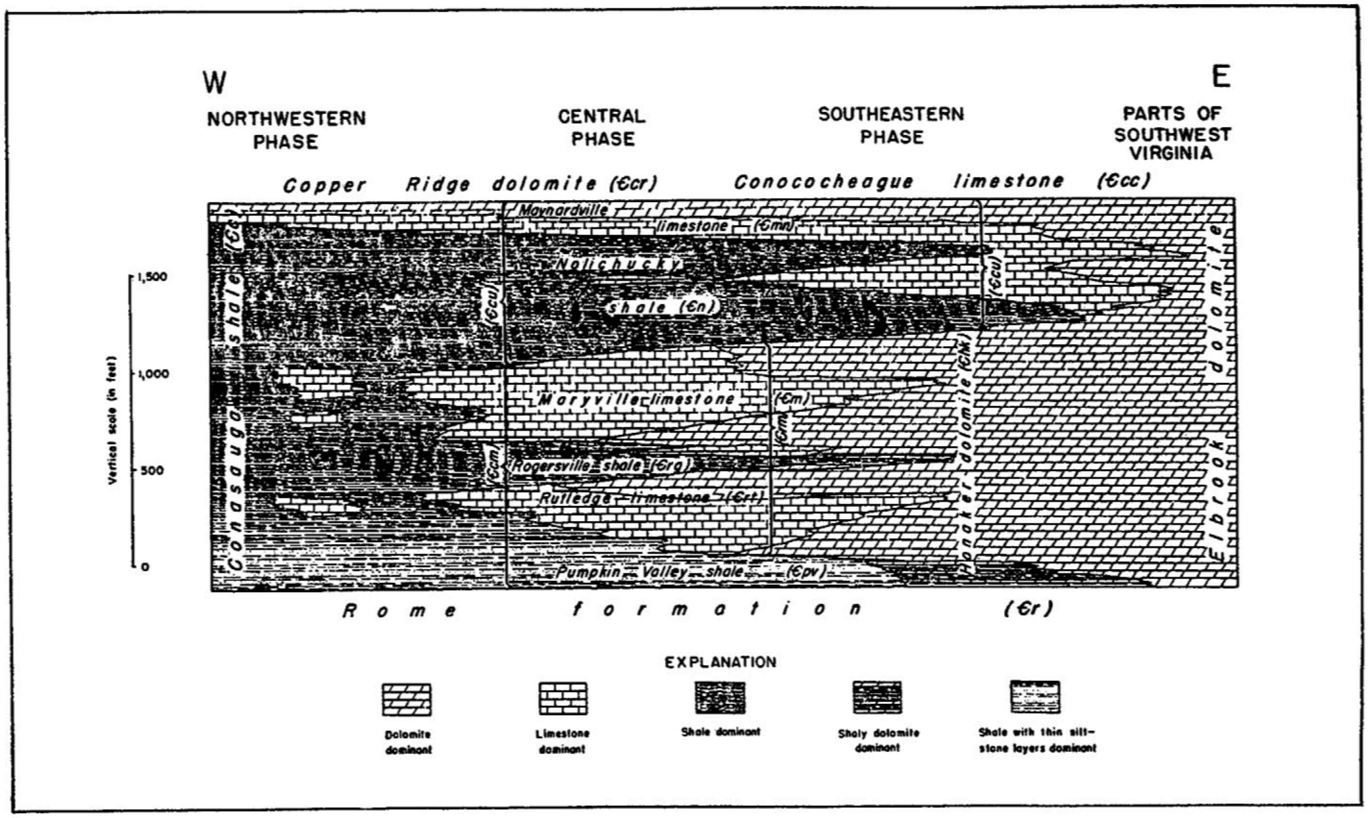


FIGURE 3. Facies relationships in the Conasauga group and equivalent rocks in East Tennessee and southwest Virginia.

CONASAUGA SHALE OR CONASAUGA GROUP (∈c)

Name, contacts.-The Conasauga shale was named for the Conasauga River in Whitfield and Murray Counties, Ga. (Hayes, 1891, p. 143; Walcott, 1891, p. 304), in the outcrop belt that the river follows where it leaves Tennessee (Cleve.). In that area the formation is dominantly shale but contains many layers and lenses of blue-gray limestone. Similar shale is present in the southern and northwestern parts of the Valley of East Tennessee. In a wide belt extending east and southeast to the Pulaski fault from a diagonal line passing approximately through Madisonville (Loud.) and a little west of Knoxville (Knox.) and Tazewell. (Mayn.), the corresponding rocks consist of a sequence of six named formations, alternately shale and limestone, which form the Conasauga group West of this belt, certain of the units, but generally not the full sequence, can be recognized locally; those that can be mapped may there be considered members of the Conasauga shale. Eastward within the belt dolomite appears in the limestone units, and east of the Pulaski fault it dominates the sequence, especially in the lower half or so (the Honaker dolomite); one after another of the shale units thins to disappearance until in parts of southwest Virginia the whole is carbonate rock with some shaly dolomite beds (the Elbrook dolomite). The interrelation of the named formations and of the 11 map units used on the present map is shown on figure 3.

Because of this lithologic variation in the Conasauga group across the Valley, three separate phases are described below: a northwestern phase largely of shale, a central phase of alternating shale and limestone formations occupying the wide belt mentioned above, and a southeastern phase principally of dolomite but still including some limestone and a little shale. The distribution of these phases leaves no doubt that the source of the mud that formed the Conasauga shale was to the northwest. Because it was assumed that the mud must have come from the southeast, the relations of the formations of the Conasauga group were reversed in the pertinent columns of the recent Cambrian correlation chart and in the widely copied diagram on that chart (Howell and others, 1944).

The base of the Conasauga is here drawn at the top of the highest prominent sandstone bed of the Rome formation, as discussed above. The top of the Conasauga shale of Hayes and Keith and of the corresponding Knox shale of Safford (1869, pp. 210-214) was drawn at the base of the unbroken carbonate sequence that includes the Knox dolomite, but on the present map it is drawn somewhat higher, above instead of below the Maynardville limestone. The reasons for this change are:. (1) the Maynardville consists partly of limestone indistinguishable from that in the Maryville and Rutledge limestones of the Conasauga group but unlike most of the limestone in the overlying Knox dolomite, and partly of light-colored dolomite such as occurs in both the Honaker and Knox dolomites; (2) residuum from the Maynardville limestone, like residuum from the other limestone units in the Conasauga group, contains little or no chert, whereas residuum from the Knox dolomite normally contains much chert. To the northwest the top of the Maynardville is taken beneath the lowest bed of the characteristic dark massive coarse-grained chert-producing dolomite of the Copper Ridge dolomite; to the southeast beneath a prominent group of sandstone beds taken as the base of the Conococheague limestone.

Northwestern phase: Conasauga shale.-The Conasauga shale consists of light-green, olive-green,. and dull-purple shale; the light-green is the purest clay-shale, the purple the most silty. Layers and lenses of limestone are common, but seem to be generally irregular in distribution, except near the line of transition to the central phase, recent work by Swingle in Bradley County shows, however, that they may be more regular than has been thought (personal communication). The limestone resembles that in the Maryville and Rutledge formations, described beyond, except that shale partings are more abundant. Limestone is lacking, however, in the basal part of the formation, where purple shale is commonest and is associated with thin siltstone layers. This part of the formation can generally be mapped separately; it was mapped as the "Rome shale" by Hayes and Keith, but is better classed as the Pumpkin Valley member of the Conasauga shale. At the top of the formation, between the shale and the base of the Copper Ridge dolomite, is a persistent member of thin-bedded blue-gray limestone and gray fine-grained dolomite, the Maynardville limestone member of the Conasauga shale. Locally, especially near the east margin of the phase, prominent silty limestone or limy siltstone layers above the middle of the formation represent a westward projection of the top of the Maryville limestone and can be used to divide the formation into Middle and Upper Cambrian portions (∈cm and ∈cu). The thickness of the Conasauga shale is unknown as it is everywhere very much crumpled, but it may be estimated at 2,000 feet or a little more.

The Conasauga shale weathers generally to a thin acid soil full of shale chips, but where limestone is present the soil is prevailingly deeper and richer. The shale normally forms valleys; these are somewhat broken by lines of low hills to the northeast, especially where the silty limestone corresponding to the top of the Maryville limestone forms a line of knobs, but they are flat and poorly drained to the southwest, where they resemble the "flatwoods" country of northwest Georgia and northeast Alabama. The more silty shale near the base of the Conasauga commonly underlies rolling country or low hills. Small scattered exposures of the shale are fairly common along roads and streams, but the complex structure normally prevents the measurement of sections. Fossils from the Conasauga shale show that it spans most if not all of Middle Cambrian time and the earlier (Dresbach) part of Late Cambrian time.

Central phase: Pumpkin Valley-Maynardville sequence. - Between Knoxville and Morristown, and north of Clinch Mountain, the Conasauga group consists of a sequence of six formations, as shown in table 4.

The shale units of this sequence resemble the Conasauga shale of the northwestern phase in most respects. The Rogersville shale on weathering has an especially bright green color, which is distinctive. The Pumpkin Valley shale is characterized particularly by dull-olive and purple colors and by thin beds of siltstone, but both these characteristics are also shown locally by the Nolichucky shale.

The limestone units of the Conasauga group in this phase consist of fairly massive blue limestone, most of which has a characteristic ribboned appearance caused by thin irregular layers of more silty and dolomitic rock, which weathers brown. Other beds of limestone are oolitic, and still others show edgewise conglomerate. Shale partings are uncommon. In addition to the limestone units listed above, limestone of the same character forms the Craig limestone member (Rodgers and Kent, 1948, p. 10) near the top of the Rogersville shale, and also a layer or, more probably, a persistent series of lenses at about the middle of the Nolichucky shale. Both shale and limestone are especially silty close to the contact between the Maryville limestone and the Nolichucky shale. Approximately the upper half of the Maynardville limestone consists of light-colored thin-bedded well-laminated fine-grained dolomite, with one or two layers of limestone. Dark crystalline dolomite occurs in place of limestone at the top of the Rutledge and the base of the Maryville from about the middle of the phase southeastward, and near the east margin it occurs also at other positions in these two

TABLE 4.—*Formations of the Conasauga group (central phase)*

Name	*Type locality*	*Original reference*	*Thickness (in feet)*	*Symbols used on present map*			
Maynardville limestone.	Maynardville, Union County (Mayn.).	Oder, 1934, pp. 475–476; see Rodgers and Kent, 1948, pp. 11–12.	150–350	€mn		€cu	€c
Nolichucky shale.	Nolichucky River, Greene County (Greene.).	Campbell, 1894a, Est. f., p. 2; Keith, 1905a, Greene. f., p. 5.	750–400	€n			
Maryville limestone.	Maryville, Blount County (Knox.).	Campbell, 1894a, Est. f., p. 2; Keith, 1895, Knox. f., pp. 3–4.	250–650	€m	€rm	€cm	
Rogersville shale.	Rogersville, Hawkins County (Morr.).	Campbell, 1894a, Est. f., p. 2; Keith, 1896b, Morr. f., p. 2.	250– 0	€rg			
Rutledge limestone.	Rutledge, Grainger County (Mayn.).	Campbell, 1894a, Est. f., p. 2; Keith, 1901, Mayn. f., p. 2.	100–500	€rt			
Pumpkin Valley shale.	Pumpkin Valley, Hawkins County (Morr.).	Rodgers and Kent, 1948, pp. 7–9.	400–200	€pv			

formations. Measurements show that in general the shale units thicken westward and northwestward and the limestone units, including those within the Rogersville and Nolichucky shales, thicken eastward and southeastward; this complementary relation is expressed by the arrangement of thickness figures in table 4 and is shown also by figure 3.

The shale units weather to a thin acid soil full of shale chips, the limestone units to deep-red or orange-red soils free of chert, except where chert is washed in from the overlying Knox group. In general the shale units form lines of low knobs, and the limestone units form valleys full of sinks, but where a stream follows the strike it commonly flows in shale, leaving the adjacent limestone units as rocky bluffs overlooking its flood plain. Everywhere the most prominent line of knobs is close to the Maryville-Nolichucky contact. Good exposures of these units are abundant and complete sections are fairly common, especially north of Clinch Mountain. Fossils show that the contact between the Maryville limestone and the Nolichucky shale is approximately the contact between the Middle and Upper Cambrian series.

Southeastern phase: Honaker dolomite, Nolichucky shale, and Maynardville limestone.-The southeast boundary of the central phase is marked by the disappearance of the Rogersville shale and the merging of the Maryville and Rutledge formations, here largely dolomite, into the Honaker dolomite (named by Campbell, 1897, Tazewell f., p. 2, for Honaker, Russell County, Va.). In Tennessee this boundary lies under or not far northwest of the Pulaski fault; in southwest Virginia it cuts at an angle northeastward across the strike and reaches the northwest margin of the Valley and Ridge province not far west of Honaker. The dolomite in the Honaker includes all types-light and dark, fine-grained and coarse-grained, shaly and massive-and limestone is also present. The overlying rocks, representing the Nolichucky shale and Maynardville limestone, consist of shale, limy siltstone, silty limestone, and limestone full of dolomite ribbons.

The following sequence may be considered standard for the belts between the Pulaski and Holston Mountain faults, though interbedded layers of other lithologies commonly occur in each unit, and most contacts other than formational boundaries are gradational.

Basal part of Conococheague limestone (∈cc):

Sandstone, medium- to coarse-grained, cross-bedded, fairly massive, interbedded with limestone interlaminated with dolomite -maximum 30 feet:

Maynardville limestone and Nolichucky shale (∈cu):

Limestone, strongly "ribboned" with dolomite; also thicker layers of well-laminated dolomite and thin layers of silty limestone……………………………………………………………………………135 feet,
Siltstone, greenish, limy,.and silty limestone; some shale in northwestern belts………………...80 feet,
Limestone, some "ribboned" with dolomite; also thin beds of dolomite; some silty limestone below…………………………………………………………………………………………235 feet,
Shale, drab green, silty, limy above approaching limy siltstone; thin beds of limestone above…………………………………………………………………………………………150 feet,

Honaker dolomite (∈hk):

Dolomite, dark, fine- to medium-crystalline, massive…………………...…………………..250 feet,
Dolomite, light, thin- to medium-bedded with many layers of blue limestone that are mostly "ribboned"; thin shale layers below……………………………………………………….…500 feet,
Dolomite, dark, massive; a few beds of light dolomite and perhaps of shale, produces much chert………………………………………………………………………….………350 feet,
Dolomite, very shaly, dark, carbonaceous, or dolomitic shale
-thickness uncertain, perhaps 200 feet.

Except southeast of the Holston Valley fault, the shaly dolomite is the lowest rock exposed and it is invariably much crumpled and sheared by movement along the adjacent thrust faults. Near Valley Forge, Carter County (Roan M.), however, this shale grades down into the red shale and siltstone of the Rome formation (southeastern phase). Presumably it represents the Pumpkin Valley shale, but proof is lacking and it has not been separately mapped. The stratigraphy of the Honaker dolomite deserves more attention than it has yet received; failure to recognize the chertiness of the lower dark dolomite led Keith into a number of errors in mapping in the Greeneville (1905a) and Roan Mountain (1907b) folios.

To the northeast in Virginia, the shale units in this sequence thin to disappearance, and there remains only one mapping unit, the Elbrook dolomite.

The Honaker dolomite weathers to a deep clay soil, very cherty over the lower part of the formation but almost free of chert over the upper part. The shale above the Honaker weathers to a thin soil, the limestone to a deep soil containing many siltstone chips. The upper siltstone and silty limestone unit, together with the basal sandstone of the overlying Conococheague limestone, commonly forms a narrow ridge; the shale next above the Honaker, a low rounded bench on one flank of this ridge; the upper part of the Honaker, a broad open valley; and the lower part of the Honaker, a rounded chert-strewn ridge. Exposures of the beds above the Honaker are fairly common, the best being along U. S. Highway 23, 4 miles southeast of Kingsport at Wexler Bend (Greene.), and again 71/2 miles southeast of Kingsport at Halls Mills (Roan M.), in Sullivan County, and along Jockey Creek 1 mile northwest of Limestone (Greene.), in Greene County. Exposures of the Honaker dolomite, except the upper part, are much rarer, and no good sections are known except alone and cast of the Doe River between Elizabethton and Valley Forge, in Carter County (Roan M.).

Fossils are rarer in the Nolichucky shale in this phase and unknown in the Honaker dolomite, except for abundant cryptozoon in the chert. It is thought that the top of the Honaker dolomite is approximately the contact between the Middle and Upper Cambrian series.

KNOX DOLOMITE OR KNOX GROUP (O∈k)

Name, subdivision.-The Knox dolomite probably underlies more of the part of East Tennessee here mapped than any other major unit. It occurs continuously along virtually every one of the main slices into which the valley rocks have been faulted, probably because its relatively competent strata were the controlling struts in that faulting.

The Knox dolomite, the Knox shale (now the Conasauga), and the Knox sandstone (now the Rome), were named by Safford (1869, p. 204) for Knoxville and Knox County, and all of them were included within his Knox or Knoxville group. His typical section of this group, carefully described and discussed (1869, pp. 204-206), was measured along Second Creek at Knoxville. The area is now within the city and not conveniently accessible, but other fairly good sections are available on the same belt, especially to the northeast. The name Knox was restricted to the dolomite unit by E. A. Smith in Alabama and by Hayes and Keith in Georgia and Tennessee at the time of the early folio mapping. For the present map, the unit extends from the top of the Maynardville limestone to the marked disconformity, observable everywhere in East Tennessee, between Lower and Middle Ordovician rocks. The basal contact has been discussed above; the top also differs from that shown in the folios in some areas. North and west of Knoxville, especially along Hinds Ridge (Mayn. and Brice.), Keith included in the Knox dolomite the prominent cherty limestone in the base of the Middle Ordovician series; around Chattanooga, on the other hand, Hayes excluded from the Knox a considerable thickness of fine-grained pure limestone of Early Ordovician age, lying below the disconformity. The considerable relief of the disconformity and the wide variety of basal deposits resting upon it give evidence of a complete cessation of marine deposition and a period of subaerial erosion.

Subdivision of the Knox dolomite has been proceeding for many years and has recently been given great impetus because of its importance in the exploration and development of zinc ore. The first to propose subdivisions within the Knox was E. 0. Ulrich (1911, and many published and unpublished charts); the first to map them was Charles Butts (1926, 1933, 1940). Butts' work, however, was largely in Alabama and Virginia. The first to map subdivisions in Tennessee was Josiah Bridge, who, with C. R. L. Oder, established the present classification for the northwestern part of the Valley. Unfortunately, neither has yet published a full account of his work, but Bridge is preparing a major report on the geology of the Mascot-Jefferson City zinc district to be published by the Tennessee Division of Geology, and that report will set forth the classification and describe the individual formations in detail. In the meantime, the new classification has been used in the field by many geologists and embodied in many recent papers and maps (for early steps in classification, see Oder, 1934; Hall and Amick, 1934; for final form, see Rodgers, 1943; Oder and Miller, 1945; Bridge, 1945; Dunlap and Rodgers, 1945; Rodgers and Kent, 1948). The present text gives a brief summary of the classification and short generalized descriptions of the individual formations.

As pointed out by Oder (1934) and others, the Knox on the northwestern side of the Valley is chiefly dolomite that produces much chert, and on the southeastern side chiefly limestone that produces little chert; thus the classification adopted for the northwestern side is not applicable to the southeastern. Accordingly, two phases of the Knox are discussed separately below. The boundary between them lies along the Pulaski fault, but the belts next to the northwest of that fault, like those near Mosheim (Greene.) and Etowah (Cleve.), show transitional characteristics such as the presence of considerable limestone in the Copper Ridge dolomite.

Where the Knox has been subdivided into formations, it is called the Knox group, but where the subdivision has not been carried out, it is convenient to consider it a formation, the Knox dolomite. As stated above, the subdivision possible on the present map differs from area to area and depends on several factors: the availability of detailed mapping, the degree of topographic expression of individual units, and the intrinsic divisibility of the rock sequence. The result is a rather patchy distribution of areas showing various degrees of subdivision. Table 5 lists the units, their correlation, and the letter symbols that denote them.

Northwestern phase: dominantly dolomite.-The northwestern phase of the Knox group is dominated by generally thick-bedded siliceous dolomite, the silica from which accumulates in the residual clay and soil as chert. The chert and other residual materials associated with each formation are commonly even more distinctive of the formation than the bedrock lithology and, because outcrops of the Knox group are few, are an important tool in separating and mapping the formations within the group. Thus the belt of large sandstone blocks from the basal sandy member of the Chepultepec dolomite separates the Knox group below the middle into a Cambrian portion (the Copper Ridge dolomite) and an Ordovician portion; the belt of excessively massive chert over the Longview dolomite and the broken ridge held up by this chert separate the Ordovician portion into three units; and, where present, a narrower belt with blocks of chert-matrix sandstone separates the upper of these units into the Kingsport and Mascot formations.

Where fully subdivided, then, the northwestern phase of the Knox group consists of five named formations, along with various members. The formations are as follows (in descending order):

Name	*Type locality*	*Original description*
Mascot dolomite (Oma)	Mascot, Knox County, (Mayn.)	Oder and Miller, 1945
Kingsport formation (0k)	Kingsport, Sullivan County (Greene.-Est.)	Oder and Miller, 1945
Longview dolomite (Olv)	Longview, Shelby County, Alabama	Butts, 1926, pp. 92-95
Chepultepec dolomite (Oc)	Chepultepec (now Allgood), Blount County, Alabama	Ulrich, 1911, pp. 638-639
Copper Ridge dolomite (∈cr)	Copper Ridge at Thorn Hill, Grainger County (Morr.)	Ulrich, 1911, pp. 635-636

(For further details on the subdivision, see Rodgers and Kent, 1948.) In some areas where the other units can be mapped the Kingsport and Mascot formations cannot be readily separated and they are classed together as the Newala formation (On), named Newala limestone by Butts (1926, pp. 95-99) for Newala, Shelby County, Ala. In one belt the Chepultepec and Longview dolomites are likewise mapped undivided (Ocl). In a few belts, only the Copper Ridge dolomite has been separately mapped and the over-

TABLE 5.—*Subdivisions of the Knox group used on present map*

<table>
<tr><th colspan="5">Northwestern phase</th><th>Southeastern phase</th></tr>
<tr><td>Mascot dolomite (Oma)</td><td colspan="2" rowspan="2">Newala formation (On)</td><td rowspan="4">Chepultepec, Longview, and Newala formations, undivided (Ocn)</td><td rowspan="5">Knox dolomite, undivided (O€k)</td><td rowspan="4">Jonesboro limestone (Ojb)</td></tr>
<tr><td>Kingsport formation (Ok)</td></tr>
<tr><td colspan="2">Longview dolomite (Olv)</td><td rowspan="2">Chepultepec and Longview dolomites, undivided (Ocl)</td></tr>
<tr><td colspan="2">Chepultepec dolomite (Oc)</td></tr>
<tr><td colspan="4">Copper Ridge dolomite (€cr)</td><td>Conococheague limestone (€cc)</td></tr>
</table>

lying Ordovician formations are classed together as the Chepultepec, Longview, and Newala formations, undivided (Ocn).

Copper Ridge dolomite.-The Copper Ridge dolomite typically consists of dark crystalline knotty dolomite interbedded with well-bedded light-gray fine-grained dolomite; some intermediate types also occur. The color of the dark dolomite is caused by small amounts of asphaltic material, readily smelled when the rock is broken. This dark dolomite is almost diagnostic of the Copper Ridge dolomite in Tennessee, though it occurs in a few layers higher in the Knox group and is also found in the Honaker dolomite southeast of the Pulaski fault. Ordinarily, however, it is wanting in the upper fourth of the Copper Ridge, and this upper part can locally be mapped separately as an upper member. Layers of dolomitic sandstone occur, commonly near the top of the formation, rarely in the main body, and locally, especially to the south- east, close to the base. Limestone is virtually unknown in the Copper Ridge except near the southeast boundary of the phase, where limestone similar to that in the Conococheague limestone largely replaces the upper part of the formation and occurs also near the base. The formation ranges in thickness from 900 to 1,100 feet.

Dark chert in nodules and thin layers is common in the dolomite; the layers may be oolitic or may show abundant cryptozoon. Oolite and cryptozoon are also found in the dolomite, but more rarely. Thick layers of light-colored oolitic chert are almost diagnostic of the upper fourth of the formation; unlike those in the higher formations of the Knox group, the ooids in these oolites are generally coarse (commonly nearly 1 mm. across, rarely as much as 2 mm.) and show colored concentric banding. In weathering, the Copper Ridge dolomite produces much dark jagged rough chert in addition to the nodules, oolitic layers, and silicified cryptozoon masses that occur in the bedrock.

Chepultepec dolomite. - The Chepultepec dolomite consists largely of well-bedded fairly light mostly fine to medium-grained dolomite, much of it slightly silty; thin layers of dark dolomite also occur. Dark bluish aphanitic limestone is prominent in the upper part in the southeastern belts, reaching as far northwest as Rogersville and Morristown (Morr.), but it is absent elsewhere. Sandstone layers, commonly cemented by dolomite but locally by quartz, are almost invariably present in the lower third of the formation, which can ordinarily be mapped separately as a basal sandy member. There may be as many as eight prominent layers of sandstone; commonly they are as much as a foot thick, and locally the basal one is much thicker, reaching 10 feet in the area between Jacksboro and Norris (Brice.). Prouty (1948) has shown that these sandstone layers not only thicken but also coarsen to the northwest. The Chepultepec is normally 700 to 750 feet thick.

Light-colored chert nodules are common in the dolomite, especially in certain layers. Ooids in oolitic chert, where present, are small and uncolored. The chert produced during weathering is generally porous and cavernous, but in some areas it is as massive and abundant as that from the Longview dolomite. It is generally light-colored and very fine-grained, but typically dull rather than porcelaneous. Over the basal sandy member, blocks of sandstone are prominent in the residuum.

Longview dolomite.-The dolomite of the Longview dolomite resembles generally that in the Chepultepec, but in the upper half of the formation it is normally interbedded with light-gray to brown aphanitic limestone, weathering with a light bluish cast. In areas of structural complexity, the limestone has been altered to relatively coarse-grained light-gray dolomite, clearly long after consolidation. Isolated sand grains are common in some layers; locally sand forms beds a few inches thick. The Longview dolomite averages about 250 feet thick.

Chert is relatively rare in the unweathered Longview dolomite, but the dolomite is highly siliceous and on weathering produces great blocks of light-colored, but rarely white, massive fine-grained to porcelaneous chert, seldom cavernous or porous. Indeed, this massive chert is the most diagnostic character of the formation, and it commonly forms a broken ridge, either along the crest or on the southeast slope of the larger ridges formed by the whole Knox group.

Kingsport formation.-Much of the Kingsport formation is massive very light colored almost aphanitic dolomite, and most of the rest of the formation is only slightly darker, coarser, and better bedded. Close to the base there is normally about 50 feet of light- gray to brown aphanitic limestone, unbroken by dolomite except where the limestone has been altered since consolidation to coarse-grained dolomite. Above this for a few feet, thin limestone layers may alternate with dolomite, but otherwise limestone is absent. The limestone layers appear to thin to the northwest. Beds of dark dolomite occur locally but are not common. Sand grains, both isolated and in beds, are common, especially toward the top. The Kingsport formation averages a little over 200 feet thick.

Chert nodules are common, and thin beds of white fine-grained oolitic chert occur. When the rock weathers, the nodules accumulate in the soil along with dull white but commonly iron-stained, generally blocky chert, which looks compact but chalky and is apparently minutely porous.

Mascot dolomite.-The Mascot dolomite is mostly well-bedded light-gray fine-grained dolomite, commonly slightly coarser and darker below the middle of the formation than above. Medium to dark-gray blue-weathering limestone occurs as thin beds in all the southeastern belts and as far northwest as Mascot (Mayn.) and Sweetwater (Loud.), also locally in the belts northwest of the Hunter Valley fault in Claiborne and Union Counties (Mayn.).

In the southwestern part of the Valley, especially around Chattanooga, limestone comes to dominate the formation, and dolomite is locally wanting, at least in the upper part. Here some of the limestone is fairly massive, light gray, aphanitic, and especially pure, containing little silica and producing little or no chert. Through much of the western and northwestern parts of the Valley, the dolomite in the upper half of the formation displays prominent yellow, pink, and red clouding. In some areas this coloring extends throughout the Mascot dolomite or even down into the Kingsport formation, as in northern Union County, one of several districts where the rock has been quarried in a small way as marble or building stone.

Almost everywhere the lower third, or less, of the Mascot dolomite contains a few thin sandstone beds; typically one to three of these beds have a matrix of chert and the lowest such bed is taken as the base of the formation. Such chert-matrix sandstone is known from Hawkins to Bradley Counties and makes valuable key beds, especially as it can often be found in the soil over the base of the formation. Even where no chert-matrix sandstone is present however, the base of the formation can still he located approximately by the other, generally dolomitic, sandstone beds.

The thickness of the Mascot dolomite ranges from 400 to 800 feet, presumably because of the disconformity at the top, for the relief on this disconformity is known to reach 200 feet even in local areas. Near the top of the Mascot dolomite in several of the belts north of Knoxville there is a bed 10 to 20 feet thick of dark mostly crystalline asphaltic dolomite like that typical of the Copper Ridge dolomite; it is very siliceous and commonly weathers to a solid ledge of massive chert. In many areas the dolomite in the lower half of the formation is likewise very siliceous and weathers to massive blocks or even ledges of white somewhat cavernous chert. In these areas the formation can be readily separated into a lower cherty member and an upper noncherty member. Apart from the chert formed from these beds and some characteristic "cannon balls" of chert in a bed just below the asphaltic dolomite bed, the chert of the Mascot, both in outcrop and after weathering, is indistinguishable from that of the Kingsport, though near the top of the formation it is commonly less in amount.

Despite differences between the individual formations, the amount of chert produced by the weathering of the Knox group increases almost regularly from belt to belt northwestward across the Valley. The compiler suggests that the same area to the northwest that furnished sand to the Rome sea (p. 44) and rnud to the Conasauga sea (p. 47), presumably the Canadian shield and its southward extensions, was virtually a peneplain during the deposition of the Knox, undergoing deep chemical weathering and furnishing chiefly the products of chemical decay: silica and carbonates. Only in Middle Ordovician time did significant amounts of detrital sediment, and then from a "normal" southeastern source, reappear in what is now East Tennessee.

The carbonate rocks of the Knox group weather to residual clay, which grades upward into a deep soil ranging in color from light tan to dark orange-red. The chert produced during weathering accumulates in the clay and especially in the surface soil. Its presence helps greatly to retard erosion, so that the Knox group in this phase normally produces a well-marked ridge or belt of knobby hills. Meanwhile, weathering proceeds unhindered, producing bodies of clay that may be several hundred feet deep. As a result, bedrock rarely crops out except near the top and base of the group, and even there it may be entirely covered by cherty slope wash from the main part of the ridge. Reasonably complete sections are therefore rare and yet are especially important for the understanding of the group. Probably the most complete section of the northwestern phase of the Knox group is the Thorn Hill section on U. S. Highway 25E, where Forked Deer Creek cuts through Copper Ridge northwest of Thorn Hill, Grainger County (Morr.); it serves as a standard section for the phase (for measurements see Hall and Amick, 1934; Oder, 1934, pp. 489-494; for present classification see Rodgers and Kent, 1948, pp. 14-32). Partial sections can be found along many of the streams that cross ridges over the Knox group, at least north and northeast of Knoxville; to the southwest exposures become rarer even in such locations. Important sections, even though mostly partial, include those at Kingsport, Sullivan County (Greene.), on U. S. Highway 23 north toward Virginia (measured by Oder and by Bridge but not yet published); at Lee Valley, Hawkins County (Morr.), where State Highway 66 crosses Copper Ridge (Rodgers and Kent, 1948, pp.

14-32); in the zinc mines of the Mascot-Jefferson City district (Oder and Miller, 1945; Crawford, 1945); along Love's Creek just northeast of Knoxville (Mayn.), on the same belt as Safford's type section (measured by Bridge and by Oder, not yet published); and on Sandy Branch just east of Pattie Gap, Roane County (Kings.), about 10 miles south of Kingston.

Fossils are rare in the Knox group and are found chiefly as molds in chert fragments in the soil. Enough have been found to show that the Copper Ridge dolomite represents the Franconia and Trempeleau stages of the Upper Cambrian series, and that the higher formations are Lower Ordovician, the Chepultepec dolomite including the Gasconade fauna, the Longview dolomite including the zone of *Lecanospira*, and the Kingsport and Mascot formations (or the Newala formation) including the zones of *Ceratopea*, at least four of which have been recognized in East Tennessee. The principal debate concerns the position of the Cambrian-Ordovician boundary within the group of sandstone beds which extend through 400 to 500 feet of strata in the upper part of the Copper Ridge and basal part of the Chepultepec. Upper Cambrian fossils have been found associated with these sandstone beds at Jockey Creek near Limestone (Greene.) in the southeastern phase (by James L. Wilson in company with the compiler) and at Thorn Hill (Morr.) in the northwestern phase (Oder, 1934, pp. 478, 493); but Lower Ordovician fossils have been found on Clear Creek a mile north of Norris (Brice.) in the northwestern phase (Josiah Bridge, personal communication). Probably the sandstone beds represent a relatively minor regression and transgression or a series of such regressions and transgressions that may correspond to the systemic boundary. Present usage tends to draw the boundary in the lower part of this group of sandstone beds, below the thicker and more prominent beds and commonly just beneath the lowest thick one, but a little above the highest of the characteristic coarsely oolitic chert layers of the upper part of the Copper Ridge dolomite.

Southeastern phase: dominantly limestone.-Much less work has been done in subdividing the Knox group in the southeastern phase than in the northwestern phase. The principal division that has been mapped, and the only one shown on the present map, is that between the Cambrian and Ordovician parts, which are separated, as to the northwest, by the prominent group of sandstone beds below the middle of the group. For the Upper Cambrian limestone below this dividing line the term Conococheague limestone, proposed by Stose (1908, pp. 701-703) for limestone of like character and age on Conococheague Creek, Franklin County, Pa., and applied by Butts (1933, 1940) to similar limestone all along the southeast side of the Valley of Virginia, is appropriate and has already been used by Oder (1934, p. 476) and others. For the Lower Ordovician limestone above the line the term Jonesboro limestone is here used. The Jonesboro limestone was named by Ulrich (1911, pp. 671-672) for Jonesboro, Washington County (Roan M.). In proposing the term, Ulrich included within it virtually the whole southeastern phase of the Knox group, as exposed in the Jockey Creek section, just as at the same time he included in his Copper Ridge chert virtually the whole northwestern phase, as exposed in the Thorn Hill section. Nevertheless it is clear from his statements that he intended to include in his Copper Ridge only "Lower Ozarkian" beds (now regarded as upper Upper Cambrian) and in the Jonesboro only "Canadian" beds (now regarded as Lower Ordovician), for he believed that the rocks in the Knox group in the Thorn Hill section are almost entirely older than those in the Jockey Creek section. Later work has shown, however, that far from being mutually exclusive with regard to age, the rocks in the two sections cover almost precisely the same time span. Accordingly, the Copper Ridge dolomite has been restricted, in the Thorn Hill section and elsewhere, to the Cambrian part of the Knox group (northwestern phase), and the Jonesboro limestone may be restricted, in the Jockey Creek section and elsewhere, to the Ordovician part of the Knox group (southeastern phase), where it has not been further subdivided into mappable units. On the present map, therefore, the southeastern phase of the Knox group is divided where the available data permit into the Conococheague limestone (Ccc) and the Jonesboro limestone (Ojb); elsewhere it is mapped as Knox group, undivided (OCk). The Conococheague limestone consists typically of dark blue-gray blue-weathering limestone containing thin even layers or reticulated partings of slightly silty dolomite that form characteristic light-colored "ribbons" on weathered surfaces. Interbedded with this "ribboned" limestone are beds of light-gray dolomite, especially in the lower quarter of the formation, and beds of unribboned limestone, some of which contain oolite or edgewise conglomerate. Sandstone beds occur close to the base and the top of the formation but have not been observed in the intervening part in Tennessee; the sandstone is coarse-grained, cross-bedded, and fairly massive. The Conococheague, as mapped at present, is 1,100 feet or more thick.

Chert occurs in the Conococheague limestone as dark nodules, layers of silicified oolite, and masses of silicified cryptozoon. These are all found in the residual clay, along with light-colored jagged or angular chert, but chert is generally much less abundant than over the Copper Ridge dolomite. Blocks from the sandstone layers at the base of the formation are prominent in the residuum.

The Jonesboro limestone consists largely of dark blue-weathering limestone. Some of it is "ribboned" with thin layers of silty dolomite, especially in the lower part of the formation, but much of it is pure and fairly massive. Fairly thick sandstone beds occur in the lower 400 feet or so, which can locally be mapped as a basal sandy member and probably corresponds to the basal sandy member of the Chepultepec dolomite in the northwestern phase. Beds of gray dolomite a few feet thick are present through about the upper third of the formation but not lower, except locally in the most northwestern belts of the phase. Several thin sandstone layers occur in the lower part of this upper third, and locally at least one of them has a chert matrix. These layers can commonly be traced in the residuum, and the upper third of the formation can be separated as a dolomitic member, probably corresponding roughly to the Mascot dolomite of the northwestern phase. The Jonesboro limestone as a whole is about 2,000 feet thick.

Chert is rare in the limestone; even on weathering relatively little is produced, and massive chert is unknown. Indeed, in the southeastern belts the middle part of the Jonesboro formation produces virtually none. The lower part produces white rough, nodular to angular, commonly slightly porous chert in pieces of moderate size; the tipper part, small annular fragments of chert of the type common in the Kingsport and Mascot formations of the northwestern phase. Blocks of sandstone can be found at the appropriate places but are much less prominent in the residuum than those from the layers at the base of the Conococheague limestone.

The limestone of the southeastern phase of the Knox group weathers deeply to residual clay and produces a deep orange-red to dark-red soil. As noted above, the chert content is variable but generally fairly small; hence, as a rule the Knox group in this phase does not make prominent ridges. Locally to the northwest, a fairly prominent ridge follows the outcrop belt of the Conococheague limestone, and elsewhere broad ill-defined ridges may be present at about the Conococheague-Jonesboro contact; but in general the Knox underlies open rolling country in contrast to the fairly sharp ridges upheld by, the siltstone of the Nolichucky and Maynardville formations and the knobs upheld by the sandy shale and sandstone of the Sevier shale.

Reasonably complete sections of the Knox group are nearly as rare in the southeastern phase as in the northwestern phase. The standard section for the phase is on Jockey Creek where it crosses the Greene-Washington County line less than a mile northwest of Limestone (Greene.) (measured by Oder, 1934, pp. 494-497). Partial sections occur near U. S. Highway 23 southeast of Halls Mills and a little north of the Sullivan County-Washington County line (Roan M.) (measured by Oder, not yet published), along the Long Fork of Lick Creek just north of Graysburg, Greene Co. (Greene.), and in the drainage basin of Little Cherokee Creek between Cherokee Mountain and the Holston Mountain fault (Roan M.).

The southeastern phase of the Knox group appears to contain representatives of the same faunal stages and zones as the northwestern phase and to span the same time. As to the northwest, the principal question relates to the position of the Cambrian-Ordovician boundary within the group of sandstone beds at the top of the Conococheague limestone and the base of the Jonesboro limestone. Upper Cambrian fossils have been found between two of these beds just below the dam at the Jockey Creek section, and the contact at present is drawn at the stratigraphically higher of these sandstone beds.

LOWER AND MIDDLE PARTS OF CHICKAMAUGA LIMESTONE AND EQUIVALENT ROCKS (Olmc)

Present status of the stratigraphy of the Chickamauga limestone. -Probably more controversy has raged over the stratigraphy of the Chickamauga limestone and equivalent rocks in the southern Appalachians than over that of any other major unit here discussed, except the Ocoee series, and this despite the generally good outcrops, the ready accessibility of the outcrop area, the well-characterized and differentiated lithologic units, the several usable key beds, and the abundant fossils. The controversy has concerned both subdivision and correlation. On the score of subdivision, the folio mappers, especially Keith, recognized six or seven lithologic units which could be mapped in certain areas, particularly the area around Knoxville. Later, Ulrich and Butts corrected some serious errors, such as the correlation of the Middle Ordovician Bays formation near Knoxville and on Bays Mountain (Greene. and Morr.) with the Upper Ordovician Juniata formation on Clinch Mountain and northwest, but in general they accepted the units recognized in the folios with a few additions, and tried to apply them not merely in the areas for which they had been proposed but throughout the southern Appalachians from Virginia to Alabama. Recently there has been a strong reaction against this wide and, in many areas, erroneous application of the older terms, and writers have tended to propose new sets of geographic names for their own local areas; in southwest Virginia and Tennessee not less than 25 new names have been proposed in the last 10 years for lower Middle Ordovician units alone. Where detailed areal mapping establishes a succession of valid units which no names already proposed will fit, no objection can be raised to the proposal of a new set of names; but surely it is as unfortunate for present-day writers to carry these new units far and wide, jumping from section to section 30 miles apart, as it was for Ulrich and Butts to do the same with the old names. In particular, there is no warrant for carrying new names into the type areas of earlier-named formations in East Tennessee where those formations are for the most part valid, merely because the earlier names were themselves misapplied in Virginia and Alabama. For the present map, which by its nature cannot be based on the detailed work that alone should serve as the foundation for new nomenclature, the compiler has restricted himself to the older terms and to such noncommittal terms as "upper part of Chickamauga limestone." He has tried, however, to make clear just what rocks are included in each map unit so that when the detailed work is done the relation of the new subdivisions to the old gross units will not be obscured by merely nomenclatorial difficulties.

On the score of correlation the controversy has been equally continuous. Safford, and after him Keith, conceived of these rocks as grading from limestone on the northwest and toward the base into shale with some sandstone on the southeast and toward the top and as including beds of special character such as marble and ferruginous sandstone, chiefly in the shale near the gradation to the limestone. Both Safford and Keith made the mistake of correlating, the Middle Ordovician Sevier shale and red Bays formation in tile southeastern belts with the Upper Ordovician Reedsville shale and red Juniata formation in the northwestern belts. This error Ulrich corrected in 1911, but at the same time he proposed a radically different interpretation of the correlation of the limestone and shale. Instead of considering them as gradational facies, he considered each to comprise several distinct formational units separated by disconformities in such a way that no limestone unit is correlative with a shale unit, or vice versa, though commonly the units so separated are mutually exclusive in areal extent. Thus for the southeastern shale units, plus the Holston marble and Tellico sandstone, Ulrich erected the Blount group (1911, pl. 27, named for Blount County), no part of which he considered to be correlative with any other formation in the area. Ulrich and Butts extended this interpretation throughout the Appalachians and supported it by using as guides such fossils as *Maclurites* and *Cryptophragmus*, which appear, however, to be restricted to certain specific rock types and are therefore missing in other rocks of the same age but different facies. These particular errors have in turn been exposed by recent writers, but several of those writers continue to postulate disconformities in the section wherever individual lithologic units and their fossils are absent, without, in the compiler's opinion, adequately considering the possibility that these fossils too are controlled by the rock facies. In general, recent opinion has tended to return to the older view of Safford and Keith that the limestone and shale are essentially contemporaneous facies, though recognizing now two northwestward encroachments of shale and redbeds over limestone, instead of one. The exact correlation of most of the individual limestone and shale units is still a matter of debate; the compiler's views on correlation within East Tennessee are stated explicitly below and are shown in figure 4, which indicates his conception of the interrelations of the units used on the present map.

The Chickamauga limestone was named by Hayes (1891, p. 143) for the valley of West Chickamauga Creek (Chatt.) in Hamilton County, Tenn., and Catoosa and Walker Counties, Ga. In this area it is about 1,600 feet thick and, as defined by Hayes, included blue-weathering limestone ranging from the upper part of the Lower Ordovician to the Maysville stage of the Upper Ordovician (Butts and Gildersleeve, 1948, pp. 18-19). In other areas, however, the folio mappers included much less within it, locally indeed not more than 50 feet of limestone at the base of the Middle Ordovician, and in general they used it for the blue limestone facies of the Middle and Upper Ordovician, however much or little that might be. For the present map, the Lower Ordovician part (Newala limestone as mapped by Butts and Gildersleeve, 1948) is classed with the Knox group; otherwise the name "Chickamauga" is used as in the folios for the limestone facies that crops out in all the northwestern belts in the Valley.

It is apparently possible everywhere in East Tennessee to divide the Chickamauga limestone and its equivalents into two major units by means of a combination of persistent key beds somewhat above the middle of the limestone where most extended. The boundary chosen marks a break between generally fine-grained and fairly light-colored slightly silty limestone with scattered though

NOTE: Figure 4 is at end of document

locally abundant fossils below, and medium-grained dark crystalline limestone packed with brachiopod shells of the groups of *Resserella ("Dalmanella"), Sowerbyella*, and *Rafinesquina* above. This distinction can be observed even where the limestone forms only isolated beds in other rocks, which are normally limy siltstone below the boundary and shale above. In many areas one or two thin beds of calcareous sandstone occur at this boundary. Even more persistent are two beds of altered volcanic ash a foot or more thick which lie within 100 feet below the boundary in the upper part of the lower major unit. Each of these ash beds is underlain by an inch or two of green chert resulting from the silicification of the top of the immediately underlying limestone layer; these chertified limestone layers are readily traceable, even where outcrops are relatively poor, and are very rarely absent. Accordingly this boundary, which the compiler suspects represents a slight disconformity, is used throughout the present map to separate the lower and middle parts of the Chickamauga limestone (Olmc) and equivalent rocks below and the upper part of the Chickamauga limestone (Ouc) and equivalent rocks above. These two major units are shown on the map by separate color patterns and are themselves subdivided into lesser units where data permit. The lower unit is discussed in the present chapter and the upper in the next chapter (pp. 94-97).

Because of the current wide differences in opinion on both the classification and the correlation of the lower and middle parts of the Chickamauga limestone and equivalents, it has seemed essential to describe the rocks themselves almost belt by belt, so that correlations made along strike where continuous mapping is possible might be separated from correlations across strike where it is not, and so that errors in the latter correlations might not vitiate the rock descriptions of the individual units. It has also seemed desirable to take up these belts in somewhat unusual order, beginning in the middle of the Valley and working first southeast and then northwest, in order to discuss first the belt passing alone the Holston River (Mayn.), through the north part of Knoxville (Knox.), and past Lenoir City (Loud.), for this belt includes the type localities of three named units comprising almost the whole of the section there preserved, and it can therefore serve as a standard of reference, whether correlations to other belts have been correctly made or not. Beginning from this standard belt, the assumed correlations from belt to belt have been discussed as explicitly as possible, and at the same time the chief alternative correlations currently proposed have also been discussed as well as the compiler could manage, though he finds he must reject them because they seem to him to deny the continuity of units that can be traced and to contravene the most probable arrangement of shifting, facies in what is essentially a great probably deltaic detrital wedge As a result of the inclusion of this material, the present chapter has been extended out of proportion to the rest of the text. Nevertheless the compiler believes that, in the present state of knowledge, any shorter discussion would merely confuse facts about individual rock units in specific sections with unproved inferences about their correlation, so that if the inferences ever proved incorrect, the rock descriptions themselves would become valueless.

Belt between the Saltville fault and the Knoxville and Rocky Valley faults (northwest part of Red Belt of Safford).-In the belt next southeast of the Saltville fault, rocks above the Knox group are continuous from about 3 miles west of New Market (Mayn.) to 2 miles north of Athens (Cleve.). To the northeast a few small outliers extend past Jefferson City (Morr.); to the southwest, beyond a 30-mile break, the rocks reappear with virtually no change 4 miles south of Cleveland (Cleve.) and continue to the Georgia line and some miles beyond. The rocks in this belt can everywhere be divided into three units, and a fourth unit appears at the top for a few miles near Lenoir City (Loud.) and again at Knoxville. These units are (in ascending order) the Lenoir limestone (Ol), the Holston formation (Oh), the Ottosee shale (Oo), and the Bays formation (Ob). This sequence is here considered as a standard of reference for the rocks of this age, and the belt is referred to in what follows as the standard belt.

The Lenoir limestone was named by Safford and Killebrew (1876) for Lenoir City, Loudon County (Loud.); Safford (1869, pp. 232-233) had previously called it the Blue or Maclurea limestone. In this belt Keith and Hayes mapped it as the Chickamauga limestone, though Hayes ignored it in Bradley County (Hayes, 1894b, Kings. f.; 1895a, Cleve. f.; Keith, 1895, Knox. f.; 1896a, Loud. f.; 1901, Mayn. f.). The name Holston marble was first used by Keith on the geologic maps in Knoxville (1895), Loudon (1896a), and Morristown (1896b) folios, but he did not mention it in text until the Maynardville folio (1901, p. 3). He apparently considered it a member or lentil in the Chickamauga limestone and he never specified a type locality, though clearly he named it for the Holston River. The Holston River flows for some miles in the belt under discussion (Mayn.) but finally deserts it and crosses the next belt southeast just before it joins the French Broad River (Knox.). The compiler proposes that the type locality of the formation be taken along and near the Holston River 7 miles east-northeast of the center of Knoxville, where the river quits the belt under discussion just south of the John Sevier yards (Mayn.), and that it include the big quarry of the Volunteer Portland Cement Co. just west of the river. A detailed geologic map covering this area is being prepared by John M. Cattermole for the U. S. Geological Survey. For the present map the compiler includes in the Holston formation the rocks that Keith and others have mapped as Tellico sandstone in this belt (see below, pp. 70-71).

The Ottosee shale was named by Ulrich (1911, pl. 27) for Lake Ottosee in Chilhowee Park in the northeastern part of Knoxville (Mayn.), where the base of the formation underlies the lake. Exposures are very poor there, but are better northeast along the strike. The whole area is being mapped by Cattermole. Keith mapped these rocks as the Sevier shale, and Ulrich specifically defined the Ottosee to include the Sevier shale in this belt, believing that the rocks here are not correlative with those that Keith mapped as Sevier either in the type belt in Sevier County (see below, p. 77) north of Chilhowee Mountain (1895, Knox. f.), where the rocks are mostly older (equivalent to part of the Athens shale according to the compiler's correlations), or in the belt north of Clinch Mountain (1896b, Morr. f.; 1901, Mayn. f.), where the rocks are younger (Martinsburg shale). The name Bays formation comes from the Gray Belt and is discussed below (p. 78). In the standard belt it was mapped by Keith as Bays at Knoxville (1895, Knox. f.) but as a sandstone lentil in the Sevier shale at Lenoir City (1896a, Loud.). As far as the compiler knows there is no question that these rocks are properly correlated with the typical Bays formation.

The Lenoir limestone in this belt consists chiefly of dark blue-weathering argillaceous somewhat nodular limestone. Northeast of Knoxville the lowest beds consist mostly of pure aphanitic limestone which has sometimes been mapped separately as the Mosheim limestone (type locality in the Gray Belt; see below, P. 76). Such limestone also occurs to the southwest along the belt, but rather as lenses in the lower part of the Lenoir limestone than as a separate unit; here the lowest beds are commonly silty. For the present map, the Mosheim is considered as a member of the Lenoir limestone that locally replaces the lower part of the formation. In a few places northeast of Knoxville, the Mosheim is itself replaced laterally by coarse-grained crystalline gray to pink limestone ("marble") not unlike some layers in the Holston formation. Locally the basal layer of the Lenoir limestone or its Mosheim member contains angular chert fragments derived from pre-Lenoir weathering of the dolomite below, and in a few places, as at the quarry across the Holston River from Strawberry Plains (Mayn.), dolomite cobbles and boulders from pockets of conglomerate or breccia. Chert also occurs sparingly in the upper part of the Lenoir limestone as indigenous rough nodules and irregular masses. Many layers of the limestone show fine specimens of the snail *Maclurites magnus* Lesueur, not uncommonly silicified. The thickness of the Lenoir at Lenoir City is about 500 feet; it is somewhat thinner in Bradley County and also locally near Knoxville.

The Lenoir limestone weathers to a fairly rich silty clay soil, but the soil tends to be removed by erosion and the limestone commonly crops out, unless hidden by wash from other formations. The formation normally underlies a valley. It is partly exposed in Lenoir City just east of the railroad station and also in the river bluff to the southwest.

The Holston formation in this belt consists of several different kinds of rocks that together form a mappable unit. All are composed largely of calcite, and most contain an appreciable amount of finely divided hematite, which colors the rocks and the derived soils pink to dark red. A dominant lithology is pink to red coarsely crystalline limestone ("marble") showing cross bedding, which was evidently deposited as a sand made of calcite grains, chiefly worn fragments of crinoid stems and bryozoans. This lime-sandstone (calcarenite) has furnished the bulk of the "Tennessee marble" of commerce, but it is neither the whole of the Holston formation nor confined to it. In a second rock type a dark-red fine-grained limestone matrix contains algal heads, unbroken bryozoans, and crinoid bases; this lithology occurs as irregular masses and heads surrounded by the lime-sandstone and clearly formed reef masses from which the sand was derived and around which it accumulated. A third rock type closely resembles the lime-sandstone except that it contains 5 to 30 percent quartz sand; in many places it overlies the other two. The presence of the quartz causes this rock to weather very differently from the others, and locally, especially where it directly overlies the reefy masses, the contrast creates the impression of a striking unconformity (cf. Stose and Schrader, 1923, pls. 13, 25, 26). Keith and others have therefore mapped it separately in this belt as the Tellico sandstone (type locality in the Gray Belt; see below, p. 80). Actually, however, it grades downward into and is interbedded with the lime-sandstone in places, and clearly the contact between them merely records the appearance of quartz sand in the reef area. The relations between these three rock types within the Holston formation is especially well displayed in the D. A. M. manganese mine in southern Bradley County, about 3 miles north of the Georgia line (Cleve.), where they can be seen in three dimensions in pinnacles laid bare by hydraulic mining.

The three rock types so far discussed are most typically displayed in the upper part of the Holston formation in this belt. The lower part is generally less red and consists of layers, rather than reefy heads, of algal bryozoan limestone interbedded with lime-sandstone, commonly finer-grained than above, and with silty and shaly limestone, typically packed with bryozoans. Quartz sand is not known in the lower part in this belt. Limy shale layers occur here and there in the lower half and also close to the top of the formation, where they are interbedded in the quartz-bearing lime-sandstone and form a transition to the overlying Ottosee shale. The thickness of the rocks mapped as Holston in this belt on the present map is about 400 feet near Knoxville and diminishes somewhat to the southwest, being about 300 feet near Sweetwater (Loud.) and less than 200 feet in southern Bradley County (Cleve.).

The Holston formation weathers very deeply, producing a characteristic, dark-red residuum high in iron; indeed, near Sweetwater (Loud.) the incoherent residuum was once directly mined as iron ore. Locally, both near Sweetwater and in southern Bradley County, this residuum contains angular pieces of hard hematite and manganese oxides that appear to have weathered out of the bedrock; these also have been mined. The residuum commonly yields a deep red somewhat silty clay soil. The quartz-bearing phase adds quartz grains to the soil but in this belt rarely forms coherent sandstone chips or blocks. The shale where present forms chips that are generally more prominent in the residuum than the shale is in the bedrock. The formation underlies a line of low knobs marked by the dark-red soil. Natural outcrops are not very common, except northeast of Knoxville, but marble quarries between Knoxville and Lenoir City and manganese mines farther southwest provide several good exposures.

The Ottosee shale in this belt consists of blue, yellow-weathering limy shale and shaly siltstone, in which are set lenses of crystalline limestone ("marble"), some of them mappable. The limestone in the cores of the larger lenses is quite massive and coarse and is generally pink or white, but above and below and to both sides it becomes thinner-bedded, finer-grained, and darker-colored, normally red, and at the margins of the lenses it grades through silty nodular limestone, commonly packed with bryozoans, into the normal calcareous shale or siltstone. Quartz sand occurs locally in the limestone in these lenses, especially around the margins, but rarely makes sizable bodies of quartz-bearing lime-sandstone. Near the base of the formation, beds of shaly and sandy limestone packed with bryozoans also appear, and these grade down into red quartz-bearing lime-sandstone, all interbedded with calcareous shale. These transitional beds can usually be mapped as a separate basal member of the Ottosee shale, though they might almost as well be considered as a top member of the Holston formation. The Ottosee shale in this belt is about 1,000 feet thick.

The Ottosee shale weathers to a rather thin and acid clay soil in which chips of weathered shale and siltstone are abundant and through which numerous outcrops appear. The larger crystalline limestone lenses make patches of richer, deeper soil. The formation in this belt underlies rolling dissected country, but the hills are generally lower than those on the adjacent formations. Exposures are abundant, but reasonably complete sections are not common; probably the best in the belt is on Hall Bend opposite Lenoir City (Loud.).

The Bays formation forming the two patches in this belt (one at Knoxville and one at Lenoir City) consists of dark-red to maroon limy siltstone and shale and silty limestone interbedded with blue silty limestone and a little yellow limy shale. Probably only a few hundred feet are preserved at either place. It weathers much like the Ottosee shale except that the resulting soil is maroon and somewhat limy. At Lenoir City it underlies slightly higher ground than the Ottosee and is fairly well exposed; at Knoxville it is mostly covered and hardly affects the topography.

Belt between the Knoxville and Rocky Valley faults and the Chestuee and Dumplin Valley faults (main Red Belt of Safford).- In the belt next southeast of the standard belt just discussed, rocks above the Knox group extend continuously from near Piedmont, Jefferson County (Mayn.), or even farther northeast, to 5 miles east of Cleveland (Cleve.), and an arm that extends northeast from the especially broad part of the belt south of Knoxville connects with the standard belt. Everywhere in this belt that high enough beds are present, the rocks can be divided into three units, and a fourth, still higher, unit appears in a large area in eastern Knox County (Knox.) and probably also in two smaller patches in northwestern Blount County (Loud.). In the compiler's opinion these units correspond exactly to the units of the standard belt, and he has shown them with the same symbols on the present map, although the Holston formation contains much more quartz sand, and the

Lenoir limestone, except for the basal 100 feet or so, becomes shaly and grades southwestward along the strike of the belt into the Athens shale. In both the upper part of the Lenoir limestone and the Athens shale, however, occurs the *Christiania* fauna, which is not known in the type Lenoir limestone and is considered by other workers to be younger than the Holston formation of the standard belt. These workers therefore prefer to separate the upper *Christiania*-bearing part of the Lenoir limestone here from the lower part, which they regard as the only true Lenoir limestone in this belt, to postulate a disconformity between the two parts, and to deny that the two units of red lime-sandstone and quartz-bearing lime-sandstone here mapped as the Holston formation can be correlative. The compiler can only suggest that perhaps the *Christiania* fauna is restricted to the shaly limestone facies and occurs in older rocks in the present belt, where such limestone invades the Lenoir limestone, than in the standard belt or farther to the northwest, where it first appears in the lower part of the Ottosee shale or equivalent rocks. Whichever correlation is correct, the units of the present belt are distinct and mappable, except that the main body of the lower limestone unit (Lenoir limestone of present map) grades imperceptibly southwestward into the type Athens shale.

The name Athens shale was proposed by Hayes and first used by him in the Kingston folio (1894b, p. 1) for Upper Ordovician shale, here assigned to the Reedsville shale, in the belt next northwest of the Whiteoak Mountain fault. In the Cleveland folio (1895a), which includes the type locality, however, he used it for the shale here in question, between a thin "Chickamauga" limestone (Lenoir limestone of Rodgers, 1953b) and the red "Tellico sandstone" (Holston marble of Rodgers, 1953b). For the present map the thin underlying limestone could not be separately shown and it is included at the base of the Athens shale (Oa).

In the Lenoir limestone of this belt, limestone like that in the type section of the Lenoir forms the basal 40 to 100 feet everywhere and also much of the rest of the formation in the northeastern part of the belt near Knoxville. Elsewhere, however, it is largely though not entirely replaced by yellow-weathering shaly nodular limestone, some of it slightly cherty, and, especially to the south and southwest, by calcareous shale. Limestone similar to that in the Mosheim member of the Lenoir occurs locally in the basal layers, though not necessarily at the base. The thickness of the Lenoir limestone in this belt is about 700 feet near Knoxville (Knox.) and at Friendsville (Loud.) and may increase southwestward where the Lenoir merges into the Athens shale. The soil from the shaly limestone and shale is shallower and poorer than that from the typical Lenoir limestone and approaches that from the Athens and Ottosee shales. Outcrops are common; the best known and most studied section in the belt is at Friendsville (Loud.).

The Athens shale in this belt consists partly of shaly nodular limestone like that in the contiguous Lenoir limestone and partly of blue, yellow-weathering very calcareous shale much like that in the Ottosee shale. The two grade into each other and the formation is perhaps more generally shaly limestone than true shale, but on weathering it breaks down into yellow shaly chips. No black or noncalcareous shale and no sandstone are present. The formation is between 800 and 1,100 feet thick. It weathers like the Ottosee shale into a thin acid soil, and exposures are common but rarely form continuous sections, especially as the beds are generally somewhat folded. At Athens (Cleve.) the "shale" is exposed along the southwest side of Oostanaula Creek southwest of the Etowah road, but a better section can be pieced together 2 miles northeast along the Athens branch of the Louisville and Nashville Railroad and alone, the stream just north, though here there is some folding. Decker (1952, p. 31) calls the railroad locality the type locality of the Athens shale.

The Lenoir limestone and Athens shale grade into each other in a vague belt near the Monroe-McMinn County line (Loud.); indeed considerable bodies of shale can be found much farther northeast on the southeastern flank of the belt. This gradation was observed and mapped by Keith (1896a, Loud. f., map), and it is difficult to understand how Keith's field observations could have been so long ignored and overlooked while the attempt was made to fit the Athens shale into the column above the Holston formation instead of below.

The Holston formation in this belt differs from that in the standard belt in that quartz sand is much more abundant and encroaches down into the lower part of the formation, and that the formation is divided into three parts by a fairly persistent middle part about 50 feet thick, consisting of shale and shaly limestone free of red color. To the northeast the lower part consists largely of pink and gray quartz-free limestone of the types already described and includes the chief marble quarries in the belt, but even near Knoxville it commonly grades up into quartz-bearing lime-sandstone and to the southwest such rock forms more than half the lower part. Quartz may form as much as 50 percent of the rock but is generally less in this part of the formation; the quartz-bearing rock is generally gray when fresh, though on weathering the hematite in it colors it brown or red. The middle part is largely yellow-weathering shaly limestone or limy shale, but it contains layers or lenses of blue-weathering silty limestone full of bryozoans. The upper part consists almost entirely of gray to red quartz-bearing lime-sandstone or limy quartz sandstone, the quartz ranging from 30 to 80 percent, but at the base there is commonly a thin layer of red or pink quartz-free lime-sandstone, and in the upper part and locally throughout are thin layers of yellow-weathering, limy shale. The quartz-bearing rock, called the Iron-limestone by Safford (1869, pp. 239-244), was mapped by Keith and Hayes and by later workers (cf. maps in Gordon and others, 1924) as the Tellico sandstone. In some places its base was taken at or close to the base of the upper part of the formation, so that it appeared to be separated from the "marble" beneath by considerable shale; in others its base was taken within the lower part so that it seemed to rest directly on the "marble" (cf. Gordon and others, 1924, pp. 39, 72, 73). To the compiler the so-called Tellico sandstone in this and the standard belts is merely a quartzose phase of the Holston formation. The thickness of the Holston formation in this belt is 400 or 500 feet.

Where it contains more than 30 percent quartz, the quartz-bearing lime-sandstone or limy quartz sandstone weathers into a deep sandy or loamy soil thickly strewn with porous chips and blocks of brown ferruginous sandstone or "rotten-rock" from which all lime has been leached. Even the quartz-free parts of the Holston formation are commonly mantled with such soil, washed from above. The formation, particularly the quartzose upper part, forms lines of prominent knobs marked by dark-red soil and commonly called Red Hills or Red Knobs. Excellent exposures can be found in the many marble quarries in the belt; away from the marble district a good section is exposed on the bluffs over the Hiwassee River in McMinn County (Cleve.).

The Ottosee shale in this belt is precisely like that in the belt already described, including, as there, lenses of crystalline limestone ("marble") that are usually mappable. These lenses include Safford's upper marble (1869, pp. 244-245), and the corresponding Vestal marble and the probably somewhat lower Meadow marble of Gordon and others (1924, pp. 39, 40, 45, 63-65, 73). Locally in the upper part of the Ottosee shale, beds of red generally quartzose lime-sandstone appear in groups which locally may be mappable as sandy units. The formation is here well over 1,000 feet thick. Exposures are numerous but disconnected and the beds are much folded in most places. The Ottosee underlies hilly country generally lower than the adjacent Red Knobs underlain by the Holston formation.

The Bays formation in this belt is like that in the standard belt, though the large area in Knox County (Knox.) includes some fairly massive and only slightly limy siltstone. The formation here forms low but distinct ridges generally higher than the surrounding hills formed by the Ottosee shale. It is well exposed along the roads through this area, such as State Highway 71 at the southwest end of the area.

Belts southeast of the Chestuee and Dumplin Valley faults and of the Saltville fault northeast of Morristown (Gray Belt of Safford and lesser belts to southeast and southwest).-The largest area of Middle Ordovician rocks in East Tennessee forms the Bays Mountain synclinorium in Sullivan, Hawkins, and Greene Counties (Greene. and Morr.) and extends southwestward along the east side of the Valley to Etowah, McMinn County (Cleve.). In the main body of this mass, extending from east of Kingsport (Greene.) to Sevierville (Knox.), four main units can be distinguished, of which the upper two are confined to Bays Mountain between Kingsport and the Nolichucky River. These units are, in ascending order, (1) a thin body of limestone, locally divisible into the Lenoir limestone, including the Mosheim member, and the Whitesburg limestone, but too thin to be separated on the present map from the overlying shale; (2) a very thick mass of blue to gray shale, sandy shale, and sandstone, here mapped as the Sevier shale (Osv); (3) a body of red to maroon shale, siltstone, and sandstone, with white sandstone beds above, the typical Bays formation (Ob); and (4) a few outlying masses of greenish and bluish shale shown by fossils to represent the Martinsburg shale (Omb). The last of these is discussed with the upper part of the Chickamauga limestone to which it is equivalent. There is apparently no question that the Bays formation here corresponds to the Bays formation in the belts already described. The Sevier shale and underlying limestone presumably include representatives of the units below the Bays in the other belts, but the exact correlation is disputed. Southwest of Sevier County, the Sevier shale as here used can be further divided; these divisions and their possible correlation are discussed below (pp. 79-80). The Bays formation also reappears in this part of the belt. The belts southeast of the Bays Mountain synclinorium contain only the Sevier shale with a very thin limestone layer at the base.

The Mosheim limestone was named by Ulrich (1911, pl. 27) for Mosheim, Greene County (Greene.); it is well exposed in a railroad cut about 1 mile to the west. Because of its distinctively different lithology and fossils, Ulrich believed it to be a separate formation beneath the Lenoir limestone, the two being separated by a disconformity, but later work has shown that the two lithologies interfinger laterally and that the fossil differences are facies differences. Indeed, rock typical of the Lenoir occurs beneath the Mosheim at the type locality. The Mosheim is therefore best considered as a member of the Lenoir limestone.

The Whitesburg limestone was first described by Ulrich in 1930 (1930, p. 2, footnote), though the name had appeared in charts published in 1924 (Gordon and others, 1924, fig. 2, p. 34; Secrist, 1924, fig. 1, p. 16; see also Butts, 1926, pp. 111-112). The name is taken from Whitesburg, Hamblen County, but the type locality is 2 miles southeast of Whitesburg south of the east end of an anticline of Knox dolomite (Morr.). Safford called these beds the Block Limestone and observed the rich trilobite fauna they contain (1869, pp. 232, 235, 250). They were included in the Chickamauga limestone by Keith. They appear to form a mappable unit in a fairly limited area in Hamblen, Hawkins, and Greene Counties, but their fossils recur locally in the limestone layers just beneath the shale as far southwest as Blount County and also in Virginia and Alabama. Their correlation with the section in the standard belt is very uncertain; the compiler suggests that they represent a special facies marginal to the shaly limestone facies with *Christiania* and are hence to be correlated with part of the Lenoir limestone, but others maintain that their fauna places them above both the Lenoir limestone and the Holston formation of the standard belt though below the Athens shale and the shaly upper part of the Lenoir limestone of the next belt southeast.

The Sevier shale was named by Keith for the wide belt of shale in Sevier County "immediately northwest of Chilhowee Mountain" (1895, Knox. f., p. 4). The first published maps on which the formation is shown are Plate 57 in the 13th Annual Report of the U. S. Geological Survey in 1893 and the Estillville folio (Campbell, 1894a); on these maps the name Sevier was applied to the whole mass of shale between the thin limestone below (called Chickamauga by Campbell and Keith) and the Bays formation above (Campbell also applied it to the younger Martinsburg shale north of Clinch Mountain, but this erroneous usage may be ignored). Later Keith attempted to subdivide the shale in the Bays Mountain area into the Athens shale below and the Sevier shale above (1896b, Morr. f.; 1903, Greene, f., p. 6), and that in the Sevier County area into three units-Athens shale, Tellico sandstone, and Sevier shale (1895, Knox. f.)-but as a result he actually mapped very little of the type belt as Sevier. Except southwest of Sevier County, Keith's subdivisions have not proved usable, partly because of the complex structure; the mass of shale forms a single mappable unit, though locally it may be possible to map members in it. The compiler therefore proposes to return to the original meaning of the term Sevier and to apply it to the whole mass of shale where undivided. As such he believes that it includes equivalents of the typical Athens and Ottosee shales, and also of the typical Lenoir and Holston formations; the first would be granted but the second denied by other workers.

The name Bays sandstone was taken from the Bays Mountain in Sullivan, Hawkins, and Greene Counties (Campbell, 1894, Est. f., p. 2; Keith, 1896b, Morr. f., p. 3; 1903, Greene. f., p. 6). It was intended to replace Safford's provisional name Clinch red shale, and both names referred to Middle Ordovician rocks in the Bays Mountain area but to Upper Ordovician rocks to the northwest. In present usage the Upper Ordovician redbeds are referred to the Juniata formation, and the name Bays is used not only for the Middle Ordovician redbeds on Bays Mountain but also for the interbedded white sandstone there, which was mapped by Keith and Campbell as Clinch. As the Bays includes much siltstone and shale and even some limestone, as well as sandstone, it is here called the Bays formation.

The Lenoir limestone with the Mosheim member are lithologically the same in this belt as in the standard belt, but are much thinner, ranging from 200 feet down to 20 feet. Apparently, however, some limestone is always present next above the Knox group, even in Taylor Knob 8 miles south of Greeneville (Greene.), where Keith mapped the Tellico sandstone directly on the Knox. As to the northwest, the basal layers commonly include angular chert fragments and, locally, pockets of dolomite breccia. Laurence (1944) has described a fossil sinkhole about 300 feet deep at Douglas Dam (Knox.), cut in the upper part of the Knox group and filled with volcanic ash and shaly dolomite containing an unusual arthropod fauna; the correlation of these rocks with other Middle Ordovician rocks remains uncertain.

Being relatively thin, these limestones rarely contribute to the soil. Commonly their outcrop belt forms a slight topographic crease between the rolling country underlain by the Knox group and the knobs underlain by the Sevier shale. Exposures are fairly common; those in the type localities of the Whitesburg and Mosheim and on Jockey Creek northwest of Limestone (Greene.) may be mentioned.

The Whitesburg limestone consists of fairly thin-bedded rubbly argillaceous silty limestone with many shaly partings, weathering light blue to nearly white. It is perhaps 300 feet thick in the Whitesburg area but thins away from there in all directions. It makes a fairly rich silty clay soil, but the rock projects through in abundant outcrops.

The Sevier shale consists in large part of blue, yellow-weathering, silty to sandy generally calcareous shale but contains thin to thick beds of several other lithologies. Blue shaly nodular limestone is common on the northwest side of the Bays Mountain synclinorium. Black carbonaceous only slightly calcareous rather fissile shale carrying graptolites forms a persistent member a hundred or more feet thick at the base in the belts southeast of the Bays Mountain synclinorium and also through much of Cocke, Sevier, and Blount Counties. Blue or gray, brown-weathering sandstone occurs here and there throughout the formation, except near the base and in the northwestern part of the Bays Mountain synclinorium. To the southeast it becomes coarse, feldspathic, and noncalcareous. At Taylor Knob 8 miles south of Greeneville (Greene.) it invades the lowest part of the formation; near the South Holston Reservoir in eastern Sullivan County (Roan M.) it contains beds of conglomerate with fragments up to cobble size of all underlying formations down to the Unicoi formation and the basement complex (Grant and Kellberg, ms.). The sandstone-bearing part of the shale southeast of the Pulaski fault was mapped as Tellico sandstone and the underlying partly black shale was mapped as Athens shale by Keith (1903, Greene. f.; 1907b, Roan M. f.) and Campbell (1899, Bris. f.); in that area a distinction into two mappable units can certainly be made. Northwest of the Pulaski fault, Keith attempted to make the same distinction between the Sevier shale above and the Athens shale below (1896b, Morr. f.; 1903, Greene. f.), but the boundary does not appear to be consistent or mappable.

In western Sevier County some of the sandstone layers in the shale contain some hematite, and southwestward they grade into red-weathering calcareous sandstone like that in the Holston formation of the belt last discussed. In Blount County, detailed work by Robert B. Neuman has shown that such sandstone layers occur at intervals through several thousand feet of shale. In this area Keith (1895, Knox. f.; 1896a, Loud. f.) mapped some of these sandstone layers; a lower group he mapped as Tellico sandstone, separating Athens shale below from Sevier shale above, and a thick and persistent layer above the middle he mapped as a sandstone "lentil" in the Sevier shale. There are others still higher, but they are more lenticular. All resemble the quartz-bearing layers of the Holston formation in the belts next northwest except that the quartz content is generally even higher, reaching 90 percent. In places at the base of the thick middle layer, as the Tellico River (Loud.), are beds of pink and red quartz-free lime-sandstone ("marble") enclosing fine-grained reefy masses, like that in the Holston formation to the northwest, and Neuman reports similar rocks in certain of the other layers.

The correlation of these layers is in dispute. The lower group of layers constitutes the type Tellico sandstone as mapped by Keith on the Tellico River, Monroe County (1896a, Loud. f.). To the compiler the thick middle layer is the representative in this belt of the sheet of red sandstone and lime-sandstone forming the Holston formation, and accordingly he has mapped it as such from the western edge of Sevier County through Blount and Monroe Counties, and has called the shale below it Athens and the shale above it Ottosee. By this correlation the lower group of layers, the typical Tellico sandstone of Keith, occurs within the Athens shale and becomes the Tellico sandstone member of the Athens shale, and the higher more lenticular layers correspond to the limestone and sandstone lenses and layers in the typical Ottosee shale. It should be pointed out, however, that Neuman disagrees with this correlation; he believes that the whole shale sequence here called Sevier is younger than the Holston formation in the standard belt. On this correlation, none of the sandstone layers in this belt can represent the Holston formation of the standard belt, though perhaps one or more of them may be equivalent to what the compiler has mapped as Holston in the belt between.

At the southwest end of Safford's Gray Belt in southeastern McMinn County (Cleve. and Mur.), in addition to the lower red-weathering sandstone layers which make the knobs northeast of Etowah, a thick layer of coarse feldspathic brown-weathering non-hematitic sandstone appears within a few hundred feet of the base of the formation and forms a pronounced ridge just west and southwest of Etowah. Where beds above the Knox group reappear near Benton in Polk County (Cleve.), similar sandstone layers are prominent and form the pronounced ridge of Sand Mountain, extending south to Georgia. East of Conasauga, a red-weathering hematitic calcareous sandstone layer appears higher in the section and continues southwest into Georgia; it is conglomeratic, containing rock fragments from older formations, half a mile east of Cisco, Ga., about 3 miles south of the State line. The compiler suggests that this layer represents the thick middle sandstone layer of Blount County and hence the Holston formation. This correlation is strengthened by the appearance, three-quarters of a mile east of Cisco, of maroon siltstone like the Bays somewhat above this sandstone layer and immediately beneath the Great Smoky or Cartersville fault.

The Sevier shale in the Bays Mountain synclinorium is not less than 2,500 feet thick and may be twice that; in Blount and Monroe Counties the equivalent rocks are nearly 7,000 feet thick. In other areas varying amounts are preserved, commonly more than a thousand feet.

The Sevier shale underlies rough knobby intricately dissected country, except locally where the lower beds free of sandstone underlie an area of nearly flat ground. Where the structure is complex or the distribution of sandstone layers is irregular, the knobs show no systematic arrangement, but in Blount and Monroe Counties the sandstone layers and groups of layers uphold prominent lines of knobs, and in Polk County they are thick enough to form fairly continuous ridges. Scattered exposures of the Sevier shale and the enclosed sandstone layers are common but because of the generally complex folding measurable sections are rare. An imperfect section can be pieced together southwest of Bulls Gap between the type locality of the Whitesburg limestone and Bays Mountain (Morr.), but even here the rocks are repeated by several folds. Better sections can be found southwest of Sevier County, for example at Blockhouse (Knox.) and along the Tellico River and Ballplay Creek (Loud.).

The Bays formation consists of maroon shale, siltstone, and silty sandstone: finer-grained and calcareous and passing into silty and shaly maroon and blue limestone below; coarser-grained and passing into white clean sandstone and fine conglomerate above. In the Bays Mountain area the white sandstone forms several thick layers interbedded with maroon sandstone and siltstone; commonly it shows *Scolithus* tubes. In most of Blount County white sandstone is absent or occurs only as thin layers at the top of the formation, but at the Little Tennessee River (Loud.) and beyond in Monroe County thicker white sandstone layers appear (these were mapped locally as Clinch sandstone by Keith, 1896a, Loud. f.). Beds of yellow limy shale and siltstone occur near the base in places, commonly associated with blue silty limestone. Some of these beds may be mappable. A layer of altered volcanic ash 5 feet thick is exposed on the road leading west from the mouth of Citico Creek in Monroe

County (Loud.); the ash bed rests on an inch or two of chert and is disconformably overlain by the Chattanooga shale. Ripple marks and mud cracks are common in the Bays formation and suggest that the sediments were deposited in extremely shallow water, if not on land, but fossil ostracodes and inarticulate brachiopods show that some layers at least are marine. Little is known of the detailed stratigraphy of the Bays formation, but it offers a promising field for study. The formation is more than 700 feet thick in the Bays Mountain synclinorium and perhaps 1,000 feet thick in Monroe County.

The Bays formation produces a shallow maroon soil, which, however, is limy and fairly fertile where the rock is calcareous. The sandstone layers in the upper part of the formation form prominent mountain ridges, both in Bays Mountain and in Monroe County. Elsewhere the formation forms hills not unlike those on the adjacent Sevier and Ottosee shales. Outcrops are numerous and measurable sections can be obtained in many of the stream valleys crossing the strike of the formation.

Belts between the Saltville fault and the Whiteoak Mountain and Hunter Valley faults (middle belts).-The lower and middle parts of the Chickamauga limestone and equivalent rocks form three belts in the middle of the Valley of East Tennessee, northwest of the standard belt passing through Knoxville and Lenoir City. Of these, the middle and most important one underlies Clinch Valley on the north side of Clinch Mountain (Morr. and Mayn.), where the full sequence of the rocks in question is present between the Knox group and the Martinsburg shale. To the southwest along the strike of the belt, however, the top of the sequence is cut out and the belt is broken. In the northwest belt, the top of the unit is not preserved, having been cut out by the Copper Creek fault throughout the extent of the belt in East Tennessee. The southeast belt consists of a short portion with a complete sequence next to the Saltville fault in Hawkins County (Morr. and Greene.) and a longer but broken portion, in which the sequence is only locally complete, beginning in Knox County at the west end of Clinch Mountain (Mayn.). All the belts end to the southwest in northern McMinn County (Kings. and Cleve.).

In the Clinch Valley belt these rocks have been divided into 13 lithologic units (A to M), which have been mapped along the strike for 40 miles (Rodgers, 1943; Rodgers and Kent. 1948). Reconnaissance and local detailed mapping have shown that most of these units can be recognized throughout this group of belts northeast of Knoxville. Farther southwest less work has been done, and in northern McMinn County what remains of the sequence is somewhat different. Because of the scale of the present map, these units are here grouped into three mapping units, designated (in ascending order) Chickamauga limestone, unit 1 (Ochi), Chickamauga limestone, unit 2 (Och2), and Moccasin formation (Om). These larger units are shown not only where detailed work has been done but also in much of the rest of these belts, but where the available data do not permit even this division, the rocks are grouped as lower and middle parts of the Chickamauga limestone, undivided (Olmc).

Unit 1 of the Chickamauga limestone includes the rocks believed to represent approximately the Lenoir and Holston formations of the standard belt, and unit 2 includes the sequence of generally shaly limestone believed to represent the Ottosee shale of the standard belt; the correlation has been made by jumping from the standard belt to the next belt in the vicinity of Fountain City, and thence to the belt in Beaver Valley which is continuous with Clinch Valley (Mayn.). As the units in question show a similar sequence from belt to belt, differing chiefly in degree of shaliness, the correlation is believed to be fairly well established.

The Moccasin limestone was named by Campbell (1894a, Est. f., p. 2) for (Big) Moccasin Creek, Scott County, Va., northeast along the strike of the Clinch Valley belt. Safford called these rocks the Brown Shale, and the rock is more a limy shale and siltstone than a limestone; hence it is here called the Moccasin formation. Where it is shown on the present map, its base is drawn below the lowest maroon and associated yellow shale and silty limestone. Campbell (1894a, Est. f.; 1899, Bris. f.), but not Keith (1896b, Morr. f.; 1901, Mayn. f.), drew the base considerably higher, above a fairly thick body of blue limestone (unit 1 of Rodgers, 1943) here included in the lower part of the Moccasin. Cooper (1942) prefers Campbell's original usage in southwest Virginia, but for the present map the compiler finds Keith's usage more satisfactory. If necessary the name as here used could be replaced by Bays formation, of which these rocks are a more limy northwestern representative.

Unit 1 of the Chickamauga limestone as here mapped includes a variety of rocks. In general it comprises a lower part of light-colored fine-grained to aphanitic limestone and an upper part of dark crystalline nodular limestone with lenses of "marble." These parts correspond to units A and B of Rodgers (1943; Rodgers and Kent, 1948) in the Clinch Valley belt.

The limestone of the lower part ranges from massive and pure, approaching that in the Mosheim member of the Lenoir limestone, to thin-bedded, silty, and locally dolomitic and cherty. In general the purer rocks lie southeast and toward the top, the siltier rocks northwest and toward the base. In places, especially to the northwest, the basal layers are red and gray calcareous or dolomitic silty shale. Angular chert fragments from the underlying Knox group are common in the basal layers and locally form lenses of chert conglomerate; 2 1/2 miles northeast of Lee Valley, just northeast of Shiloh (Morr.), one such lens 500 feet wide and at least 150 feet thick fills a channel cut in the underlying Mascot dolomite. In general the lower part is somewhat more than 100 feet thick to the southeast but considerably thinner to the northwest. Fossils indicate that much of it at least correlates with the Lenoir limestone of the type area.

The upper part varies even more widely. In the southeastern belt in Hawkins County and in the Fountain City and Beaver Valley areas as far northeast as Luttrell (Mayn.), coarsely crystalline red, pink, and, at the top, white limestone ("marble") predominates over the dark limestone, whereas to the northwest "marble" is rare and considerable bodies of the limestone become very cherty. Where chertiest the limestone is lighter in color and much finer-grained. The same transition is even more abrupt in McMinn County (Rodgers, 1953a), where in the southeastern belts red and pink lime-sandstone ("marble") is over- and underlain by very cherty limestone; in the northwestern belt in that area the two layers of cherty limestone are separated instead by red limy siltstone or very silty limestone. These beds average 250 feet in thickness; in general the cherty limestone and associated beds on the northwest are a little thicker than the "marble" and dark limestone on the southeast, and it is probable that they span a little more time, encroaching into the beds above and below the "marble" zone. They are probably roughly correlative with the Holston formation, but the correlation is by no means established.

The rocks assigned to unit 1 of the Chickamauga limestone generally crop out extensively, except where covered by slope wash from the adjacent Knox group; between the outcrops is a rich clay soil. The cherty limestone, however, rarely crops out but is hidden beneath a thick mantle of very cherty residuum and soil. Where not cherty, the unit underlies a valley or a line of sinks, but throughout the belt along the Copper Creek fault the cherty limestone upholds a line of prominent spurs and knobs on the southeast flank of Chestnut Ridge and its continuations, and in Knox and

Anderson Counties (Brice. and Mayn.) it even forms an independent ridge called Flint Ridge.

Unit 2 of the Chickamauga limestone as here mapped includes several types of shaly and argillaceous limestone and limy shale in which are interbedded layers and lenses of purer limestone and “marble.” In the southeastern belt, shale dominates, though silty nodular limestone with shaly partings appears in the upper part. In the northwestern belts, shaly, generally nodular limestone dominates, dark and crystalline below, lighter, fine-grained, and somewhat silty above, but large bodies of limy shale are present locally, as in the Clinch Valley belt near Lee Valley (Morr.). The purer limestone may occur at any level but is most persistent below the middle; at this level through most of the northwestern belts, and locally in the southeastern belt, massive light-colored limestone, varying irregularly from aphanitic to coarse-grained, forms a body 100 to 15.0 feet thick. Above this body and separated from it by a sharp contact are less widespread lenses of generally thin-bedded red to pink limestone, some coarse-grained, some an intimate mixture of coarse and fine; these lenses grade laterally into blue platy shaly limestone and even into limy shale. In the Clinch Valley belt, units C to F of Rodgers (1943; Rodgers and Kent, 1948) are included; in ascending order they consist of (C) nodular shaly limestone, (D) light-colored massive limestone and "marble," (E) red "marble" lenses grading into platy limestone and shale, and (F) nodular shaly and silty limestone. In northern McMinn County that part of unit 2 of the Chickamauga still preserved is mostly shale in the southeastern belts, but it is a mixture of blue shaly limestone and pink very silty limestone or limy siltstone in the northwestern belt. The total thickness of unit 2 in these belts ranges from 800 to 1,000 feet. That some part of these beds is correlative with the Ottosee shale of the standard belt there is little doubt, but some workers believe that much of the lower part is represented in that belt either in the Holston formation or by disconformity.

Unit 2 of the Chickamauga limestone is normally covered by a rather thin mantle of residuum and soil, more fertile over the purer limestone than over the shaly limestone. Outcrops are common in the rough country of Hawkins, Hancock, and Grainger Counties; farther southwest the rock is more likely to be buried beneath wash from other formations. The unit commonly underlies the lowest parts of the valleys underlain by Chickamauga limestone, but its variably resistant rocks diversify those valleys with minor ridges, valleys, and lines of sinks.

The Moccasin formation is as regular in lithology and sequence as the underlying formations are variable. The following generalized section, though based on the Clinch Valley belt, will serve with only slight modification for the whole group of belts (lettered units are those of Rodgers, 1943; Rodgers and Kent, 1948):

Shale and siltstone, limy, and silty limestone, mixed greenish, yellowish, and maroon (upper part of unit M)	25 feet
Upper altered volcanic ash bed (about 2 feet thick)	
Siltstone, somewhat limy, entirely maroon (lower part of unit M)	65 feet
Lower altered volcanic ash bed (about 2 feet thick)	
Shale and siltstone, limy, and a little silty limestone, mostly maroon but including some blue limestone and a little yellow shale and siltstone in upper and lower thirds (unit L)	180 feet
Limestone, mostly pure and blue-weathering, silty and yellowish at top and base; much black chert in upper half (unit K)	60 feet
Shale and siltstone, limy, and silty limestone, much of it maroon, but including considerable blue limestone and yellow shale and siltstone, especially near top and base (unit J)	150 feet
Limestone, mostly pure and blue-weathering, silty at top and base and in thin middle streak, there pink and yellow (unit 1)	230 feet
Shale and siltstone, limy, and silty limestone, maroon, yellow and blue (unit H)	100 feet
Shale and siltstone, limy, and silty limestone, yellow and blue, rare maroon streaks (unit G)	140 feet

Thus the formation consists of mainly maroon calcareous shale, siltstone, and silty limestone alternating with blue-weathering mainly nonsilty limestone. The latter was called the Lowville limestone (type locality in New York) by Butts (1933, p. 18; 1940, pp. 179- 191), and lie correctly considered the maroon and blue rocks to be contemporaneous intertonguing facies, though the name Lowville is unsatisfactory for use here because of the great distance from the type locality and the uncertain correlation between. Thus in the southeastern belt in Hawkins County, the blue limestone units contain many pink silty streaks and are evidently grading toward the almost solidly maroon Bays formation; in the belt along the Copper Creek fault on the other hand the maroon units, especially the lower ones, are invaded by many more layers of blue and yellow silty limestone and shale and are evidently grading toward the blue and yellow silty limestone here mapped as unit 3 of the Chickamauga limestone in the belts beyond the Hunter Valley fault. Like the Bays formation, the maroon parts of the Moccasin commonly show ripple marks and mud cracks and also, locally, fossil ostracodes. The thickness ranges from 800 feet on the northwest to 1,000 feet or a little more on the southeast.

The Moccasin formation produces a very shallow but somewhat limy soil full of reddish chips, generally a mere veneer over the bedrock. The blue limestone units have a somewhat deeper clay soil but even here outcrops are common. The formation commonly underlies a series of irregular spurs on the southeast side of the valley formed over the Chickamauga limestone, but the lower blue limestone body (unit I of Rodgers, 1943) makes lower ground and is locally in the axis of the valley.

Well-exposed sections through these formations are readily obtained in the hilly country of Hawkins, Hancock, and Grainger Counties; measurements have been published by Rodgers and Kent (1948, pp. 32-44) for the section at Lee Valley, Hawkins County (Morr.), and by Hall and Amick (1934) for the lower part of the section at Thom Hill, Grainger County (Morr.), both in the Clinch Valley belt. Farther southwest sections must be pieced together from more widely scattered outcrops.

Belts northwest of the Whiteoak Mountain and Hunter Valley faults (northwestern belts).-Northwest of the Whiteoak Mountain and Hunter Valley faults, the rocks included in the lower and middle parts of the Chickamauga limestone have been divided for the present map in certain areas only, chiefly in Claiborne and Union Counties (Mayn. and Brice.). In those areas 9 or 10 mappable units have been traced, some of which correspond closely and others rather less closely to the units mapped in the Clinch Valley belt by Rodgers (1943). For the present map they are grouped into three numbered units (Och_1, Och_2, Och_3), intended to correspond to the three units in the middle belts. The term unit 3 of the Chickamauga limestone replaces the controversial terms Black River limestone and Lowville limestone, which were also extended far down into unit 2 as used on the present map and in general were applied to all blue-weathering limestone carrying a fauna like that of the Black River group. Likewise the term unit I of the Chickamauga limestone replaces in these belts the term Stones River limestone, for the beds in question represent only the lowest part of the typical Stones River of Middle Tennessee.

Unit I of the Chickamauga limestone in Claiborne and Union Counties consists of massive light-colored aphanitic limestone, better-bedded somewhat darker fine-grained cherty limestone, thin-bedded to nodular much darker somewhat coarser-grained limestone, and yellow and pink silty limestone and dolomite, the last especially near the base. Red and yellow, limy siltstone and silty shale layers occur in many places at the base and more rarely higher; the basal layers commonly contain angular chert fragments from the Knox group. The massive and cherty limestones form in general two bodies of thick-bedded relatively clean limestone, separated and underlain by bodies of thin-bedded limestone; these divisions can be mapped in some areas but not in others. The upper thick-bedded body is commonly very cherty above, massive and chert-free below, and these parts have been called the Lenoir limestone and the Mosheim limestone, respectively; however, if equivalents of the Lenoir are present at all in these belts they probably underlie the lower thick-bedded body. Miller and Brosge' (1950) have given several new names to the divisions of this unit in Lee County, Va., the application of which in Tennessee must await detailed mapping. The thickness of unit I ranges from 300 to 400 feet, in part at least, because the material was deposited on an irregular surface. It is tempting to correlate the cherty limestone at the top with the cherty limestone forming the upper part of unit I in the belt along the Copper Creek fault, but more probably the top of the cherty limestone facies rises steadily higher in the section northwestward.

The various kinds of limestone produce different kinds of soil: the silty limestone a thin, poor soil, the massive limestone a somewhat deeper, richer soil, and the cherty limestone a deep, very cherty soil. The cherty limestone, especially that near the top of the unit, holds up low but pronounced knobs or ridges, on the scarp face of which the massive limestone commonly crops out; the rest of the unit may form a broken valley or a line of sinks between the low knobs and ridges and the higher ridge underlain by the Knox group.

Unit 2 of the Chickamauga limestone in these belts includes massive aphanitic limestone, well-laminated to platy fine-grained limestone, nodular cherty limestone, nodular slightly silty limestone, and yellow thin-bedded silty limestone. In many sections the purer limestone and the siltier limestone alternate in bodies 30 to 50 feet thick, the purer limestone being more massive in the lower part of the unit, more laminated in the upper part. Streaks of pink and yellow siltstone and shale occur in the silty limestone layers in many areas. The uppermost part of the unit, however, consists chiefly of the nodular slightly silty limestone, generally containing a prominent zone of *Stromatocerium* and a prominent zone of brachiopods (chiefly *Hesperorthis*) about 100 feet from the top. At the top, such limestone grades up into the flaggy limestone of the next unit. Unit 2 in these belts is from 350 to 550 feet thick. Probably both contacts lie higher in the section here than in the middle belts.

The rocks of unit 2 of the Chickamauga limestone are covered by a generally thin but fertile soil through which ledges appear. They generally underlie the lowest parts of the valleys formed over the Chickamauga limestone, but the alternating layers of different kinds of limestone create low, parallel ridges and troughs within the larger valleys.

Unit 3 of the Chickamauga limestone shows a consistent sequence of beds that can be closely correlated with the sequence in the Moccasin formation of the middle belts. Miller and Brosge’ (1950) have given new names to the several parts of this sequence in Lee County, Va. A Generalized section is as follows (lettered units correspond roughly to those of Rodgers, 1943; Rodgers and Kent., 1948):

Limestone, both blue and nonsilty and greenish or yellowish and silty, and yellow limy siltstone (upper part of unit M)	5-20 feet
Upper altered volcanic ash bed (about 2 feet thick)	
Siltstone and shale, limy, yellow (locally pink to the southeast) (lower part of unit M)	50 feet
Lower altered volcanic ash bed (about 2 feet thick)	
Limestone, generally somewhat silty and cherty, blue and yellow (upper third of unit L)	50 feet
Siltstone and shale, limy, yellow (a few pink layers to southeast) (middle third of unit L)	50 feet
Limestone, somewhat silty and cherty, blue and yellow (lower third of unit L)	75 feet
Limestone, blue, very little silt; much black chert in upper half (unit K)	50 feet
Limestone, silty, yellow; some beds of purer blue limestone and some of limy siltstone and shale(unit J)	150 feet
Limestone, flaggy, blue, uniform; silty limestone streak in middle to southeast (unit 1)	200 feet

The lowest units of the Moccasin formation (units G and H) are apparently not represented by a distinct tongue of silty limestone; probably their equivalents are included partly in unit 3 and partly in unit 2.

The limestone in unit 3 of the Chickamauga produces shallower or deeper, poorer or richer soils according to whether the limestone is silty or not, but none of the soils is very thick. Outcrops, especially of the purer limestone, are fairly common. Unit 3 of the Chickamauga limestone, except the blue flaggy limestone at the base, underlies slightly hillier ground than unit 2.

Southwest of Clinton (Brice.), less is known about the possible subdivisions of the rocks included in the lower and middle parts of the Chickamauga limestone in these belts and they are mapped as a single unit (Olmc). The same lithologies persist but the proportions differ. Layers of cherty limestone somewhat above the base commonly make a low ridge and perhaps mark the top of the equivalent of unit 1. Pink silty limestone and limy siltstone become very important in the lower half in some areas, and are present locally near the top west of Whiteoak Mountain (Chatt.). The yellow siltstone layers in the upper part are generally thinner, limier, and less well marked in the western belts; thus the two ash beds are only 25 feet apart near Chattanooga. The ash beds themselves, their thin underlying chert layers, and the cherty limestone representing the lower part of unit L and the upper part of unit K appear to persist, however, throughout the area. The total thickness ranges from about 1,600 to about 1,000 feet.

Correlation beyond East Tennessee.-The marked disconformity below the Chickamauga limestone is readily traced throughout the southern Appalachians as far north as northern Virginia; chert conglomerate lenses are known to rest upon it in many areas, especially in north-central Alabama where they have been named the Attalla chert conglomerate member of the Chickamauga limestone (Butts, 1910, p. 4; 1926, p. 120). The contact here used to divide the Chickamauga limestone and equivalent rocks into two major units (pp. 66-67) is hardly less recognizable; it corresponds to the base of the "Trenton" limestone as it has been mapped from Virginia to Alabama or to the base of the equivalent Martinsburg shale. The correlation of the beds between is as much in dispute outside East Tennessee as within, and it will probably be some time before agreement is reached on correlations between the standard section in the Knoxville area in East Tennessee and the standard sections recently set up for Tazewell County in southwest Virginia (Cooper and Prouty, 1943) and the Shenandoah Valley in northern Virginia (Cooper and Cooper, 1946).

The section in the northwestern belts in East Tennessee and down the strike into Georgia and Alabama has often been likened to the Middle Ordovician section of Middle Tennessee. The basal disconformity is not exposed in Middle Tennessee, except in the isolated Wells Creek dome in Stewart County, and it lies about 400 feet beneath the surface at the high point of the Nashville dome, but it has been reached in many oil wells (Bentall and Collins, 1945, fig. 12, table). The contact between the two major units of the Chickamauga limestone is believed to be precisely the contact between the Carters limestone of the Stones River group and the Hermitage limestone of the Nashville group as those terms are at present used in Middle Tennessee (Wilson, 1949, footnote, pp. 23-24). Hence the major unit here described as the lower and middle parts of the Chickamauga limestone and equivalent rocks appears to correspond exactly to the Stones River group of Middle Tennessee, except that the lowest beds in East Tennessee, the ones which ironically enough have alone been called Stones River in the past, either are correlative with beds beneath the surface in Middle Tennessee or, more likely, are not represented there at all, having been cut out in between, against the basal disconformity. Correlation with the individual formations of the Stones River group is much less assured; unit M of Rodgers (1943) with its two thick ash beds undoubtedly is correlative with the upper member of the Carters limestone with its two thick ash beds, and the lower member of the Carters is probably represented by the cherty limestone of units K and L. Likewise, unit I is believed to represent at least a part of the Lebanon limestone. Lower in the section the facies changes appear to be too great to permit correlation; it is fairly certain, however, that the cherty limestone in the lower part of the Chickamauga limestone in the northwestern belts and the Murfreesboro limestone are in some part equivalent.

Correlation of the East Tennessee sequence with the standard New York sequence is also difficult. The basal disconformity clearly separates rocks of Beekmantown age from rocks of Chazy age and younger and hence corresponds to the boundary between the Lower and Middle Ordovician series. How much of the Chickamauga limestone is of Chazy age is still in dispute; it is generally agreed that the type Lenoir limestone in the standard belt and probably the lower part of unit I of the Chickamauga limestone as here mapped in the middle belts contain Chazy fossils, and possibly some part of the overlying cherty limestone in the middle belts and of the Holston formation of the standard belt is also of Chazy age. On the other hand, the shaly upper part of the Lenoir limestone and the equivalent Athens shale contain the Christiania fauna, to which a Black River age is commonly assigned. Until the extent to which the fossils are controlled by facies has been determined, both in East Tennessee and in New York, the matter must remain in this unsatisfactory state.

The upper boundary of the major unit here being discussed (the lower and middle parts of the Chickamauga limestone and equivalent rocks) appears to correspond to what used to be considered the base of the Trenton limestone in New York, but of recent years additional formations below have been assigned to the Trenton group in New York, and the boundary here in question falls within the group, probably at the base of the Sherman Fall and Shoreham limestones of Kay (1937). Much or all of unit 3 of the Chickamauga limestone and of the Moccasin and Bays formations may therefore be of Trenton age, according to this usage. In summary, the unit here considered corresponds essentially to the Stones River group of Middle Tennessee and represents the Black River and probably parts of the Chazy and Trenton stages of the standard New York sequence of the Middle Ordovician series.

Synthesis.-The large mass of detail concerning nomenclature and correlation in the present chapter may obscure the broad history that can be read from the rocks themselves (see fig. 4). As already noted, the disconformity at the base records a period of subaerial erosion that produced a surface of considerable relief. Everywhere the first unit of rocks above the disconformity is chiefly limestone (contrasting with the dolomite dominant in the underlying Knox group), indicating that seas largely clear of terrigenous sediment spread over the irregular surface, though much silt, sand, and chert gravel that remained on that surface was incorporated into the basal layers of sediment. Probably the sea advanced from the southeast, so that the lowest beds above the disconformity are older there than to the northwest, though how much older cannot at present be stated. In these waters, lime-sand and lime-mud were deposited, probably formed partly by abrasion of the shells of animals that swarmed on the bottom and partly, locally at least, by direct chemical precipitation of calcium carbonate. Occasionally, also, actual reefs were built up by algae and bryozoans and were inhabited by crinoids and other animals.

Almost immediately after the first invasion of the sea, however, vast quantities of mud and sand from a southeastern source began to encroach into the southeastern part of what is now East Tennessee, where thousands of feet of what is now shale, sandstone, and conglomerate were rapidly deposited; these detrital materials pushed gradually and somewhat irregularly northwestward, muddying the waters and markedly changing the conditions affecting animal life. Probably these materials came from a newly uplifted highland or a group of high islands, perhaps not far southeast of the present North Carolina line. The conglomerate near the South Holston Reservoir (p. 79) contains pebbles of many of the underlying formations down to the pre-Cambrian basement and shows that in the new highland all these older rocks had been uplifted above sea level and were being eroded. Probably also some terrigenous material came from the northwest, where the low and perhaps still peneplained central platform of the continent could still furnish the red mud and dissolved silica now present in the silty and cherty limestone in unit I of the Chickamauga limestone.

At several times, periods of sand deposition on the southeast side of the area coincided with the appearance in part of the sea of much finely divided hematite, perhaps contributed by a single river discharging into the sea in what is now southern Blount County. One such period coincided, moreover, with a period of especially widespread reef building, and the reef masses, the lime-sand worn from them by the waves, and also considerable quartz sand that encroached from the southeast into the reef area became deeply colored by hematite from Hawkins County to the Georgia line. Perhaps the reef conditions favored the spread of the hematite, or perhaps the conditions responsible for the spread of the hematite favored reef building. In any case, the result was a vast sheet of red sand, chiefly calcite to the northwest and chiefly quartz to the southeast, interspersed to the northwest with reefs, perhaps to a large extent fused into a great barrier reef.

Following this episode, the advance of detrital material continued; now and then reefs and bodies of sand derived partly from them appeared, grew, and spread, and were then choked off and buried as lenses in the mud. Meanwhile, conditions to the northwest remained little changed, though less and less silica came from the Canadian shield. Later, red or maroon mud began to replace yellow mud on the sea floor, perhaps because of a change in climate in the highland, perhaps because the sea became shallower or even a tidal flat, so that the bottom was better oxidized. The mud spread quickly farther northwest than ever, and then for a considerable period the mud limit shifted back and forth, producing an alternation of pure limestone and red or, to the northwest, yellow shale and siltstone. Finally, on the southeast white sand and gravel, perhaps beach deposits, invaded the area of the red mud flats; on the northwest in the clearer seas silica from some source, perhaps volcanic, reappeared in considerable amount; and over the whole area volcanic ash began to rain down, first in small amounts, then culminating in two vast sheets recording two great volcanic explo- sions or groups of explosions and probably coming from volcanoes in the new highland area to the southeast. Shortly thereafter the sea retreated briefly, or at least the character of its deposits changed abruptly, becoming generally much finer-grained, new animals spread into the new sea, and a new epoch began. The vast wedge of detrital material in these formations, especially in those that Ulrich proposed to place in his Blount group, thus records the raising of a new highland or highlands to the southeast, where apparently there had been none since very early Cambrian time. In the character and distribution of rock facies, this wedge shows a remarkable parallelism to a wedge centered in the Upper Ordovician deposits of New York and Pennsylvania, which records a similar but later uplift, known to have deformed the rocks of western New England and eastern New York and generally considered to be the climactic phase of the Taconian orogeny. The thickness and coarseness of the Middle Ordovician deposits in Tennessee show that the earlier uplift was little if any lower, though their geographic distribution, extending only from central Virginia to central Alabama and barely reaching across the Appalachian Valley, shows that it was less widely extended and lay perhaps farther east of the present outcrop belt of the rocks that record it. This uplift may therefore be called the Blountian phase of the Taconian orogeny; it began in Chazy time and reached its climax in what is now regarded as early Trenton time, its paroxysm apparently punctuated by immense volcanic explosions.

UPPER PART OF CHICKAMAUGA LIMESTONE AND EQUIVALENT ROCKS (Ouc)

By contrast with the great complexity of the facies changes and correlations in the lower and middle parts of the Chickamauga limestone and equivalents, the gradation of the upper part of the Chickamauga limestone southeastward into the Martinsburg shale seems simplicity itself, but perhaps this appearance of simplicity is partly the result of ignorance, for the equivalent rocks in Middle Tennessee have been shown by Wilson (1949) to exhibit some well-marked facies changes. Indeed, these rocks in East Tennessee offer a promising field for detailed stratigraphic work, which will be greatly aided by the abundant fossils, though at the same time hindered by the local prevalence of fairly complex folding.

Northwest of the Kingston fault, as far northeast as Harriman (Kings.), and a little beyond (Loud.), these rocks are dominantly limestone, though commonly shaly at the top, and they are here mapped as the upper part of the Chickamauga limestone (Ouc). Between the Kingston and Jacksboro faults and the Whiteoak Mountain and Hunter Valley faults, and also in the belts at the edge of the Cumberland Plateau near Clinton and Oliver Springs (Brice.), the upper third, or so, of this unit is shale and the rest limestone, and these are mapped separately as Reedsville shale (Or) and unit 4 of the Chickamauga limestone (Och4). Southeast of the Hunter Valley fault, the rocks are dominantly shale, though beds of limestone are present in all areas, and the unit is mapped as the Martinsburg shale (Omb).

The term upper part of the Chickamauga limestone is used here instead of Trenton limestone because apparently the beds in question do not include all limestone of Trenton age in the area, and in the westernmost belts they include some younger limestone. The name Reedsville shale was proposed by Ulrich (1911, pl. 27) for Reedsville, Mifflin County, Pa., and it has been used from Pennsylvania to Tennessee for Upper Ordovician shale where it rests on Middle Ordovician limestone. In the folio mapping the Reedsville shale was largely ignored, though Hayes locally called it Athens shale (1894b; Kings. f.; 1895a, Cleve. f.) and Keith thought it represented the feather edge of the Sevier shale (1901, Mayn. f., p. 3). The name Martinsburg shale was proposed by Geiger and Keith (1891, p. 161) for Martinsburg, Berkeley County, W. Va., in the Shenandoah Valley, and it has been used from New Jersey to Tennessee wherever the shale includes both Middle and Upper Ordovician beds. In the folio mapping the Martinsburg shale was classed as Sevier shale on Clinch Mountain and as Rockwood formation on Bays Mountain, though the lithology and fauna are the same in both areas.

Unit 4 of the Chickamauga limestone consists of fairly dark blue to gray well-bedded or platy to nodular limestone, generally, though by no means entirely, medium-grained and commonly interbedded with thin shaly partings. Many layers are crowded with brachiopod shells, particularly in the lower part of the unit. A few volcanic ash beds, mostly thin, have been found near the base, and the basal layers are commonly silty or sandy. Probably careful work would permit subdividing these rocks into mappable units, perhaps the same as those recognized by Wilson (1949, pp. 75-156) in Middle Tennessee and the Sequatchie Valley. East of the Kingston fault the limestone grades tip into the Reedsville shale, which resembles the Martinsburg shale described below; west of that fault it grades up into equivalent shaly limestone, the shaly material occurring partly as layers interbedded between layers of only slightly argillaceous limestone, partly intimately and irregularly mixed with the limestone, which in that case is generally nodular and argillaceous. Because of lack of data, this shaly limestone has not been separated from the underlying limestone on the present map, but it undoubtedly forms a mappable unit and perhaps can be further subdivided into portions of Eden and Maysville age, following Wilson (1949, pp. 175-190). Unit 4 ranges from 350 to 600 feet in thickness, being thinnest to the west and southwest, thickest to the cast and northeast. The shaly limestone above it west of the Kingston fault is 100 to 250 feet thick; the Reedsville shale east of that fault is 250 to 400 feet thick.

The upper part of the Chickamauga limestone forms rich clay soils through which outcrops may project, especially to the northeast. It underlies part of the generally wide valleys formed over the Chickamauga limestone but that part is a bit more rolling than the rest, especially in the southeastern belts. The Reedsville shale commonly forms short, steep spurs along the ridges upheld by the Rockwood formation, but locally it forms separate knobby hills, such as some of the Texas Knobs northeast of Georgetown (Cleve.). The equivalent shaly limestone west of the Kingston fault has no particular topographic expression.

The Martinsburg shale consists of greenish to bluish, yellow to orange-weathering mostly calcareous shale with which are interbedded many thin layers of dark medium grained very fossiliferous limestone, especially close to the base and above the middle, and also layers of silty shale and shaly calcareous siltstone, especially near and above the middle. The Reedsville shale is composed of the same rock types. A few beds of altered volcanic ash occur near the base of the Martinsburg, and locally a thick one may rest on an inch of chert, as do the thick persistent ash beds in the immediately underlying formations. At the base there is commonly a layer or two of calcareous sandstone that weathers to characteristic brown porous blocks. Close to the top at Thorn Hill, Grainger County (Morr.), and elsewhere are other layers of calcareous sandstone, mainly finer-grained and silty and containing *Orthorhynchula linneyi* (James), which has been found in this lithologic position from here to Pennsylvania. The Martinsburg shale is apparently somewhat over a thousand feet thick on Clinch Mountain, though minor folding makes exact measurement difficult; 700 feet or so are preserved in the Bays Mountain synclinorium.

The Martinsburg shale weathers to a fairly thin and slightly acid clay soil, whose characteristic bright orange color appears in the gullies with which the hillsides are too commonly scored. Good outcrops are not common except in road cuts, but slabs from the limestone layers or porous blocks of weathered sandstone litter the slopes in certain areas. On the north face of Clinch Mountain blocks of Clinch sandstone also are common, some of great size. Here the Martinsburg forms a series of fairly short but steep spurs projecting from the scarp face of the mountain, commonly with small knobs near the top marking the sandstone layers in the upper part. Elsewhere the Martinsburg, makes knobby country, as in the Bays Mountain synclinorium southwest of Kingsport (Greene.).

Though the fossils in unit 4 of the Chickamauga limestone in East Tennessee have been little studied, they show that it is Middle Ordovician and correlates with the Nashville group of Wilson

(1949) in Middle Tennessee and the main part of the Trenton group in New York. The Reedsville shale and the equivalent shady limestone are Upper Ordovician and include the Eden and Maysville stages, and the Martinsburg shale represents the same interval as the others together.

JUNIATA FORMATION (Oj) AND SEQUATCHIE FORMATION (Os)

The Juniata and Sequatchie formations form a sheet of red or maroon sediments extraordinarily similar in lithology to the older sheet represented by the Bays and Moccasin formations and long confused with it. Moreover, this sheet holds the same position in the great wedge of detrital deposits spanning the Ordovician-Silurian boundary that the other sheet holds in the great wedge in the Middle Ordovician series-between bluish calcareous to sandy shale below and white *Scolithus*-bearing sandstone above, though in the younger wedge maroon rocks are not interbedded with the white sandstone. The younger wedge, though its representatives in Tennessee are thinner than those of the older wedge, is of much greater extent, reaching from Alabama to Quebec, and even in Tennessee comparable facies reach farther west and northwest. This younger wedge reflects the main phase of the Taconian orogeny, which was taking place during late Ordovician and perhaps earliest Silurian time.

The Juniata and Sequatchie formations, like the Bays and Moccasin formations, are respectively the less and more calcareous portions of the sedimentary sheet; they intergrade laterally and the boundary between them is essentially an arbitrary one. For the present map it has been taken along the line of the Hunter Valley and Whiteoak Mountain faults, but the belts northwest of these faults as far as the Powell River anticline and the Kingston fault are transitional and, though shown on the map as the Sequatchie formation, could equally well have been mapped as the Juniata formation.

The name Juniata formation was proposed by Darton and Taff (1896, p. 2) for the rocks then called the Red Medina sandstone in Pennsylvania, Maryland, and West Virginia, and has since been carried across Virginia into Tennessee. The name was taken from the Juniata River in central Pennsylvania. Safford (1869, pp. 293 ff.) called these rocks the Clinch red shale, and in the folios they were mapped as Bays sandstone. The name Sequatchie formation was proposed by Ulrich (1914, pp. 614, 648-649) for the more calcareous phase, the name being taken from the Sequatchie Valley, which lies in the counties next west of the area covered by the present map. Keith generally mapped the Sequatchie formation as the Bays limestone (1896a, Loud. f.; 1896c, Brice. f.; 1901, Mayn. f.), but Hayes included it in the Rockwood formation.

The Juniata formation, which crops out on Clinch and Stone Mountains (Greene., Morr., and Mayn.), consists of largely non-calcareous maroon shale, siltstone, and fine-grained silty sandstone; taken as a whole it is quite uniform. In the Sequatchie formation much pinkish, bluish, and greenish argillaceous limestone appears, and to the west and southwest it replaces the siltstone and sandstone and most of the shale. Around Chattanooga the limestone is more blue than pink, though still mainly argillaceous (here Fox and Grant, 1944, p. 329, recognize a bed of altered volcanic ash), and in the Sequatchie Valley pink or red color appears only in the upper part of the formation in the northern portion of the valley (Wilson, 1949, pp. 221, 236). The Juniata formation is about 400 feet thick on Clinch Mountain. The Sequatchie formation is about 300 feet thick in Claiborne County but thins to 200 feet or so to the southwest.

The Juniata formation crops out close to the top of the scarp faces held up by the Clinch sandstone and has little effect on soils or topography. In its southeastern belts, the Sequatchie formation occurs mainly in a similar position relative to the Rockwood formation, though locally it forms independent knobs, such as some of the Texas Knobs northeast of Georgetown (Cleve.). In its northwestern belts it commonly produces a band of maroon calcareous silty fairly shallow soil along the foot of ridges formed by the Rockwood formation or the Fort Payne chert. Natural outcrops of the two formations are not very common, but road and railroad cuts provide good sections in many places, as above Thorn Hill, Grainger County (Morr.) and southeast of Cumberland Gap, Claiborne County (Mayn.), and also along several roads between Rockwood and Chattanooga.

The fossils of the Sequatchie formation show it to represent the Richmond stage of the Upper Ordovician series, but careful study may show that the lowest beds are older. The Juniata formation is simply the less calcareous phase, perhaps partly littoral or even terrestrial, of the Sequatchie.

SILURIAN AND LOWER DEVONIAN ROCKS

The Silurian rocks of East Tennessee have been divided into several mappable units, most of which differ considerably in strati-

TABLE 5.—*Subdivisions of the Knox group used on present map*

<table>
<tr><th colspan="5">Northwestern phase</th><th>Southeastern phase</th></tr>
<tr><td>Mascot dolomite (Oma)</td><td colspan="2" rowspan="2">Newala formation (On)</td><td rowspan="4">Chepultepec, Longview, and Newala formations, undivided (Ocn)</td><td rowspan="5">Knox dolomite, undivided (O€k)</td><td rowspan="4">Jonesboro limestone (Ojb)</td></tr>
<tr><td>Kingsport formation (Ok)</td></tr>
<tr><td colspan="2">Longview dolomite (Olv)</td><td rowspan="2">Chepultepec and Longview dolomites, undivided (Ocl)</td></tr>
<tr><td colspan="2">Chepultepec dolomite (Oc)</td></tr>
<tr><td colspan="4">Copper Ridge dolomite (€cr)</td><td>Conococheague limestone (€cc)</td></tr>
</table>

graphic range from area to area. Table 6 shows the approximate correlation of the units used in different parts of the present map. The stratigraphy of the Silurian rocks, especially east and northeast of Clinton (Brice.), was studied by the late W. F. Prouty, but only generalized abstracts have been published (Prouty and Douglas, 1934; Prouty, 1935, 1941). More recently the stratigraphy of the Silurian rocks and also of the underlying Sequatchie formation southwest of Clinton has been studied in detail by Helmuth Wedow, Jr., and his report when completed will replace the part of the present discussion that covers that area.

The Clinch sandstone (Sc) was named by Safford (1856, p. 157; 1869, pp. 292-299; he commonly called it the Clinch Mountain sandstone) for Clinch Mountain, which it upholds (Mayn., Morr., and Greene.). His description makes clear that in that belt he included in it the whole thickness of the rocks now classed in the Silurian system. Keith (1896b, Morr. f.; 1901, Mayn. f.) followed the same usage in mapping this belt. Probably both lower and middle Silurian rocks are included, and a few feet of upper Silurian or even lower Devonian sandstone is present at the top, but the representatives of the different series do not appear to be separately mappable, and on the present map the whole unit in this belt is mapped as Clinch sandstone. This usage differs from that of Butts (1933, pp. 24-9-6; 1940, pp. 229-237), who wished to restrict the term Clinch to lower Silurian rocks and call the overlying middle Silurian rocks the Clinton formation (type locality in New York), though he did not map the two separately (1933). Although some such distinction can be made in belts farther northwest, it is apparently not practicable on Clinch Mountain.

The name Rockwood formation (Sr) was proposed by Hayes (1891) to replace Safford's term Dyestone group (1869, pp. 302- 311), and was taken from Rockwood, Roane County (Kings.). It was widely used in the folios to cover all the rocks now classed as Silurian other than the Clinch sandstone and the Hancock (Sneedville) limestone; Hayes, and locally Keith, included the underlying Sequatchie formation as well. The Sequatchie, however, is everywhere a separately mappable unit. At Rockwood, the Rockwood formation, if the Sequatchie formation is removed, is entirely lower Silurian (Ulrich, quoted by Burchard, 1913, pp. 31 ff.; confirmed by Wedow), but in other areas middle Silurian rocks, and perhaps locally even higher rocks, are present, and they have been included in the Rockwood for the present map.

The Clinch sandstone and the Rockwood formation are therefore mainly contemporaneous phases of the lower and middle

Silurian, and in areas intermediate between the two type localities they grade into each other, though in any one section the sandstone lies chiefly below. Cullison and others in their map of the Norris Reservoir basin for the Tennessee Valley Authority (unpublished ms.) mapped these two phases separately on Big Ridge and Lone Mountain, and the present map there shows them as the Clinch sandstone and the Rockwood formation. Elsewhere in these intermediate belts available data did not permit their separation, and they are grouped as Silurian sandstone and shale, undivided (Ssu).

The Sneedville limestone was named by Safford (1856, p. 157; 1869, p. 312) for Sneedville, Hancock County (Morr.). Precisely the same rocks in the same area were later named the Hancock limestone (Dsh), for Hancock County, by Campbell (1894a, Est. f., p. 2) and Keith (1896b, Morr. f., p. 3), and that name is now accepted by the U. S. Geological Survey.

The Clinch sandstone on Clinch and Stone Mountains consists of thick-bedded to massive white or lightly iron-stained nearly pure quartz sandstone, commonly with a silica cement. The sand is ordinarily medium to coarse, well sorted, and well rounded, but locally very fine to fine pebbles occur, especially on Stone Mountain, Short Mountain, and the Devils Nose in Hawkins County (Morr.), the southeasternmost exposures of the formation. The beds are especially thick below and thinner near the top, where they are interbedded with layers of white to pale brown very sandy shale. The sandstone beds are commonly riddled with *Scolithus* tubes, especially in the upper half of the formation. At the base the formation appears to grade down through a thin transition zone of white to pale brown thin-bedded sandstone and sandy shale into the maroon sandstone and siltstone of the Juniata formation. At the top complete sections on the old and new locations of U. S. Highway 25E southeast of Thorn Hill, Grainger County (Morr.), show 3 feet of dark rusty sandstone containing bodies of sandy iron and manganese oxides, capped by 1 foot of lighter-colored silica- cemented sandstone. The rusty sandstone was probably dolomitic when fresh and may represent the feather edge of the Hancock limestone. Float blocks of rusty sandstone, some showing indistinct molds of brachiopod shells, have been found elsewhere on Clinch Mountain, and also on Stone Mountain, and probably represent the same beds. The Clinch sandstone on Clinch Mountain is about 500 feet thick.

Similar sandstone, but in places more iron-stained, crops out on Powell Mountain, Walden Ridge, Lone Mountain, and Big Ridge (sometimes also called Lone Mountain) (Morr., Mayn., and Brice.).

It is not more than 200 feet thick on Powell Mountain, even less on the others. It generally grades up into reddish-brown sandstone, highly ferruginous and locally fossiliferous, probably with partly calcareous cement, and into sandy shale belonging to the Rockwood formation. The reddish-brown sandstone continues southwest along the strike from Big Ridge in the belts next northwest of the Whiteoak Mountain fault to Whiteoak Mountain (Cleve. and Chatt.), where Safford called it the Whiteoak Mountain sandstone (1869, pp. 299-303); indeed, he recognized it all the way northeast to Powell Mountain. It may well prove to be a mappable member of the Rockwood formation or of the Clinch sandstone. It is 100 feet or less thick in most areas but, including the interbedded shale layers, may reach 500 feet in Whiteoak Mountain in Tennessee and Georgia.

The Clinch sandstone crops out in bare ledges and dip slopes or breaks up into great blocks that litter the mountain slopes; only a thin sandy stony mantle with little if any true soil is produced. It is a ridge maker, forming the highest mountains between the Unaka Mountains and the Cumberland Escarpment. It is well exposed along the roads that cross Clinch Mountain, especially along U. S. Highway 25E (Morr.).

The Rockwood formation near Rockwood and elsewhere northwest of the Kingston fault consists largely of greenish to brownish shale, some calcareous, some silty or sandy, with thin layers of siltstone and, locally, of limestone. It contains scattered layers of hematitic iron ore from a few inches to 3 or 4 feet thick, which are very hematitic fossiliferous or oolitic lime-sandstone where fresh but which weather to generally porous pure to silty or sandy hematite. The shale is rarely red or maroon in these belts, except close to the Georgia line, where varicolored beds appear near the top. The thickness of the Rockwood formation in these belts ranges from 350 feet to the northeast to less than 250 feet near Chattanooga.

Between the Kingston and Whiteoak Mountain faults southwest of Clinton the Rockwood formation is thicker, its shale is less calcareous, more sandy, and more varicolored, and the reddish-brown sandstone layers already described are common in the lower part. The thickness here, including the sandstone beds, ranges from 500 to 800 feet. Along the same strike northeast of Clinton the formation is similar, but it thins northeastward as the Clinch sandstone beneath thickens.

The belt of the Rockwood along the Cumberland Escarpment between the Jacksboro fault and Cumberland Gap (Brice. and Mayn.) is intermediate in character between those already described.

Little of the shale is red or maroon; fossiliferous limestone layers occur, notably at Cumberland Gap; and a fairly thick layer (or several layers) of light-colored sandstone is present somewhat above the base in the eastern half of the belt. This layer (or layers) probably represents the Clinch sandstone and has been so mapped in Lee County, Va., by Miller (Miller and Fuller, 1947; in press; Miller and Brosge', 1950).

The Rockwood formation weathers to a rather thin soil full of siltstone or sandstone chips, but the thicker sandstone layers form a sandy stony soil and crop out in places as continuous ledges. The formation forms ridges wherever the sandstone layers occur, the height of the ridge being proportionate to the thickness of the sandstone layers in the Rockwood and Clinch formations taken together. Where the sandstone layers are thin, the ridge degenerates into a line of knobs, and in the belts along the front of the Cumberland Plateau southwest of the Jacksboro fault, the formation produces only a belt of low spurs or rolling country on one side of the ridge upheld by the Fort Payne chert or is without topographic expression.

The Hancock limestone consists mainly of fairly thick-bedded limestone and dolomite, many layers being sandy and a few cherty. Some layers, especially at the base or where the formation is thin, contain so much sand as to grade into calcareous or dolomitic sandstone. Sandstone carrying Lower Devonian fossils at the igneous bodies in Union County (Mayn.) (Hall and Amick, 1944) is one example; the 4 feet of rusty sandstone at the top of the Clinch sandstone on Clinch Mountain may be another. The Hancock limestone may be more than 300 feet thick locally in the belt along the south side of Powell Mountain, but elsewhere it is much thinner. On the south side of Powell Mountain it is thick enough to produce a fairly deep sandy clay soil, where it is not covered with wash from the underlying ridge-making formations, and to form a line of low spurs or bluffs on one or the other side of Big Sycamore and Blackwater Creeks (Morr.); elsewhere it is too thin to affect soils or topography. Good exposures are common near Big Sycamore and Blackwater Creeks, and also in and near Sneedville.

The bulk of the Clinch sandstone and Rockwood formation is apparently lower Silurian, but middle Silurian rocks are also present in places in the Rockwood and apparently in the typical Clinch. The Hancock limestone is known to include both upper Silurian and Lower Devonian rocks, but practically nothing is known about their distribution within the formation; these rocks and their faunas deserve study. The irregular distribution of the younger Silurian rocks is largely the result of post-Silurian pre-

Chattanooga erosion, which produced the second major disconformity within the Paleozoic sequence in East Tennessee (the first being the one at the top of the Knox group), but minor disconformities within the Silurian may also be partly responsible.

CHATTANOOGA SHALE (MDc) AND OTHER DEVONIAN AND BASAL MISSISSIPPIAN[4] SHALE (MDs)

Transgressing across the Silurian rocks, and on the southeast side of the Valley resting on rocks as low as Middle Ordovician, is a sheet of black shale, very thin to the southwest but thickening eastward and northeastward. Where thickest, in the belts between the Saltville and Wallen Valley faults northeast of Knoxville, the black shale is split into two fingers by a wedge of gray silty shale and siltstone and, locally, sandstone. Where this wedge is wanting the name Chattanooga shale (MDc) is applicable, but where the wedge is present and the unit is threefold the rocks are shown on the present map simply as Devonian and basal Mississippian shale (MDs).

The Chattanooga shale was named by Hayes (1891, p. 143) for Chattanooga, Hamilton County (Chatt.), and he specified as typical the section at the north end of Cameron Hill within the city (1894c, p. 1). Safford (1856, p. 158; 1869, pp. 332-333) had called these rocks the Black Slate or Shale. Keith apparently did not recognize the wedge of gray shale and his mapping is inconsistent (1896b, Morr. f.; 1901, Mayn. f.), but Campbell described the threefold sequence very clearly in discussing the rocks along Clinch Mountain near the Tennessee-Virginia State line (1894a, Est. f., p. 2). Several names have been proposed for subdivisions of this shale sequence in southwest Virginia (Campbell, 1894b, pp. 176-177; Stose in Eby, 1923, pp. 46-53; Swartz, 1927; Butts, 1940, pp. 321- 322, pl. 45), but the interrelations of these units is not clear there, and in the present state of knowledge the names cannot be applied in Tennessee. The Chattanooga shale in the belts from Rockwood to Chattanooga and along Whiteoak Mountain has been studied in detail by Louis C. Conant and Wilbert H. Hass for the U. S. Geological Survey, and a report is in preparation. The shale in the belt along Clinch Mountain is being studied by John E. Sanders for the Tennessee Division of Geology.

The Chattanooga shale consists of black fissile bituminous and pyritiferous shale. Commonly it contains considerable fine silt as minute laminae, and some layers contain enough to be dark gray

---

[4] The Tennessee Division of Geology recognizes the Mississippian and Pennsylvanian as Systems, but the U. S. Geological Survey classes them as series of the Carboniferous system.

rather than black. Locally sandy layers occur at the base, and on the southeast side of the Valley in Blount and Monroe Counties layers of silty gray shale appear interbedded with the black shale. Also a persistent middle layer of fissile gray shale has been identified in the sections in Hamilton County and from La Follette (Brice.) northeast (Swartz, 1924, 1927; Hass, 1947). The Chattanooga shale is about 12 feet thick at Chattanooga, but is progressively thicker eastward and northeastward, reaching 30 to 50 feet in Blount County (Knox.), 50 to 80 feet northwest of Clinton (Brice.), and about 400 feet at Cumberland Gap (Mayn.).

In the areas where the wedge of gray silty shale is present, the black shale fingers do not differ essentially from the Chattanooga shale, but the wedge between them consists of gray, brown-weathering thin-bedded and well-laminated silty and sandy shale and siltstone, commonly containing much detrital mica. Layers of fine-grained well-bedded silty sandstone are common in parts of some sections along Clinch Mountain but are missing in other sections; they do not seem to show regular distribution. The thickness of the whole unit in the belt along Clinch Mountain ranges from 400 feet or a little more at the southwest end to about 900 feet at the Virginia line; of this the lower finger of black shale is a little less than half, the wedge of gray silty shale a little more than half, and the upper finger of black shale merely 20 to 50 feet at the top. In the other belts showing the threefold division the thickness is within this range.

Where thin the black shale has no effect on soil or topography, but where thick it produces a thin acid silty clay soil and forms strike valleys, commonly called Poor Valley. The silty shales of the wedge make low rounded hills in these valleys, but where sandstone layers are common they hold up ridges as prominently as the Grainger formation with which they are easily confused. In the northwesternmost belts the Chattanooga shale is exposed in many road and railroad cuts in gaps through the ridges upheld by the Fort Payne chert. Other good exposures are on the highway and railroad at the north edge of the village of Cumberland Gap, the highway cut being in Virginia (Mayn.), and on the road west from the mouth of Citico Creek in Monroe County (Loud.) and elsewhere in that belt. Along Clinch Mountain the wedge of silty shale is well exposed in many places, notably about 11/2 miles north of Mooresburg just southeast of Mooresburg Springs, Hawkins County (Morr.), but the black shale fingers are less commonly exposed. The upper finger can be seen at the Mooresburg Springs locality, and parts of both are exposed along U. S. Highway 25E (Morr.).

The rocks are also exposed in several places around Sneedville, and on the roads down the north face of Newman Ridge, especially the road north from Sneedville (Morr.).

The age of the Chattanooga shale has long been in dispute; it has been held to be all Upper Devonian, all basal Mississippian, or partly both. The last view seems to be favored at present, the system boundary being drawn near but not at the top (Hass, 1947). The wedge of gray silty shale to the northeast is almost certainly Upper Devonian and the lower finger of black shale may include a thin representative of the Middle Devonian series at its base, as it does up the strike in Virginia. The age of the upper finger is subject to the same dispute as the Chattanooga shale. The gray silty shale with its sandstone layers represents the extreme southwestern edge of a great deltaic wedge of detrital material centering in eastern New York and Pennsylvania and recording at least an episode of the Acadian orogeny of New England and the Maritime Provinces of Canada.

GRAINGER FORMATION (Mg) AND FORT PAYNE CHERT (Mfp)

The rocks next above the black shale grade from a detrital phase on the east and southeast to a cherty limestone phase on the west and northwest. These rocks were all called the Siliceous Group by Safford (1856, p. 159; 1869, p. 348, following Troost); Hayes and Keith recognized the two phases as separate formations but apparently did not realize their equivalence. Keith named the detrital phase the Grainger shale (Campbell, 1893, p. 38; 1894a, Est. f., p. 3; Keith, 1895, Knox. f., p. 4; 1896b, Morr. f., p. 3) for the Grainger County portion of the belt southeast of Clinch Mountain, but the rocks include so much sandstone that they are better called the Grainger formation. The same beds have generally been called the Price formation in southwest Virginia (Campbell, 1894b; Butts, 1933, p. 36; 1940, pp. 336-350). For the cherty phase Hayes used the name Fort Payne chert, proposed by Smith (1890, pp. 155-156) for Fort Payne, De Kalb County, Ala.; Keith included these rocks in the overlying Newman limestone. On the present map the Grainger formation (Mg) is recognized in the belts southeast of the Whiteoak Mountain and Wallen Valley faults, and the Fort Payne chert (Mfp) in those northwest, except that the belt along the Cumberland Escarpment northeast of the Jacksboro fault is shown as grading from Fort Payne chert near La Follette (Brice.) to Grainger formation near Cumberland Gap (Mayn.).

The Grainger formation consists of bluish, greenish, and brownish argillaceous shale, sandy shale, sandy siltstone, and generally silty and thin-bedded sandstone. Thin coaly beds and highly glauconitic sandstone layers occur in the upper half of the formation and locally, especially near the top, there are layers of coarse sandstone or even fine conglomerate. John E. Sanders has mapped two groups of sandstone beds as members of the Grainger formation in Hawkins County, and doubtless the formation could be divided elsewhere. At the top of the Grainger in most of the belts red shale and siltstone occur through 50 or 100 feet, commonly forming a mappable unit that corresponds to the Maccrady shale of southwest Virginia (Stose, 1913, pp. 233-235; Butts, 1940, pp. 350-354), but it is not separated from the Grainger formation on the present map. Keith may have included these beds in the Newman limestone rather than in the Grainger. The thickness of the Grainger formation is about 1,100 feet on the southeast side of the Valley in Blount and Monroe Counties, about 900 feet in the belt southeast of Clinch Mountain, about 500 feet in the belts in Hancock and eastern Claiborne Counties, and a little less than 350 feet at Cumberland Gap, where there is very little sandstone but 15 feet of chert, like that in the Fort Payne, at the top (Butts, 1940, pp. 337, 354-355, 360).

The Grainger formation produces a thin sandy stony soil of little fertility. In the southeastern belts, as along Clinch Mountain, it forms a prominent sharp ridge or line of knobs, but in the northwestern belts it crops out chiefly on the scarp faces of ridges upheld by higher formations. The sandstone layers commonly crop out on hillsides, and exposures of both sandstone and shale are common in valleys or along roads that cross the formation. Good exposures occur at Cumberland Gap (in Virginia on the road from the village to the gap) (Mayn.), on the road north of Sneedville where it descends the north face of Newman Ridge (Morr.), on U. S. Highway 25E south of Clinch Mountain (Morr.), just east of Mooresburg Springs 11/2 miles north of Mooresburg (Mory.), and in Butterfly and other gaps through Little Mountain in Blount County (Knox. and Loud.).

The Fort Payne chert where fresh is a very siliceous cherty limestone, the chert occurring as nodular layers and typically forming 30 percent of the rock, and more locally. Some of the limestone is pure and consists largely of crinoid fragments, some is silty or shaly and may grade into thin layers of calcareous shale and siltstone between cherty layers. On weathered exposures, such as most road cuts, chert dominates, the rest of the rock being represented by thin layers or partings of clay, silty clay, or silty weathered shale between the chert layers. At the base there is typically 2 feet or less of greenish noncherty silty shale (the Glendale shale of Swartz, 1924, p. 24), which grades up into silty cherty limestone and down into the Chattanooga black shale; it contains phosphate nodules an inch or so across and represents the Maury phosphatic green shale member of Middle Tennessee (Safford and Killebrew, 1900, pp. 141-142). The Fort Payne chert is 100 to 200 feet thick.

The Fort Payne chert weathers deeply and produces a very cherty soil, resembling the chertiest soil produced by the Knox group. The two can ordinarily be distinguished, however, because some of the chert from the Knox contains molds of minute dolomite rhombs and most of that from the Fort Payne contains molds of crinoid stem segments. The Fort Payne forms fairly low but sharply defined linear ridges, broken every half mile or so by a gap, but where the Rockwood formation contains considerable sandstone and forms a ridge, such as Whiteoak Mountain for example (Chatt. and Cleve.), the Fort Payne may make knobby spurs beside that ridge. Exposures of the weathered Fort Payne chert are common in the gaps through the ridges, but unweathered exposures are quite rare.

The fossils of the Grainger and Fort Payne formations show that they correlate with the Osage group of the Upper Mississippi Valley States, but it is not certain just what parts of the Osage are represented in each formation. Possibly the lowest layers in each may include an equivalent of the Kinderhook group.

NEWMAN LIMESTONE (Mn)

The Newman limestone was named by Campbell (1893, p. 38; 1894a, Est. f., p. 3) and Keith (1895, Knox. f., pp. 4-5; 1896b, Morr. f., p. 3) for Newman Ridge in Hancock County (Morr.). It had been called the Mountain Limestone by Safford (1856, pp. 160-161; 1869, pp. 351-352, 362). Hayes used the name Bangor limestone, proposed by Smith (1890, pp. 155-157) in Alabama, but that name is now used in Alabama only for the part of the limestone sequence that is equivalent to the middle part of the Chester group.

The Mississippian limestone sequence, here called the Newman limestone has been subdivided into five or six formations in southwest Virginia, northwest Georgia, and northern Alabama (Butts, 1926; 1933; 1940; Butts and Gildersleeve, 1948), and the same units are certainly present in East Tennessee. Work has already been started in several areas-by Paris B. Stockdale and Harry J. Klepser in Rhea County, by John E. Sanders in Hawkins County, and by

Robert B. Neuman in Blount County-but is not yet far enough advanced to make it feasible to show the units separately on the present map. In general, limestone units equivalent to the Warsaw limestone, the St. Louis limestone, the Ste. Genevieve limestone together with the lower part of the Chester group, and the middle part of the Chester group of the Upper Mississippi Valley States can be recognized. The limestone units equivalent to the lower and middle parts of the Chester are separated in many areas by a fairly persistent and prominent calcareous sandstone layer as much as 50 feet thick, presumably the same layer as that called the Hartselle sandstone in northern Alabama and northwest Georgia (Smith, 1894; Butts, 1926, pp. 192-195), the "Cypress" sandstone in Middle Tennessee (Bassier, 1932, p. 159), and the Fido sandstone in southwest Virginia (Butts, 1927a, p. 16). When these units are separately mapped it may still prove desirable to retain the name Newman as a group term.

The Newman limestone varies considerably in character across the Valley. In the belts close to the Cumberland Plateau it is mostly pure gray massive limestone, which differs somewhat from unit to unit. Thus much of it is dark, aphanitic, and cherty in the unit equivalent to the St. Louis limestone, but lighter and medium-grained, commonly oolitic or crinoidal, in the unit equivalent to the Ste. Genevieve limestone and the lower part of the Chester group. Some shaly limestone is present, especially in the unit equivalent to the middle part of the Chester group. A unit equivalent to the Warsaw limestone has not been recognized in these belts; if present it may have been mapped with the Fort Payne chert instead of the Newman limestone. The thickness of the Newman limestone in these belts ranges from 600 to 850 feet, the unit equivalent to the middle part of the Chester making about half the total, or a little more. In the Newman Ridge belt in Hancock County the formation is generally similar, but oolitic limestone is rarer and shaly limestone layers appear sporadically lower in the sequence. In Hawkins County, a basal unit of alternating argillaceous limestone and dolomite, calcareous shale, siltstone, and sandstone is equivalent to the Warsaw limestone, and shaly limestone or calcareous shale or siltstone appears sparingly in the unit equivalent to the St. Louis limestone and abundantly in the higher units. Several layers of sandstone are present in the units equivalent to the Chester group, including one that represents the Fido sandstone. In this belt the thickness of the Newman is 2,800 feet or more. The small patch of Newman limestone along the State line in Sullivan County (Roan M.) has been mapped by Averitt (1941) as shaly limestone of middle Chester age. In Blount County, the Newman is apparently all shaly limestone and calcareous shale; about 1,200 feet is preserved. In the belt along Whiteoak Mountain (Chatt.), the Newman is somewhat similar, but beds of purer limestone occur in the unit equivalent to the Ste. Genevieve limestone and the lower part of the Chester group. Here the formation is between 1,200 and 1,500 feet thick; about the lower half was mapped by Hayes (1894a, Ring. f.; 1894c, Chatt. f.) as Floyd shale, a term used for the shaly equivalent of the Newman limestone in Georgia and Alabama.

The purer limestone beds in the Newman produce a deep fertile clay soil, generally somewhat cherty over the lower part of the formation; the shalier limestone produces a somewhat siltier shallower, but still fertile, soil. The Newman normally underlies a belt of lower ground than the adjacent formations, but the belt is generally rolling or hilly over the shalier phase. Parts of the crest of Newman Ridge are held up by the limestone, however. In the Hawkins County belt, different units in the Newman underlie minor strike ridges and valleys. Along the front of the Cumberland Plateau the Newman commonly crops out in cliffs on the scarp face below the capping Pennsylvanian sandstone. Well-exposed sections of the Newman limestone may be found on the road north of Cumberland Gap village (Mayn.) in Virginia (described by Butts, 1940, pp. 360, 367, 375, 383-386), at La Follette (Brice.), on the roads at the north end of Lookout Mountain (Chatt.) (described by Butts and Gildersleeve, 1948, pp. 45-48), on the north face of Newman Ridge along the road north of Sneedville (Morr.), along several streams crossing the main Hawkins County belt in Caney Valley (Greene.), and along the old road from Butterfly Gap up the face of Chilhowee Mountain to Emerine Gap, 5 miles southwest of the Little River (Knox.).

PENNINGTON FORMATION (Mp)

Campbell (1893, p. 37) named the Pennington shale for Pennington Gap, Lee County, Va., about 40 miles northeast along the strike from Cumberland Gap (Mayn.). The name was used by Keith for the equivalent rocks along the Cumberland Escarpment southwest to the west edge of the Loudon quadrangle (1896a, Loud. f.; 1896c, Brice. f.; 1901, Mayn. f.), but Hayes mapped no separate unit, including these beds in the top of the underlying (Bangor) limestone, as Safford (1869, pp. 352 ff.) also had done. Keith (1896b, Morr. f.) also mapped the Pennington at the southwest end of Newman Ridge, but he and Campbell called the Pennington in northern Hawkins County and adjacent Virginia the Grainger shale (Keith, 1903, Greene. f.; Campbell, 1894a, Est. f.). This error was corrected by Butts (1933), who also altered the name to Pennington formation, as the unit includes sandstone and limestone layers.

The Pennington formation is heterogeneous and varicolored, including red, purple, and green clay shale, pink, red, green, and brown (normally calcareous) sandstone, and yellow shaly or silty fossiliferous limestone. The limestone is everywhere minor in amount; the proportions of shale and sandstone vary widely. Shale predominates from the Georgia line to Rockwood (Kings.), but thin sandstone beds are present, and these become thicker and more numerous farther northeast, though shale continues to form more than half the formation. In this area the formation shows many resemblances to the Rome formation. On Newman Ridge and in Hawkins County, on the other hand, the pink and red sandstone predominates, and some of it is finely conglomeratic. Reddish sandstone and shale in an isolated patch in Blount County (Knox.) has been doubtfully identified as Pennington by Robert B. Neuman.

The upper contact of the Pennington formation in the northwestern belts is not clearly defined except northeast of the Jacksboro fault, where the base of the Pennsylvanian system is drawn at the base of a thick layer of pebbly white sandstone, which may be disconformable on the Mississippian rocks. Elsewhere the contact is drawn in a transitional zone between red clay shale with scattered fossiliferous limestone beds and gray or brown sandy and silty shale with scattered coal beds. The contact thus records the change from marine to nonmarine deposition, but it may not be drawn at the same level everywhere and possibly some beds included in the Pennington formation northeast of the Jacksboro fault are equivalent to some included in the Pennsylvanian farther southwest. As a result, the thickness of the Pennington is not consistent. It is 200 feet or less near Chattanooga, but 450 feet near Dayton (Chatt.), perhaps 400 feet northwest of Clinton (Brice.), but only about 150 feet at Cumberland Gap (Mayn.). A thickness of only a few hundred feet is preserved on Newman Ridge, but over a thousand feet is present in northern Hawkins County and Averitt (1941, pp. 11-14) found 2,250 feet with the top missing along the same belt in Virginia (the area he studied includes the small area in Sullivan County, Tenn., northeast of Arcadia) (Roan M.).

The shale of the Pennington formation breaks down readily to clay and produces a fairly deep soil, but the sandstone, where abundant, produces a thin sandy stony soil. Moreover, in the northwestern belts the formation generally appears on the scarp face of the Cumberland Plateau and is covered with wash from the Pennsylvanian rocks. Where it crops out away from the Plateau it makes knobby country. On Newman Ridge and in Hawkins County, on the other hand, it is a ridge maker; indeed the western part of Newman Ridge, underlain by the Pennington formation, is higher than the adjacent part of Powell Mountain, underlain by the Clinch sandstone, here of less than maximum thickness. In the Hawkins County belt, the Pennington forms a wide belt of irregular knobs little higher than the ridge over the Grainger formation. Outcrops of the Pennington can be found along most of the roads that climb the front of the Cumberland Plateau, but continuous sections are rare; a fairly complete one is exposed on the ridge west of Dayton (Chatt.). In the eastern belts, the sandstone beds crop out as ledges on hillsides, but well-exposed sections are rare here also. The Pennington formation is equivalent in age to the upper part of the Chester group of Kentucky and Illinois.

The three major units of Mississippian rocks just described all exhibit a parallel lateral gradation from finer, thinner, and less detrital sediments on the northwest side of the Valley to coarser, thicker, and more detrital sediments on the southeast side. Thus the Fort Payne chert (actually cherty limestone) grades over into the Grainger formation (shale and sandstone), the Newman limestone grades from pure limestone to shaly limestone or calcareous shale (Floyd shale), and the Pennington formation grades from shale with some limestone to sandstone with some shale; together these units thicken from less than a thousand feet near Chattanooga to about a mile in Hawkins County. This gradation reflects, of course, a southeastern or eastern source of detrital materials; such materials were abundant and spread far to the west chiefly in early Mississippian (Osage) and late Mississippian (late Chester) time, and the Newman limestone records a lull between. The distribution of detrital and nondetrital formations of these ages in adjoining States indicates that the detrital material in the Grainger formation came from the east or northeast, perhaps from an uplift raised by a late pulse of the Acadian orogeny in the northern Appalachians, whereas that in the Pennington formation (and probably also that in the Newman limestone and Floyd shale) came from the southeast and records renewed uplift in the southern Appalachians, uplift which increased into the Pennsylvanian and apparently culminated in the Appalachian orogeny, the climax of which probably occurred during the Permian.

PENNSYLVANIAN ROCKS (Pu)

The present map stops at the eastern edge of the Pennsylvanian rocks forming the Cumberland Plateau, and therefore no attempt is made here to describe those rocks except those that immediately overlie the Pennington formation. Northeast of the Jacksboro fault, the base of the Pennsylvanian system is drawn at the base of a layer of massive conglomeratic sandstone 50 to 100 feet thick, itself one of a group of sandstone layers 200 to 250 feet thick, directly overlying the mainly marine Pennington. This layer, or perhaps the group of layers, is thought to be the same as the first thick and conglomeratic layer above the Pennington formation southwest of the Jacksboro fault, which averages 100 feet in thickness and is called the Sewanee conglomerate (Safford, 1892) for Sewanee, Franklin County. There, however, a considerable thickness of coal-bearing rocks appears beneath, ranging in thickness from perhaps 200 feet at Rockwood to 400 or 500 feet at Chattanooga. These rocks, called the Gizzard formation (Safford, 1869, pp. 369-370) for the Little Fiery Gizzard at Tracy City, Grundy County, consist of gray or brown sandy shale and thin-bedded sandstone with more than one workable coal bed and with one generally prominent layer of thick-bedded to massive sandstone, normally about 30 feet thick but locally thicker, above the middle of the unit. Whether any part of the Gizzard formation is correlative with any part of the basal beds of the Pennsylvanian northeast of the Jacksboro fault, or whether instead any part of it is correlative with any part of the Pennington formation, which thickens northeastward as far as Rockwood as the Gizzard thins, remains to be determined. Detailed work on the Pennsylvanian rocks is now in progress in several parts of the Plateau by parties of the Tennessee Division of Geology.

A few outliers of Pennsylvanian rocks occur in the Valley of East Tennessee, mostly close to the Plateau. Notable are the peculiar masses of folded sandstone and shale (locally with coal beds) that appear to rest across the beveled edges of the older strata in places from Rockwood southwest beyond Spring City (Kings.) (see p. 129). More orthodox synclinal or faulted outliers containing thick sandstone layers occur near Dayton (Chatt.), near Elverton (Loud.), and on the Powell Mountain near Cumberland Gap (Mayn.). Finally the isolated outlier of Grindstone Mountain, close to the Whiteoak Mountain fault 2 miles east of Ooltewah (Chatt.), proves the former extent of the Pennsylvanian rocks across at least the western part of the Valley.

PALEOZOIC INTRUSIVE ROCKS (ig)

Three groups of igneous rock bodies intrusive into the sedimentary sequence are known in East Tennessee: one in Union County (Mayn.), one in Sevier County (Knox. and Mt. G.), and one in Polk County (Mur.).

The igneous bodies in Union County were first mentioned by Safford (1869, p. 175), who assigned them to his metamorphic group, and have been studied in some detail by Hall and Amick (1944). The rock is mica-peridotite, now serpentinized, containing crystals and grains of magnetite and garnet. It forms two small plugs a few hundred feet across along the Wallen Valley thrust fault. These intrude mainly the Hancock dolomite on the lower block but also cut the overlying Chattanooga shale, and the rock is considerably sheared close to the fault. These facts suggest that intrusion took place during the regional deformation, hence late in the Paleozoic era.

The igneous bodies in Sevier County were discovered by J. B. Hadley (personal communication) during recent work in the Great Smoky Mountains. In addition to the outcrops shown on the present map (Knox. and Mt. G.), smaller bodies have been found on Mt. Leconte and on Greenbrier Pinnacle (Mt. G.). The rock is metadiorite, much of it now foliated, and it forms sheets parallel to the bedding and foliation of the enclosing Great Smoky conglomerate. Again the facts suggest that intrusion took place during regional deformation, but as the rocks intruded are possibly of pre-Cambrian age, the age of the intrusives is by no means certain. The bodies appear to be outliers of a larger group of such intrusives previously reported in the Hazel Creek area in Swain County, N. C., along the strike to the southwest (Emmons, 1940, p. 318; P. P. Fox, ms. map of Fontana Reservoir, for TVA; G. H. Espenshade, ms. report on Hazel Creek copper mine, for U. S. Geol. Survey; see also Keith, 1907a, Nant. f., pp. 5-6).

The igneous bodies in Polk County are in the Ducktown district (Mur.), where they have been described by LaForge and Phalen (1913, Ell. f., p. 8) and by Emmons and Laney (1926, pp. 22-23) as altered gabbro sheets, generally parallel to the bedding of the enclosing metamorphosed graywacke of the Ocoee series. Apparently they are much like the sheets in Sevier County in occurrence.

UNCONSOLIDATED MANTLE

Over the consolidated Paleozoic and pre-Cambrian rocks of East Tennessee lies a nearly continuous mantle of unconsolidated material. On the present map it has unfortunately been necessary to ignore this mantle, except in so far as, by reflecting the bedrock, it has furnished clues to the distribution of the different formations. But the mantle is altogether too important to be ignored. Most of the barite and manganese mined in East Tennessee, and in earlier days much iron and zinc also, came from it; it is of considerable importance in the distribution of ground water and of major significance for engineering works such as the dams of the Tennessee Valley Authority; and, most important, the upper part of the mantle (locally all of it) is the soil that supports vegetable and animal life. Indeed soil scientists have studied it far more systematically than geologists, and at the present time the reports and maps of the U. S. Soil Survey are the principal source of information on the mantle of the southeastern United States. A few strictly geological studies have been made, some by the Geologic Branch of the Tennessee Valley Authority of areas around dam sites (Moneymaker, Leonard, and others, 1949), some by U. S. Geological Survey parties studying bauxite and manganese (Bridge, 1950; King and others, 1944; Craig, ms.), but many more are needed; the mantle in the Southeastern States should be studied as intensively as the glacially transported mantle of the Northern States. A brief summary of the principal types of mantle material and their distribution, based in large part on the work of the Soil Survey, is here presented, but obviously it can make no claim to be complete or thorough and can only hope to point the way to further work.

Residuum.-The processes of weathering attacking the bedrock in the South have produced in most places a residual mantle tens to hundreds of feet deep, almost completely leached of soluble material. Over some types of rock this mantle retains much of the original structure of the parent rock, so that a road cut may exhibit measurable bedding, joints, or foliation in material easily dug with a shovel, yet no fresh sample showing the original nature of the rock can be obtained. Over others, especially the cherty carbonate rocks, the mantle may not retain any decipherable structure, yet it may completely cover the bedrock over square miles of country. Geologic work in such areas can become very frustrating, as one attempts to map rock units that one rarely sees in their unweathered state. Hence well-exposed sections of fresh rock, even where partial, are very important in deciphering the geology of a district. But if such standard sections are available even minor differences in the mantle may be mappable clues to differences in the bedrock;

the mantle then ceases to frustrate the geologist and becomes a useful tool.

Such a mantle differs in many respects from the mantle familiar to geologists in the cooler North or the drier West of our country. In much of the North, the mantle consists of materials deposited only recently, during or after the last major advance of ice during the Pleistocene, and hardly altered since, any preexisting residual mantle having been cleaned away by the ice. Even where older residual materials are present, chemical weathering has been much less vigorous than farther south, so that the mantle is thinner and fresh bedrock more commonly exposed. In most of the West, chemical weathering is even more retarded, and in particular the leaching of soluble matter, so characteristic of humid climates is reduced or absent. Rock outcrops are ubiquitous, except in the wide areas covered by recently transported material, and fresh samples can be obtained almost at will. In both these regions, transported mantle predominates over residual mantle, and hence the mantle offers few clues to the bedrock geology but is studied (if at all) separately from the bedrock, often by different Geologists using different techniques. The largely residual mantle in the South is probably not matched elsewhere within the United States, resembling the mantle in the humid tropical areas of the world.

The residual mantle in East Tennessee, as elsewhere in the South, is commonly very characteristic of the individual formations over which it lies, and it can often be used for their identification; many examples are cited in the preceding pages. Some generalizations may be made here. Relatively pure limestone and dolomite produce a deep fairly uniform clay residuum, normally sharply set off from the bedrock. The upper surface of the bedrock, exhibited in hydraulic mines in a few localities (for example, Bumpus Cove southwest of Embreeville [Roan M., Greene.] and the Cleveland Red Hills manganese district in southern Bradley County (Cleve.]), is extraordinarily irregular, forming a forest of bizarre pinnacles separated by deep pockets of clay. In places residuum over limestone or dolomite has accumulated to depths of hundreds of feet, especially where the bedrock contains chert, or silica that on weathering forms chert, so that the residuum is protected from sheet erosion. In such areas, the mapper must depend very largely on recognizing the chert characteristic of the residuum of each individual formation. Even in those areas, however, any outcrops are of sound, unweathered rock. Impure limestone, on the other hand, weathers less deeply (though equally irregularly); the weathered material is less sharply set off from the unweathered and commonly it grades from merely leached material next the bedrock into thoroughly reconstituted residuum or soil toward the surface of the ground.

Much of the generally shallow residuum over shale retains the original volume of the bedrock and such structures as bedding and fossils, but its calcium carbonate or other cementing material is leached, so that typically the rock is converted into weak, punky silty clay, and its iron is oxidized and redistributed along cracks. In general the residuum grades down into the unweathered shale. Over some shale the upper part of the residuum is more thoroughly broken down to a clay soil, but over much of it weathered shale chips persist to the grass roots and are turned up abundantly by the plow. Where pure limestone and shale are interbedded, the limestone weathers deeply and is represented only by clay seams in a residuum dominated by chips of weathered shale.

Over siltstone and impure sandstone, for example, the feldspathic graywacke of the Ocoee series, the residuum is not unlike that over shale, only more quartzose. Even some conglomerate weathers in this way. Calcareous sandstone may disintegrate entirely to quartz grains in a clay matrix, or some of it may remain as porous "rottenstone." On the other hand, purer quartz sandstone and conglomerate such as are common in the Chilhowee group resist weathering, except for the oxidation of their iron, and form little or no true residuum, though they may contribute blocks of all sizes to adjacent areas or even produce bodies of talus.

Over crystalline rocks, such as granite, gneiss, and schist, weathering commonly proceeds deeply though irregularly, attacking the silicate minerals and producing saprolite, the weathered material retaining the original structure of the rock but virtually lacking cohesion. In general, the saprolite grades through a layer only inches thick into the unaltered bedrock. A fairly thick loamy soil commonly forms above the saprolite.

The distribution of the residuum faithfully reflects the distribution of the parent rocks, of course, and where the ground is flat, bedrock contacts can be accurately traced in the residuum. The residual mantle gives rise to the "soils of the uplands" of the Soil Survey reports, probably covering more than half of East Tennessee. Like the types of residuum, these upland soils are highly characteristic of individual geologic formations.

Locally transported mantle.-Even on flat land most residuum shifts a little, and on slopes it is moved down slope by creep and other gravity-aided processes. In moving, the residuum is commonly churned up, so that original structures are crumpled or lost and extraneous material may become incorporated (see King and others, 1944, fig. 4, p. 26). In general, the residuum is not greatly altered in this process, though perhaps more oxidized and leached, but a surface layer of looser and sometimes stonier soil may be formed. The resistant materials that occur in the residuum, such as chert and nodules of iron and manganese oxides, are commonly concentrated in this soil layer and spread widely beyond the limits of the source residuum.

When material on slopes is picked up by sheet or gully erosion, however, even if it is redeposited at the foot of the first slope, it loses the character of residuum and becomes part of the transported mantle. Though still entirely derived from the weathering of the local bedrock, it is generally better sorted in detail by loss of clay, yet more mixed in the larger mass because of contributions from several sources. Bodies of such material accumulate in swales and sinkholes, in small hollows and larger creek valleys, and at the bottoms of steep slopes. In mountainous areas, great aprons of stony material have been built up at breaks in slope; among the largest examples are the wide fanlike bodies along the northwest foot of Holston Mountain (Roan M., Cran.), at the north foot of the Great Smoky Mountains, especially to the east, as between Pittman Center and Cosby (Mt. G.), and north of the east end of Chilhowee Mountain (Knox.). Such material is generally called slope wash by geologists but colluvium by the soil scientists (local alluvium would be better, as the term colluvium is properly reserved for material moved by landslide or creep). On it have developed the "soils of the colluvial lands" of the Soil Survey reports.

River alluvium.-The local alluvium along the smallest streams is purely local in source, but along larger and larger streams more and more material from beyond the immediate locality enters the alluvium, and all along the major rivers occur well-rounded pebbles and cobbles of quartzite and other resistant materials. Such rivers have covered their wide bottom lands with a sheet of alluvium as much as 40 feet thick; in general it thickens downstream along any given river. Pebbles and cobbles, though conspicuous, are normally rather minor in amount, and typically form the lowest part of the sheet; much of the alluvial material is silty sand, and some is largely silty loam. These materials give rise to the "soils of the bottom lands" of the Soil Survey reports, and the soil scientists have shown that the soil and underlying alluvium actually reflect the underlying geology much more than would be at first expected. Thus where such transverse rivers as the Nolichucky and the Little Tennessee cross from an area dominantly of one rock type to one dominantly of another, the alluvium becomes markedly different in character within a mile or so downstream, changing from material derived mainly from the first rock type to that derived mainly from the second. Hence, despite the conspicuous foreign material, the bulk of the alluvial material is derived from a fairly nearby source.

In the vicinity of these same larger rivers (except for the Powell and the upper Clinch), similar but generally strongly leached and oxidized alluvial material occurs in bodies at various elevations above the rivers, normally underlying flat terraces which evidently were once flood plains. These bodies, as much as 50 feet thick and 400 feet above the nearby rivers, were recognized by Safford (1856, p. 163; 1869, p. 438) and called by him the Eastern gravel. On them have developed the "soils of the terraces" of the Soil Survey reports. Like the bottomland alluvium, the terrace alluvium reflects in a general way the surrounding bedrock, though pebbles and cobbles of quartzite from the Unaka Mountains are conspicuous in many deposits. Clearly the distribution of these bodies records the former courses of the rivers near which they are found and is deserting of careful study.

Minor constituents of the mantle.-Here and there, in divide areas out in the Valley of East Tennessee and far from the major streams, isolated pebbles of quartzite fromthe Unaka Mountains can be found in soil that otherwise is derived entirely from the local residuum. So far as known, no large bodies of gravel made of such pebbles have been found, but the stray pebbles apparently represent the last remnants of some gravelly deposit, which may have been spread over large parts of the Valley, at least southeast of Bays and Clinch Mountains and southwest of Knoxville. As these remnants are recognized as nonresidual only because they consist of rock quite exotic to their present location, it may be that considerable finer-grained and less distinctive material from such a general alluvial deposit has survived and still contaminates the "upland soils," but of this there is no positive evidence. Possibly certain ancient gravel bodies close to the mountains, uncovered during manganese mining in northeast Tennessee (King and others, 1944, p. 45) and in Virginia (King, 1949a, pp. 83-85), are also remnants of such a deposit.

Even more anomalous than these remnants are local pockets, rarely over 200 feet in diameter but locally 100 feet or more deep, of nonresidual highly kaolinic clay, found in a few places in the

Valley embedded in the residuum over carbonate rock, especially dolomite. Several of these pockets contain masses of bauxitic clay and bauxite that have been mined; for example, near Keenburg north of Elizabethton in Carter County (Roan M.), and along Missionary Ridge, and also the ridge west of Ooltewah in Hamilton County (Chatt.) (Bridge, 1950, pp. 189-195, bibliography; Craig, in King and others, 1944, pp. 210-214). Lignite and lignitic clay are also commonly associated with these bodies. There is little doubt that they represent the fillings of ancient sinkholes by transported material (Adams, 1923), probably material transported from residual kaolin formed over the crystalline rocks in and east of the Unaka Mountains (Bridge, 1950, pp. 195-196, and references there cited).

Age.-Much of the bottom alluvium alone the rivers and smaller streams is clearly very young, some bodies having been deposited in their present position within historic time. The older parts of it, however, may date back several tens of thousands of years. The alluvium of the terraces is older, of course, than the bottom alluvium, and that of the higher terraces than that of the lower. Though there is little direct evidence on the age of these deposits, they are probably largely if not entirely Pleistocene (King, 1949a, p. 89).

The great aprons of slope wash in front of the mountains also are probably Pleistocene, like the inactive and now forested taluses higher in the mountains, and they may well represent the periods of lowered timber line; that are recorded by various inactive "peri-glacial" phenomena in the high mountains. The ancient gravel deposit now represented by the scattered pebbles away from the rivers may, however, be much older than Pleistocene. Likewise the bodies of bauxite-bearing clay must be much older than the terrace deposits and perhaps are of the same age as the ancient gravel deposit. On the basis of fossil plants, R. W. Brown of the U. S. Geological Survey has concluded that the bauxite-bearing clay in similar deposits in Alabama and Georgia is not younger than the earliest Eocene, may well be Paleocene, and possibly is even Cretaceous (Cloud and Brown, 1944; Bridge, 1950, p. 194). The implications of this dating for the later history of the Appalachian Mountains are discussed by King (1949a) and Bridge (1950).

The age of the residuum is even less definite. Weathering is going on and presumably some residuum is being formed now, yet some residuum was apparently already present when the bauxite-bearing, clay bodies formed in their sinkholes. Thus it has probably been forming virtually throughout Cenozoic time, though perhaps at a greater rate at certain times, such as those of little stream erosion, than at others. Several lines of evidence suggest a time of particularly intensive chemical decay and activity during or after the formation of the "Valley Floor peneplain" in the Appalachian Valley, perhaps in the earlier Cenozoic (King and others, 1944, pp. 24-25, 59; Rodgers, 1948, pp. 15, 40; King, 1949a, pp. 82-83; Bridge, 1950).

LARGER STRUCTURAL FEATURES

UNCONFORMITIES AND FACIES CHANGES

No discussion of the structural geology of an area should neglect unconformities and lateral shifts in rock facies, for these record structural or diastrophic events and furnish the principal data on the age of the structural features; the facies may suggest the location of the events as well. Unconformities may be divided into two classes: (1) disconformities, those unconformities in bedded rocks where bedding below the unconformity is everywhere approximately parallel to that above, and (2) nonconformities, those where bedding below is at an appreciable angle to that above or where the rocks below are not bedded rocks. Shifting, facies produce patterns of many kinds, but structural interpretation is principally concerned with detrital wedges, built up by the advance and retreat of facies as more or less detritus is brought into a depositional basin from a waxing or waning uplift at one side.

The lowest unconformity recognized in East Tennessee is the profound nonconformity above the pre-Cambrian crystalline complex or basement. As it truncates impartially both granitic rocks and included schists, it records a long period of erosion following at least one major pre-Cambrian orogeny during which preexisting rocks were highly metamorphosed and intruded by granite. Radioactive age determinations (see Rodgers, 1952) indicate one period of granitic intrusion in western North Carolina about 600 million years ago and hint at another about 800 million years ago, coeval with a period of intrusion in the Blue Ridge of Virginia, nearly 200 miles northeast along the strike in the same anticlinorium of basement rocks. These pre-Cambrian orogenies are presumably responsible for many of the structural features in the basement rocks but not, of course, for any in the younger rocks; nevertheless, at least some of the structual features in the basement were caused by later deformation, as for example mylonite zones marking thrust faults that also cut the younger rocks, and anticlinoria involving both sediments and crystalline complex. The pre-Cambrian orogeny (or orogenies) therefore produced only a very small part of the structural features in East Tennessee.

Within the thick sedimentary sequence above the first non-conformity no others have been definitely established, but disconformities are not rare. Indeed some stratigraphers unsympathetic to interpretations based on the concept of facies chance have postulated a score or more. The compiler leans far in the opposite direction and recognizes only a few; perhaps the truth lies somewhere between.

In the vastly thick detrital rocks of the Ocoee series no disconformities have been recognized, and the facies merely record a nearby source of sediments, perhaps to the southeast, which supplied first coarse, then fine detritus. Possibly this source was produced by the same orogeny that is recorded in the crystalline complex, but it seems unlikely, for marginally at least the Ocoee series rests on the eroded surface of granitic rocks intruded during, that orogeny. In any case the source must have been uplifted repeatedly to supply such a thick mass of sediments, which probably deposited very rapidly in a relatively narrow and rapidly subsiding trough.

A disconformity has been reported between the Ocoee series and the Chilhowee group in more than one area (pp. 27, 29), and the Chilhowee group certainly overlaps the Ocoee series northeastward to rest on the basement rocks. In extreme northeast Tennessee and beyond in Virginia, the Chilhowee group overlaps the Mount Rogers volcanic group in the same way. According to King, (1949b, p. 635), there was at this time a considerable shift in the nature and location of the basin of deposition, and he suggests that , this shift be taken to represent, for the Appalachians, the base of the Cambrian system. There is no evidence of an orogeny at this time, however; the Ocoee series was deformed and metamorphosed later, along with the overlying Paleozoic rocks, probably near the end of the Paleozoic era. Like the Ocoee series, the Chilhowee group records a source of detritus, probably to the southeast, but deposition was of a different character and became less and less rapid.

After the deposition of the Chilhowee group, the area appears to have been diastrophically stable throughout the Cambrian period and the Early Ordovician epoch, though the sand and mud now found in the Rome formation and the Conasauga slide and the sand in the middle part of the Knox group may record feeble up lifts of the central platform of North America. Apparently there are no disconformities in this sequence except possibly among the sandstone layers below the middle of the Knox group. A major disconformity, however, separates the Knox group from the overlying rocks; it is marked by sinkholes and stream valleys at least a few hundred feet deep, and Leland F. Grant and John M. Kellberg (personal communication) report evidence that in Sullivan County the Knox group was gently arched and beveled along the axis of a present-day anticline before deposition was resumed, producing a slight angular discordance. The younger rocks are not known to overlap rocks older than the Newala formation in East Tennessee, but in parts of northern Alabama they rest on the Chepultepec dolomite or even on the Copper Ridge dolomite. On the other hand, rocks younger than the Newala appear below the disconformity in west-central Virginia and farther north (Josiah Bridge, personal communication).

As set forth above in the chapters on the Middle and Upper Ordovician rocks and as illustrated by figure 4, the compiler believes that the facies shrifts in those rocks in East Tennessee furnish evidence of two orogenic phases: first the Blountian phase in Middle Ordovician time, centered in the Southern Appalachians probably somewhere southeast of the Valley of East Tennessee, and second the main Taconian phase in Late Ordovician and possibly earliest Silurian time, centered in the southern part of the Northern Appalachians and perhaps extending into the Central Appalachians as well. Indeed, disturbances of this general period are known as far northeast as Newfoundland; they may all appropriately be grouped as phases of the Taconian orogeny. Radioactive age determinations indicate a period of granitic intrusion in the western Carolinas about 350 million years ago probably at the time of this orogeny (Rodgers, 1952). The possible disconformity at the base of the upper part of the Chickamauga limestone and the Martinsburg shale may record some pulse of the Blountian phase, but the main Taconian phase does not appear to be represented in East Tennessee by any disconformity in or at the top of the Upper Ordovician rocks, though as far southwest as eastern Pennsylvania it is recorded by angular nonconformity beneath the Silurian system. In Middle Tennessee, however, Wilson (1948) has shown the existence of a disconformity with more than 100 feet of relief (and of a very local nonconformity over a cryptovolcanic structure) beneath rocks of Richmond age, and possibly some such disconformity extends into East Tennessee, at least into the southwestern part.

The shift of facies in the Silurian rocks of East Tennessee records the waning phase of Ordovician diastrophism. There may be a disconformity between the middle Silurian shale and sandstone and the overlying upper Silurian and Lower Devonian limestone, and there may be others within the limestone sequence, but these need confirmation by more careful work on the rocks in question. Even if present, they are overshadowed by the disconformity beneath the Devonian and basal Mississippian black shale. So far as known there is little relief on this disconformity in East Tennessee, but in Middle Tennessee there is more, reaching 300 feet at one point over a cryptovolcanic structure (Wilson and Born, 1936, p. 822). On the other hand, the black shale bevels across older rocks from the Lower Devonian part of the Hancock limestone in Claiborne and Hancock Counties to the Middle Ordovician Bays formation in Blount and Monroe Counties, and at places along the southeastern side of the Appalachian Valley in Georgia and Alabama Mississippian rocks come to rest on Lower Ordovician rocks belonging to the Knox group. Moreover, the disconformity is of regional extent to the westward, reaching, to the Ozark region of Missouri and the Llano-Burnet region of Texas.

The Devonian beds above the disconformity show, a detrital wedge which is the extreme outer margin of the great "Catskill delta" of the Central Appalachians, the result of a pulse of the Acadian orogeny in the Northern Appalachians. The post-Devonian rocks record further disturbances, presumably southeast of the Appalachian Valley and Ridge province; one in Osage time is represented by the detrital material in the Grainger formation, another beginning in late Chester time is represented by the Pennington formation and the Pennsylvanian rocks. No obvious disconformities are present in the Mississippian rocks in East Tennessee, for although beds equivalent to the Warsaw limestone are apparently absent from the Newman limestone in the northwestern belts they may be present in the underlying Fort Payne chert. A disconformity appears to cap the Mississippian system, however, at least close to the Virginia line, and this disconformity becomes more and more pronounced northward and northeastward into Ohio and Pennsylvania, where in certain areas Pennsylvanian rocks rest on lower Mississippian rocks. Coming as it does at a temporary climax of westward facies shift, this disconformity may record a pulse of orogeny farther east or northeast, but no nonconformity of this date is known in the Appalachian Valley and Ridge province. In East Tennessee the Pennsylvanian rocks show perfect parallelism with the older rocks (leaving out of account the peculiar outliers from Rockwood to Spring City), not only along the front of the Cumberland Plateau but also in Grindstone Mountain along the Whiteoak Mountain fault 16 miles to the southeast. The same is true of similar outliers within the Appalachian Valley and Ridge province from Alabama to Pennsylvania. In the Georges Creek basin of western Maryland, at the west edge of the province, rocks of presumed Permian age are present, folded with the older rocks.

At the top of the Paleozoic sequence, as at its base, is a profound nonconformity, for at various places each of the Paleozoic formations is covered with angular discordance by transported mantle. This unconformity records the final orogeny of the region, the Appalachian orogeny. In East Tennessee it is not possible to date the orogeny except within very wide limits, for the oldest dated deposits above the unconformity are the scattered lignite and bauxitic clay deposits, which are probably about latest Paleocene in age (Bridge, 1950, p. 194). In the Central Appalachians, however, Upper Triassic rocks rest on deformed Cambrian and Ordovician rocks and contain pebbles of rocks as young as Devonian, and in general there is little doubt that the climax of the Appalachian orogeny came within the Permian period. Perhaps the helium age determinations (average 230 million years) from Ducktown record this orogeny (Rodgers, 1952). In the absence of conflicting evidence, it is believed that this orogeny produced virtually all the structural features to be observed in East Tennessee, outside of the areas of basement rocks, including all those described in the following paragraphs.

FOLDS AND FAULTS OF THE CUMBERLAND PLATEAU AND THE PLATEAU FRONT

The names and locations of the structural features described below are shown on figure 5. The description proceeds from the outlying faults and folds within the Cumberland Plateau, northwest of the area covered by the present map, southeastward to the Unaka Mountains.

Pine Mountain and Jacksboro faults.-The Pine Mountain fault extends from the head of Elk Valley in northwestern Campbell County east-northeastward for 120 miles along the northwest face of Pine Mountain through Kentucky to the Breaks of the Big Sandy River in Dickenson County, Va. For most of this distance basal Mississippian or uppermost Devonian rocks are thrust over Pennsylvanian rocks, but in Elk Valley lower rocks appear, certainly the Rockwood formation and probably the Chickamauga limestone. Glenn (192'9, P. 139) states indeed that the limestone mapped as Chickamauga by Keith (1896c, Brice. f.) is Mississippian, but Safford (1869, p. 252) also mentions Ordovician limestone, and the compiler would be surprised if Safford were mistaken. Between the Pine Mountain fault and the front of the Cumberland Plateau is a flat-bottomed synclinal basin of Pennsylvanian rocks 8 miles or more wide, the Middlesboro coal basin. The southwestern part of this basin is crossed diagonally by two lines of buckling, at least in part faulted, one in Tennessee along Tackett Creek in Claiborne

Note: Figure 5 is at the end of the document.

and Campbell Counties, the other in Kentucky extending north from Cumberland Gap at the State-line corner (Ashley and Glenn, 1906, pp. 47-50; Rich. 1934, pp. 1587, 1591-1592, fig. 1).

That the Pine Mountain fault underlies at relatively shallow depth both the Middlesboro basin and much of the Powell River anticline to the southeast is proved by the presence of several windows along the axis of the anticline in Lee County, Va., the southwesternmost coming within 1,000 feet of the State line near the northwest corner of Hancock County (Butts, 1927b; Miller and Brosge', 1950; Miller and Fuller, in press). Several domes occur on the anticline in Tennessee but none of them exposes the fault.

At its southwest end the Pine Mountain fault turns abruptly into the Jacksboro fault, which combines the features of a thrust fault and a left-handed strike-slip or cross fault. Near Jacksboro (Brice.) it strikes about S. 30° E. and cuts off the Middlesboro synclinal basin and the Powell River anticline, but south of Lake City it swings to the southwest and comes to resemble the other thrust faults of the Valley (see p. 131). Here the Rome formation occurs above the fault, but around the windows in Lee County, Va., the lowest formation present is the Nolichucky shale.

Sequatchie anticline, Emory River line, and related features.- The Sequatchie anticline begins in the Crab Orchard Mountains of eastern Cumberland County as a low arch in the Pennsylvanian rocks and rises southwestward to the head of Sequatchie Valley near the Bledsoe County line. Here its northwest flank is cut by the Sequatchie Valley thrust fault; fault and anticline continue southwestward far into Alabama, the total length of the fold being more than 200 miles. The crest of the fold exposes the Knox group through much of its extent, and the fault generally throws the Knox group or the Chickamauga limestone against various Mississippian formations. Between the Sequatchie anticline and the front of the Cumberland Plateau is a flat-bottomed synclinal basin of Pennsylvanian rocks 7 miles or so wide, forming Walden Ridge.

Assuming an analogy between the Sequatchie anticline and the Pine Mountain fault, the compiler (Rodgers, 1950, p. 677) has suggested that the Sequatchie Valley fault underlies at relatively shallow depth both Walden Ridge and that part of the Valley southeast of it as far as the Chattanooga fault, and he interprets the areas of Ordovician and Silurian rocks surrounded by Cambrian rocks at Postoak, 3 miles cast of Rockwood, Roane County, and at Rhea Springs, 2 miles east of Spring City, Rhea County

(Kings.) as windows through this fault. As these windows lie against the Chattanooga fault, they are eyelid windows (Oriel, 1950, p. 46). Except at the southwest end of the Postoak window, the oldest formation on the block supposed to overlie this fault is the Conasauga shale. Apparently the youngest formation within these windows is the Rockwood formation, not the Fort Payne chert as formerly stated (Rodgers, 1950, p. 680).

Northwest of the Sequatchie anticline in Cumberland County, a series of smaller anticlines arranged *en echelon* crosses the county from southwest to northeast. Northeastward these come to an abrupt end at the Emory River line, a pronounced line of buckling, with some thrust faulting, in the Pennsylvanian rocks of south-central Morgan County, extending from the Emory River southwest of Wartburg in an arc convex to the south to the vicinity of Oliver Springs, at the corner of Morgan, Roane, and Anderson Counties (Brice.). Although the Sequatchie anticline does not reach quite to the line, the analogy noted above suggests that the line corresponds to the Jacksboro fault, combining thrust movement with right-handed strike-slip movement. The structure of the area southwest and west of this line is being investigated by Richard G. Stearns and others for the Tennessee Division of Geology.

Features along the Cumberland Plateau front.-Between Harriman (Kings.) and Elverton (Loud.), Roane County, directly south of the sharpest bend in the Emory River line, the Cumberland front is set back about a mile from its normal position around a trapezoid of pre-Pennsylvanian rocks, 5 to 7 miles long, which may be called the Harriman corner. The ends of the Harriman corner are apparently marked by combination thrust-cross faults similar to, though smaller than, the Jacksboro fault. The rocks exposed within it comprise two unbroken sequences from Cambrian to Pennsylvanian, separated by a fault upthrown on the northwest - either a normal fault or a northwest-dipping thrust fault, though in this case probably the former. Other faults of similar displacement which, however, are probably northwest-dipping thrust faults, occur elsewhere along the front, as at the Powell Mountain southwest of Cumberland Gap (Mayn.) and on the southeast face of Dutcher Knob just north of Dayton (Chatt.) (the latter fault was pointed out to the compiler by Paris B. Stockdale). According to the usual genetic nomenclature, these faults would be "under-thrusts" in contrast to the ordinary Appalachian "overthrusts," but as we do not know in either case which blocks actively moved over or under, it is better to use the noncommittal term "backthrust" for those thrust faults whose dip is opposite the prevailing dip of thrust faults and axial planes of folds. The finest example in the Appalachians is on the southeast side of the Murphrees Valley anticline in Etowah and Blount Counties, Ala.

Even more unusual than these faults are a line of patches of Pennsylvanian rocks that lie at the foot of the Cumberland Escarpment from Rockwood to Spring City and a little beyond (Kings.). The Pennsylvanian rocks in these outliers are folded, in places tightly, but they appear to lie discordantly across the edges of vertical Ordovician to Mississippian strata that otherwise border the escarpment in this area. These outliers, half a mile to a mile wide and several miles long, were first observed by Safford (1869, pp. 143, 388), who suggested that "great blocks of the *Coal Measures* have been detached and thrown over the crest [of the escarpment], and now rest against the slope, or lie flat in the Valley." They remain very puzzling, and the compiler has no ready explanation for them. Three theories, among others, suggest themselves, though none is satisfactory. Perhaps the discordance is stratigraphic, the Pennsylvanian rocks resting with angular nonconformity on the bevelled edges of the older rocks. Nowhere else in the area, however, is there any other evidence of such an unconformity, either where the base of the Pennsylvanian system is exposed along the Plateau front within a few thousand feet of these unusual outliers or in ordinary outliers to the southeast, presumably closer to the center of any disturbance. Perhaps the discordance is structural, the Pennsylvanian rocks being brought into place along a nearly horizontal fault of some kind. No "roots" to any such fault have been discovered, however, either in the immediately underlying rocks or to the southeast. Perhaps the discordance is physiographic, the Pennsylvanian rocks having slid down from a higher position over the already eroded edges of the older rocks. This explanation (suggested to the compiler by Leland F. Grant) fails to explain, however, the great size and continuity of the masses and especially the folds they exhibit, and it meets difficulty in attempting a reasonable reconstruction of the topography that existed before the sliding. The compiler leans to the structural interpretation, though without strong conviction, suggesting that a steep backthrust formed early in the deformation of the region, bringing Pennsylvanian rocks under and into contact with older formations, and that it was later tilted through 90° or more when the older formations were folded to their present vertical attitude during the main deformation, the "roots" of the older fault being cut off by the Chattanooga fault to the southeast. Perhaps the supposed normal fault in the Harriman corner is a backthrust that has been tilted through a lesser angle, and thus records an intermediate stage between the simple backthrusts like the one near Dayton and the fault responsible for these anomalous outliers.

From Dayton southwest, other patches of Pennsylvanian rocks occur southeast of and below the crest of the Cumberland Escarpment, but they are brought down by simple synclines or by synclines cut on the southeast flank by ordinary southeast-dipping thrust faults and are separated from the flat-lying, rocks of the plateau by normal anticlines. The largest syncline and anticline form Lookout Mountain and Lookout Valley southwest of Chattanooga; their common flank is not simple as formerly mapped (Hayes, 1894c, Chatt. f.) but is cut by a southeast-dipping thrust fault of small throw (first mapped by Portland P. Fox, unpublished map in files of TVA).

BELT OF DOMINANT FAULTING

Southeast of the Cumberland Escarpment and the structural features along it and of the Powell River anticline is a belt 16 to 20 miles wide in which almost all the rocks dip southeast, the rock sequence being, repeated in belt after belt between southeast-dipping faults of large throw. Major folds are rare, and even smaller folds are found mainly close to the thrust faults. On the other hand, minor cross faults are common and minor thrust faults abundant, especially close to the major faults; doubtless only a small percentage of them, those found by detailed mapping or by attention to topographic expression, are shown on the present mat). The major faults that dominate this belt can be classed into three groups or families, here named after prominent members, the Kingston, Whiteoak Mountain, and Saltville families of faults. Almost all these faults bring up the Rome formation for many miles, generally in the northeastern parts of their courses; elsewhere the Conasauga group or in places the lower beds of the Knox group lie next southeast of them. Almost any formation above the Rome may lie next northwest; perhaps the Chickamauga limestone and its shale equivalents are the commonest. In general the dips of these faults are moderate, probably about parallel in any given area to the average dips of the rocks above them, but in several areas they are nearly horizontal.

Faults of the Kingston family.-In Anderson County east of Oliver Springs (Brice.), a few miles southwest of the point where the Jacksboro fault swings from an abnormal southeast to a normal southwest strike, it appears to split into two major faults which extend southwestward into Georgia. The fault on the southeast is the Kingston fault; the fault on the northwest has hitherto been recognized only in places. It is here mapped as a continuous fault and named the Chattanooga fault. The Chattanooga fault bounds the Harriman corner and the Postoak and Rhea Springs windows on the southeast; near them it shows several branch faults (Kings.), but elsewhere it is single, except at Chattanooga. The Kingston fault likewise shows few branches, the principal ones being the folded fault underlying a horse of the Knox group and resting in the syncline of the Rockwood formation that makes the Euchee iron range 7 miles east of Spring City (Kings.), and the Missionary Ridge fault (Chatt.), which appears to branch off about 15 miles northeast of Chattanooga and to extend past the Georgia line. Some miles south of the State line, however, both the Missionary Ridge and the Chattanooga faults die out along the plateau front. A short distance south of the State line, the block between them is crossed diagonally by a fault with the northwest side upthrown; like the similar fault in the Harriman corner, it may be a normal fault or a northwest-dipping thrust fault. The rocks northwest of the Kingston fault show a shallow syncline of considerable length, the deepest part of which contains the Euchee iron range. The Kingston fault is the longest fault of the family, extending entirely across the northwest corner of Georgia at the edge of the Plateau, but in Tennessee it generally has less stratigraphic throw than the Chattanooga fault.

Faults of the Whiteoak Mountain family.-Four thrust faults enter Hancock County from Virginia: the Wallen Valley, Hunter Valley (St. Paul of Butts, 1940), Clinchport, and Copper Creek faults. One by one these faults merge as they are traced southwest, in each case in an area of great structural complexity. The Clinchport fault and the Hunter Valley fault merge east of Sneedville (Morr.), though they may divide again around the large fault slices of the Rome formation and Conasauga group southwest of Sneedville (Morr.) and southeast of Tazewell (Morr., Mayn.). The Hunter Valley and Wallen Valley faults appear to merge near Clinton (Brice.) to form the Whiteoak Mountain fault, but a belt of long narrow horses extends along the fault for more than 25 miles farther southwest (Loud.). Finally, in western Bradley County (Cleve.) the Copper Creek fault enters a complexly imbricated area and at least one branch of it merges with the Whiteoak Mountain fault, but another branch emerges on the far side of the imbricated area as the Pine Hill fault. According to Butts (Butts and Gildersleeve, 1948), the Pine Hill fault extends 10 miles into Georgia and the Whiteoak Mountain fault 40 miles, the latter dying out in Floyd County northwest of Rome.

The faults of this family also extend well into Virginia. The Wallen Valley fault extends 35 miles east-northeast before dying out on the southeast flank of the northeast-plunging Powell River anticline. The Hunter Valley and Clinchport faults apparently merge 30 miles east-northeast of the State line; 35 miles farther on, in an area of considerable complexity around Big A Mountain, they join the Russell Fork fault, which forms the northeast side of the quadrilateral block behind the Pine Mountain fault. The fault formed by their junction, called the St. Clair fault, continues another 110 miles east-northeast to the vicinity of Sweet Springs, W. Va., where it finally dies out in an asymmetrical anticline. The Copper Creek fault extends 65 miles into Virginia; after a gap of 25 miles in which the fault is replaced by an unbroken anticline, it reappears as the Narrows fault and carries on for 65 miles more.

Except for the Pine Hill fault and the northeast part of the Wallen Valley fault, the faults of this family bring up the Rome formation throughout their extent in Tennessee. Many of the numerous minor faults along them cut the Rome formation, but short lenslike horses of the Knox group are also common, especially along the Whiteoak Mountain fault. The rocks northwest of the Whiteoak Mountain fault are folded into a tight syncline; Fort Payne chert is preserved in several areas and Pennsylvanian rocks cap Grindstone Mountain east of Ooltewah (Chatt.). In Hancock County and the adjacent part of Claiborne County (Morr.), Mississippian rocks between the Wallen Valley and Hunter Valley faults also form a deep syncline bordered on the southwest by domelike anticlines and by faults. South of Maynardville (Mayn.) some of the minor faults southeast of the Copper Creek fault appear to be strongly folded; in this area and locally to the northeast the Copper Creek fault itself has a low dip, producing a sinuous trace and a klippe or two. Unique is the isoclinal drag folding with a wave length of half a mile or so that involves the entire Knox group beneath the Wallen Valley fault in the Straight Creek area, about 4 miles southwest of Tazewell (Mayn.). The igneous bodies in Union County (p. 114) also occur along the Wallen Valley fault (Mayn.).

Faults of the Saltville family.-From Knoxville to the Georgia line the Saltville family consists of three faults: the Beaver Valley, Saltville, and Knoxville faults. The Rome formation appears alone the Beaver Valley and Saltville faults at Knoxville but disappears to the southwest, about 25 miles away on the Beaver Valley fault and at the city limits on the Saltville fault. In general the Beaver Valley fault has the largest stratigraphic throw of the three. Traced southwestward the three faults come closer and closer together. Butts' map of northwest Georgia (Butts and Gildersleeve. 1948) ignores the Saltville fault and shows the Knoxville fault dying out near Dalton, 14 miles south of the State line, but Arthur C. Munyan (1951) has shown that they both continue past Dalton and probably the three faults merge a few miles farther south to form the great Rome fault, which continues across Georgia and far into Alabama.

Minor faults are common in certain areas. The complicated structure near the northwest limits of the cit), of Knoxville (Knox. and Mayn.) is interpreted by the writer as a horse of the Knox group and the formations next above and below resting in a syncline of Chickamauga limestone, but other interpretations are possible. Southwestward this syncline extends into the Knox group and is accompanied on the southeast by an anticline, but both disappear under the Saltville fault less than 10 miles from Knoxville. Other folds occur where the Conasauga group lies southeast of one of these faults or the Chickamauga limestone lies northwest. From Lenoir City nearly to Sweetwater (Loud.), the Knoxville fault has an unusually low dip, as shown by its trace and by actual outcrops of the fault surface; perhaps, however, the main fault lies farther southeast within the outcrop belt of the Knox group, and the nearly flat fault is only a branch. Near Sweetwater the Knoxville fault and the Saltville fault show almost parallel irregularities (Loud., Kings.), in each case connected with the southwest end of a belt of Middle Ordovician formations on the northwest and the northeast end of a belt of Conasauga shale or Nolichucky shale on the southeast. Where the Knoxville fault reaches the Georgia line, the rocks northwest of it seem to be cut by a normal fault, up-thrown on the northwest; but perhaps the structure should be differently interpreted, as a faulted thrust fault or in some other way.

Northeast from Knoxville remarkable changes appear. The Beaver Valley fault comes to an end in a few miles (Mayn.), apparently partly by sending off a short curved branch that seems to end the major part of the displacement, and partly by being absorbed in folding in the incompetent Martinsburg shale west of the southwest end of Clinch Mountain. The Knoxville fault disappears similarly into a mass of crumpled Ottosee shale just cast of Knoxville (Knox.), but seems to reappear south of Strawberry Plains as the Rocky Valley fault, notable for its sinuous trace and generally flat attitude (though down dip to the southeast the dip steepens) and for its relation to the Rocky Valley anticline in the upper block (Bridge, 1945; ms.). Between these two faults, the Saltville fault virtually doubles its stratigraphic throw, and Mississippian rocks occur on the block northwest of it from the southwest edge of Grainger County (Mayn.) to the Virginia line and for many miles beyond. In Hawkins County northwest of Rogersville, however, its trace retreats 3 miles to the southeast for a distance of about 16 miles (Morr., Greene.), revealing the southeast limb of a complex, faulted, strongly overturned and virtually isoclinal syncline or synclinorium, which may well be present under cover of the fault both northeast and southwest. This area is being mapped by John E. Sanders for the Tennessee Division of Geology. Southeast of the main fault as it skirts this reentrant the rocks are intensely imbricated; the present map can only hint at the complexity of this area. From the southwest end of the imbricated area the Cherokee anticline extends southwestward, passing close to the Cherokee Dam (Mayn.) and plunging into a reentrant in the trace of the Rocky Valley fault. To the west, beyond a minor thrust fault, other folds affect the rocks between the Saltville and Rocky Valley faults (Bridge, ms.). Indeed, the whole area between Knoxville and Rogersville is notably more folded than any other in the belt dominated by the families of faults being described, and it resembles rather the next major belt southeast. The displacement of the Rocky Valley fault lessens east of Jefferson City (Morr.), but the fault probably continues across the belt of the Knox group passing through Morristown and enters the imbricated area near Rogersville. At the far end of that area another fairly large fault, the Carter Valley fault, appears and continues northeast, merging with the Saltville fault just north of the Virginia line north of Kingsport (Greene.). Ten miles farther east the Saltville fault reenters Tennessee for 2 miles (Averitt, 1941); it then extends east-northeast into Virginia for 130 miles. The Knoxville, Rocky Valley, and Carter Valley faults may represent a single line of faulting, though it may not be possible to prove that they are continuous.

BELT OF DOMINANT FOLDING

Southeast of the Saltville family of faults northwest dips are much less of a rarity, and the rocks form many anticlines and synclines, some fairly continuous but many of the anticlines domical. Thrust faults are by no means absent, and one group, extending from Morristown to the Georgia line, forms a family almost as distinct as those to the northwest; however, the faults do not dominate the structure and several of them die out in folds, as none of those to the northwest do within East Tennessee. These features characterize a belt that is 16 to 20 miles wide except close to the Virginia line. It lies nearly in the middle of the Valley to the northeast, but along its southeast side in the center and south.

In Washington County, Va., the belt between the Saltville and Pulaski faults hardly differs from those to the northwest, and as it enters Tennessee it is only 2 to 3 miles wide; but in western Sullivan County the two faults diverge and between them appears the Bays Mountain synclinorium, containing a vast mass of Middle Ordovician shale and sandstone, the northeast end of the Gray Belt of Safford (see p. 76). Two principal synclines, each of them compound and each extending for more than 30 miles, form the core of the synclinorium, and they are flanked by a number of shorter folds. Most of the folds in the synclinorium are straight and have sharp crests and troughs. Around its south flank, however, between Greeneville and Morristown, domical anticlines expose the Knox group, separated either by narrow, tight synclines or by wider belts of crumpled shale; such domes, some long, some short, occur here and there as far as Blount County (Knox.), and perhaps also at Etowah, at the southwest end of the Gray Belt, and south of Benton, even farther southwest on the same strike (Cleve.).

Faults are virtually absent in the synclinorium and are not common in the Gray Belt or its enclosed domes farther southwest, but a belt of close imbrication appears along the southeast margin. Both at Fall Branch, Washington County, and northwest of Greeneville (Greene.) detailed mapping has shown a spacing of five thrust faults to the half mile, and doubtless the same intensity could be found elsewhere in this belt. Though not necessarily continuous, the belt parallels the Pulaski fault from western Sullivan County (Roan M.) past Greeneville; farther southwest, where the Pulaski fault doubles back, it probably continues undetected. Detailed work near Newport (Mt. G.) has shown comparable imbrication there, and probably the belt reappears in Sevier County on the flanks of the dome next northwest of the Great Smoky fault. Close to Sevierville (Knox.), the Guess Creek fault is the largest of a similar group of imbricate faults, which can be traced southwest, near the mountain front, apparently to the Little Tennessee River. (Loud.).

Faults also appear northwest of the Gray Belt, associated with a belt of the Conasauga group that begins south of Morristown and extends to the Georgia line. Two faults stand out in this group or family: the Dumplin Valley fault, extending from near Morristown to Maryville (Knox.) and probably from there, though with diminished throw, past Madisonville (Loud.) nearly to Englewood (Mur.), and the Chestuee fault, which probably begins north of Maryville, becomes prominent near Madisonville, and can be traced almost or quite to the Georgia line. There are others parallel to these, especially on both sides of Madisonville (Loud., Mur.) and north of Sevierville and Dandridge (Knox., Mayn., Morr.), but they are smaller; only the Dumplin Valley fault and an unnamed fault at the Georgia line bring the Rome formation to the surface. Long tight folds accompany some of these faults, and the anticline at Greenback (Loud.), which also brings the Rome to light, is largely independent of them. In eastern Bradley County, George D. Swingle has discovered a remarkable klippe, presumably related to the Chestuee fault (Cleve.).

Between these faults and the Knoxville and Rocky Valley faults are more folds, largely unfaulted, which bring the Middle Ordovician formations down to form the main Red Belt of Safford. The Rocky Valley anticline, whose northeast end has slid forward rootlessly on the Rocky Valley fault (p. 134) (Mayn.), is flanked south of Knoxville by two synclines (Knox.), the southeastern of which extends continuously to Bradley County (Cleve.).

PULASKI FAULT BLOCK

The Pulaski fault, which extends for more than 200 miles along strike in Virginia, enters Tennessee about 5 miles west of Bristol (Roan M.) and has a length of at least 60 miles in Tennessee. The block between this fault and the Unaka Mountains differs somewhat in both stratigraphy and structure from the area northwest of the fault. On the present map the geology of this block has been considerably revised. Recent work, based on new, knowledge of the stratigraphy and close attention to the expressive topographic maps, has shown that the main thrust faults within the block are more continuous than shown on earlier maps, that many anomalies in the northeastern part of the block in East Tennessee are the result of right-handed cross faults, and that the Pulaski fault does not end near Greeneville but continues, tracing an S-curve, to the edge of the Unaka Mountains in eastern Cocke County (Greene., .Morr., and Mt. G.). Here the Pulaski fault block, which forms a belt about 15 miles wide in Sullivan and Washington Counties, is entirely overridden by the thrust sheets of the mountains. Whether this disappearance merely means that the fault block is cut off as the Pulaski fault approaches the faults of the mountains, or whether the fault block actually continues on beneath the higher thrust sheets, which in that case have been displaced some tens of miles over it, cannot at present be decided. The structure exposed in the windows in Blount and western Sevier County (Knox.) resembles that in the belt of dominant folding northwest of the Pulaski fault rather than that in the Pulaski fault block, but, as noted below, structure like that in the Pulaski fault block may recur southeast of the Bullet Mountain fault in Monroe County (Mur.) and the Harrison Mill fault in Polk County (Cleve.).

The three main faults of the block, the Pulaski, Dunham Ridge, and Spurgeon faults, form a distinct family, like those farther northwest. In northwestern Washington County (Greene., Roan M.) they are spaced at about 5-mile intervals, but northeastward they converge; the Dunham Ridge fault merges with the Pulaski fault north of Blountville (Roan M.), and the Spurgeon fault enters Virginia only a mile southeast of the Pulaski fault. The course of the Spurgeon fault in Virginia is not clear from existing evidence, but apparently it splits just northwest of Bristol. The southeast branch, here named the Bristol fault, swings east and south in an arc just outside the city limits and reenters Tennessee, where it dips west and even northwest. The southwest end of this remarkable fault is uncertain, but it may continue to the Cross Mountain cross fault; however, the whole course of the fault needs verification. Southwestward the Spurgeon fault has not been traced out of Washington County, but the Pulaski and Dunham Ridge faults continue entirely across Greene County and finally merge in this direction also, where the Pulaski fault makes its S-curve at the Cocke County line (Greene., Morr.). Along much of their courses these three faults bring up the shaly beds at the base of the Honaker dolomite, which are everywhere highly crumpled and sheared, the carbonaceous matter showing abundant slickensides, but nowhere on this block in Tennessee northeast of Cocke County is the Rome formation exposed. Minor thrust faults occur especially between the Pulaski and Dunham Ridge faults; they are not common farther southeast on the block.

Through much of the Pulaski block in Tennessee the rocks dip more steeply than farther northwest in the Valley; in the southwestern part, indeed, they are nearly vertical over considerable areas. Here they outline several nearly or quite isoclinal folds, whose axial planes, by contrast to the folds farther northwest, dip almost as commonly northwest as southeast, though they are rarely far from vertical. In this area only a few of the synclines bring down the Sevier shale, notably the curiously reticulate synclines near Limestone (Greene.). Apparently the thrust faults in this area likewise are quite steep, the most remarkable exception being the Pulaski fault under the curious folded flap southeast of Baileyton (Greene.), if indeed the structure here is correctly interpreted on the present map. In the northeastern part of the block the dips of the rocks (and probably of the thrust faults) are somewhat less steep and the folds a little less tight, and the Sevier shale, generally crumpled, is preserved in thick masses in a number of synclines, separated by arches or domes of the Knox group. Also characteristic of this part of the block are the east-west right-handed cross faults, the largest of which, the Cross Mountain fault, extends into the mountains to the east. On the present map (Roan M.) this fault is shown cutting the Spurgeon and Dunham Ridge faults and ending near the Pulaski fault, but detailed mapping may alter this interpretation.

In eastern Cocke County (Mt. G.) the Pulaski fault approaches the faults along the front of the Unaka Mountains and disappears under or merges with the foremost of these faults, which underlies a slice of the Rome formation in front of the main line of faulting. Whether this slice should be reckoned with the Pulaski block or with the thrust sheets of the mountains is uncertain; the compiler leans to the former view. Beyond the French Broad River the slice comes to an abrupt end in an area for which no satisfactory interpretation is yet available; the tentative guess shown on the present map will be superseded when detailed work now planned is completed. A major fault crosses the Pigeon River between the outcrop areas of the Knox and Shady dolomites; it is tempting to see it as the Pulaski fault reappearing for a short distance from under the mountain faults, but more likely it is a higher fault.

Much farther southwest, in the Tellico Plains area of Monroe County (Mur.), the Bullet Mountain fault separates a narrow belt of almost isoclinally folded Lower Cambrian rocks (Rome to Nichols formations) from broader folds in the Valley. The sharp anticlines of the Chilhowee group forming Guide, Bullet, and Groundhog Mountains resemble somewhat the folds of the Doe Mountain anticlinorium, here interpreted as part of the Pulaski block exposed in the Mountain City window (p. 140), and of the

Glade and Lick Mountain anticlinoria of southwest Virginia, also on the Pulaski block (Miller, 1944; Stead and Stose, 1943). Possibly the Bullet Mountain fault represents not necessarily the Pulaski fault but the southwestern continuation of the same fault trend. Still farther southwest, the trend may be represented by the Harrison Mill fault on the west face of Bean Mountain east of Benton (Cleve.), which likewise brings up the Shady dolomite, otherwise quite unknown within the main part of the Valley of East Tennessee. East of Eton, Ga., about 12 miles south of the State line, A. C. Munyan (1951) has found that the Chilhowee group reappears once more in Campground Mountain in front of the Great Smoky (Cartersville) thrust fault.

THRUST SHEETS OF THE UNAKA MOUNTAINS

Structurally the Unaka Mountains differ from the Valley of East Tennessee not only in their greater complexity but also because they are composed chiefly of a lower part of the sedimentary sequence and include areas of the basement complex. Indeed these latter differences are also the cause of the topographic contrast. Whereas, except as noted in the last paragraphs, no formations below the Rome formation are exposed within the Valley, formations above the Rome are rare in the mountains, the largest area of these formations being around and southwest of Elizabethton, an area that physiographically is reckoned with the Valley. Whereas with few exceptions the thrust faults of the Valley follow one another in regular order from the structurally lowest on the northwest to the structurally highest on the southeast, the thrust faults of the mountains have themselves been deformed, and this deformation must first be deciphered before the thrust faults can be unscrambled. Perhaps the most spectacular structural features of the mountains are the windows, and the windows within windows, that result from this scrambling; windows are present within this belt for 75 of the 150 miles between the Little Tennessee River and the northeast corner of the State.

Folded thrust sheets of northeast Tennessee.-The work of King and others (1944, pp. 11-13, fig. 2) has established that in the mountains of Johnson, Carter, and Unicoi Counties a series of thrust sheets has been stacked one upon another and then folded into a large syncline to the northwest and a large anticline (or anticlinorium) to the southeast. Because of the folding, the lower sheets are now exposed chiefly southeast of the higher ones where erosion has cut into the anticline to produce the great Mountain

City window, 60 miles long (Cran., Roan M.). The window is bounded by the Iron Mountain, Catface, Stone Mountain, and Unaka Mountain faults; it is compound and includes two inner windows. One of these, the Doe Mountain inner window, appears to form the entire northeastern half of the Mountain City window, and it is separated from the southwestern half by the southwest-dipping Little Pond Mountain thrust fault (Roan M.) (misinterpreted as a cross fault by King and others, 1944, fig. 2, also p. 144; present interpretation worked out more recently by Ferguson, ms. b.). The other, the Limestone Cove inner window in the southwestern part of the Mountain City window, is much smaller and is separated from the rest of the window by the northwest-dipping Limestone Cove thrust fault (Roan M.). The remainder of the Mountain City window lies structurally higher than the two inner windows and may be called the Hampton thrust sheet.

The compiler suggests that the Doe Mountain inner window belongs to the Pulaski fault block, chiefly because of the extraordinary similarity of the Doe Mountain imbricated anticlinorium (Cran., Roan M.) to the Glade Mountain and Lick Mountain anticlinoria in Smyth and Wythe Counties in southwest Virginia (Miller, 1944; Stead and Stose, 1943). Each of these three anticlinoria consists of the upper part of the Chilhowee group, intensely faulted (the Hampton formation is the oldest formation exposed in the Virginia anticlinoria but the Unicoi formation is reported in a few places in the Doe Mountain anticlinorium), the faults being mainly steep thrust faults but including in each anticlinorium a few normal faults, and each of the anticlinoria is surrounded by a sea of crumpled Rome formation. Even though the Doe Mountain anticlinorium is in the Mountain City window within the mountains 25 miles southeast of the Pulaski fault, and the Virginia anticlinoria are north of the main front of the mountains close to the fault, the three are not far off strike with respect to each other. On the other hand, basement rocks appear within the Doe Mountain inner window in the curious appendix at its southern corner along Elk River (Cran.), whereas they do not appear anywhere else on the Pulaski block.

Whether the Limestone Cove inner window is at the same structural level as the Doe Mountain inner window is not known. Basement rocks are present along its southeast side, and an unbroken sequence up to the Rome formation dips to the north and northwest under the Limestone Cove thrust fault.

The next structural layer in northeast Tennessee is the Hampton thrust sheet, which forms most of the southwestern part of the

Mountain City window. The northeastern part of the sheet contains a simple northwest-dipping sequence from the pre-Cambrian basement complex on the southeast to the Rome formation on the northwest, but the southwestern part is sliced into three sequences by two lesser faults roughly parallel to the Limestone Cove and Iron Mountain faults which bound the sheet. All these faults were originally southeast-dipping thrust faults, but they have been folded until they dip steeply northwest or are practically vertical on the northwest limb of the window anticline. Near Hampton the thrust sheet is crossed by two right-handed cross faults, one of which cuts the Iron Mountain fault and the overlying thrust sheet. On the present map these cross faults are shown cutting the Bald Mountain fault as well and continuing some miles to the southeast, but the only evidence for this continuation is that strong topographic lineaments extend from the known location of the faults to the North Carolina line. The base of the Hampton thrust sheet is formed by the Little Pond Mountain and Limestone Cove thrust faults, but whether these are part of the same fault or, if not, which is structurally the higher, is quite uncertain. The sheet has not been recognized elsewhere, unless perhaps it reappears as the sheet above the Sugar Grove and Laswell thrust faults on the southeast margin of the Valley in Smyth and Wythe Counties, Va. (Currier, 1935, pl. 2).

Next above the Hampton thrust sheet is the Shady Valley thrust sheet, which contains a complete sequence from the pre-Cambrian basement complex to the Sevier shale, folded into the simple Stony Creek syncline complementary to the window anticline (Roan M., Cran.). Complications are remarkably few, the chief one being the Cross Mountain cross fault which cuts diagonally across the sheet, displacing the synclinal axis to the right about 3 miles. That part of the sheet northwest of the Mountain City window is bounded by the Holston Mountain fault on the northwest and the Iron Mountain fault on the southeast, and there is little doubt that these are parts of the same fault, folded with the overlying rocks into the syncline. At the ends of the Mountain City window, however, the Iron Mountain fault (including the Catface fault, its continuation east of the north end of the window) intersects higher faults at considerable angles, and the Shady Valley thrust sheet passes under or is cut off by these faults. Northeastward the sheet appears to continue for many miles into Virginia above the "Iron Mountain overthrust" and the Poplar Camp thrust of Currier (1935, pl. 2). Southwestward it disappears under the next higher sheet where the Holston Mountain fault meets the Buffalo Mountain fault in southwestern Washington County (Greene.). Probably the Shady Valley thrust sheet also reappears to the southeast in the Grandfather Mountain window in North Carolina, for these two structural units are the only ones that contain the Mount Rogers volcanic group.

The next higher thrust sheet forms a tonguelike mass nested in the southwestern part of the Stony Creek syncline above the Shady Valley thrust sheet (Roan NI.). It was included in the Bald Mountain thrust sheet by Kino, and others (1944, p. 12, fig. 2), but that sheet is perhaps split into two sheets by the postulated fault here called the Devil Fork fault (Greene., Roan M.). The northwestern sheet, which forms the tongue mentioned, is here called the Buffalo Mountain thrust sheet and the fault beneath it the Buffalo Mountain thrust fault (Keith, 1907b, Roan M. f., pp. 8-9, figs. 1, 2). The northeastern end of the tongue (Roan M.) has been mapped by Richard J. Ordway (ms.) who recognizes three thrust blocks within the sheet: the Cherokee Mountain block to the northwest, an intermediate block, and the Pinnacle block forming the main mass of Buffalo Mountain to the southeast. These blocks reappear in the Bumpus Cove area southwest of Embreeville (Roan M., Greene.), (Rodgers, 1948), the first two apparently merging in Bumpus Cove and the third forming Rich Mountain to the southeast. Apparently the fault between continues for miles southwestward along the northwest face of the Big Butt range. The sheet contains the basement complex, the Ocoee series (moderately thick), the Chilhowee group (apparently exceptionally thick), and the Shady dolo- mite; the Shady occurs only on the northwestern blocks, the Ocoee on the southeastern block, and the basement rocks only to the southwest outside the tongue, possibly separated from the rest of the sheet by a fault. From the northeast end of the tongue the Buffalo Mountain fault can be traced southwestward along both sides of the tongue, dipping southeastward on the northwest side and practically vertical on the southeast side. From the southeast side it swings around the southwest-plunging end of the window anticline (Spivey Creek fault of Lowry [ms.], who has shown that this end of the anticline is cut by several cross faults) and merges with (or is cut off by) the Devil Fork fault (Roan M., Greene.). It may be double around the end of the anticline, with a slice of basement complex between the two parts.

As already mentioned, the Iron Mountain fault is cut off at both ends of the Mountain City window by higher faults, so that the window is an eyelid window, as are both of its inner windows. The fault along the southeast side of the Doe Mountain inner window is called the Stone Mountain fault (Cran.), and that along the southeast side of the Hampton sheet and the Limestone Cove inner window is called the Unaka Mountain fault (Roan M.); both have brought forward basement rocks and probably they are parts of the same fault. Whether the fault is continued southwestward by the Devil Fork fault or the Buffalo Mountain fault or splits to form both is not certain.

The compiler suggests the possible existence of a still higher fault, entirely within the basement complex in North Carolina; it is shown on figure 5 as the Snow Mountain fault, but the idea of such a fault has not yet been checked by field mapping. It would lie along the southeast side of the southern appendix of the Doe Mountain window (Cran.), its trace swinging south and east from the south corner of the appendix into the north margin of the Grandfather Mountain window. According to Keith (1903, Cran. f.), contacts to the northeast show a similar curvature. Southwest of the Snow Mountain fault an opposite curvature appears, well shown by the line of magnetite mines in Carter County, Tenn., and Mitchell and Avery Counties, N. C., (Bayley, 1923, pl. 1, p. 34); the two curvatures outline a structural saddle between the Mountain City and Grandfather Mountain windows.

Folded thrust sheets of the French Broad area.-Where the French Broad River cuts across the Unaka Mountains (Ashe., Mt. G.), Ferguson (Ferguson and Jewell, 1951) and Oriel (1950) have worked out a sequence of thrust sheets comparable to the sequence in northeast Tennessee, but in the absence of detailed mapping between, the relations of the thrust sheets in the two areas can only be conjectured on evidence from reconnaissance traverses and from the stratigraphic columns on the different thrust sheets. Probably the lowest sheet in the French Broad area is that lying along the Pigeon River northwest of Hartford and extending west to Cosby (Mt. G.). It contains the formations from the Unicoi to the Rome dipping mainly north and northwest, but the details of the structure have not been worked out. Whether it is represented farther northeast is quite uncertain; as already suggested above, it may be the Pulaski block reappearing, but it may also be the Hampton thrust sheet or a sheet not known in northeast Tennessee.

Perhaps the next higher thrust sheet is the one exposed in the Hot Springs window, mainly in Madison County, N. C., but extending a short distance into Cocke County, Tenn. (Ashe.). The Hot Springs window is bounded by the Mine Ridge, Hot Springs, Rector Branch, and Brushy Mountain faults. According to Oriel

(1950, pp. 39-40), who has mapped it in detail, the window is compound, the area of basement rocks in the east corner forming an inner window; his reasons for considering the contact between the basement rocks and the adjacent Snowbird formation to be a fault are the mineralized mylonite along it and the great variation in the thickness of the Snowbird above it. In the rest of the window the formations follow in order from the Snowbird on the southeast to the Honaker dolomite on the northwest. On stratigraphic grounds, Ferguson (Ferguson and Jewell, 1951, p. 38) has suggested that the sheet exposed in the Hot Springs window is the same as the Shady Valley thrust sheet, a reasonable conjecture.

The belt between the Mine Ridge fault on the northwest side of the Hot Springs window and the Meadow Creek Mountain fault at the front of the mountains is called by Ferguson (Ferguson and Jewell, 1951, p. 9) the Del Rio thrust sheet; indeed, as he suggests, the two faults are probably parts of the same folded fault. The sequence from the Snowbird formation to the Rome formation is partially repeated several times by lesser, apparently steeper thrust faults, which cut the sheet tip into a number of blocks (Mt. G., Ashe., Greene.). If the Rome slice at the mountain front near the French Broad River be left out of account, the first and third blocks from the northwest differ somewhat in stratigraphy from the others, and the fault between the second and third has certain peculiarities, such as horses of the Rome formation and apparently reversed displacement in certain stretches. Possibly the first block represents a lower thrust sheet than the main Del Rio sheet, brought to light again in the third block by a steeper fault that has displaced the fault under the Del Rio sheet. It should be stated that Ferguson considers this interpretation unnecessary; detailed mapping to the southwest, which he has planned, should provide the evidence to settle the matter.

In its stratigraphy the Del Rio sheet resembles the Buffalo Mountain thrust sheet of northeast Tennessee, but apparently it is separated from the southwestern continuation of that sheet in the Big Butt range by an arcuate fault here called the Hot Springs fault. This fault, having formed the northeast side of the Hot Springs window, swings north and northeast cutting off several of the lesser faults on the Del Rio sheet and merging with the Meadow Creek Mountain fault to form the Buffalo Mountain fault. The critical part of this fault, however, has not yet been mapped in detail. The folio mapping (Keith, 1904, Ashe. f.; 1905a, Greene. f.) and what reconnaissance the compiler has done suggest that the block above it is divided by a fault along the upper course of Paint

Creek into a northwestern foothill block, in which the Chilhowee group and a small part of the Ocoee series dip southeast and are repeated by faulting, and a southeastern block forming the Big Butt range, in which the Ocoee series and a small part of the Chilhowee group are folded into a syncline. These two blocks can apparently be traced into the blocks in the Buffalo Mountain sheet near Bumpus Cove. Hence the Del Rio sheet probably lies structurally lower than any part of the Buffalo Mountain sheet, and it may not be represented at all in northeast Tennessee.

The curve of the Hot Springs fault is mirrored, across the structural saddle northwest of the window, by some minor faults within the Del Rio sheet and to a certain extent by the Brushy Mountain fault, which in turn forms the southwest side of the window. In position the sheet above this fault corresponds to the Buffalo Mountain sheet across the window, but it contains large areas of basement rocks beside the lower part of the Ocoee series and may be structurally higher. A mylonite zone in the southeast part of the sheet marks the Meadow Fork fault. The present map shows the Brushy Mountain fault splitting southwestward, both branches dying out in the Snowbird formation farther south and southwest (Ashe., Mt. G.); this interpretation is based on reconnaissance only and will presumably be changed when detailed work is done.

The highest thrust sheet recognized in the area is the one above the Rector Branch fault, on the south side of the Hot Springs window. The fault has brought forward chiefly basement rocks, though some slices of the basal beds of the Ocoee series are present between its branches east of the window. To the northeast it probably continues into the Devil Fork fault but the connection has not been traced.

Faulted thrust sheets of the Great Smoky Mountains.-The welt of basement rocks that extends from Virginia to the French Broad River, partly in Tennessee but mainly in North Carolina, appears to continue only a few miles on to the southwest, fraying out in a group of short tongues that may be thrust slices in Haywood County, N. C., near the Pigeon River. From here southwest, at least as far as the Georgia line, the Unaka Mountains consist of the Ocoee series, complexly faulted and carried forward on the low-angle Great Smoky thrust fault. Recently much of the Great Smoky Mountains, especially that part in Sevier County, has been mapped by a party of the U. S. Geological Survey and the Tennessee Division of Geology under the direction of Philip B. King, and their work has provided a new insight into the structure of the area. Preliminary results have been published by King, (1949b, figs. 7, 9); the present account is based also on personal discussions with King, Hadley, and others of the party.

At the outer edge of the mountains, the Chilhowee group is preserved in synclines in three areas: English Mountain in Cocke County (Mt. G.), Chilhowee Mountain in Sevier and Blount Counties (Knox., Loud.), and Starr and Bean Mountains in Monroe and Polk Counties (Mur., Cleve.). These bodies of Chilhowee rocks have generally been thought to be separated from the Ocoee series to the southwest by thrust faults and have even been interpreted as klippen; the Miller Cove fault separates Chilhowee Mountain from the main mass of the Ocoee series but even here the Chilhowee group also rests on the Ocoee northwest of the fault, and in the other two areas there is no evidence of such a fault. The Shady dolomite and the Rome formation occur beside English and Chilhowee Mountains; in Starr Mountain the Shady is represented only by residual clay and jasperoid.

Southeast of these synclines is a wide belt of the generally fine-grained detrital rocks that form the upper part of the Ocoee series. In Sevier County the belt is split lengthwise by several high-angle thrust faults (Knox., Mt. G.); slice by slice to the southeast older rocks appear and the grade of metamorphism rises, the argillaceous rocks becoming slate and even phyllite. Similar faults are undoubtedly present farther southwest as well, and those marked by topographic lineaments like the lineaments along known faults in Sevier County are shown on the present map. In Blount County and the western part of Sevier County (Knox.), half a dozen windows of various sizes expose the practically unmetamorphosed Sevier shale and the upper part of the Knox group beneath the Great Smoky fault. Structurally the rocks in the windows probably belong to the belt of folds and domes which here forms the southeast side of the Valley; the central parts of the larger windows seem to be structurally simple, but the margins show considerable imbricate faulting.

In eastern Sevier and western Cocke Counties the belt of fine-grained rocks is bounded on the south by the relatively low-angle Greenbrier fault, southeast of which the coarse-grained detrital rocks of the lower part of the Ocoee series form the main range of the Great Smoky Mountains (Mt. G., Knox.). Similar coarse grained rocks also appear northwest of the trace of the Greenbrier fault in Webb Mountain (Mt. G.), Cove Mountain (Knox.), an area just west along the Little River (Knox.), and Hannah Mountain west of Cades Cove (Knox.). King (1949b, figs. 7, 8, 9) first interpreted Webb and Cove Mountain as anticlines projecting through the overlying fine-grained rocks, but Ferguson (ms. a.) has shown that the area along the Little River is a klippe, the coarse-grained rocks lying over the fine-grained, and King now believes that the other masses are also klippen, formed not by folding but by faulting of preexisting low-angle faults. On this view the Cove Mountain mass is an outlier of the sheet overlying the low-angle Greenbrier thrust fault, preserved on the downthrown northwest side of the high-angle Gatlinburg thrust fault; the same structure in miniature is repeated several times on the north and east sides of Cove Mountain. Indeed the Gatlinburg fault itself is cut by later faults. On the present map this interpretation has been adopted for Cove Mountain, where detailed work has located the faults, but not for Webb and Hannah Mountains, where in the absence of accurate information the true position of the presumed faults is not known.

Southwest of Gatlinburg (Knox.) the Gatlinburg fault intersects the Greenbrier fault, and farther southwest it forms the boundary between the dominantly fine-grained rocks of the foothills to the northwest and the dominantly coarse-grained rocks of the main range to the southeast. The Gatlinburg fault can be traced by a topographic lineament to a point 3 miles northeast of Tellico Plains, Monroe County (Mur.), where it merges with the Great Smoky fault, but the Sylco Creek fault farther southwest (Mur., Cleve.) may be its continuation. In eastern Monroe County, however, the lithologic contact diverges from the fault and takes an independent course southwestward along the front of the higher mountains. The nature of this part of the contact is unknown (see pp. 32-33).

In the block southeast of the Gatlinburg and Greenbrier faults are several cross faults, all apparently right-handed; notable for its topographic expression is the Oconaluftee fault (Knox., Mt. G.), traceable for some miles across the crest of the mountains into North Carolina. In this block also metamorphism of middle grade first appears. Metadiorite sills occur near the crest of the range, and bodies of granite (post-Ocoee in age) crop out farther southeast.

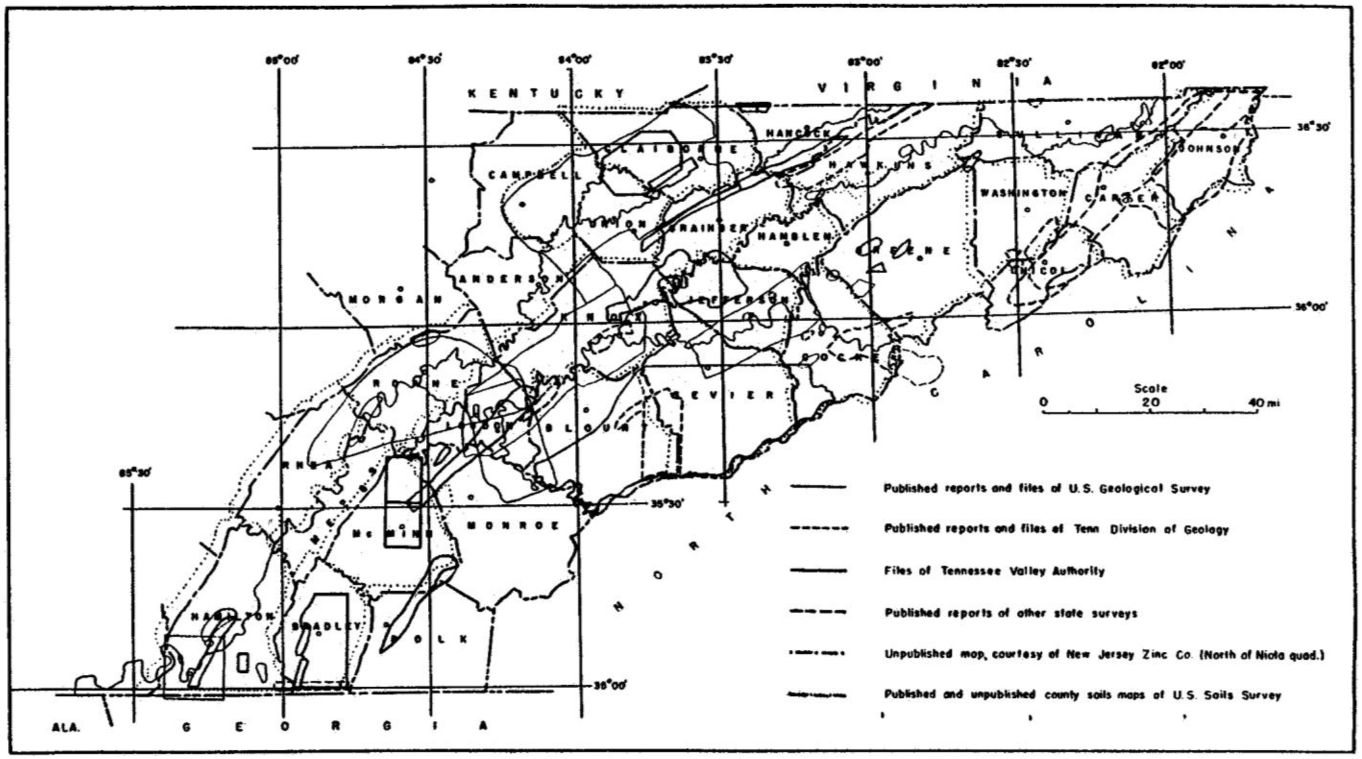


FIGURE 6. Index map of source materials (other than geologic folios of the U. S. Geological Survey) used in compiling Geologic map of East Tennessee.

SOURCE MATERIALS AND OUTSTANDING FUTURE PROJECTS

(See fig. 6)

Plate 1, Briceville.-Parts of plate 1 are covered by unpublished maps prepared for the Geologic Branch of the Tennessee Valley Authority: a map of the Norris Reservoir basin by James S. Cullison and others covers the part northeast of Lake City and Norris, and a map of the Fort Loudon Reservoir basin by Chilton E. Prouty covers the part southeast of the Beaver Valley fault. Joseph W. Lessig,, Joseph B. Cathey, Jr., Hugh M. MacMillan, and Malcolm W. Kemp, graduate students at the University of Tennessee, kindly gave the compiler information on certain critical localities in the Norris and Lake City 7 1/2-minute quadrangles. Unpublished soils maps were available only for the Norris Reservoir basin and Knox County. In general the geology was compiled from the Briceville folio (Keith, 1896c), but on the basis of his own reconnaissance the compiler has introduced some further subdivision and some changes, notably along the Cumberland Escarpment. Regrettably it was not possible to obtain enough information in Elk Valley (lying in the north part of plate 1) to warrant including that area in the compilation.

See projects 1 to 8 in list below (p. 158).

Plate 2, Maynardville.-Much of plate 2 is covered by recent detailed maps. The Mascot-Jefferson City zinc district in the southeastern part has been mapped by Josiah Bridge (1945), and the Powell River and Straight Creek zinc districts in the northern part, by the compiler (Brokaw, ms.). The compiler has also mapped the Chickamauga and Moccasin formations between Copper Ridge and Clinch Mountain from Luttrell northeast. John M. Cattermole is mapping the Fountain City and John Sevier 7 1/2-minute quadrangles as part of a study of the Knoxville metropolitan area, and Robert A. Laurence is mapping the Big Ridge Park 7 1/2-minute quadrangle; their early results were available to the compiler. The unpublished map of the Norris Reservoir basin, prepared for the Geologic Branch of the Tennessee Valley Authority by James S. Cullison and others, covers about the north half of the plate, and maps by Chilton E. Prouty and John M. Kellberg, cover part of the southwest quarter. A dam-site report by Robert A. Laurence, also for the TVA, covers a small area on the Holston River west of New Market. With the help of the Maynardville folio (Keith, 1901) and of soils maps covering, virtually the entire area, most of the rest of the plate was easily filled in by extrapolation from areas of detailed mapping. The most significant areas for which information was insufficient are the Powell Mountain southwest of Cumberland Gap village, the area south and southwest of Maynardville, and the area east of Strawberry Plains; these were completed by road traverses and a few foot traverses, but the present mapping is by no means final.

See projects 7 and 9 to 16a in list below (pp. 158-159).

Plate 3, Morristown.-Several patches within plate 3 have been mapped in detail. Bridge's map of the Mascot-Jefferson City zinc district (1945) extends a few miles east and southeast from Jefferson City, and Bridge has provided additional information in this general area. C. R. L. Oder has mapped the belt of the Knox group passing through Morristown and Russellville, but his mapping was not available to the compiler; when Oder's map and report are published they will supersede the present map. Ralph L. Miller and associates have mapped much of Lee County, Va., and a small part of Hancock County, Tenn. (Miller and Fuller, 1947; in press; Miller and Brosge’, 1950). As a result of the U. S. Geological Survey's zinc studies during the war (Brokaw, ms.), a map by Thomas N. Walthier of the vicinity of the Felknor lead mine south of White Pine, Jefferson County (prepared for the Tennessee Division of Geology), a map by John C. Dunlap of the west end of the Mosheim anticline, Greene County (along the east edge of the plate), and a map by the compiler of the belt between the Copper Creek fault and Clinch Mountain were available. The area between Clinch Mountain and the Saltville fault is being mapped by John E. Sanders for the Tennessee Division of Geology, and he has kindly permitted the compiler to use his mapping through 1950 (chiefly from Mooresburg northeastward). Maps in the files of the Geologic Branch of the Tennessee Valley Authority also cover several areas. The Norris Reservoir basin map by James S. Cullison and others includes a small area alone, Clinch River, in the northwestern part of the plate; a smaller-scale map of the Douglas Reservoir basin by Helmuth Wedow, Jr., shows the upper contact of the Knox group from Dandridge to the Nolichucky River; and dam-site maps, mostly by R. A. Laurence and P. W. Mattocks, cover small areas on the Holston River near Mooresburg, on the Nolichucky where it crosses the two anticlines exposing the

Knox group, and on the French Broad at Dandridge. Soils maps have been published for Jefferson, Hamblen, Grainger, and Claiborne Counties, and unpublished maps of Cocke and Greene Counties and of that part of Hawkins County close to the Cherokee Reservoir were available. From these materials most of the area was readily compiled, but the belt between Powell Mountain and the Clinch River and the belt next southeast of the Dumplin Valley fault required considerable reconnaissance.

See projects 15 to 21 and 24 in list below (pp. 159-160).

Plate 4, Greeneville.-Only small scattered patches within plate 4 have been recently mapped. For the U. S. Geological Survey's zinc studies the compiler mapped an area around the Fall Branch mine, John C. Dunlap and the compiler mapped the Mosheim dome, and Dunlap mapped the northeast end of the Hartman dome (31/2 miles south of Mosheim) and the imbricated area north and northwest of Greeneville (Brokaw, ms.). Manganese studies sponsored by the Tennessee Division of Geology and the U. S. Geological Survey led to mapping of Bumpus Cove at the east edge of the plate (Rodgers, 1948) and of the area south of the Meadow Creek Mountain fault at the south edge (Ferguson and Jewell, 1951). John E. Sanders is mapping the area between Clinch Mountain and the Saltville fault for the State, and kindly made his results through 1950 available to the compiler. The mapping in a small area near South Indian Creek at the east edge of the plate comes from the work of E. J. Lowry (ms.), also for the State. TVA dam site studies cover a small area on the Nolichucky River at the west edge of the plate (by R. A. Laurence and P. W. Mattocks) and on the Holston River at Surgoinsville (by B. D. Moneymaker and L. F. Grant). Elsewhere the folios (Campbell, 1894a, Est. f.; Keith, 1905a, Greene. f.), soils maps (unpublished, none available for Hawkins, Hancock, and Unicoi Counties), and the very expressive topographic maps were used, but the geology is based largely on information from reconnaissance traverses by the compiler, which were especially numerous in the area southeast of the Pulaski fault where the folio interpretation is invalidated by errors in stratigraphy. On his reconnaissance trips in the mountains shown in the southeastern part of the plate, the compiler was accompanied by Herman W. Ferguson, whose knowledge of the mountain rocks was helpful in reaching the tentative interpretation shown.

See projects 17, 20 to 27, and 34 to 35 in list below (pp. 159-161).

Plate 5, Roan Mountain.-The southeast half of plate 5 is almost entirely covered by recent mapping, published or to be published by the Tennessee Division of Geology (King and others, 1944; Rodgers, 1948; Ordway, ms.; Lowry, ms.; Ferguson, ms. b). For the rest, however, virtually nothing was available, except Averitt's map of the area north of the Saltville fault north of Arcadia (Averitt, 1941) and TVA dam-site reports: on the South Holston dam and saddle dam by Leland F. Grant and John M. Kellberg, and on a site about 5 miles downstream by H. N. Eaton and C. B. McGavock; the last was especially valuable because it provided critical information on the Cross Mountain cross fault. The geology was accordingly compiled from the folios (Campbell, 1899, Bris. f.; Keith, 1907b, Roan M. f.) and the unpublished soils maps (available except for Unicoi County), and from a number of reconnaissance traverses. The present map differs from earlier) maps mainly in showing the Pulaski and associated faults as continuous and in recognizing the many right-handed cross faults, especially those grouped around the Cross Mountain fault (some of them first mapped by King and others, 1944, see fig. 2). The complex area where these groups of faults intersect is probably the least accurately portrayed.

See projects 22, 28 to 31, and 33 to 34 in list below (pp. 159-161).

Plate 6, Cranberry.-All parts of plate 6 within Tennessee, except the crystalline complex to the southeast and the northwest corner northwest of the Holston Mountain fault, are covered by recent maps published or to be published by the Tennessee Division of Geology (King and others, 1944; Ferguson, ms. b). The northwest corner was compiled with the help of Butts' map of adjacent Virginia (1933), the soils maps of Washington County, Va., and Sullivan County, Tenn. (the latter unpublished), and field notes by Philip B. King.

See projects 32 and 58 in list below (pp. 160, 162).

Plate 7, Kingston.-Much of plate 7 is covered by the reconnaissance map of the Watts Bar Reservoir basin prepared for the Geologic Branch of the TVA by Portland P. Fox, and detailed maps from its files were available for the Watts Bar dam site and the Euchee iron range 4 to 8 miles northeast by Portland P. Fox and Leland F. Grant, and for the Harriman iron ranges by Helmuth Wedow, Jr. Other detailed maps used were a map of the Niota 7 1/2-minute quadrangle, in the southeast comer, by the compiler (Rodgers, 1953a), and a map of an area just to the north by E. P. Kaiser, permission to use which was kindly granted by the New Jersey Zinc Exploration Company. Soils maps were available for all parts of the plate except Loudon and Monroe Counties (the

McMinn County map is unpublished), but the Meigs County map is not of modern caliber. The geology was compiled from these sources and from the Kingston folio (Hayes, 1894b), by the use of topographic expression and by reconnaissance traverses. The principal innovation has been to show the Postoak and Rhea Springs areas as windows and the patches of Pennsylvanian rocks at the foot of the Cumberland Escarpment as rootless fault outliers (see p. 129).

See projects 37 to 39 in list below (p. 161).

Plate 8, Loudon.-Much of plate 8 is covered by reconnaissance reservoir basin maps prepared for the Geologic Branch of the Tennessee Valley Authority: for the Watts Bar Reservoir by Portland P. Fox, and for the Fort Loudon and Fort Loudon Extension Reservoirs by Chilton E. Prouty. Detailed maps were available only for limited areas, however - for the Friendsville marble belt, by K. K. Kimball and Charles Butts (Gordon and others, 1924), for part of the area in the northwest corner, northwest of the Chattanooga fault, by Helmuth Wedow, Jr. (files of the Geologic Branch of the TVA), for the belt of the Knox group southeast of the Knoxville fault, by John C. Dunlap (Brokaw, ms.), and for a small area northwest of that fault near Sweetwater, by the compiler. Soils maps were available for Roane County, Knox County, and McMinn County and a small area in Monroe County in the Chestuee Creek drainage basin; only the Roane County map is published. The geology was compiled from these sources and the Loudon folio (Keith, 1896a), supplemented by a number of reconnaissance traverses which permitted greater subdivision and local revision of contacts. In particular, the mapping in the belt of the Conasauga group in the southern part of the plate has been somewhat revised.

See projects 39 to 44, 55, and 57 in list below (pp. 161-162).

Plate 9, Knoxville.-The mountainous southern half of plate 9 is being mapped by the Great Smoky Mountain party of the U. S. Geological Survey and the Tennessee Division of Geology, and detailed maps by Philip B. King, Jarvis B. Hadley, Herman W. Ferguson, Robert B. Neuman, George D. Swingle, and Charles H. Tucker were available for virtually all that part of the plate southeast of the northwest edge of the main belt of Sevier shale and northeast of a line from Blockhouse to Thunderhead Mountain. The rest of the mountain area was compiled by Philip B. King and the compiler on the basis of scattered reconnaissance traverses. For the northwestern part of the plate northwest of the Dumplin Valley fault, a map of the Fort Loudon Reservoir basin prepared by Chilton E. Prouty for the Geologic Branch of the TVA and a map of the marble belt south of Knoxville, by K. K. Kimball and A. C. MacFarlan (Gordon and others, 1924), were available. The Geologic Branch of the TVA also supplied information on the Douglas dam site and vicinity by Robert A. Laurence and by Helmuth Wedow, Jr., and on a dam site about 7 miles downstream by Laurence and Benjamin Gildersleeve. The rest of the quadrangle was compiled from the Knoxville folio (Keith, 1895) and unpublished soils maps of Knox and Sevier Counties, and from information obtained by reconnaissance. The only important changes in interpretation in the northwestern part of the plate are along the Dumplin Valley fault and in the Inskip area on the northwest outskirts of Knoxville.

See projects 15, 44, and 57 in list below (pp. 159, 161, 162).

Plate 10, Mount Guyot.-Most of the mountainous area shown on plate 10 has been or will soon be mapped in detail. The mountains along the French Broad River on the northeast have been mapped by Herman W. Ferguson (Ferguson and Jewell, 1951). The area underlain by the Ocoee series southwest of the Pigeon River is being mapped by Philip B. King, Jarvis B. Hadley, and Robert B. Neuman of the U. S. Geological Survey, and the compiler had access to their results through 1950, which were especially complete in the higher mountains. The intervening area was compiled on the basis of reconnaissance traverses in which the compiler was accompanied by King, Ferguson, and Hadley; it will be mapped by Ferguson whose results will supersede the present map. For the rest of the plate information was more meager. The compiler had access to incomplete maps prepared by Keith for a Mt. Guyot folio (assembled by P. B. King) and to soils maps of the area (unpublished except for Jefferson County). For the imbricated area near Newport he drew on field notes by Herman W. Ferguson, a TVA dam-site report by Benjamin Gildersleeve and Charles E. Hunter, the soils maps, and the results of a reconnaissance traverse. The upper contact of the Knox group in the northwestern part of the plate was obtained from a map of the Douglas Reservoir basin by Helmuth Wedow, Jr., from field notes by Robert B. Neuman, and from the soils maps and a traverse or two.

See projects 24, 45, and 46 (pp. 160-161).

Plate 11, Asheville.-Detailed maps by Ferguson (Ferguson and Jewell, 1951) and Oriel (1950) cover the heart of the area mapped on plate 11, and the rest was compiled from reconnaissance traverses by Philip B. King, Herman W. Ferguson, and the compiler, at times accompanied by Jarvis B. Hadley. Further detailed mapping will doubtless change the present interpretation in the outlying areas.

See projects 24, 35, and 36 (pp. 160-161).

Plate 12, Chattanooga.-Only a few patches on plate 12 are covered by detailed maps. As part of the bauxite studies of the U. S. Geological Survey, John C. Dunlap and James S. Cullison mapped the older formations of the Knox group along the Missionary Ridge fault and in a small area southwest of Ooltewah. Benjamin Gildersleeve has mapped the vicinity of the baukite mine west of Apison for the Regional Minerals section of the TVA and kindly made his map available to the compiler. Maps of the Chickamauga dam site, of the belt of rocks younger than the Knox group to the north, and of the Chattanooga area, mostly by Portland P. Fox, were available in the files of the Geologic Branch of the TVA. Soils maps were available for the whole area, that for Bradley County being unpublished. The map was compiled from these sources and from the folios (Hayes, 1894a, Ring. f.; 1894c, Chatt. f.; 1895b, Pike. f.), supplemented by reconnaissance traverses, some of them in company with Paris B. Stockdale, who, with Harry J. Klepser and students of the University of Tennessee summer geology camp, is mapping the area around Dayton and who kindly made available his information on the area from there to Chattanooga. The principal innovations on the present map concern the course and continuity of the Chattanooga and Kingston faults.

See projects 47 to 51 in list below (pp. 161-162).

Plate 13, Cleveland.-Several areas within plate 13 have recently been mapped for the U. S. Geological Survey. The compiler has mapped in detail the Athens 7 1/2-minute quadrangle in the northeast corner of the plate (Rodgers, 1953b) and the belt of rocks younger than the Knox group northwest of the Knoxville fault south of Cleveland, and has made a reconnaissance map of the Chilhowee group of Starr and Bean Mountains. John C. Dunlap has mapped the belt of the Knox group northwest of the Saltville fault at Cleveland and southwest past the Hardwick lead mine (Brokaw, ms.). George D. Swingle is mapping the area shown in the southwest quarter of the plate and kindly made available his results through 1950. In addition, Arthur C. Munyan (1951) has mapped the Dalton 15-minute quadrangle, including the west half of the southern margin of this plate, for the Georgia Geological Survey, and he and Capt. Garland Peyton, State Geologist of Georgia, kindly permitted the compiler to use Munyan's map in advance of publication. For other areas the geology was compiled from the Cleveland folio (Hayes, 1895a), from soils maps, published for Hamilton, Rhea, and Meigs Counties, unpublished for McMinn and Bradley Counties, and from information obtained on traverses through the area, some of them in company with George D. Swingle. The principal changes from older maps are in the belt immediately northwest of the Great Smoky fault and in the area underlain by the Ocoee series to the southeast; the fault shown by Hayes (1895a, Cleve. f.) southeast of Starr Mountain and the window shown on the Geologic Map of the United States along Sheeds Creek have been deleted as incompatible with the field evidence, but the Sheeds Creek-Sylco Creek lineament, which separates rocks of somewhat different lithology, is shown as a continuous fault.

See projects 49, 52 to 54, and 57 (p. 162).

Plate 14, Murphy.-Aside from incomplete maps prepared by Hayes and Keith for a Murphy folio (assembled by P. B. King), the Ellijay folio (LaForge and Phalen, 1913), published maps of the Ducktown district (Emmons and Laney, 1926; Simmons, 1950), and his own map of Starr Mountain, no geologic maps of the Tennessee portion of plate 14 were available to the compiler. Unpublished soils maps cover only McMinn County and the small part of Monroe County drained by Chestuee Creek. The geology was compiled almost entirely from traverses by the compiler, some of them in company with Herman W. Ferguson, and from field notes by Philip B. King, and unpublished cross sections of power tunnels along the Hiwassee and Ocoee Rivers, prepared for the Geologic Branch of the TVA by John M. Kellberg and Leland F. Grant. Particular attention was paid to the belt between the Bullet Mountain and Great Smoky faults. The mapping in the Ocoee series is of necessity highly generalized.

See projects 42 and 54 to 57 in list below (pp. 161-162).

List of outstanding projects for future geologic mapping in East Tennessee (see fig. 7).-The following list of projects by no means exhausts the areas in East Tennessee where future mapping might be profitable. Further subdivision of the larger units, such as the Conasauga and Knox groups, should be feasible in many areas not here mentioned, and in areas not yet mapped in detail further work should uncover additional faults and folds, even in belts that are subdivided on the present map. The projects in the list below were chosen mainly because detailed maps of these areas

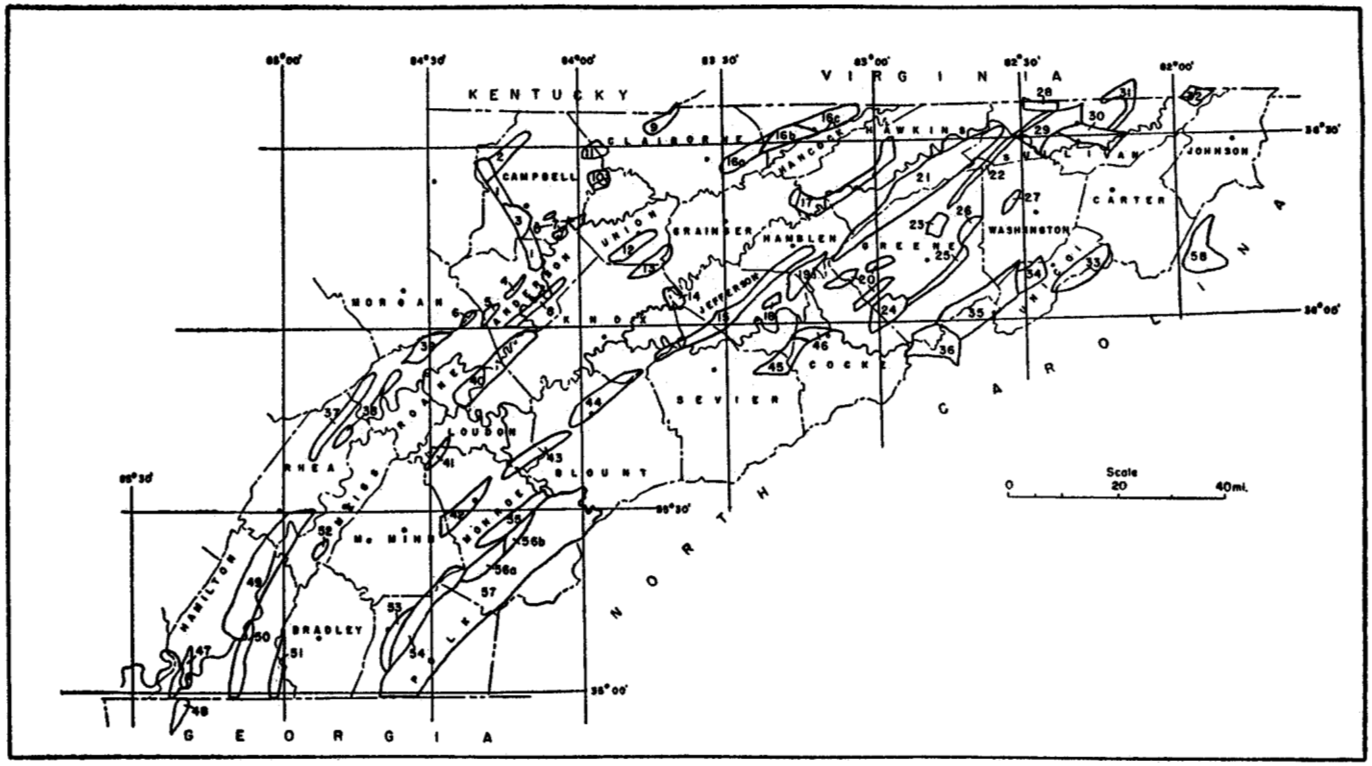


FIGURE 7. Index map of projects for future geologic mapping in East Tennessee.

should provide structural information of more than merely local importance, such as information on the interrelation of major structural features or on the mechanics of the deformation. The compiler hopes that those who undertake these projects will be helped by the premature guesses he has made for each area, but warns against being unduly influenced, by these guesses, either to uncritical acceptance or to uncritical opposition.

1. Jacksboro fault (Brice.). The mechanics of the Jacksboro fault is of great interest, and a thorough study might reveal much about it. Perhaps, however, the project should be broken into several projects (2 to 5 below). The part of the fault on the Lake City 7 1/2-minute quadrangle has recently been mapped by Joseph B. Cathey, Jr.

2. North end of Jacksboro fault and Elk Valley (Brice.). The north end of the Jacksboro fault frays out into a wide belt of faulting that extends northeastward for 7 or 8 miles before narrowing to a single Pine Mountain fault.

3. Area around Caryville (Brice.). Here the monocline along the Cumberland Escarpment approaches the Jacksboro fault.

4. Southern end of Dutch Valley (Brice.).

5. Area east of Oliver Springs (Brice.). Here the Jacksboro fault appears to split into the Kingston and Chattanooga faults.

6. Area west of Oliver Springs (Brice.). This area may include the east end of the Emory River line of disturbance.

7. Antictinal uplifts of Nolichucky and Maynardville formations on Powell River anticline (Brice., Mayn.).

8. Belt of slices along Hunter Valley and Whiteoak Mountain faults (Brice.). In this belt the Wallen Valley fault merges with the Hunter Valley fault to form the Whitcoak Mountain fault. The rocks shown doubtfully as Rome formation may be the Apison member of the Rome, but the structure may well be much more complex than shown.

9. Powell Mountain and vicinity (southwest of Cumberland Gap) (Mayn.). The area is traversed by a northwest-dipping thrust fault.

10. Davis Creek dome on Powell River anticline (Mayn.).

11. Offsets in Cumberland Escarpment near Well Springs (Mayn.). These offsets seem to be related to the Davis Creek and Lead Mine Bend domes to the south and to the Tackett Creek flexure to the north.

12. Belt of Rome formation south and southwest of Maynardville, and belt of Knox group in Buffalo Ridge (Mayn.). The area seems to contain folded thrust faults, but because of the extreme imbrication of the Rome formation it will be difficult to map.

13. Southwest end of Clinch Mountain and belt of folded Ordovician rocks to west (Mayn.). Here the Beaver Valley fault dies out and the Saltville fault almost doubles in throw.

14. Imbricated area cast of Strawberry Plains (Mayn.).

15. Belt of faulting, along Dumplin Valley fault (Knox., Mayn., Morr.).

16. Belt between Powell Mountain on northwest and Caney Valley and Clinch River on southeast (Mayn., Morr.). It might be subdivided into three parts as follows:

> 16a. Howard Quarter area. West ends of Powell Mountain and Newman Ridge in relation to Hunter Valley fault. Anticline south of Howard Quarter.
>
> 16b. Evanston area. Synclinal basin in Rome and younger formations bounded by thrust fault. Includes Evanston zinc district.
>
> 16c. Sneedville-Kyles Ford area. Faulted anticline in Devonian and Mississippian rocks. Junction of Hunter Valley and Clinchport faults in area of imbrication.

17. Area south of Saltville fault from Mooresburg to Rogersville and beyond (Morr., Greene.). An area of close imbrication surrounds a reentrant in the trace of the Saltville fault. The Rocky Valley fault may enter the southwest end and the Carter Valley fault the northeast end; their possible relation needs investigation.

18. Inliers of rocks older than the Knox group northeast of Dandridge (Morr.). These inliers were first discovered by study of the Jefferson County soil map; no detailed geologic work has been done.

19. Anticlines in Knox group around White Pine (Morr.).

20. Anticlines in Knox group near Nolichucky River (Morr., Greene.).

21. Bays Mountain synclinorium (Greene., Morr.). The folding here appears to be fairly simple and unbroken by faults.

22. Belt between the Pulaski and The Cliffs faults (Greene., Roan M.). This belt is known to be intensely imbricated, and it may not yield results commensurate with the effort necessary to decipher it.

23. Babb Knobs area, southeast of Baileyton (Greene.). The compiler has interpreted this area as a flap, almost a klippe, above the Pulaski fault, but other interpretations are possible and should be tested.

24. Pulaski and associated faults southwest of Nolichucky River (Greene., Morr., Mt. G., Ashe.). The S-shaped curve of the Pulaski fault shown on the present map is based on scattered observations and needs verification. The belts of Nolichucky shale should also be traced northeast past Greeneville.

25. Dunham Ridge fault and associated anticline along Nolichucky River (Greene.). This belt includes the type locality of the Nolichucky shale.

26. Quaker Knobs, northwest of Chuckey (Greene.). The relation of the Nolichucky shale forming the knobs to the dolomite to the southeast and to the Dunham Ridge fault is quite uncertain.

27. Cruickshank Knob anticline, north of Leesburg (Greene.). The anticline shows the normal Appalachian asymmetry but its southeast flank is cut by a fault upthrown on the northwest.

28. Arcadia area (Roan M.). Belt of northwest strikes. The cross fault mapped at Timbertree Branch needs verification.

29. Belt southeast of Pulaski fault from the South Fork of the Holston River northeast past Blountville (Roan M.). In this area the Cross Mountain and associated cross faults intersect the Pulaski family of thrust faults; also the faults of the Pulaski family converge and the Dunham Ridge fault merges with the Pulaski fault.

30. Area southeast of Blountville (Roan M.). Here the Cross Mountain and associated faults cross and offset several folds.

31. Bristol area (Roan M.). The Bristol fault appears to be an arcuate thrust fault, dipping mainly west in Tennessee. To the southwest it may end against the Cross Mountain fault; to the northwest it may swing, around Bristol and merge with the Spurgeon fault.

32. Denton Valley, on State line just northwest of Holston Mountain fault (Cran.). The block between the cross faults is not a horst but a block shoved sideways if the intersection of the faults with the Holston Valley fault has been correctly interpreted. This interpretation needs confirmation.

33. Limestone Cove (Roan M.). This is perhaps the deepest window in the mountains of northeast Tennessee. The Unaka Mountain fault needs to be traced northeast through the crystalline complex. Perhaps the hematitic magnetite deposits recorded by Bayley (1923, pp. 240-252) lie on or close to this fault.

34. Rich Mountain (Roan M., Greene.). This area contains the northeasternmost exposure of the Ocoee series on the highest thrust block in northeast Tennessee.

35. Big Butt range and foothills (Greene., Ashe.). Repeated faulting in foothill belt. Relation of Chilhowee group to Ocoee series and of Ocoee series to crystalline complex. Each of these points might make a separate project. The area is very difficult of access.

36. North side of Hot Springs window (Ashe.). The faults extending north and northeast from the window should be traced into the faults of the Big Butt area.

37. Outliers of Pennsylvanian rock from Rockwood to a point beyond Spring City (Kings.). The mode of emplacement of these outliers is not known (p. 129).

38. The Rhea Springs and Postoak windows (Kings.). That these are windows needs verification. Unfortunately, parts of both are now under the Watts Bar Reservoir.

39. Harriman corner (Kings., Loud.). The Harriman corner is one of the most complex small areas in East Tennessee. It is bounded and cut by cross faults and apparently includes a fault of large displacement upthrown on the northwest, whose mechanics needs study. Its relation to the Emory River line also needs investigation.

40. Belt of Knox group northwest of Beaver Valley fault (Loud.).

41. Faulted area along Saltville fault northwest of Sweetwater (Loud.). This area shows similarities to the faulted area on the Knoxville fault close to Sweetwater.

42. Madisonville area (Loud., Mur.). Fault blocks of the Knox and Conasauga groups.

43. Greenback anticline (Loud.).

44. Southwest end of Bays Mountain and Maryville area (Knox., Loud.). Imbricate faulting along the Dumplin Valley fault.

45. English Mountain (Mt. G.). The structural relation of the Chilhowee group in the mountain to the Ocoee series to the south needs to be determined. Unfortunately, the inhabitants of this area do not encourage strangers.

46. Newport area (Mt. G.). Small-scale imbrication in the Knox group and overlying shale.

47. Faults on flanks of Lookout Mountain syncline (Chatt.).

48. Chattanooga Valley south of State line (Chatt.-Ring.). Here apparently a northwest-dipping thrust fault cuts diagonally across the block between the Chattanooga and Missionary Ridge faults.

49. Belt of Knox group southeast of Chattanooga fault (Chatt., Cleve.). At the south end the relation of the Missionary Ridge fault to the Kingston fault is not clear.

50. Tyner Valley belt of Conasauga group and extensions (Chatt.). The continuity of the Kingston fault through this area needs to be verified.

51. Southeast limb of Whiteoak syncline near Apison (Chatt.). This limb is complexly faulted and folded northwest of the Whiteoak Mountain fault.

52. Mt. Carmel Ridge north of Hiwassee River (Cleve.). This is the largest of several horses of the Knox group along the Whiteoak Mountain fault.

53. Foothill belt east of Benton (Cleve.). The faulted belt on the face of Bean Mountain includes an unusual outcrop of Shady dolomite within the main part of the Valley, and also a dome of the Knox group.

54. Starr and Bean Mountains (Cleve., Mur.). Apparently the Chilhowee group forms a simple syncline broken by only one fault and shows an unbroken stratigraphic succession down to the Ocoee series. A disconformity between the two units should be looked for here.

55. Laurel Mountain-Butler Mountain area (Mur., Loud.). Syncline containing the southeasternmost belts of the Bays, Chattanooga, and Grainger formations.

56. Tellico Plains (a) and Guide Mountain (b) areas (Mur.). Perhaps this should be considered as two projects. Guide, Bullet, and Groundhog Mountains are shown on the present map as tightly folded anticlines rather than klippen; the two alternatives should be tested. The stratigraphy of the Shady dolomite in this area may be unusual.

57. Ocoee series southwest of Little Tennessee River (Loud., Knox., Mur., Cleve.). Several projects could be started here, but all will depend on completion of the mapping of the Great Smoky Mountain Park area to the northeast. The Sylco Creek fault needs verification, and the nature of the contact between the fine-grained and the coarse-grained parts of the Ocoee must be determined.

58. Snow Mountain fault and connections (Cran.). Here a fault appears to extend from the southeast side of an arm of the Mountain City window to the northwest side of the Grandfather Mountain window.

REFERENCES CITED

ADAMS, G. I., 1923, The formation of bauxite in sink holes: Econ. Geology, vol. 18, pp. 410-412.

ASHLEY, G. H., and GLENN, L. C., 1906, Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky: U. S. Geol. Survey Prof. Paper 49.

AVERITT, PAUL, 1941, The Early Grove gas field, Scott and Washington Counties, Virginia: Virginia Geol. Survey Bull. 56.

BASSLER, R. S., 1932, The stratigraphy of the Central Basin of Tennessee: Tennessee Div. Geology Bull. 38.

BAYLEY, W. S., 1923, The magnetic iron ores of East Tennessee and western North Carolina: Tennessee Div. Geology Bull. 29; North Carolina Geol. and Econ. Survey Bull. 32.

BENTALL, RAY, and COLLINS, J. B., 1945, Subsurface stratigraphy and structure of the pre-Trenton Ordovician and Upper Cambrian rocks in central Tennessee: Tennessee Div. Geology Oil and Gas Invs.,Prelim. Chart 4.

BRIDGE, JOSIAH, 1945, Geologic map and structure sections of the Mascot-Jefferson City zinc mining district, Tennessee: Tennessee Div. Geology.

----------, 1950, Bauxite deposits of the southeastern United States: Symposium on mineral resources of the southeastern United States, 1949 Proc., pp. 170-201, Univ. Tennessee Press, Knoxville.

----------, ms., The stratigraphy of the Mascot-Jefferson City zinc district, Tennessee: to be published by Tennessee Div. Geology.

BROKAW, A. L., ms., Geology of the East Tennessee zinc deposits: to be published by U. S. Geol. Survey.

BURCHARD, E. F., 1913, The red iron ores of East Tennessee: Tennessee Div. Geology Bull. 16.

BUTTS, CHARLES, 1910, U. S. Geol. Survey Geol. Atlas, Birmingham folio (no. 175).

----------, 1926, The Paleozoic rocks, *in* Geology of Alabama: Alabama Geol. Survey Spec. Rept. 14.

----------, 1927a, Oil and gas possibilities at Early Grove, Scott County, Virginia: Virginia Geol. Survey Bull. 27.

----------, 1927b, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28.

----------, 1933, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42.

----------, 1940, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52.

BUTTS, CHARLES, and GILDERSLEEVE:, BENJAMIN, 1948, Geology and mineral resources of the Paleozoic area in northwest Georgia: Georgia Geol. Survey Bull. 54.

CAMPBELL, M.R., 1893, Geology of the Big Stone Gap coal field of Virginia and Kentucky: U. S. Geol. Survey Bull. 111.

----------, 1894a, U. S. Geol. Survey Geol. Atlas, Estillville folio (no. 12).

----------, 1894b, Paleozoic overlaps in Montgomery and Pulaski Counties, Virginia: Geol. Soc. America Bull., vol. 5, pp. 171-190.

----------, 1897, U. S. Geol. Survey Geol. Atlas, Tazewell folio (no. 44).

----------, 1899, U. S. Geol. Survey Geol. Atlas, Bristol folio (no. 59).

CLOUD, P. E., JR., and BROWN, R. W., 1944, Early Cenozoic sediments in the Appalachian region: Geol. Soc. America Bull., vol. 55, p. 1466.

COOPER, B. N., 1942, Moccasin formation in southwestern Virginia: Geol. Soc. America Bull., vol. 53, pp. 1799-1800.

----------, 1944, Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60.

COOPER. B. N., and COOPER, G. A., 1946, Lower Middle Ordovician stratigraphy of the Shenandoah Valley, Virginia: Geol. Soc. America Bull., vol. 57, pp. 35-113.

COOPER, B. N., and PROUTY, C. E., 1943, Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, pp. 819-886.

CRAIG, L. C., ms., Final report on U. S. Bureau of Mines project in the Sweetwater Red Hills manganese district, Tennessee: files of U. S. Geol. Survey.

CRAWFORD, JOHNSON, 1945, Structural and stratigraphic control of zinc deposits in East Tennessee: Econ. Geology, vol. 40, pp. 408-415.

CURRIER, L. W., 1935, Zinc and lead region of southwestern Virginia: Virginia Geol. Survey Bull. 43.

DARTON, N. H., and TAFF, J. A., 1896, U. S. Geol. Survey Geol. Atlas, Piedmont folio (no. 28).

DECKER, C. E., 1952, Stratigraphic significance of graptolites of Athens shale: Am. Assoc. Petroleum Geologists Bull., vol. 36, pp. 1-145.

DUNLAP, J. C., and RODGERS, JOHN, 1945, Geologic map of the Mosheim anticline, Greene County, Tennessee: U. S. Geol. Survey Strategic Minerals Invs. Prelim. Map.

EBY, J. B. (with chapters by M. R. Campbell and G. W. Stose), 1923, The geology and mineral resources of Wise County and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24.

EMMONS, W. H., 1940, The principles of economic geology, 2d ed., McGraw-Hill Book Co., New York.

EMMONS, W. H., and LANEY, F. B., 1926, Geology and ore deposits of the Ducktown mining district, Tennessee: U. S. Geol. Survey Prof. Paper 139.

FERGUSON, H. W., ms. a., Geologic map of Walden Creek and Wear Cove quadrangles, Tennessee: files of Tennessee Div. Geology.

----------, ms. b., Geology of the Johnson County Cove, Tennessee: files of Tennessee Div. Geology.

FERGUSON, H. W., and JEWELL, W. B., 1951, Geology and barite deposits of the Del Rio district, Cocke County, Tennessee: Tennessee Div. Geology Bull. 57.

FOX, P. P., and GRANT, L. F., 1944, Ordovician bentonites in Tennessee and adjacent states: jour. Geology, vol. 52, pp. 319-332.

GEIGER, H. R., and KEITH, ARTHUR, 1891, The structure of the Blue Ridge near Harpers Ferry: Geol. Soc. America Bull., vol. 2, pp. 155-163.

GLENN, L. C., 1925, The northern Tennessee coal field: Tennessee Div. Geology Bull. 33-B.

GORDON, C. H., and others, 1924, Marble deposits of East Tennessee: Tennessee Div. Geology Bull. 28.

GRANT, L. F., and KELLBERG, J.M., ms., Middle Ordovician conglomerates in the southern Appalachian Valley: in preparation.

HALL, G. M., and AMICK, H. C., 1934, The section on the west side of Clinch Mountain, Tennessee: Tennessee Acad. Sci. Jour., vol. 9, pp. 157-168, 195-220.

----------, 1944, Igneous rock areas in the Norris region, Tennessee: jour. Geology, vol. 52, pp. 424-430.

HASS, W. H., 1947, The Chattanooga shale type area: Geol. Soc. America, vol. 58, p. 1189.

HAYES, C. W., 1891, The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, pp. 141-152.

----------, 1894a, U. S. Geol. Survey Geol. Atlas, Ringgold folio (no. 2).

----------, 1894b, U. S. Geol. Survey Geol. Atlas, Kingston folio (no. 4).

----------, 1894c, U. S. Geol. Survey Geol. Atlas, Chattanooga folio (no. 6).

----------, 1895a, U. S. Geol. Survey Geol. Atlas, Cleveland folio (no. 20).

----------, 1895b, U. S. Geol. Survey Geol. Atlas, Pikeville folio (no. 21).

HOWELL, B. F., and others, 1944, Correlation of the Cambrian formations of North America: Geol. Soc. America Bull., vol. 55, pp. 993-1003, chart.

JONAS, A. I., and STOSE, G. W., 1939, Age relation of the pre-Cambrian rocks in the Catoctin Mountain-Blue Ridge and Mount Rogers anticlinoria in Virginia: Am. Jour. Sci., vol. 237, pp. 575-593.

KAY, G. M., 1937, Stratigraphy of the Trenton group: Geol. Soc. America Bull., vol. 48, pp. 233-302.

KEITH, ARTHUR., 1892, Geology of Chilhowee Mountain in Tennessee: Philos. Soc. Washington Bull., vol. 12, pp. 71-88.

----------, 1895, U. S. Geol. Survey Geol. Atlas, Knoxville folio (no. 16).

----------, 1896a, U. S. Geol. Survey Geol. Atlas, Loudon folio (no. 25).

----------, 1896b, U. S. Geol. Survey Geol. Atlas, Morristown folio (no. 27).

----------, 1896c, U. S. Geol. Survey Geol. Atlas, Briceville folio (no. 33).

----------, 1901, U. S. Geol. Survey Geol. Atlas, Maynardville folio (no. 75).

----------, 1903, U. S. Geol. Survey Geol. Atlas, Cranberry folio (no. 90).

----------, 1904, U. S. Geol. Survey Geol. Atlas, Asheville folio (no. 116).

----------, 1905a, U. S. Geol. Survey Geol. Atlas, Greeneville folio (no. 118).

----------, 1905b, U. S. Geol. Survey Geol. Atlas, Mount Mitchell folio (no. 124).

----------, 1907a, U. S. Geol. Survey Geol. Atlas, Nantahala folio (no. 143).

----------, 1907b, U. S. Geol. Survey Geol. Atlas, Roan Mountain folia (no. 151).

KESLER, T. L., 1950, Geology and mineral deposits of the Cartersville district, Georgia: U. S. Geol. Survey Prof. Paper 224.

KING,, P. B., 1949a, The floor of the Shenandoah Valley: Am. Jour. Sci., vol. 247, pp. 73-93.

----------, 1949b, The base of the Cambrian in the southern Appalachians: Am. Jour. Sci., vol. 247, pp. 513-530, 622-645.

----------, 1950, Tectonic framework of southeastern United States: Am. Assoc. Petroleum Geologists Bull., vol. 34, pp. 635-671.

KING, P. B., FERGUSON, H. W., CRAIG, L. C., and RODGERS, JOHN, 1944, Geology and manganese deposits of northeastern Tennessee: Tennessee Div. Geology Bull. 52.

KING, P. B., and STUPKA, ARTHUR, 1950. The Great Smoky Mountains - their Geology and natural history: Sci. Monthly, vol. 71, pp. 31-43.

LAFORGE, LAURENCE, and PHALEN, W. C., 1913, U. S. Geol. Survey Geol. Atlas, Ellijay folio (no. 187).

LAURENCE, R. A., 1944, An early Ordovician sinkhole deposit of volcanic ash and fossiliferous sediments in East Tennessee: Jour. Geology, vol. 52, pp. 235-249.

LOWRY, E. J., ms., The southwest end of the Mountain City window, northeastern Tennessee: to be published by the Tennessee Div. of Geology.

MILLER, R. L., 1944, Geology and manganese deposits of the Glade Mountain district, Virginia: Virginia Geol. Survey Bull. 61.

MILLER, R. L., and BROSGE, W. P., 1950, Geology of the Jonesville district, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invs. Prelim. Map 104.

MILLER, R. L., and FULLER, J. O., 1947, Geologic and structure maps of the Rose Hill oil field, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invs. Prelim. Map 76.

----------, in press. Geology and oil resources of the Rose Hill district, Lee County, Virginia: Virginia Geol. Survey Bull. 71.

MONEYMAKER, B. C., LEONARD, G. K., and others, 1949, Geology and foundation treatment, Tennessee Valley Authority projects: Tennessee Valley Authority Tech. Rept. 22.

MUNYAN, A. C., 1951, Geology and mineral resources of the Dalton quadrangle, Georgia-Tennessee: Georgia Geol. Survey Bull. 57.

ODER, C. R. L., 1934, Preliminary subdivision of the Knox dolomite in East Tennessee: Jour. Geology, vol. 42, pp. 469-497.

ODER, C. R. L., and MILLER, H. W., 1945, Stratigraphy of the Mascot-Jefferson City zinc district: Am. Inst. Min. Met. Eng. Tech. Pub. 1818.

ORDWAY, R. J., rns., Geology and structure of the Buffalo Mountain-Cherokee Mountain area in northeastern Tennessee: to be published by Tennessee Div. Geology.

ORIEL, S. S., 1950, Geology and mineral resources of the Hot Springs window. Madison County, North Carolina: North Carolina Div. Mineral Resources Bull. 60.

PROUTY, C. E., 1948, Paleogeographic significance of Cambro-Ordovician sandstone of northeast Tennessee: Geol. Soc. America Bull., vol. 59, pp. 1344- 1345.

PROUTY, W. F., 1935, Silurian of eastern Tennessee: Elisha Mitchell Sci. Soc. Jour., vol. 51, pp. 219-220; Geol. Soc. America Proc. 1935, p. 97.

----------, 1941, Silurian of eastern Tennessee: Elisha Mitchell Sci. Soc. Jour., vol. 57, p. 209.

PROUTY, W. F., and DOUGLAS, J. G., 1934, Notes on the Silurian system of eastern Tennessee: Elisha Mitchell Sci. Soc. Jour., vol. 50, p. 51.

RICH, J. L., 1934, Mechanics of low-angle overthrust faulting as illustrated by Cumberland thrust block, Virginia, Kentucky, and Tennessee: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1584-1596.

RODGERS, JOHN, 1943, Geologic map of Copper Ridge district, Hawkins, Hancock, and Grainger Counties, Tennessee: U. S. Geol. Survey Strategic Minerals Invs. Prelim. Map.

----------, 1948, Geology and mineral deposits of Bumpus Cove, Unicoi and Washington Counties, Tennessee: Tennessee Div. Geology Bull. 54.

----------, 1950, Mechanics of Appalachian folding as illustrated by Sequatchie anticline, Tennessee and Alabama: Am. Assoc. Petroleum Geologists Bull., vol. 34, pp. 672-681.

----------, 1952, Absolute ages of radioactive minerals from the Appalachian region: Am. Jour. Sci., vol. 250, pp. 411-427.

----------, 1953a, U. S. Geol. Survey Geol. Quad. Maps, Niota quadrangle, Tennessee.

----------, 1953b, U. S. Geol. Survey Geol. Quad. Maps, Athens quadrangle, Tennessee.

RODGERS, JOHN, and KENT, D. F., 1948, Stratigraphic section at Lee Valley, Hawkins County, Tennessee: Tennessee Div. Geology Bull. 55.

SAFFORD, J. M., 1856, A geological reconnaissance of the state of Tennessee: State Geologist, 1st Bienn. Rept., Nashville.

----------, 1869, Geology of Tennessee, State of Tennessee, Nashville.

----------, 1892, The topography, geology, and water supply of Sewanee: Tennessee State Board of Health Bull., vol. 8, no. 6, pp. 89-98 (Nashville).

SAFFORD, J. M., and KILLEBREW, J. B., 1876, The elementary geology of Tennessee, Nashville.

----------, 1900. The elements of the geology of Tennessee, Nashville.

SECRIST, M. H., 1924, Zinc deposits of East Tennessee: Tennessee Div. Geology Bull. 31.

SIMMONS, W. W., 1950, Recent geological investigations in the Ducktown mining district, Tennessee: Symposium on mineral resources of the southeastern United States, 1949 Proc., pp. 67-71, map, Univ. Tennessee Press, Knoxville.

SMITH, E. A., 1890, Geological structures and description of the valley regions adjacent to the Cahaba coal field: Alabama Geol. Survey Rept. on Cahaba coal field, pp. 133-180.

----------, 1894, Geological map of Alabama, with explanatory chart: Alabama Geol. Survey.

STEAD, F. W., and STOSE:, G. W., 1943, Manganese and quartzite deposits in the Lick Mountain district, Wythe County, Virginia: Virginia Geol. Survey Bull. 59.

STOSE, G. W., 1908, The Cambro-Ordovician limestones of the Appalachian Valley in southern Pennsylvania: Jour. Geology, vol. 16, pp. 698-714.

----------, 1913, Geology of the salt and gypsum deposits of southwestern Virginia: Virginia Geol. Survey Bull. 8, pp. 51-73; U. S. Geol. Survey Bull. 530, pp. 232-255.

STOSE, G. W., and SCHRADER, F. C., 1923, Manganese deposits of East Tennessee: U. S. Geol. Survey Bull. 737.

STOSE, G. W., and STOSE:, A. J., 1944, The Chilhowee group and Ocoee series of the southern Appalachians: Am. Jour. Sci., vol. 242, pp. 367-390, 401-416.

----------, 1947, Origin of the hot springs at Hot Springs, North Carolina: Am. Jour. Sci., vol. 245, pp. 624-644.

----------, 1949, Ocoee series of the southern Appalachians: Geol. Soc. America Bull., vol. 60, pp. 267-320.

SWARTZ, J. H., 1924, The age of the Chattanooga shale of Tennessee: Am. Jour. Sci., 5th ser., vol. 7, pp. 24-30.

----------, 1927, The Chattanoogan age of the Big Stone Gap shale: Am. Jour. Sci., 5th ser., vol. 14, pp. 485-499.

SWINGLE, G. D., ms., Geology of the eastern part of Chilhowee Mountain, Tennessee: in files of Tennessee Div. Geology.

TUCKER, C. H., ms., Geology of Miller Cove, Tennessee: in files of U. S. Geol. Survey.

ULRICH, E. O., 1911, Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 281-680. Index: vol. 24, pp. 625-668, 1913.

----------, 1914, The Ordovician-Silurian boundary: 12th Internat. Geol. Cong. Compte-rendu, pp. 593-667.

----------, 1930, Ordovician trilobites of the family Telephidae and concerned stratigraphic relations: U. S. Nat. Mus. Proc., vol. 76, art. 21.

WALCOTT, C. D., 1890, The fauna of the Lower Cambrian or Olenellus zone: U. S. Geol. Survey 10th Ann. Rept., pt. 1, pp. 509-761.

----------, 1891, Correlation papers: Cambrian: U. S. Geol. Survey Bull. 81.

WILMARTH M. G., 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896.

WILSON, C. W., JR., 1948, Channels and channel-filling sediments of Richmond age in south-central Tennessee: Geol. Soc. America Bull., vol. 59, pp. 733- 765.

----------, 1949, Pre-Chattanooga stratigraphy in Central Tennessee: Tennessee Div. Geology Bull. 56.

WILSON, C. W., JR., and BORN, K. E., 1936, The Flynn Creek disturbance, Jackson County, Tennessee: Jour. Geology, vol. 44, pp. 815-835.

WRIGHT, F. J., 1931, The Older Appalachians of the South: Denison Univ. Bull., Sci. Lab. Jour., vol. 26, pp. 143-250.

----------, 1934, The Newer Appalachians of the South: Part 1, Between the Potomac and New Rivers: Denison Univ. Bull., Sci. Lab. Jour., vol. 29, pp. 1-105.

----------, 1936, The Newer Appalachians of the South: Part II, South of the New River: Denison Univ. Bull., Sci. Lab. Jour., vol. 31, pp. 93-142.

Tennessee Department of Environment and Conservation, Authorization No. 327446,
1,000 copies. This public document was promulgated at a cost of $4.60 per copy. April 1993.

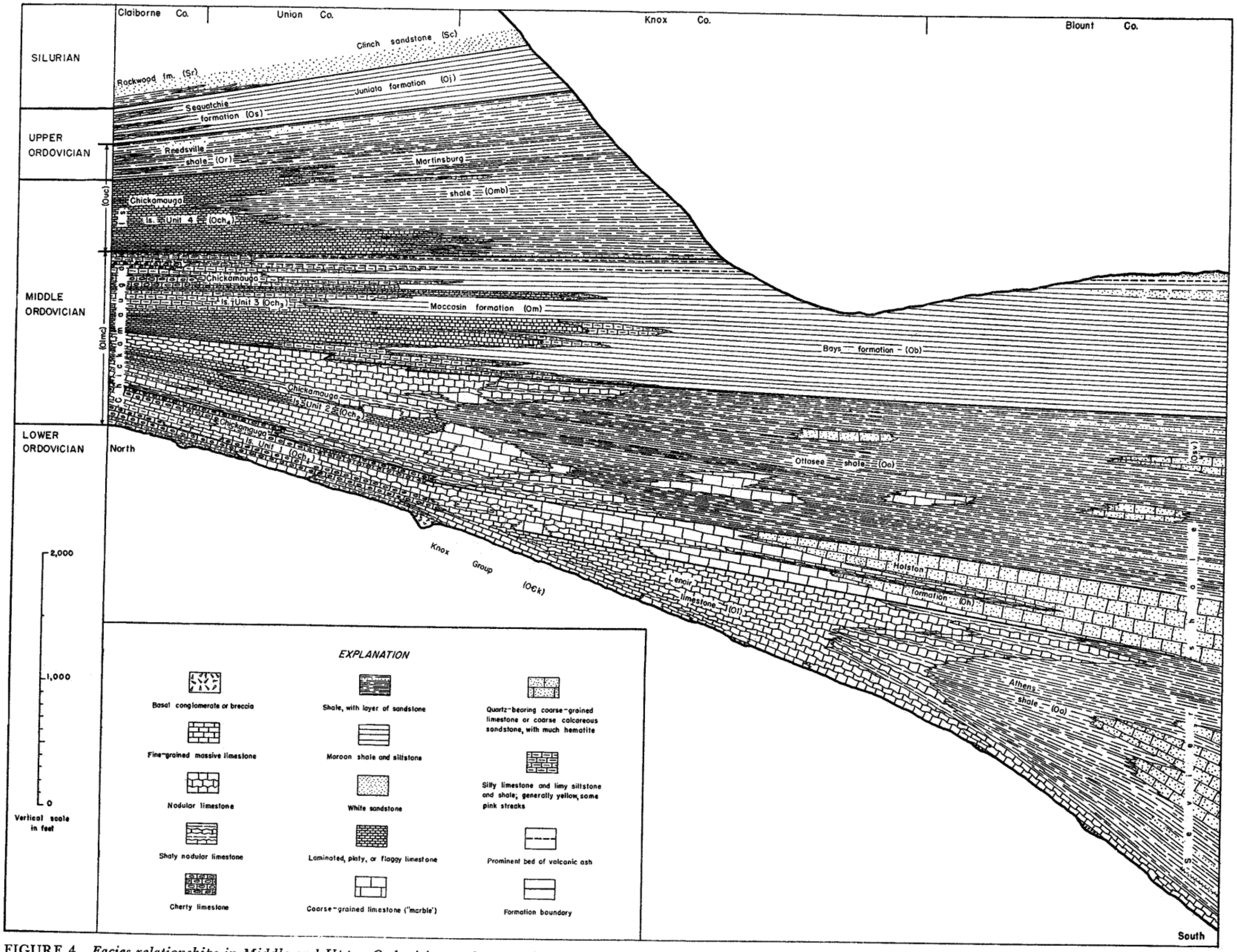


FIGURE 4. *Facies relationships in Middle and Upper Ordovician rocks near the 84th meridian in East Tennessee.*

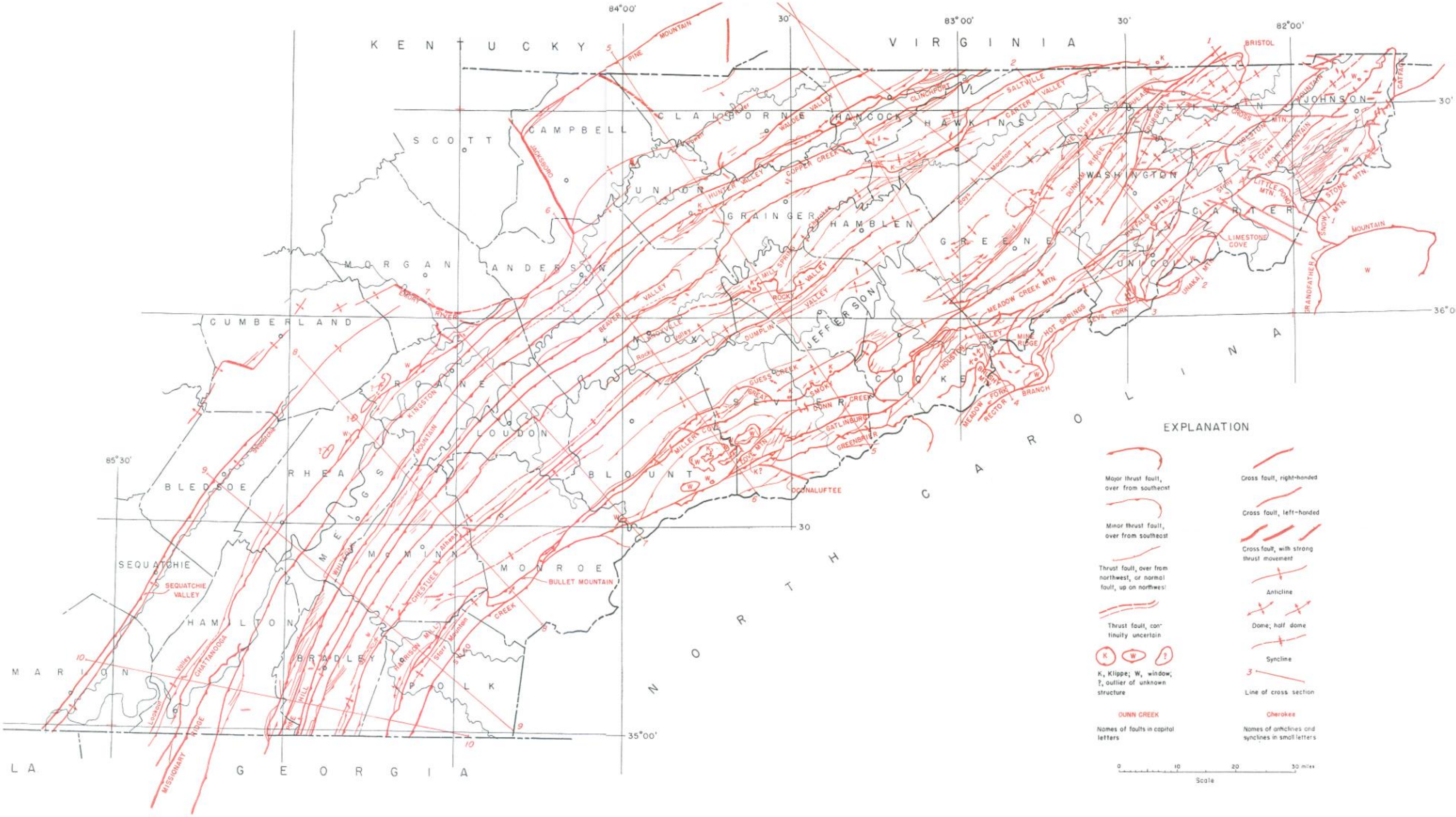


FIGURE 5. *Main structural features of East Tennessee.*