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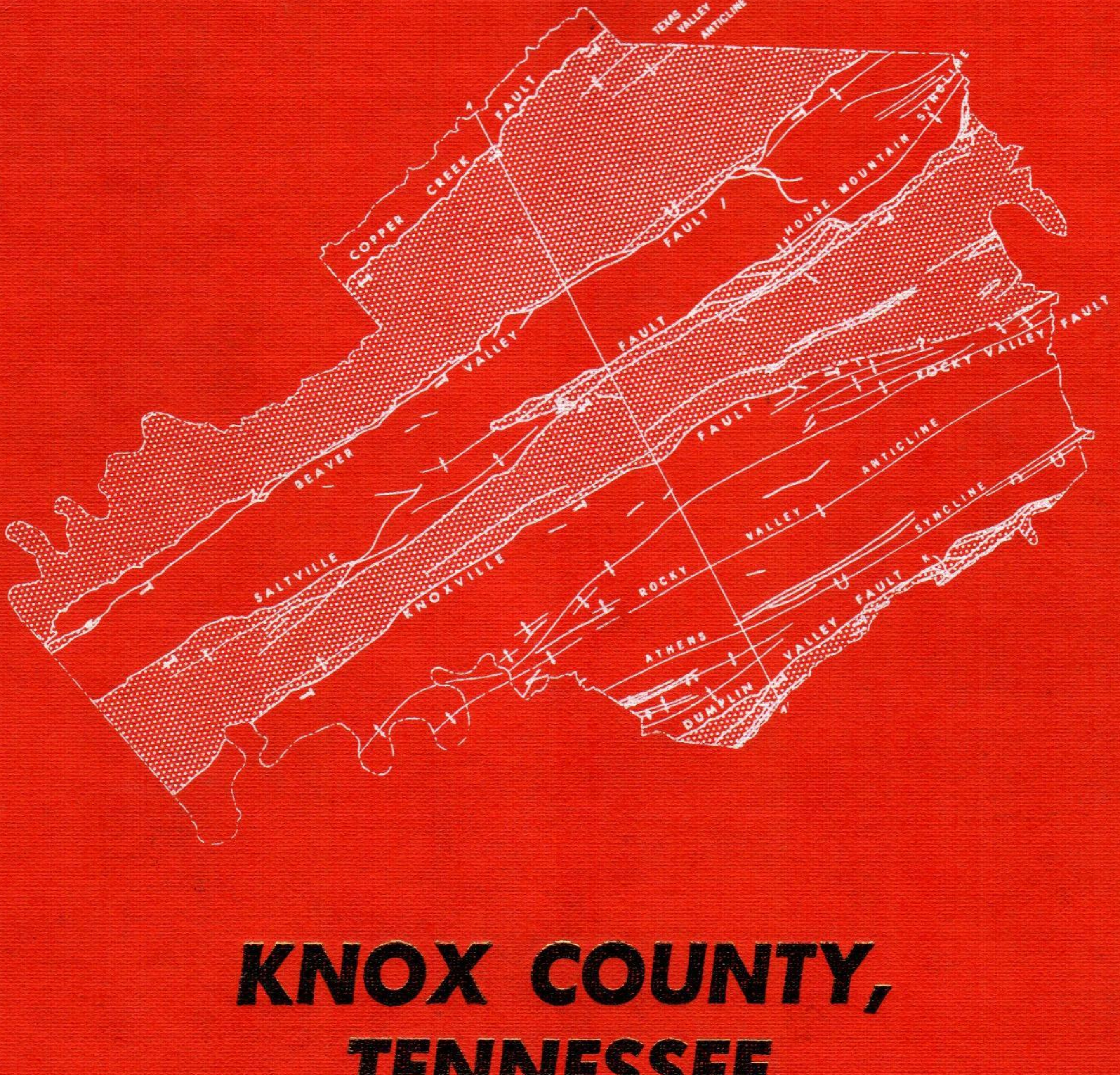

KNOX COUNTY, TENNESSEE

GEOLOGY OF KNOX COUNTY, TENNESSEE

with Field Trips for the
Geological Society of America Southeastern Section
Meeting at Knoxville
April 11-14, 1973

TENNESSEE DIVISION OF GEOLOGY
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DEPARTMENT OF CONSERVATION

GRANVILLE HINTON, Commissioner

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FOREWORD

For many years Knoxville has been a central headquarters in the South for earth scientists working not only in eastern Tennessee but throughout the Southern Appalachians. Organizations such as the Department of Geology, University of Tennessee, the Tennessee Valley Authority, the U. S. Geological Survey, the U. S. Department of Agriculture, and the Tennessee Division of Geology have ambitious programs in both academic research and in applied geology. A number of companies interested in mineral exploration, mining, and marketing of raw materials maintain their headquarters in Knoxville or in nearby areas.

This Bulletin, *The Geology of Knox County, Tennessee,* was prepared in conjunction with the 1973 meeting of the Southeastern Section of the Geological Society of America at Knoxville. Each chapter was prepared by a different writer, each with his own fields of study and points of view, and the topics range widely through several phases of earth science. The field trips are to points of interest In Knox County, and the stops selected represent only a fraction of the geological phenomena of this area. Like the main text of the Bulletin, the field trips were prepared through the cooperation of several earth scientists, each applying his own field of speciality to the problems at hand.

The Division of Geology expresses its appreciation to the contributors. The manuscripts and illustrations were prepared for publication by Phyllis M. Garman, Sue Jay Hunter, and Elva Soapes.

Robert E. Hershey
State Geologist

SOME GEOMORPHIC ASPECTS AND PROBLEMS RELATED TO THE KNOX COUNTY AREA, TENNESSEE

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INTRODUCTION

Modern geomorphology is the discipline treating systematic description, interpretation, and synthesis of those processes and events that produce and modify topographic forms. Much current geomorphic work is interdisciplinary in character and often involves researchers from related fields including botany, ecology, geography, and soil science.

Today man interacts with landscapes and regoliths that are the complex products of changing climatic and geomorphic processes that have operated on earth materials over long spans of geologic time. There is evidence that episodes of continental climatic cooling with alternating warm phases have been in progress since Cretaceous time (Beckinsale, 1965). Geomorphology must provide fundamental knowledge of the aspects of landscapes and substrates required by planners, engineering geologists, and other earth scientists. The nature, rates, and effects of differential weathering, erosion and sedimentation, hillslope movements, flooding, and other geomorphic processes must be quantified and evaluated so that environmental specialists will have information on which to base sound decisions. As population pressures and land values rise so does the need for increasingly reliable data; current states of knowledge may prove totally inadequate for dealing with problems of the future.

The scope of this paper extends beyond Knox County geographic boundaries in order to bring perspective to this discussion, and the balance of topics presented is a necessary reflection of available literature. In that detailed field research in geomorphology has not been done in Knox County, little can be written meaningfully on many important geomorphic problems in the area.

DESCRIPTIVE LANDSCAPE CHARACTERISTICS

Knox County lies wholly within the Valley and Ridge physiographic province (fig. 1). Topographically, the county is included in the Open Hills surface type in the Appalachian Rough Lands Subdivision of the United States (Hammond, 1964). In this type, 20-50 percent of the land is occupied by gentle slopes, more than three-quarters of the gentle slopes are in lowlands and local relief predominantly ranges from 300-500 feet (91-152 m).

Differential weathering and erosion of folded and faulted sedimentary lithologies of Cambrian to Silurian age (U.S. Geol. Survey, 1972; Harris, 1972) have produced a series of subparallel valleys and ridges composing an overall topographic grain oriented approximately N 55° E. Elevations range from 740 feet (225 m) on Clinch River to 2128 feet (649 m) on House Mountain. Relief between valley floors and ridge crests normally is between 180-400 feet (55-122 m), decreasing slightly from northeast to southwest across the county.

Northeast of Knox County, Clinch Mountain in Tennessee and in Virginia has been the subject of quantitative drainage basin analyses (Miller, 1953; Smart and Moruzzi, 1970). Because of the relatively uniform lithology and structure in the areas studied, varying dip slope angles and scarp slope angles can be studied as a function of bedding dip angle. Analagous studies in the Knox County area on lithologies other than the Clinch Sandstone would require the incorporation of additional variables into drainage basin analysis. Few Appalachian mountain slopes appear as simple as those on Clinch Mountain.

There is urgent need for objective and meaningful landform and drainage description. In order to understand how landforms interact with natural processes and to cope with land-use purposes (Hammond, 1958), modern research problems in physical geography, geomorphology, ecology, and other disciplines dealing with landscape studies require precise quantitative landscape morphology description. Many published landscape descriptions show little if any advance in quantification or clarification over the classic "word pictures" of Safford (1869). His writings often have been quoted by authors whose prime responsibilities were other than physiographic (cf Rodgers, 1953, p. 11-17).

All of Knox County is within the Tennessee Valley Drainage Basin (fig. 1). The Holston and French Broad rivers meet at the eastern side of Knoxville to form the Tennessee River. Meander and bend patterns of these streams have long evoked interest, and structural control may play a part in specific channel reach location. Harris (1972) graphically depicted joint orientations that visually align with river channel directions.

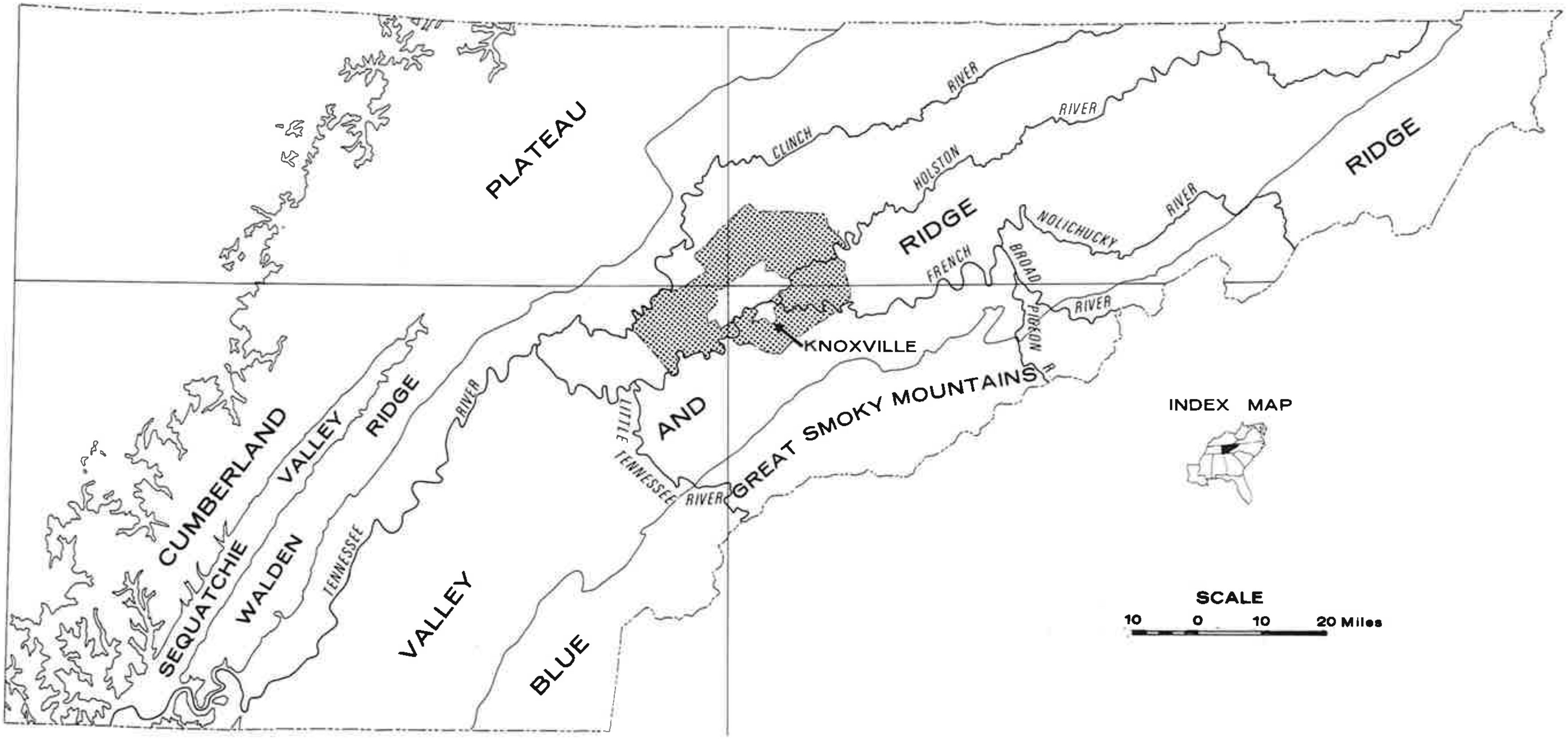

FIGURE 1.- Location of Knox County, Tennessee

CLIMATE

Present Climate

Topography apparently acts to moderate temperature extremes in Valley and Ridge climate of the Knox County area. To the southeast, the Blue Ridge physiographic province acts as a barrier to divert hot summer southerly winds from high pressure systems off the South Atlantic Coast. To the northwest, the Cumberland Plateau has an ameliorating effect on winter cold fronts. Near surface valley wind velocities are relatively low, and tornadoes are rare (Dickson, 1960).

Large-scale storms are more frequent in winter and early spring than in the rest of the year and result in a precipitation maximum for most weather stations. A secondary minor precipitation maximum in midsummer is related to shower and thunderstorm activity; this effect is more pronounced at Blue Ridge weather stations than at those in Valley and Ridge locations. Least precipitation occurs mainly in September and October and is associated with the maximum occurrence of slow-moving high pressure cells over the Valley and Ridge province (Dickson, 1960).

Climatic data for stations pertinent to Knox County are shown in table I. Possible effects of urbanization upon the meteorological records at different weather stations should be considered. Data bearing on weather modification by urbanization are difficult to interpret (Neuberger and Cahir, 1969, p. 127), but available evidence suggests that downtown city areas of moderate to large size, such as Knoxville, are commonly warmer and wetter than the surrounding countryside. The records reported for Knoxville, however, do not show that effect (table I).

TABLE I. CLIMATIC DATA

PERTINENT TO KNOX COUNTY, TENNESSEE. *

STATION NAME	Knoxville WSO AP (Blount County)	Knoxville U of Tenn (Knox County)
LATITUDE & LONGITUDE	35° 49′ N 83° 55′ W	35° 57′ N 83° 55′ W
ELEVATION	980 ft (299 m)	895 ft (273 m)
MEAN DAYS BETWEEN FROST DATES	215[a]	221[aM]
AVERAGE YEARLY AIR TEMPERATURE (long term)	59.6°F (15.3°C)	59.6°F (15.3°C)
AVERAGE YEARLY PRECIPITATION	45.85 in[c] (1165 mm) bME	45.5 in (1156 m)

[a] 1950-1971

[b] 1952-1971

[c] long term

M = missing data in interval

E = estimates incorporated

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*U. S. Weather Bureau (Environmental Data Service), 1950-1971

In addition to urban modifications there are even more subtle and more complex global effects of man on climate. The interaction of atmospheric changes with the oceans through geologically significant time is difficult to assess.

A notable effect of topography upon climate is mirrored in precipitation data. Very generally, in low mountains of the world precipitation increases with altitude. An excellent nearby example is the contrast between precipitation in the Valley of East Tennessee and precipitation in the Great Smoky Mountains in the Mt. LeConte vicinity, for which Bogucki (1970) has prepared a climatic summary. However, even smaller altitudinal and roughness variations can produce significant climatic differences over horizontal distances of a few miles or even less (Neuberger and Cahir, 1969, p. 121-122). Some local variation probably results from valley and ridge effects in Knox County.

Geomorphic Effects

Large-scale floods are most common in the interval December through March and are associated with the more frequent passage of large-scale storms during these months. Local, or "flash" flooding, on the other hand, is common in summer months and is associated with thunderstorm heavy rains. In the past, serious flooding has occurred frequently in mountainous areas of the Blue Ridge southeast of Knox County. The storm of 1 September 1951 on Mt. LeConte in the Great Smoky Mountains and the associated flooding of Gatlinburg, Tennessee, is a specific case (Bogucki, 1970). The study of these events provides valuable knowledge of the nature, distribution, and potential recurrence interval of such floods.

Air temperature and frost-free period data (table I) suggest the importance of frost action effects on soil creep and on rock weathering rates in the Knox County area. Information on mean annual soil temperatures (table 2) is superior in ascertaining certain weathering aspects. Surface frosts are common in Knox County during winter months; however, the ground is rarely frozen to depths of more than several inches or for more than several days at a time except beneath areas of vegetation-free surface. The average yearly snow and sleet total is approximately one foot (305 mm) or less at valley elevations; snow rarely remains on the ground for more than several consecutive days. Insulating effects of snow are therefore not significant today. Hence, this is a factual basis for the idea that the deeper and more intensely weathered soil profiles in the Southeastern States are in part a reflection of year-round weathering essentially uninterrupted by prolonged ground frost.

Areal climatic data give only a general concept of geomorphic weathering and erosional parameters. It is noteworthy that instrumental monitoring of microclimate and soil climate over small areas such as first order drainage basins and individual hillslopes provides the best information of the interactions between climate and the mechanisms and rates of geomorphic processes.

TABLE 2. PRECIPITATION AND SOIL TEMPERATURES FOR THE UNIVERSITY OF TENNESSEE PLANT SCIENCE FARM *

YEAR OF RECORD	TOTAL YEAR PRECIPITATION	MEAN YEAR SOIL TEMPERATURE	
		BARE GROUND 20" (50.8 cm)	BERMUDAGRASS 20" (50.8 cm)
1 Mar 1966 - 28 Feb 1967	52.79 in (1341 mm)		65.3°F (18.5°C)
1 Mar 1967 - 29 Feb 1968	54.64 in (1388 mm)	60.3°F (15.7°C)	62.0°F (16.7°C)
1 Mar 1968 - 28 Feb 1969	41.63 in (1057 mm)	62.5°F (16.9°C)	65.0°F (18.3°C)
1 Mar 1969 - 28 Feb 1970	47.55 in (1207 mm)	56.0°F (13.3°C)	65.0°F (18.3°C)
1 Mar 1970 - 28 Feb 1971	60.75 in (1543 mm)	59.0°F (15.0°C)	66.0°F (18.9°C)

*35° 53' 30" N; 83° 57' 30" W. Elevation 830 ft (253 m)

Climatic Change

Climatic evidence, both physical and biotic, indicates that past world climatic conditions often differed from those of today. Since Late Cenozoic time, evidence of formerly cold climates has been reported frequently in the literature. However, compared to European standards, there are few reported effects of Pleistocene climatic changes in the Appalachians south of the glacial border, particularly with regard to physical evidence. One reason for this may be the lack of interested workers. There is also the suggestion that affected zones beyond the margins of Pleistocene North American ice sheets were narrow and weakly developed (Wright, 1961, p. 939). Other possibilities are that the physical features developed in the Appalachians may be of types different from those found in the classical periglacial[1] areas of Europe, and that their discovery in the Appalachians has been retarded by lack of access and by the obscuring effects of vegetation and of soil.

Physical Evidence for Climatic Change

The documentation of physical evidence for climatic change in the Southern Appalachians goes back at least to the time of Kerr (1881). Wentworth (1928) reported occurrences of striated cobbles that occur only on and in stream terraces and that have not been found (except in reworked form) in modern stream gravels. In northeastern Tennessee, striated cobbles occur most abundantly in Holston River terraces northeast of Knoxville; other finds by Wentworth (1928) were along the French Broad, Nolichucky, and Little Tennessee rivers. Especially large boulders displaying striations were discovered along the Big Pigeon River (fig. 1). Both the provenance of the resistant lithologies composing the cobbles and the fact that finds are restricted to streams draining headwater sources indicate high elevation source areas. Cobbles often occur in clusters within otherwise fine-grained alluvium and display a characteristic surface nature on striated faces. An origin related to the movement of thick cobble-containing river ice is consistent with the available evidence, and with probable Pleistocene cold phase climatic conditions (Flint, 1971, p. 312-313).

Southeast of Knoxville, bedrock geologic mapping in the Great Smoky Mountains National Park area also revealed the presence of large forested blockfields and blockstreams[2] composed of coarse angular blocks commonly derived from the Thunderhead Sandstone (Hadley and Goldsmith, 1963, p. B-108; King, 1964, p. 136). The physical significance of these deposits has been discussed by King and Stupka (1950, p. 37), who suggested a Pleistocene cold phase origin perhaps above an upper forest limit of 4000 or 5000 feet (1219-1524 m). More recently, Michalek (1968) in a reconnaissance study of blockfields, blockstreams, and fanlike features in the southern Blue Ridge including the Great Smoky Mountains National Park, placed the upper forest limit between 3000 and 3500 feet (912-1067 m). Few definite conclusions can be drawn from just the surface mapping of block deposits partly because knowledge is lacking on the environments of comparable active features in cold climates today, and partly because cessation in blockfield and blockstream development may occur locally because of factors other than climatic change (Wright, 1961, p. 946). However, if these estimates are even qualitatively correct, Knox County climatic conditions must have been markedly more severe during the time spans in which the features described in this section were formed.

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[1] The term, "periglacial," was originally introduced by Lozinski (1912, p. 1039) as a general term referring to the area adjacent to Pleistocene ice sheets, the climatic conditions there, and by extension the features produced. Black (1966) related the term to cold climates in which frost action is a dominant process, possibly accompanied by strong mass wasting and wind action.

[2] The terms, "blockfield" and "blockstream," properly refer respectively to equant and elongate (in plan view) shaped block deposits of low slope angle, usually less than 15 degrees, comprised of contiguous blocks, and lacking interstitial fines in the surface layers. Where such deposits do contain fines and are vegetated, the term, "vegetated blockfield," has been applied (Caine, 1968, p. 6-7).

Biologic Evidence of Climatic Change

The reported biotic evidence of climatic change is more impressive than the physical record not only in amount, but also, in terms of its paleoclimatic significance. Comparatively more is known concerning the geographical distribution and environmental conditions of living plant and animal species whose fossil analogs are found preserved in favorable sites, such as in cave and pond sediments.

Little is known of pre-Quaternary mammalian fauna (Guilday, 1971, p. 234). The Pleistocene record, however, is more prolific. Cavern finds in Overton and Sullivan counties, Tennessee, have provided evidence for a minimum southern cold phase limit of a dense coniferous forest of boreal type (Guilday, 1971, p. 247) at relatively low elevations. Late Pleistocene and Holocene finds are especially numerous (Guilday, 1971, p. 243), although as yet there is no definite evidence of any northern range expansions associated with a Postglacial Climatic Optimum (Guilday, 1971, p. 257). Significant dateable finds in the Knox County area would be valuable in extending the ranges of key species that probably were associated with specific vegetational associations.

Knowledge of Pleistocene and Holocene vegetation is often derived from the study of pond and sinkhole fillings rich in organic remains. Watts (1970) provided detailed information on Wisconsinan age sediments containing glacial age pollen and macrofossils in ponds developed on Knox Group rocks in northwest Georgia. Many of the described taxa have, at present, definite boreal distributions and would require a southward displacement of about 1100 km to occur at this latitude today (Watts, 1970). More discoveries of such sites containing a relatively continuous record of vegetational history are needed to fill gaps in the picture of climatic change.

Based on existing knowledge, Schumm (1965, p. 786) estimated that nonglaciated portions of the United States underwent approximate mean annual temperature decreases of 10°F (5.5° C), and precipitation increases of 10 inches (25.4 cm) during Pleistocene cold phase conditions. Schumm (1965) also calculated that the Postglacial Climatic Optimum was characterized by a mean annual temperature increase of about 4°F (2.2°C), and with precipitation about 5 inches (12.7 cm) less than at present. Such order-of-magnitude paleohydrologic estimates provide checks on paleoclimatic reconstructions; they must be revised from time to time as knowledge is supplemented. Whatever the detailed Late Cenozoic paleoclimatic history of the Knox County area, marked changes such as these would have significantly affected geomorphic processes and resulting landforms. Thus, there is danger in explaining present topographic form and regolith origin solely on the basis of present environmental conditions.

REGOLITHS

A variably thick nearly-continuous regolith mantles most of the bedrock in Knox County. This unconsolidated material deserves intensive study because: (1) it may contain or mask mineral deposits, (2) regolith interacts with subsurface water often creating drainage problems, (3) there are important geological engineering properties of regolith (Kellberg, this volume), and (4) there is evidence that regoliths contain genetic links between bedrock and soil profile development (Miller, 1972). Maps depicting soil and overburden relations respectively, in Knox County have been prepared (U.S. Geol. Survey, in press; Harris and Kellberg, in press). In many nearby counties, however, soil survey reports published at different times furnish the only comprehensive published information and deal predominantly with near-surface materials.

Many areas are blanketed by an essentially in-place residuum which may or may not preserve parent material structures. In many cases the residuum is diagnostic of underlying rock units. Examples and generalizations of the interrelationships between differing parent-rock types and residuua that develop upon them are given by Rodgers (1953, p. 115-117) and by Kellberg (this volume).

Transported regoliths commonly intergrade with residual mantles, especially at and near the base of ridges. Southeast of Knox County, striking examples of transported regolith on Chilhowee Mountain (Bluff Mountain), Sevier County, have been mapped and described by King (1964a p. 136 and pl.1). There are also examples reported from the Great Smoky Mountains (Hadley and Goldsmith, 1963, p. B108-B111; King, 1964a, p. 136-141). There, wells commonly have penetrated up to 50-75 feet (15-23 m), and locally over 100 feet (30+ m) of regolith (McMaster and Hubbard, 1970). Less obvious, but analagous transport of material down the flanks of Knox County ridges has given rise to similar slope deposits. Study of these deposits is needed to determine the mechanisms and times of emplacement, as well as to provide data on the engineering properties of these materials.

In relation to the size of streams passing through the county, the total area underlain by alluvium is not large. Floodplains along the Tennessee, French Broad, Holston, and Clinch rivers characteristically are 300-800 feet (91-244 m) wide.

There are areas underlain by alluvial terraces 15-140 feet (4.6-43 m) higher than present adjacent floodplain levels, and the relation of these depositional remnants to Pleistocene environmental change is of interest to the Quaternary geologist. Stream regimen changes have been inferred in streams that drain areas formerly under a frost climate; alluvial fills by analogy are usually correlated in time with glacial cold phase maxima, episodes of trenching are related to interglacials (Flint, 1971, p. 310). The genetic relations of stream channel geometry, and of channel and floodplain erosion and deposition, have not been established, and sediments accumulated during relatively longer periods of aggradation must be distinguished from those deposited during single large floods. Comprehensive field study is needed if the origins of Knox County area terrace deposits are to be understood. One promising study area is within the French Broad River drainage southeast of Knoxville. Here, matching and tracing of terrace levels headward across the Valley and Ridge province into the fanlike piedmont cove deposits in the Great Smoky Mountains National Park might demonstrate important genetic alluvial-colluvial relationships.

LONG-TERM EROSIONAL GEOMORPHOLOGY

Introduction

As outlined by Hack (1969), the southern Appalachians have been undergoing erosion for more than 200 million years, and the thickness of rocks now exposed in the Valley and Ridge province indicates that as much as 5 or 6 miles (8 to 9.6 km) of lithologic material may have been removed from some areas. Such a prolonged erosional history, coupled with isostatic readjustments, leaves little remaining evidence for the historical geomorphologist attempting to reconstruct physiographic or drainage history. Tennessee Valley drainage goes eventually to the Gulf of Mexico, so the study of Atlantic Coastal Plain sediments cannot provide significant assistance in deciphering geologic and paleogeographic history. Coastal Plain sediments are useful farther north in the Appalachians where Atlantic Slope rivers cross the Blue Ridge after draining the Ridge and Valley and Appalachian plateaus physiographic provinces.

The geomorphic potential of plate tectonics theory for providing a framework in understanding the endogenic controls and history of regional landscape evolution is essentially untapped. Future collaboration among geophysicists, tectonic geologists, and geomorphologists offers an opportunity to relate landscape evolution to plate tectonic history.

Historical Geomorphology

Following Davis (1889, 1891), early Appalachian geomorphologists and other geologists whose work was primarily non-geomorphic, extended the multiple erosion cycle hypothesis to the southern Appalachians including the Valley and Ridge province of east Tennessee (cf Hayes and Campbell, 1894). Davis' concept of Appalachian geomorphic history was based primarily on three lines of evidence; first, the existence of accordant ridge crests and valley surface levels over wide areas; second, drainage patterns transverse to structural trends; and third, the existence beneath the Atlantic Coastal Plain sediments of an erosion surface believed to be a buried peneplain that once had extended westward across the Appalachians.

The identification, correlation, and age of ridge crest surfaces that formerly may have developed to a common level is partly contingent upon the ability to assess effects of subsequent modification. Cooper (1944, p. 213-214) cited evidence that ridge crests in the Burkes Garden area of the Valley and Ridge province of southwestern Virginia have been lowered significantly, probably in Quaternary time. Evidence exists that middle latitude areas may have undergone some cryoplanation[3] beyond the continental ice sheet margins for varying lengths of time during Pleistocene cold phases (cf Demek, 1969, 1972; Waters, 1962).

Raup (1951, p. 112) justified the search for topographic evidence of cryoplanation in the Appalachians south of the glacial border on the basis of assumed cold climates beyond the ice sheets. This offers an alternative hypothesis to explain topographic forms that bevel differing lithologies where such truncation cannot be explained by the protection of weak beds by resistant lithologies as was argued for the Cumberland Plateau and Highland Rim of Tennessee by Ashley (1935). In his study of the areas cited above by Ashley, Hack (1966, p. C5) has indicated that a discordant relationship is valid only if a very large area is considered and if local features are ignored. In any event, geomorphologists attempting interarea elevational correlations of traceable pre-Quaternary erosional surfaces must consider the possibility of regional epierogeny such as that noted by Dennison and Johnson (1971, p. 502-503).

The origins and subsequent modifications of valley floor surfaces may present quite different problems due to resistant rock base level controls in valleys upstream from water gaps, and because of differential lowering of the land surface by solution in areas underlain by carbonate rocks. The presence in the East Tennessee Valley and Ridge province of isolated lignite deposits having a probable age span of Cretaceous to Tertiary probably cannot be used to precisely date valley surface levels. Such deposits may have been lowered significantly by subsequent solution of the underlying bedrock (Pierce, 1965, p. C154-C155).

Study of local relationships among topography, structure, lithology, and surficial deposits in Knox County would provide at least some of the evidence needed to reconstruct ridge crest and valley floor topographic evolution. Theoretical constraints on the development of a region's topography can be imposed by the correlation of relief and denudation rates (Ahnert, 1970) to allow order-of-magnitude estimates of relief development parameters. In climates lacking a pronounced rainfall seasonality, Ahnert (1970, p. 262) calculated that to reduce an area's relief to 1 percent of its initial value would require 22 million years without crustal movement and 37 million years with isostatic adjustment. Whatever the "initial" relief in the Knox County area may have been when removal of the overlying lithologies began, even without renewed uplift, enormous time spans have been necessary for the development of present landforms. The varied nature of the sediments probably contributed much to alter the shape of topographic evolution through time; unroofing of the folded and faulted Clinch Sandstone, now present in the county only on House Mountain (fig. 1), is a case in point.

The subject areas of stream encroachment magnitude and frequency, imminent piracy, and stream capture, all critical to older hypotheses of landform development, are currently under debate (cf Ross, 1971, p. 11-12), and actual field data necessary to resolve these issues appear lacking. Ross (1971) describes examples of postulated drainage changes in the Tennessee River and selected tributaries; supportive arguments are drawn from geologic and biologic observations of previous workers. Arguments favoring the possibility that the present southern Appalachian drainage divide may approximate or have genetic relation to the "original postorogenic drainage divide" have been restated by Meyerhoff (1972, p. 1711-1712).

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[3] The term, "cryoplanation," was introduced by Eakin (1916) for the collective cold climate processes responsible for producing flattened summits and bench-like features bounded by steeper scarps composed of talus.

As a modern alternative philosophical basis of landscape evolution, Hack (1960) proposed the concept of dynamic equilibrium for humid temperate areas being actively lowered towards a base level of erosion. For an area southwest of Knox County (Hack 1966) this hypothesis has received documentation, but comparable field work has not been done here. There are other major schemes of landform development; some imply that disequilibrium conditions may obtain, as, during and for some time after periods of climatic and/or tectonic instability. Detailed field studies will be necessary within the Knox County environs before the relative merits of proposed landscape origin hypotheses can be assessed. Indeed, it may be possible that one single hypothesis of landscape evolution is inadequate for all of the region. Many modern geomorphic research problems can be approached without assuming a single overriding philosophical basis for landscape development.

GEOMORPHIC PROCESSES

Weathering and Soils

Geomorphically oriented studies of weathering processes, rates, and effects in the Knox County vicinity are few; one such is the attempt by Fox (1941) to estimate Tennessee River solution rates on exposed carbonate rock. Area soils have been studied from a developmental viewpoint, and additional detailed genetic research on residual soil profiles and the subjacent rock (cf Miller, 1972) is needed in order to answer important questions bearing on soil chemistry, residuua formation, and associated environmental problems of surface subsidence and drainage. Moneymaker (this volume) has described the pedologic characteristics and the distribution of Knox County soils. Harris (in press a) has prepared a map depicting soil association patterns.

Hillslopes

Some effects of needle ice "mush-frost" on vegetation-free soils in the southern Appalachians were noted by Deckert (1913, p. 155-156). Indeed the geomorphic, if not economic, effects of frost creep can be observed on damp soils in bare road cuts during cold winter mornings. Under favorable conditions, frost action may form faint orientations and patterns in rock fragments similar to those described by Rozanski (1943, p. 336-339) near Fontana, North Carolina.

Little is known either of the absolute rates and volumetric importance of soil creep on hillslopes in the county, or of quantitative aspects of surface wash and gully erosion. Studies elsewhere (Wolman, 1971) indicate that slope erosion is locally accelerated by building and construction activities. Subsequently, erosion decreases rapidly when construction is completed and vegetation is reestablished.

Rapid mass movements on relatively steep slopes have received considerably more geomorphic study than processes involving slower moving material. The Webb Mountain, Sevier County, Tennessee, cloudburst of 5 August 1938 produced numerous debris slides and gullies, and extensive stream channel and floodplain changes occurred due to erosion and deposition (Moneymaker, 1939). Bogucki (1970) reported on the 1 September 1951 cloudburst centered over the Mt. LeConte-Sugarland Mountain area in the Great Smoky Mountains National Park. The main geomorphic effects studied were debris slides, channel and floodplain changes, and extensive flooding. If a storm comparable in magnitude and in intensity to those cited above were to develop over one or more Knox County ridges, similar geomorphic effects might well occur; where valley floors are densely populated near the bases of ridges, the loss of life and property could be catastrophic.

Stream Channels and Floodplains

The effects of flooding within the Tennessee Valley have been documented extensively by the Tennessee Valley Authority. For example, the widespread floods of March 1963 were the subject of a two-volume report (Tennessee Valley Authority, 1964). Other Federal and State agencies have participated in flood studies that have included Knox County, adding to available data, and permitting comparisons of flooding dating back to early European settlement in the region. As an illustration, these data indicate that the flood of March 1867 on the Tennessee River at Knoxville is probably the greatest of record, even including the flood of March 1791 (Jenkins, 1960, p. 53-54). Flood hazard areas in Knox County have been mapped by Harris (in press b) as an aid to planning.

KARST AND SPELEOLOGY

Introduction

As used here, the term karst topography implies a terrain having distinctive drainage and relief characteristics associated with relatively higher rock solubilities in natural waters than rock solubilities found elsewhere (Jennings, 1971, p. 1). In humid temperate regions carbonate rocks are the lithologies most likely to develop karst forms. The processes involved include water circulation, corrosion, corrasion, subsidence, and deposition in and along fissures initially widened by solution. In karst research the emphasis is placed on surface forms; in speleology subsurface cavern nature, processes, and origin are stressed.

Karst Landforms

Knox County and the rest of the surrounding Valley and Ridge province are within the East-Central (United States Karst) region of Paleozoic and older rocks as defined by Davies and LeGrand (1972, fig. 1, p. 470). In many areas within Knox County (cf Moore, this volume) incipient karst land forms are developed, and Harris (in press c) has prepared a map of areas with abundant sinkholes.

Surface features associated with karst in the Valley and Ridge province in and around Knox County are usually limited to a few types including dolines, uvalas, collapse sinks, and karren ridges. There are many problems in karst terminology; Monroe (1970) has prepared a comprehensive karst glossary. Quinlan (1972) has outlined a genetic classification of sinkholes and associated karst depressions.

Findings during subsurface dam and mineral exploration have demonstrated deep carbonate rock solutional effects. Filled and open cavities that have affected or that will eventually affect topography commonly occur from the bedrock surface to far below present water-table levels (Moneymaker, 1948). Jointing and other rock structures appear more important than does chemical purity of the carbonate rocks in localizing cavities.

Major genetic problems facing karst researchers today include quantification of both long-term climatic and catastrophic flood effects on karst processes and landforms and on the rates of denudation and relative geomorphic ages of karst plains (White, et al, 1970).

Kellberg (this volume) discussed engineering geologic problems that arise in areas underlain by relatively soluble carbonate rocks; deep residuum and irregular bedrock surfaces present difficulties in building and construction. Subsidence and flooding hazards are important subsequent dangers. Harris (in press d) has mapped large subsurface drainage areas of Knox County. Ground water hydrologic relations present difficulties in karst terrains; for example water well locations and solid waste disposals both require extreme care in their planning and development. The construction of water-tight reservoirs creates difficult problems for the engineering geologist (Moneymaker, 1969). Bedding planes, joints, solution cavities, and other openings serve as leakage paths unless they are avoided during dam construction or are sealed.

Speleology

Descriptions of Tennessee caverns are contained in Barr (1961) and in Matthews (1971). For Knox County, Moore (plate I) has mapped the known cavern locations, many of which exhibit characteristics of Appalachian type caves (Barr, 1961, p. 12-13) such as the presence of along-strike passages, occurrence of two or more levels offset downdip, and the existence of domepits.

With exceptions (cf Wood, 1969) cavern sediments have received little detailed sedimentological study. In addition to contributing knowledge of cavern history and origin, anthropological, botanical and zoological records frequently are preserved in cave-mouth or near-cave-mouth sites. A proposed classification that is sensitive to the complex nature of cavern sediments has been presented by Wolfe (1972).

In contrast with older hypotheses of cave formation which specified unique water-table positions with respect to most cavern development, modern studies emphasize the complexity of cavern evolution. For example, White, et al (1970) inferred that major essentially horizontal passages originated between the high and low levels of a seasonally-fluctuating base level, whereas vertical shafts formed independently and later by solution due to seepage down joint intersections. Significant cavern development is now known to occur above, at, and below established water table positions. Some factors that interact to determine the position of the majority of cave formation with respect to water tables are fissure density, bedding attitude, and the local relief between sinkpoints and springs (Ford, 1972). Most accessible caves are in the vadose zone, but even here hypotheses of origin cannot be easily tested, partly because of lack of knowledge on past cavern history and partly because of scanty data for assessing storm recharge effects on cavern development (Doehring and Vierbuchen, 1971).

THE STRATIGRAPHY OF KNOX COUNTY, TENNESSEE

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INTRODUCTION

The strata which underlie Knox County range in age from Early Cambrian to Silurian and are assigned to the Shady Dolomite, Rome Formation, formations of the Conasauga, Knox, and Chickamauga groups, and to the Sequatchie and Clinch formations (table 1). The Sequatchie and Clinch are preserved in one small area (House Mountain) in northeastern Knox County, and the Shady Dolomite was recognized only southeast of the Dumplin Valley fault. However, the remainder of the formations are exposed widely across the county where they are thrown to the surface by six major Appalachian faults. The thrusts have telescoped strata which were originally deposited many miles apart, thereby making regional facies reconstruction more difficult.

The methods and purposes of stratigraphic investigations have changed markedly over the last several decades. Geological mapping of the Appalachians by the U. S. Geological Survey at the turn of the century required regional stratigraphic studies designed to outline major rock units. Because sedimentary formations change along strike fossils were used to effect regional correlations and to assist in projection of rock stratigraphic boundaries.

The regional reconnaissance approach was perhaps best applied by Charles Butts in his studies from Alabama to Pennsylvania. He used fossils and gross lithology to define "formations" along great lengths of the Appalachians. With the advent of geologic mapping on 1:62,500 or larger topographic maps, rock stratigraphic units (formations) were better defined; eventually, formations were restricted to units mappable on topographic base maps with scales on the order of 1:25,000 (A.A.P.G. Code of Stratigraphic Nomenclature, 1961, Article 6). Because geologic mapping was done in greater detail and formations could be traced stepwise across maps, paleontologic stratigraphy was rarely used. Geologists working in widely separated areas established units which were suitable to their needs and only a little progress was made on interregional correlations.

More recently, within the last 10 or 15 years, the cataloguing of strata into mappable geologic formations has been by-passed by the environmental stratigrapher or sedimentologist who views stratigraphy as an intermediate step in a study designed to reveal the origin of strata. Specialists on the origin of carbonate rocks and on rocks composed of terrigenous clastics now study strata in considerable detail in an attempt to recognize features which appear to be analogous to sedimentary features in Recent sediments. The product of the environmental stratigrapher's work is a "model," a concept of how the particular rocks under study may have formed. Studies of ancient depositional environments have resulted in a resurgence of paleontology, not so much in the classical sense, but directed more toward the reconstruction of the paleoecology of the ancient sedimentary environments.

The biostratigraphy of Knox County has been discussed by McLaughlin elsewhere in this volume. Descriptions of the field trip stops listed in the Appendix are an attempt by several workers to deduce depositional environments of some of the ancient rocks in Knox County. The purpose of this chapter is to summarize the stratigraphic results of two decades of geological mapping in the Valley and Ridge in and around Knox County. The discussion is limited to studies made since the synthesis of Rodgers (1953), and this synthesis is based mostly upon the geologic mapping of Cattermole (1955, 1958, 1960, 1962, 1966a, 1966b), Neuman (1960), Swingle and others (1967a), and Bridge (1956).

SHADY DOLOMITE

The Shady Dolomite was mapped only in the southeastern part of Knox County where it was identified by Cattermole (1955) from its characteristic saprolite. The residuum identified as Shady, on the hanging wall of the Dumplin Valley fault, is reddish-brown to greenish-yellow clay which contains finely crystalline silica and concentrically banded chert. Neuman (1960) rejected Cattermole's identification and assigned the saprolite to calcareous layers in the Rome Formation. Swingle (Hardeman, Miller, and Swingle, 1966) did not show Shady in Knox County on the Geologic Map of Tennessee, and that interpretation was followed by U.S.G.S. (1972).

ROME FORMATION

The Rome Formation, exposed in five linear belts in Knox County, is in general the oldest unit brought to the surface in the Valley and Ridge along hanging walls of major Appalachian thrusts. Complete undeformed sections are unknown; however, the single largest Rome section in the vicinity of Knoxville is in Anderson County where I-75 cuts through Pine Ridge.

The Rome underlies the Bays Mountains in southeastern Knox County southeast of the Dumplin Valley fault, and the best exposure in that belt is along the road and railroad cut through Shooks Gap (Shooks Gap quadrangle). Both Sharp Ridge along the Saltville fault and the ridge northwest of Dutch Valley in the central part of Knox County are underlain by the Rome. The formation is well exposed where roads cut through these ridges, and particularly so in the I-75 cut through Sharp Gap. Next northwest is Beaver Ridge where Spigai (1963) measured 218.5 feet of Rome along US 25W, and then Bull Run Ridge marks the last Rome exposure in the county. Only a few beds of Rome are exposed along the Beaver Valley fault where I-75 cuts Beaver Ridge, and there Rome is thrust on Moccasin red beds. Interstate Route 40 crosses Beaver Ridge just west of Knox County, making an excellent cut in that strike belt. The Rome is well exposed in the Bull Run Ridge section along I-75 in northwestern Knox County, and that section is described in detail by Samman (this volume). There the Rome gives way to variegated siltstones of the Pumpkin Valley Shale with a decrease in ledge-forming sandstone (fig. 1).

Figure 1. Small fault and ledge-forming sandstone in Rome Formation at Diggs Gap (Field trip 2, Stop 3).

The lowermost beds of the Rome are generally not exposed in the Valley and Ridge because of thrust faulting, and if Cattermole's identification of the Shady is correct, such beds would be at the surface only in the southeastern corner of Knox County. In addition, Cattermole (1960) tentatively recognized a lower member of the Rome Formation along the north side of Beaver Ridge near Byington. There the lower member is composed of gray silty limestone and green sericite shale. If these rocks are indeed a part of the Rome, then they too represent strata in the lower part of the formation which are generally below the Valley and Ridge decollement.

The lithologic heterogeneity of the Rome has long been recognized and described by many. The formation consists of shale, siltstone and sandstone, with small amounts of dolomite. Regionally, the Rome is thinnest and predominantly sandstone and siltstone in the northwestern parts, and is thickest and contains an abundance of shale and limestone in eastern parts of the Valley and Ridge (Spigai, 1963; Rodgers, 1953). In Knox County, sandstones, ranging from orthoquartzites to impure hematitic or glauconitic sandstones, dominate the section in many places. The quartzites and sandstones range from gray to brown, orange, yellow, greenish gray and grayish red. Some beds contain abundant minor sedimentary features (Spigai, 1963). Ripple marks, burrows, sole marks, small scale cross-beds, and mud cracks are common. In addition, Harvey and Maher (1948) described such things as swash marks, foam impressions and rain prints. Beds range from a few inches to a few feet, although parts of the section may contain sandstones as much as 75 feet thick (Cattermole, 1955, 1958, 1960).

Shales and siltstones are olive gray, greenish gray, yellowish brown, grayish brown or grayish red, and range in thickness from a few inches to 20 feet or more. Lamination of sandstone is common, and some beds which are flasered indicate by their structures that they may have formed in a tidal flat environment (van Straaten, 1959).

Dolomite in the lower part of the section is generally less than 10 feet thick and some beds are mottled shades of gray. Superficially these beds resemble the stromatolites of younger Cambrian rocks, but the more random nature of the mottlings suggests that they probably resulted from burrowing organisms (fucoids). Other dolomite layers are laminated and weather to a yellowish gray color.

Because of internal structure, thicknesses are difficult to estimate; however, the exposed part of the Rome ranges from about 1500 feet in the southwestern part of the county to 450-500 feet to the northwest.

CONASAUGA GROUP

In the southeastern part of Knox County the Conasauga Group is composed of interbedded shale and limestone formations—the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. To the northwest, shale increases at the expense of limestone and northwest of the Saltville fault the Rutledge Limestone is generally not mappable as a separate formation.

Lithologically the group is heterogeneous, although similar rock types from different formations have features in common. Limestones are generally medium to medium dark gray and dense. Some are ribboned or banded; others are oolitic. The Pumpkin Valley and Nolichucky shales appear similar, particularly where they are weathered. In places grayish-red and olive-gray shales are common to both formations as are interbeds of limestone. Only the Rogersville Shale weathers to a distinctive light-greenish-gray or pale-olive color which facilitates its identification.

Conasauga facies in Knox County reflect the regional facies of the group, but on a much smaller scale. Because limestone units do not persist to northwestern parts of the Valley and Ridge, the group there is not subdivided and is called the Conasauga Shale, with the Maynardville Limestone a member (Rodgers, 1953; Harris, 1964). Northeast of Knox County on the hanging wall of the Pulaski thrust, the Rogersville thins so that the Rutledge and Maryville combine to form the Honaker Dolomite (Rodgers, 1953). Farther northeast both the Pumpkin Valley and Nolichucky are replaced by limestone and dolomite, making a thick carbonate unit called Elbrook. The Elbrook Dolomite lies mostly in southwestern Virginia. Rodgers (1953) did not recognize Elbrook in Tennessee, but King and Ferguson (1960, pl. 1) show two small patches at the state line northwest of Holston Mountain.

Pumpkin Valley Shale

The Pumpkin Valley Shale was separated from the Rome Formation by Rodgers and Kent as, " . . . a readily recognizable and mappable lithologic unit (1948, p. 7)." The formation, expressed topographically as a shale valley between Rome sandstone and Rutledge limestone hills, is mappable in Conasauga strike belts throughout Knox County.

In general, the formation consists of shales, siltstones, thin sandstones and limestones or dolomites. Thin sandstones are confined to sections in northwestern Knox County and are generally absent to the southeast in the Shooks Gap, Maryville and Wildwood quadrangles. Shale and siltstone layers are reddish brown to grayish red, greenish and olive gray, and some are yellowish gray. Limestones and dolomites, which are usually evident only in unweathered or slightly weathered exposures, are gray and weather to yellowish gray.

One of the best exposures of lower Pumpkin Valley beds in Knox County is on the southwest side of Bull Run Ridge at Diggs Gap in cuts of recently constructed Interstate 75. There the lower beds are glauconitic and hematitic siltstones. Weathered overlying beds are red and green or gray shale chips more typical of the formation.

The Pumpkin Valley apparently thickens to the northwest at the expense of the overlying Rutledge Limestone. The shale formation is 100 to 200 feet thick in the southeastern strike belts and ranges up to about 750 feet thick over the remainder of Knox County.

Rutledge Limestone

The Rutledge Limestone is generally mappable in Knox County southeast of the Saltville fault. Northwest of the fault, with the exception of a 3-mile belt in Hines Valley south and east of Crippen Gap, the Rutledge was combined with the Rogersville Shale by Cattermole (1960, 1966a, 1966b).

Neuman (1960) recognized 3 parts of the Rutledge in the Wildwood quadrangle. "Fine-grained limestone with closely spaced argillaceous partings dominates the basal 50 to 75 feet; these give way upward into less argillaceous limestone, including some with irregularly mottled weathered surfaces, and several beds of pelletal limestone formed of round pellets 1 to 2 millimeters in diameter. The uppermost 50 feet is fine-grained obscurely bedded dolomite overlain by the Rogersville Shale at a sharp and abrupt contact."

The upper dolomite beds were recognized by Swingle and others (1967a) on the Boyds Creek quadrangle, where the remainder of the formation is impure, ribboned or banded gray limestone with interbeds of shale. Except for upper dolomite beds, Cattermole mapped similar lithologies in the Rutledge on the Fountain City, John Sevier, and Shooks Gap quadrangles.

Rutledge carbonate strata are generally thinner and interbedded with shale northwest of the Saltville fault, where the base of the formation was mapped at the base of the lowest calcareous shale. Upper Rutledge beds are gray limestones, about 30 feet thick, but apparently are not well enough exposed to permit detailed mapping of the Rutledge-Rogersville contact in that area (Cattermole, 1960, 1966a, 1966b). The Rutledge ranges from as much as 325 feet thick on the Boyds Creek quadrangle to as little as 115 feet on the Fountain City quadrangle. Where mapped together the Rutledge-Rogersville ranges from about 450 to 575 feet thick in northwestern Knox County (Cattermole, 1958, 1960).

Rogersville Shale

As a formation, the Rogersville Shale has the same distribution as the Rutledge Limestone, i.e., with little exception it was mapped southeast of the Saltville fault.

The formation consists of light-greenish-gray and pale-olive shale, and in places contains a few thin gray siltstone beds and small amounts of dark-gray dolomite and gray limestone. Northeast of Knox County the Rogersville contains a prominent 50-foot thick limestone, the Craig Limestone Member (Swingle and others, 1967b, Rodgers and Kent, 1948, p. 10; Bridge, 1956, p. 9). The Craig interval was recognized (but not mapped) by Cattermole (1955, 1966a, 1966b) on the Shooks Gap, Fountain City and John Sevier quadrangles, where it is represented by interbedded shale and thin limestone beds. Thickness of the Rogersville ranges from 100 to 325 feet in Knox County.

Maryville Limestone

The Maryville Limestone is more resistant to erosion than overlying and underlying shale formations and typically forms a low ridge or series of knobs near the middle of Conasauga strike valleys. The formation is thicker and contains less shale in the southeastern part than it does in northern and western parts of the county.

The limestone is generally thick bedded, medium to dark gray and aphanitic to finely crystalline. Thin beds are common in parts of the section as are beds of oolitic and intraclastic limestone. On the Bearden quadrangle Cattermole (1960) reported oolites up to one-fourth inch across, but these may be *Girvenella* (Harris, 1972, personal communication). Cattermole divided the Maryville into a thick-bedded lower part and a thin-bedded shaly upper part on the Knoxville and Bearden quadrangles (1958, 1960).

The thickness of the Maryville Limestone ranges from 700 feet on the Boyds Creek quadrangle (Swingle and others, 1967a) to 250 feet on the Fountain City and Bearden quadrangles (Cattermole, 1966, 1960).

Nolichucky Shale

The Nolichucky Shale consists of dark-gray, grayish-red, yellowish- to olive-green calcareous shale that weathers to olive green and yellowish brown. Numerous beds of oolitic and intraclastic limestones, as well as stromatolitic bioherms (fig. 2) and cobbly-weathering limestones are interbedded with the shale. A detailed section of the upper part of the formation is given in the Appendix (Field Trip 2, Stop 2).

From limited data it is apparent that depositional strike of the formation in Knox County is not concordant with structural strike. Cattermole (1958, 1960) separated the Nolichucky into two facies on the Knoxville and Bearden quadrangles. On the Saltville thrust block northeast of Third Creek and in Hines Valley on the Beaver Valley thrust block the Nolichucky is mostly shale and thin interbedded limestones, with two or three 15- to 50-foot thick limestones in the upper part of the formation. Southwest of Third Creek along the hanging wall of the Saltville fault the Nolichucky, ". . . contains a high proportion of interbedded limestone in the lower part and is almost entirely blue-gray limestone in the upper part (Cattermole, 1960)."

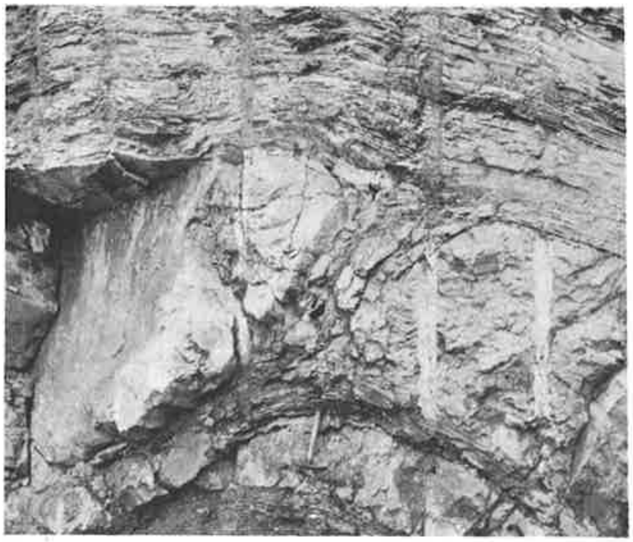


Figure 2. Stromatolites in Nolichucky Shale on northwest flank of Copper Ridge, I-75 (Field trip 2, Stop 2).

Southeast of Knox County, in Union Valley, Blount County, the Nolichucky consists of three parts, " . . . the lower 500 feet and upper 350 feet predominantly shale with thin interbeds of fine-grained limestone, and a middle limestone member about 150 feet thick (Neuman, 1960)." Some of the middle limestone member is thin bedded and fine grained; other beds are calcarenites or are oolitic. Cattermole (1955) recognized a similar three-fold subdivision of the Nolichucky in the Union Valley strike belt, Shooks Gap quadrangle, with about 95 feet of crystalline limestone in the upper half of the formation.

The Union Valley strike belt is a southwest continuation of the Beech Springs-Bailey School area in adjacent Sevier and Jefferson counties, where Oder and Bumgarner (1961) recognized a thick stromatolitic bioherm in strata which they classified as Maynardville. Elsewhere in the Valley and Ridge, shales intervene between the stromatolites and solid limestones of the Maynardville and the bioherms are within the Nolichucky (for example, Oder and Milici, 1965). Thus, there is a complex facies relationship between the Nolichucky and Maynardville involving the position of stromatolitic bioherms, the top of the Nolichucky is not everywhere the same, and it seems likely that some of the thick Nolichucky limestones mapped by Neuman (1960) and Cattermole (1955) are related to the Maynardville stromatolitic bioherms described by Oder and Bumgarner (1961).

The Nolichucky Shale ranges considerably in thickness, from 750 feet in the southern and western parts of the county to as much as 1400 feet on the Knoxville quadrangle (Cattermole, 1955, 1958, 1960). Cattermole reported 600 to 800 feet for the formation in northern and eastern Knox County (1966a, 1966b).

Maynardville Limestone

The Maynardville Limestone has long been regarded as lithologically transitional between the shales of the Nolichucky and dolomites of the Copper Ridge. Both contacts of the Maynardville have been selected differently by different workers, and an excellent summary of ideas concerning the formation is given by Bridge (1956, p. 11-17).

Bridge considered the Maynardville as a member of the Nolichucky Formation, and placed its lower boundary, " . . . at that level in the section above which limestone predominates over shale (1956, p. 13)," the criterion which Oder and Bumgarner (1961, fig. 2) followed in their studies of Maynardville stromatolitic bioherms. In contrast, Tarkoy excluded any shale beds greater than 2 feet thick from the Maynardville and placed the top of the Nolichucky at the base of gray ribbon-mottled limestones (1970, fig. 1).

As mapped by Cattermole on the Shooks Gap quadrangle, the lower part of the Maynardville Formation consists of interbedded limestones and shales. Elsewhere in Knox County Cattermole excluded shale from the Maynardville and selected the lower boundary below the massive ribboned or mottled limestones, at least that's where he shows it on the stratigraphic columns for the Fountain City and John Sevier quadrangles.

The upper contact of the Maynardville is commonly placed between dark-gray coarsely crystalline dolomite of the Copper Ridge and underlying crystalline limestone or ". . . fine-grained, thin bedded well stratified light colored non-cherty unfossiliferous somewhat calcitic dolomite (Bridge, 1956, p. 13)." Oder and Bumgarner (1961, table 1) recognized similar lithologic differences at the Maynardville-Copper Ridge boundary in the Beech Spring-Bailey School area, and in addition they described a 2- to 6-foot thick sandstone at the base of the Copper Ridge. Near Morristown, Oder and Milici (1965) mapped the top of the Maynardville at the top of the straticulate dolomite member and below thin (generally less than one foot) sandstones and similar boundary was used by Swingle and others (1967a) for similar boundary was used by Swingle and others (1967) for the top of the Maynardville on the Boyds Creek quadrangle.

In the Clinchport fault belt west of Knox County, Tarkoy used an arbitrary criterion proposed by Miller and Fuller (1954) and he placed the Maynardville-Copper Ridge boundary where strata characteristic of each of the formations are in approximately equal amounts.

Cattermole in his maps of the Knox County area appears to have mapped the Copper Ridge-Maynardville boundary differently than other workers. He placed the base of the Copper Ridge at the base of dark-gray dolomites that contain chert and included some dark-gray thick-bedded dolomites in the top of the Maynardville.

In spite of differences of opinion regarding boundaries the Maynardville consists of two widely recognized members, a lower limestone unit and an upper dolomite unit. The lower ribboned or mottled limestone member has more lithologic variation than reported by Cattermole, and in places contains stromatolites, oolites, and intraclasts (Tarkoy, 1970, p. 310, and Field Trip 2, Stop 2, this volume). This unit corresponds roughly to the division in southwestern Virginia called the Low Hollow Member (Miller and Fuller, 1954). The upper dolomite unit, approximately equivalent to Miller and Fuller's (1954) Chances Branch Member, consists of gray straticulate dolomite, and in Knox County contains chert-free dark-gray crystalline dolomites at the top.

The thickness of the Maynardville Formation ranges from 180 to as much as 400 feet in Knox County and adjacent areas; Oder and Bumgarner (1961) measured 582 feet of Maynardville in the Beech Springs-Bailey School area; Bridge (1956, p. 13-14, 29) described 315 feet of Maynardville at its type section in Union County and 303 feet in the section along Loves Creek, Knox County (John Sevier quadrangle).

KNOX GROUP

In Knox County the Knox Group consists of some 2,600 to 3,000 feet of strata, mostly dolomite but with some interbeds of limestone and a few zones of quartz sandstone, which are classified into the Copper Ridge, Chepultepec, Longview, Kingsport and Mascot formations. The Cambrian-Ordovician systemic boundary is within the group at or near the top of the Copper Ridge. Regionally, the Knox is dolomite to the west and limestone to the east, and on the Pulaski block in northeastern Tennessee the limestone phase of the Knox is divided into the Conococheague (Cambrian) and Jonesboro (Ordovician) limestones (Rodgers, 1953).

The Knox weathers to a deep, grayish-orange cherty residuum which underlies low, wide ridges between Conasauga and Chickamauga strike valleys. The Copper Ridge and Longview dolomites underlie the most prominent ridges, and Nubbins Ridge, Blackoak Ridge and Copper Ridge, are persistent topographic features across the county.

The Knox has been studied and subdivided since the time of Ulrich (1911), but it was the development of the Mascot-Jefferson City zinc district which provided the impetus for the stratigraphic studies of Oder (1934), Bridge (1956) and Harris (1969) as well as the extremely detailed studies of the zinc company geologists. Both Rodgers (1953) and Bridge (1956) present a detailed discussion of Knox terminology that need not be repeated here.

In some places in Knox County, Cattermole divided the Knox Group into the Copper Ridge, Chepultepec, Longview, Kingsport and Mascot formations. More commonly he combined the Kingsport and Mascot into the Newala Formation (Rodgers, 1953). Thus subdivided, the group consists of some formations which were named and described from exposures in eastern Tennessee and others that were named from exposures in Alabama and then correlated by fossils into the Knox County area.

Paleontologic correlations within the Knox from type sections in Alabama and Tennessee are at best inaccurate and for this group, too, different workers used different boundaries for the same formations. In an attempt to reduce inacccuracies and to simplify the difficult task of mapping the group, Harris (1969) revised the nomenclature and stratigraphic boundaries of the upper part of the Knox. He discarded the Longview Dolomite and lowered the contacts for the Kingsport.

Harris' revision (1969) of the Knox stratigraphy into the Copper Ridge, Chepultepec, Kingsport, and Mascot formations is now used north of Knoxville (Brent, in press). However, this text is largely a compilation of the older works of Cattermole and Bridge and the discussion herein conforms to their maps.

Copper Ridge Dolomite

The Copper Ridge Dolomite is the youngest Cambrian formation in eastern Tennessee. Only cryptozoa have been found in the Mascot-Jefferson City zinc district, but because Late Cambrian fossils are in the formation elsewhere in eastern Tennessee, the top of the Copper Ridge is generally regarded as close to the Cambrian and Ordovician systemic boundary. Bridge (1956, p. 42-45) discussed the paleontologic basis for the Cambro-Ordovician boundary in considerable detail, and the interested reader is referred to that paper. Like the base of the formation, the upper contact of the Copper Ridge was placed differently by different workers until that problem was resolved by the field conferences of the forties. The conferences resulted in arbitrary placement of the base of the Chepultepec at the base of a prominent sandstone zone but above oolitic chert beds of the Copper Ridge (Rodgers, 1953, p. 61; Bridge, 1956, p. 27). Thus defined, the Copper Ridge ". . . could be logically divided into two members: a thick lower member composed mainly of dark thick-bedded cherty dolomite, and an upper member consisting of light-colored thinner bedded dolomite, also chert-bearing and containing many arenaceous beds (Bridge, 1956, p. 33)."

Cattermole recognized the same general subdivisions in Knox County. The medium- to dark-gray dolomites of the lower member are medium to coarse crystalline and generally thick bedded. Some beds freshly broken give an asphaltic odor. Stromatolite (cryptozoan) reefs or bioherms are common in the lower member and in numerous places algal structures are chertified and are in the residuum. Several varieties of cryptozoa were described by Bridge (1956, p. 32). Dolomites of the upper member of the Copper Ridge are generally lighter colored gray and thinner bedded than those of the lower member, although in places the two lithologies are interbedded.

Bridge (1956, p. 31-32) described the residual clay, chert and sandstone of the Copper Ridge in detail. The clays are orange or red; most of the residual chert is dull, opaque, grayish white and is stained yellow, red and black by iron and manganese oxides. Some of the chert is oolitic and the oolites are fine to coarse grained. Weathered punky and friable sandstone blocks are in residuum above the upper 200 feet of the Copper Ridge on the Bearden and Knoxville quadrangles (Cattermole, 1958, 1960). Dolomitic sandstones 1 to 3 feet thick are in the upper 100 feet of the Copper Ridge on the Fountain City and John Sevier quadrangles (Cattermole, 1966a, 1966b).

Collins (1958, p. 172-183) studied the petrology of the basal Copper Ridge sandstones regionally in eastern Tennessee. The sandstones are quartzose or feldspathic, with feldspar in percentages as high as 28.1. The sandstones become thicker, coarser, more poorly sorted, and less well-rounded to the north and northeast. Percentages of feldspar and modified igneous and metamorphic quartz increase in the same directions and Collins concluded that the principal source of the basal Knox sandstones lay north and northeast of eastern Tennessee.

Some of the best exposures of the Copper Ridge in Knox County are on the John Sevier quadrangle along Loves, Woods, Strong, and Roseberry creeks. Bridge (1956, p. 28-29) described the Copper Ridge at the Loves Creek section. There the formation is 943 feet thick. The lower 298 feet are mostly light-gray dolomite in beds 1 to 3 feet thick. Next are 106 feet of dark-gray and brown, fine- to medium-crystalline dolomite in beds 10 inches to 2 feet thick. The rock contains irregularly laminated masses of chert, dark-gray to black where fresh, and light-gray where weathered. Then there are 66 feet of medium-gray to brownish-gray dolomite in beds 10 inches or more thick. These contain platy black semitranslucent chert which is associated with beds of silicified cryptozoa. Above these beds are 375 feet of lighter gray dolomites which are interbedded with a few dark-gray or brown beds. Some beds 1 to 3 inches are interstratified with other layers 5 to 8 inches thick. The zone contains several beds of honey-colored chert. The uppermost unit consists of 98 feet of dolomite and arenaceous dolomite which weathers to a sandy residuum. Distinctive oolitic chert beds 44 to 96 feet below the top of the formation are key beds which Bridge correlated with the Thorn Hill section.

The Copper Ridge is remarkably consistent in thickness in Knox County. Cattermole reported a thickness range in the 5 quadrangles he mapped from 900 to 950 feet. The formation is apparently a little thicker to the southeast, where Swingle and others (1967a) reported 1100 feet on the Boyds Creek quadrangle.

Chepultepec Dolomite

The Chepultepec Dolomite consists mainly of light-gray finely crystalline dolomite. Some beds are pinkish brown or yellowish brown. The lower one hundred feet of the Chepultepec contains thin sand beds (Bridge, 1956, p. 38) and in Knox County Cattermole mapped the lower boundary of the formation at the base of a prominent 2- to 8-foot sandstone which is between coarsely oolitic cherts of the Copper Ridge and cherts characteristic of the Chepultepec. Cummings (1960) studied the basal Chepultepec sandstone throughout the Valley and Ridge of Tennessee. He classified the sandstone as orthoquartzite or quartzose sandstone and observed such sedimentary features as rain prints, cross-beds and ripple marks. The areal distribution of Chepultepec heavy minerals, which are in quantities less than 0.01 weight-percent, suggests a north and northwestern provenance for Chepultepec sands. Cummings suggested that the sandstones may have resulted from a late Cambrian regression; however a depositional model for these beds has not yet been made.

The basal sandstone is near the middle of an arenaceous zone some 200 feet thick which spans the Copper Ridge-Chepultepec boundary and Bridge (1956, p. 44) noted that there was little physical evidence for a disconformity between the two formations. Cummings (1960, p. 228) also described the Cambro-Ordovician boundary as conformable. However, Oder and Ricketts (1961, fig. 2) illustrate a disconformity between the formations in the Mascot-Jefferson City zinc district.

The upper boundary of the Chepultepec of Bridge (1956, p. 37) and Cattermole (1955, 1958, 1960, 1966a, 1966b) is difficult to pick on a lithologic basis; rather those geologists (and many others) relied considerably on residual cherts, fossils, and on topography to locate the formational boundary.

Chepultepec cherts are of several varieties; Bridge (1956, p. 40) described them in detail, and a synopsis is given here. Some dull orange-red cherts are in flattened oval nodules 8 inches across and 2 inches thick. Others are dull gray, reddish brown, granular and porous, containing irregular branching tubes. The cherts characteristic of the Chepultepec, however, are light colored, white, yellowish gray or yellowish brown and are lightweight, porous, soft and mealy, and many of these are dolomoldic. In general, the Chepultepec cherts are moderately fossiliferous, although silicified cryptozoans such as those in Copper Ridge residuum are virtually absent.

The Chepultepec is fairly well exposed along Loves Creek (John Sevier quadrangle) and Bridge published a measured section for the lower 85 feet of the formation (1956, p. 27, 28). There the lower beds are poorly exposed arenaceous dolomites which are covered with residual soils containing sandstone blocks. Some residual cherts are oolitic; others are white, compact and platy. The base of the formation is marked by 8 feet of medium-grained sandstone.

Like the Copper Ridge the thickness of the Chepultepec is fairly consistent in Knox County, and according to the mapping of Cattermole ranges from 725 to 880 feet.

Longview Dolomite

The Longview Dolomite was abandoned by Harris (1969, p. 8) in his revision of upper Knox stratigraphy, and he redefined the boundaries of the Kingsport and Mascot.

Table 2 compares the Knox stratigraphy of Bridge (1956) and Harris (1969) in terms of the Lee Valley section, Hawkins County, (Rodgers, and Kent, 1948) and the Thorn Hill section, Grainger County, Tennessee. The Thorn Hill section was described by Hall and Amick (1934), and has since served as the standard reference section for the Knox Group in eastern Tennessee.

The Longview of Bridge and Cattermole is thin- to thick-bedded, fine-grained, saccharoidal, light-gray dolomite similar to that of the Chepultepec. Aphanitic light-gray limestone beds are in the upper half or third of the formation. In some places coarser grained, granular gray dolomite called "recrystalline" in the Mascot-Jefferson City zinc district replaces the finer grained dolomite and aphanitic limestone; recrystalline is commonly associated with zinc mineralization in the Knox.

The Longview commonly weathers to a light-gray residual soil with abundant large irregular masses of chert. Chert characteristic of the formation is white, light pink, brown or gray in masses up to 2 feet across. The chert is brittle and readily breaks into small splinters (Bridge, 1956, p. 48). Because chert is more abundant in both the Copper Ridge and Longview than in the Chepultepec, the Chepultepec lies in a valley between low ridges.

The boundary between the Longview and Kingsport of Bridge (1956, p. 47) is at the base of an aphanitic, semilithographic, moderately fossiliferous limestone from 25 to 50 feet thick. However, the formation was mapped generally in Knox County and adjacent areas by means of its characteristic residuum. The Longview-Kingsport boundary was described as conformable by Bridge (1956) but as disconformable by Oder and Ricketts (1961, p. 6-7, fig. 2). Oder and Ricketts (1961) related unmineralized, "dry" breccias to uplift and development of a paleokarst topography on the upper part of the Longview.

The Longview Dolomite ranges from 250 to 450 feet thick in Knox County (Cattermole, 1955, 1958, 1960, 1966a, 1966b). In general, the formation is thinner to the southeast and thickens across the county to the northwest.

Kingsport Formation

The Kingsport Formation of Bridge and Cattermole consists of limestone and two types of dolomite; some beds are very fine grained and light gray and other beds are the more coarsely crystalline, granular gray recrystalline variety (Bridge, 1956, p. 54). Bridge described Kingsport limestones as thick bedded, aphanitic, sublithographic and in shades of gray or brown. Some Kingsport limestones contain beds of intraformational conglomerate; others consist of fine pellets or oolites (Harris, 1969, p. 9).

Algal stromatolites are an important constituent of the Kingsport and Harris found that beds of these fossils constitute as much as 35 percent of the formation.

Cherts of the Kingsport are in flattened light-gray nodules which parallel the bedding of some layers, and in abundant small white blocks in red or orange residual soils. Sandstones are in only small amounts in the Kingsport but they appear to persist for miles along strike (Bridge, 1956, p. 54). Harris (1969) ascribed 3 modes of origin for Kingsport cherts; primary cherts, penecontemporaneous replacement cherts, and as secondary cherts associated with the alteration of limestone to dolomite.

Alteration, formation of collapse breccias, and zinc mineralization of these breccias are important features of the Kingsport Formation, and they have been described in detail in the geologic literature (for example, Oder and Ricketts, 1961; and Tenn. Div. Geology Rept. Invs. No. 23).

Cattermole divided the upper Knox into the Kingsport and Mascot formations in some places in Knox County, based upon the chert matrix sandstone of Oder. The subdivision was made only on the Fountain City and John Sevier quadrangles, and there only on the Saltville and Beaver Valley thrust blocks. Elsewhere in the county Cattermole mapped the Kingsport and Mascot formations together and called the unit thus combined the Newala Formation (1955, 1958, 1960, 1966a, 1966b).

Rodgers (1953, p. 55) introduced the term Newala into Tennessee because Butts (1926, p. 95-99) had used the term for the Kingsport-Mascot interval in Shelby County, Alabama. However, in northwestern Georgia the Newala of Butts and Gildersleeve (1948) is above the post-Knox unconformity and in that area is a part of the Chickamauga, rather than Knox (Milici and Smith, 1969, p. 14). In the writer's opinion the name Newala should no longer be used in Tennessee because of the confusion generated by earlier workers, and because Harris (1969) revised the nomenclature and boundaries of the Kingsport and Mascot formations.

The Kingsport Formation is about 300 feet thick on the John Sevier and Fountain City quadrangles (Cattermole, 1966a, 1966b). The formation is consistent in thickness throughout eastern Tennessee and ranges generally between 200 and 320 feet (Bridge, 1956, p. 53).

Mascot Dolomite

The upper Knox stratigraphy of the Mascot-Jefferson City zinc district has been studied in considerable detail by zinc company geologists (see Oder and Miller, 1945; Crawford 1945; and Oder and Ricketts, 1961), and the reader is referred to those papers for a more comprehensive discussion of the strata.

The Mascot Dolomite generally consists of very finely crystalline gray dolomite. In places the formation contains some beds of stromatolites, and some beds are banded, laminated or mottled, gray and grayish red (see Harris, 1969, and Harris and Milici, this volume). Stromatolite beds (fig. 3) are in two varieties which may constitute as much as 25 percent of the formation (Harris, 1969, p. 17). In places the Mascot contains beds of aphanitic light- to medium-light-gray limestone in the upper part of the formation, and these beds are remarkably similar to Middle Ordovician Mosheim limestones.

Mascot cherts are gray to light colored, and are in balls and layers 2 to 6 inches thick (Cattermole, 1966a, 1966b).

Thickness of the formation ranges widely throughout the Valley and Ridge in Tennessee because of the post-Knox unconformity at its top, and in Knox County Cattermole determined the thickness of the Mascot to be about 650 feet.

Figure 3. Stratiform algal stromatolite bed in the Mascot Formation on the northwest side of Raccoon Valley along I-75.

THE POST-KNOX UNCONFORMITY

The contact between the Knox and Chickamauga groups is marked by an unconformity of regional extent. The boundary between the upper Mascot and the lowermost Middle Ordovician beds is usually marked by a change from fine-grained light-gray dolomite to gray limestone. However, in some places aphanitic limestone similar to that of the overlying Mosheim Member of the Lenoir Limestone is in the Mascot, but these commonly lack the calcite filled birdseyes of the Mosheim (Bridge, 1956, p. 58). In other places dolomites are in the basal Lenoir, either as distinct beds, or as the matrix around angular rock pebbles and larger breccia blocks of sedimentary origin. Matrix dolomite such as this is generally light greenish gray, and apparently was derived from weathering and erosion of the underlying Mascot (fig. 4).

In most places in the Mascot-Jefferson City zinc district there is little or no angularity between the Knox and Chickamauga and the contact appears conformable (Bridge, 1956, p. 57). In other places there is structural discordance between the two groups which resulted from gentle pre-Middle Ordovician folding (Finlayson and Swingle, 1962; Swingle, cited by Oder and Ricketts, 1961, p. 5-6). In many places there is ample evidence that the Knox was exposed to erosion prior to Middle Ordovician deposition, and near Knox County pre-Middle Ordovician topography of considerable relief has been described by Laurence (1944) and Bridge (1955).

In the writer's opinion it has yet to be proved that all of the upper Mascot was exposed with interruption of sedimentation throughout the southern Appalachians. Depositional environments and sedimentary models of the upper Mascot and lower Chickamauga have been made in a few places (Appendix), and it seems possible that vertical sequences across the Mascot-Chickamauga boundary reflect the horizontal distribution of time-equivalent facies, rather than record a regional hiatus. For example, upper Mascot beds may represent deposition in hypersaline lagoons landward of low islands underlain by carbonates. Seaward of these islands more normal marine conditions existed and are now represented by fossiliferous Chickamauga strata. Migration of the environments resulted in the vertical sequences now observed, and fossils reflect depositional environments rather than time.

Figure 4. Top-of-the-Knox conglomerate, Governor John Sevier Highway, on northwest side of French Broad River. Dolomite breccia blocks are in a matrix of impure fine-grained dolomite and limestone.

THE CHICKAMAUGA GROUP

The Chickamauga Group includes all strata between the top of the Knox Group and the base of the Sequatchie and Juniata formations (Swingle, 1964). The group contains many varied lithologies arranged in complex relationships, and carbonate facies are complicated by an influx of terrigenous clastics from southeastern sources.

To the east of Knox County, the Chickamauga is composed almost entirely of terrigenous sediments called Sevier (Rodgers, 1953). In Knox County Cattermole (1955, 1958, 1960, 1966a, 1966b) divided the Chickamauga Group into a number of formations. Southeast of the Saltville fault the sequence consists of the Lenoir, Holston, Chapman Ridge, Ottosee, Bays and Martinsburg formations. Between the Saltville and Copper Creek faults the Chapman Ridge is missing, Bays is replaced by Moccasin, and the sequence is Lenoir, Holston, Ottosee, Moccasin, and then Martinsburg. Northwest of the Copper Creek fault in Raccoon Valley, the Lenoir, Holston and Ottosee are not recognizable as formations and Chickamauga limestones in many ways similar to those in Sequatchie Valley or in the Central Basin are interbedded with Moccasin-like mudstones. The Raccoon Valley strike belt has been described in detail by McLaughlin (this volume).

Lenoir Limestone

The Lenoir Limestone consists of medium-gray, medium- to thick-bedded, argillaceous and silty, fossiliferous limestone. In fresh cuts the rock is mottled shades of gray and brownish gray and is finely crystalline. Because clay and silt are concentrated along irregular bedding planes the beds weather nodular or cobbly. Clay and silt content generally decreases northwest across the county, and northwest of the Saltville fault the Lenoir consists of gray limestones with argillaceous partings, a few thin chert beds, and a few thin beds of yellowish-gray weathering, or mottled-gray dolomite.

Relatively pure aphanitic gray limestones are in the Lenoir, generally near the base of the formation, and where locally mappable this rock is the Mosheim Member. In places Mosheim calcilutite grades into coarser grained rock which in a few places is coarse enough to be "marble." In other places Mosheim grades or interfingers into the main body of the Lenoir with an increase in terrigenous clays and silts. Typically, the Mosheim contains an abundance of calcite-filled openings called birdseyes. Although some are small calcite-filled fossils, many structures such as these apparently are fillings of voids formed from gas bubbles generated by decomposition of organic matter, and these have been interpreted by some to be indicative of supratidal deposition (Shinn, 1968). The Mosheim Member commonly ranges up to 60 feet thick in Knox County, but is 150 feet thick in the Forks of the River (S. N. Cameron, personal communication, 1972).

The Knox-Lenoir contact is commonly sharp and almost always contains some evidence of post-Knox erosion. Even where beds at the boundary appear conformable, angular pebbles of chert in the basal Lenoir indicate that nearby beds of Knox were exposed and shedding sediment. The upper contact of the Lenoir with the Holston is commonly gradational and in places marble is interbedded with argillaceous limestones.

The Lenoir thins markedly to the northwest across Knox County. Southeast of the Saltville fault the formation ranges from 380 to 600 feet, generally decreasing both in thickness and in argillaceous content to the northwest. Northwest of the Saltville fault strata called Lenoir by Cattermole because of their position in sequence are 120 to 210 feet thick (Shooks Gap, Knoxville, and Bearden quadrangles). Where thinnest in Beaver Valley (Fountain City and John Sevier quadrangles) the Lenoir is as little as 40 feet thick and there consists mostly of the Mosheim Member (Cattermole, 1955, 1958, 1960, 1966a, 1966b).

Holston Formation

The Holston Formation consists of unmetamorphosed but generally dense coarsely crystalline limestone, known as Tennessee marble (fig. 5). Rodgers (1953) mapped calcareous sandstones of the Tellico (Chapman Ridge of Cattermole) with the Holston because they grade into and in places are interbedded with marble. Subsequently, quadrangle mapping in Knox County has demonstrated that the sandstone unit is mappable, and workers again restricted the Holston to non-sandy carbonates.

Marble ranges from shades of pink, to grayish red and reddish brown. Marble beds are commonly thick to massive and much of the formation is nearly pure calcium carbonate. Beds of shaly and nodular limestones are not unusual, and in places are interbedded with marble. Some beds are abundantly fossiliferous, with fragments of bryozoans and crinoids among those of other fossils, all in a calcarenite matrix. In some beds cephalopods are up to a foot or more long and these are commonly filled with white calcite spar. Some weathered marble outcrops show crossbeds; stylolites are abundant.

The Holston is not a persistent unit and in places grades laterally into surrounding Ottosee shales and Chapman Ridge (Tellico) sandstones. Southeast of the Saltville fault the Holston can be divided into two units, a lower unit composed mostly of gray, pale-orange or orange-pink marble, and upper beds that are more typically grayish red or reddish brown. Like other formations, the Holston thins markedly northwest of the Saltville fault, and there is mostly massive pink marble (Cattermole, 1955, 1958, 1960).

Rodgers (1953, p. 70-71) considered the Holston to be representative of reefs formed from algal heads, bryozoans and crinoids, that were surrounded by calcarenites. Walker and others (this volume) described Holston reef tract sediments, and the reader is referred there for detailed discussions of carbonate petrology and depositional environments of the formation.

Cattermole recognized a lower tongue of the Ottosee Shale between the Holston Formation and Chapman Ridge Sandstone throughout much of Knox County. The unit was generally too thin to be mapped and Cattermole included it with the Chapman Ridge. In places the lower tongue of the Ottosee is as thick as 70 feet (Cattermole, 1966a, 1966b) but elsewhere in the county it is more commonly 20 or 30 feet thick. In many places the upper contact of the Holston is gradational with the lower tongue of the Ottosee, and where those beds are absent Holston may be gradational with Chapman Ridge. In other places weathered Holston contrasts markedly with weathered Chapman Ridge and, " . . . the contact creates the impression of a striking unconformity (Rodgers, 1953, p. 70)."

Holston thicknesses range widely in Knox County, from where it grades into adjacent strata up to as much as 525 feet on the John Sevier quadrangle. Cattermole (1958) observed that some thickness variations may result from small scale faulting within the formation, but other changes are stratigraphic.

Figure 5. Abandoned marble quarry in Forks of the River district; marble was quarried from within the Holston Formation.

Chapman Ridge Sandstone

The Chapman Ridge Sandstone was named by Cattermole (1955) for strata previously called Tellico in the Knoxville area, and he selected a type section along Alcoa Pike where that road cuts through Chapman Ridge south of Looney Island, Knoxville quadrangle.

Cattermole (1955) justified renaming of the unit because, ". . . of the current belief that the sandstone in the Knoxville area, now included in the Chapman Ridge sandstone, does not correlate with the Tellico sandstone at its type locality on the Tellico River." However, he provided no data to prove his contention. Cooper (1956, p. 93) suggested that "fossils" show that type Tellico is older than strata called Tellico in belts north of Athens, Tennessee.

Neuman (1955) redefined much of the stratigraphy in the Tellico-Sevier belt to the south and east of Knox County, and in effect extended the name Tellico to include rocks previously mapped as Sevier. The machinations of Neuman, Cooper and Cattermole were rejected by Swingle and others (1967a) as unnecessary; they retained the name Tellico for the Chapman Ridge of Cattermole (1955), and the name Sevier for the Blockhouse and Tellico of Neuman (1956).

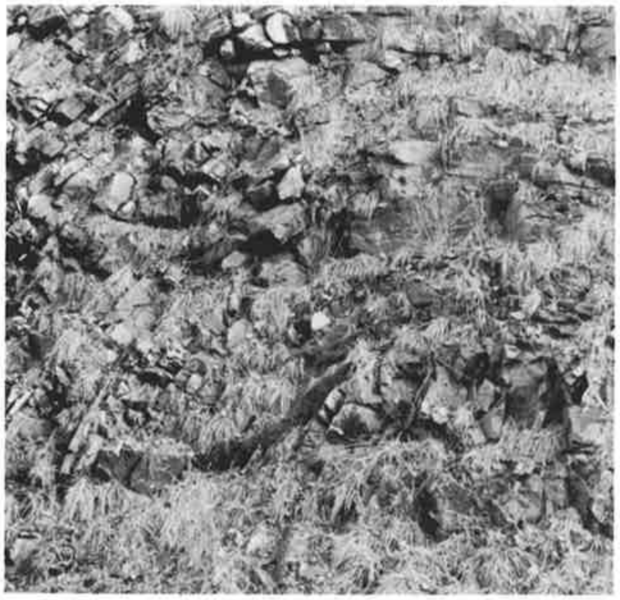


Figure 6. Fold in the Chapman Ridge Sandstone, Alcoa Pike.

The Chapman Ridge Sandstone of Cattermole (Tellico of Swingle and others, 1967a) includes all of the strata between the lower tongue of the Ottosee, or Holston where the lower tongue is missing, and the base of the main body of Ottosee Shale. The Chapman Ridge consists mostly of fine- to medium-grained calcareous sandstone; some beds contain fossil fragments. The formation is commonly well bedded and in places is crossbedded. Unweathered calcareous sandstones are dark greenish gray, but these weather to punky reddish-brown hematitic saprolite. The sandstones contain subordinate amounts of gray or olive-gray calcareous shales and silty shale that weathers to yellowish-gray or reddish-brown soils.

Chapman Ridge shales are similar to those of the Ottosee, both above and below, and the interbedding of the two lithologies is indicative of the facies relationships between these two formations. Marble similar to that of the Holston is not uncommon within the main body of the Chapman Ridge, but was mapped separately only in southern Knox County along Stock Creek Ridge (Cattermole 1962).

The Chapman Ridge ranges considerably in thickness; generally it is between 600 and 900 feet in southeastern Knox County; northwest of the Knoxville fault the formation may be as thick as 500 feet, but elsewhere grades into sandy Ottosee shales.

Ottosee Shale

The Ottosee Shale consists of a heterogeneous mixture of fossiliferous shale, siltstone, some sandstone, and marble similar to that of the Holston. The type locality of the formation (now poorly exposed) is in Knoxville, in Chilhowee Park near Lake Ottosee (Ulrich, 1911). Shales are shades of brown, brownish gray or medium to dark gray where unweathered and contain crystals of calcite or pods or thin laminated beds of limestone. Weathered shale is generally yellowish gray or yellowish brown. Ottosee limestones range from coarse and argillaceous to relatively pure aphanitic material that is similar to the Mosheim. Thin beds of pink and grayish-red marble like those of the Holston are scattered throughout the formation, but in places southeast of the Saltville fault they are as much as 200 feet thick and were mapped by Cattermole (1955, 1958) as a separate member.

The Ottosee is mostly shale on the Shooks Gap quadrangle, but limy shale and discontinuous limestone lenses are important constituents of the main body of the Ottosee southeast of the Saltville fault on the Knoxville and Bearden quadrangles. Northwest of the Saltville fault, near Dead Horse Lake, Bearden quadrangle, the Chapman Ridge grades into the Ottosee Shale and is represented by fossiliferous thin- to medium-bedded sandy red limestones. In the next belt to the northwest, in Beaver Valley , lower Ottosee is aphanitic to finely crystalline limestone, with shale and thin slabby gray limestones above.

The main body of the Ottosee ranges from a maximum thickness of 2000 feet on the Boyds Creek quadrangle to about 700 feet on the John Sevier quadrangle.

Bays Formation

The Bays Formation is only in two synclinal structures in Knox County, one through the center of Knoxville, between Marble City and Park City, Knoxville quadrangle, and the other on the Shooks Gap and Boyds Creek quadrangles, in the belt northwest of the Dumplin Valley fault. Only in the latter is the formation complete, and there upper beds are preserved at the base of the Martinsburg near Johnson Bible College, Shooks Gap quadrangle.

The Bays consists mostly of silty, grayish-red mudstone. Beds range from a few inches to several feet thick and some bedding surfaces show well developed mudcracks. The lower part of the formation contains little or no calcium carbonate, but the upper part is calcareous.

Cattermole (1955) reported two thin zones of metabentonite, one 60 feet below and the other 80 feet below the top of the formation. He used these to correlate the Bays with Moccasin in belts to the northwest, and concluded that at least the upper boundary of the Bays was in the same position as that of the Moccasin.

The formation is about 700 feet thick on the Shooks Gap quadrangle, but only partial sections are available on the Knoxville and Boyds Creek quadrangles (Cattermole, 1955, 1958; Swingle and others, 1967a).

Moccasin Formation

In Knox County the Moccasin Formation is in three Middle Ordovician strike belts northwest of the Saltville fault, in the valley between Inskip and House Mountain, in Beaver Valley northwest of the Beaver Valley fault, and in Raccoon Valley northwest of the Copper Creek fault. In general, the Moccasin is more calcareous than the Bays, and grades westward into gray fossiliferous limestones.

On the Fountain City and John Sevier quadrangles, where the formation is complete, the Moccasin consists of three shale units separated by two limestone units. In contrast to the Bays, almost all of the Moccasin is calcareous. The limestone units are gray and fossiliferous; the upper limestone is about 60 feet thick and contains black chert. The lower limestone unit is about 230 feet thick. The upper and middle shale units are grayish red; some shales are silty and the units include some gray limestone. The lower shale unit is mostly yellowish-gray calcareous shale, but contains a few beds of grayish-red shale. Mudcracks are common in the lower part of the formation.

Two bentonites are about 25 and 90 feet below the top of the formation, and a third was recognized about 120 feet below the top.

The Moccasin-Ottosee contact appears gradational. On the Bearden quadrangle Cattermole (1960) regarded basal Moccasin yellowish-gray mudcracked shales and interbedded gray slabby limestones as transitional between the two formations.

In northwestern Knox County the Moccasin is about 950 feet thick (Cattermole, 1966a, 1966b).

A detailed section for the part of the Moccasin exposed at Diggs Gap, where I-75 cuts through Bull Run Ridge is given in the section on Field Trip 2, Stop 4. The beds described there are faulted at the top by the Copper Creek fault, but apparently are the upper shale and limestone units of the formation (fig. 7). Part of the Moccasin is also exposed in I-75 cuts through Beaver Ridge. Like the other, that section, too, is faulted and Rome is thrust over Moccasin by the Beaver Valley fault. However, the Beaver Ridge section is probably the longest continuous exposure of Moccasin in Knox County.

Figure 7. Copper Creek fault, Rome on Moccasin, I-75 at Diggs Gap (Field trip 2, Stops 3 and 4).

Martinsburg Shale

The boundary between Middle and Upper Ordovician strata lies somewhere within the Martinsburg Shale. The formation becomes more calcareous to the west and in the western part of the Valley and Ridge may be divided into a lower limestone unit and upper shale unit. Where completely developed the limestone unit is equivalent to the Nashville Group, and the writer has recognized the Hermitage, Cannon, and Catheys formations along Watts Bar Lake near Kingston. The shale unit is in places both Middle and Upper Ordovician (argillaceous limestones of the Catheys weather to shale), but where restricted most is called Reedsville and is equivalent to the Inman and Leipers formations of Sequatchie Valley. In a few places along Bacon Ridge (and its extensions) and in exposures along Watts Bar Lake (Bacon Gap quadrangle) near Kingston both Inman and Leipers lithologies are distinct and there these units are mappable formations (Milici and Wedow, in preparation).

The Martinsburg Shale crops out in three places in Knox County, in a small patch west of Johnson Bible College, (Shooks Gap quadrangle) around House Mountain (John Sevier, Mascot and Graveston quadrangles), and in Beaver Valley (Fountain City, John Sevier, and Graveston quadrangles). The formation consists of sandy shale, calcareous siltstone and thin limestone lenses. Shales and siltstones are gray to greenish gray; the limestones are light to dark gray and fossiliferous. The base of the formation is marked by a calcareous quartz sandstone bed 2 or 3 feet thick.

Cattermole (1966a) estimated the thickness of the formation to be about 700 feet in Beaver Valley, but probably because of complicated minor structures he declined to estimate a thickness for the exposures around House Mountain. The 700 feet in Beaver Valley must be a minimum because the upper part of the formation is not exposed there.

SEQUATCHIE FORMATION

Milici and Wedow (in preparation) made an extensive study of the Sequatchie Formation and its equivalents in Sequatchie Valley and in parts of the adjacent Valley and Ridge to the west of Knox County. Calcareous red mudstones, generally unfossiliferous, grade laterally into silty gray fossiliferous limestones from northern to southern Sequatchie Valley, and along the eastern Cumberland Escarpment from Rockwood to Chattanooga. The calcareous red mudstone facies is the Sequatchie, and they proposed the name Shellmound Formation for its gray limestone equivalents.

The facies boundary between the Sequatchie and Juniata is an arbitrary one (Rodgers, 1953, p. 97), depending upon presence or absence of marine fossils and the relative amount of terrigenous and calcareous materials. Historically, the boundary in Tennessee is placed west of Clinch Mountain, which contains Juniata (Rodgers, 1953; Hardeman, Miller and Swingle, 1966); however these regional geologic maps differ between Clinch Mountain and Cumberland Gap. In contrast with the compilations, detailed geologic quadrangle maps in southwestern Virginia and northern Tennessee have called Upper Ordovician red beds on Clinch Mountain Sequatchie rather than Juniata (Harris and Miller, 1958, 1963; Brent, 1963, in press). Other maps on Clinch Mountain near Knox County (Swingle and others, 1967b; Finlayson and others, 1965) called Upper Ordovician red beds Juniata, and Cattermole (1966b) called the same formation on House Mountain Sequatchie. Obviously, there is no agreement in Tennessee concerning Upper Ordovician red bed nomenclature, mainly because the regional facies and depositional environments are not at all understood.

The origin of some Tennessee Juniata may be similar to the fluvial environment ascribed to the formation in Pennsylvania (Thompson, 1970a, p. 602-603). In contrast, calcareous grayish-red and greenish-gray Sequatchie beds (described as "intertongued Sequatchie and Juniata facies" by Thompson, 1970b, (fig. 1) apparently were deposited in environments that range from open shallow marine shelf to tidal flat deposits which were in places subaerially exposed (Thompson, 1970b). Thompson's descriptions are useful providing the reader is aware that he called calcareous red beds Juniata and gray limestones Sequatchie, a distinction generally not made in eastern Tennessee.

In Knox County strata called Sequatchie by Cattermole (1966b) are exposed only on the upper slopes of House Mountain. The formation consists of about 450 feet of grayish-red calcareous siltstone, shale, and gray silty limestone, but it is deeply weathered and not well exposed. Swingle and others (1967b) described the Upper Ordovician red beds nearby on Clinch Mountain as generally noncalcareous thin- to thick-bedded siltstones and shales that are red or mottled red and green.

CLINCH SANDSTONE

Silurian strata range from Clinch and younger quartzitic sandstones on Clinch and House Mountains, through the Rockwood sandstones, siltstones, shales and limestones in the western Valley and Ridge and in Sequatchie Valley, to the shale and limestone formations of Central Tennessee. Silurian formations are usually overlain by the Devonian-Mississippian Chattanooga Shale, although in places on Clinch Mountain others beds may intervene (Wildcat Valley Formation, Dennison and Boucot, 1969).

In Knox County, House Mountain is capped by about 200 feet of quartzose Clinch sandstones. The lower 50 feet of the formation is silty sandstone in beds 1 to 4 inches thick. The remaining sandstones consist mostly of medium to coarse sand which has a siliceous cement, but there are some beds of quartz grit conglomerate. The stone is in beds 1 to 3 feet thick; freshly broken rock is commonly white, but where weathered is iron stained. About 60 percent of the beds are crossbedded (Cattermole, 1966b). On nearby Clinch Mountain in adjacent Union and Grainger counties Swingle and others (1967b) recorded quartz pebbles as large as ½ inch and the locally abundant burrows of *Scolithus* in similar Clinch strata.

TABLE I.

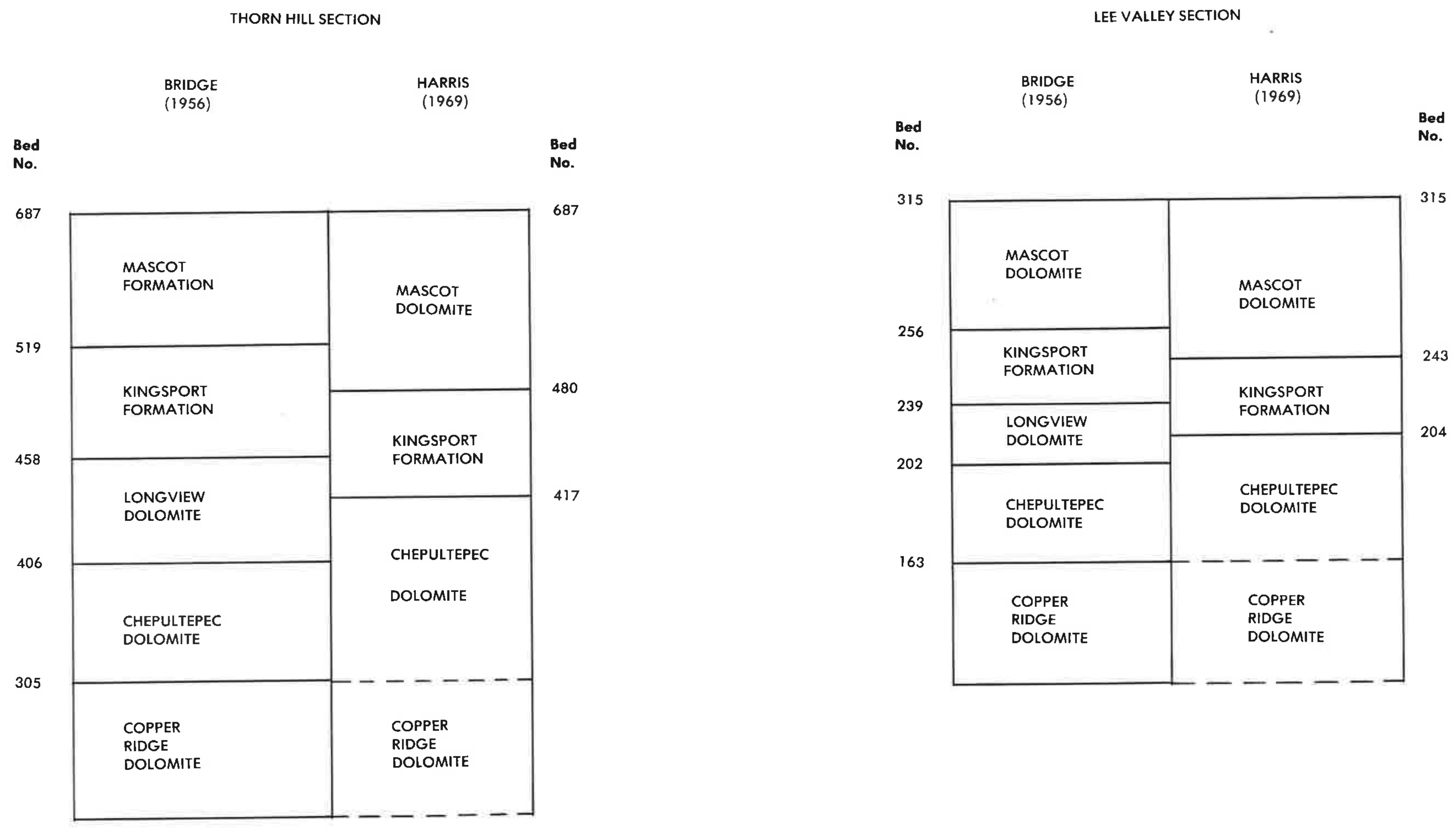
GEOLOGIC FORMATIONS OF KNOX COUNTY

Age	Name		Character	Thickness (in feet)
SILURIAN	**CLINCH SANDSTONE**		Sandstone, quartzose, with some grit conglomerate; cross bedded; white except where iron stained.	200 feet preserved
UPPER ORDOVICIAN	**SEQUATCHIE FORMATION**		Mudstone, siltstone and shale, grayish-red; and silty limestone, gray.	450
	CHICKAMAUGA GROUP	**MARTINSBURG SHALE**	Shale and siltstone, sandy, calcareous, gray to greenish-gray, and limestone, argillaceous, gray, fossiliferous.	700++
MIDDLE ORDOVICIAN		**BAYS FORMATION**	Mudstones, silty, grayish-red; some with mud cracks; calcareous in upper part; with two thin zones of metabentonite in upper part.	700
		MOCCASIN FORMATION	Mudstones, calcareous, grayish-red, greenish-gray; with shrinkage cracks, mudcracks, ostracod zones; with thick zones of fossiliferous gray limestones; with two thin metabentonites in upper part.	950
		OTTOSEE SHALE	Shale, siltstone, some sandstone, and marble; shales and siltstones are brown, brownish gray, medium to dark gray, fossiliferous, calcareous; limestones are argillaceous to pure, gray; marble is pink and grayish red.	700-2000
		CHAPMAN RIDGE (TELLICO) SANDSTONE	Sandstone, calcareous and calcarenite, arenaceous, fossiliferous, cross-bedded, dark-greenish-gray to reddish-brown; with some shale interbeds similar to those of the Ottosee, and some beds of marble.	up to 900
		HOLSTON LIMESTONE	Marble, calcarenite, fine- to coarse-grained, shades of gray, pink, red; thick-bedded; with some interbeds of nodular gray limestone; fossiliferous.	up to 525
		LENOIR LIMESTONE	Limestone, argillaceous or silty, gray, weathers nodular or cobbly, fossiliferous; with sedimentary breccias at base.	120-600
		MOSHEIM MEMBER	Limestone, aphanitic, gray, thick-bedded; with birdseyes.	up to 150
LOWER ORDOVICIAN	**KNOX GROUP**	**MASCOT DOLOMITE**	Dolomite, finely crystalline, gray, some grayish-red, laminated or mottled, with stromatolites; with some aphanitic gray limestone; with unconformity at top; with some chert.	650
		KINGSPORT FORMATION	Dolomite, very finely crystalline, light-gray; and "recrystalline" dolomite, medium- to coarse-crystalline, medium-gray; limestone, aphanitic, gray; with collapse breccias and associated sphalerite deposits; with some chert.	300
		LONGVIEW DOLOMITE of Cattermole and Bridge	Dolomite, fine- to medium-crystalline, light-gray; with limestone, aphanitic, gray, and some "recrystalline;" with abundant chert.	250-450
		CHEPULTEPEC DOLOMITE	Dolomite, fine-crystalline, light-gray; with prominent calcareous sandstone at base; cherty.	725-880

TABLE I. (Continued)

Age	Name		Character	Thickness (in feet)
UPPER CAMBRIAN	KNOX GROUP	**COPPER RIDGE**	Dolomite, medium- to coarse-crystalline, dark-gray, asphaltic, thick-bedded; with stromatolite bioherms, thin sandstones, lower part; upper part is light- to medium-gray dolomite and generally not as thick bedded; cherty, with oolites, cryptozoans preserved in residuum.	900-1100
	CONASAUGA GROUP	**MAYNARDVILLE LIMESTONE**	Lower member, limestone, ribboned or mottled; with stromatolites, oolites, intraclasts; upper member, straticulate dolomite and thick-bedded dark-gray non-cherty dolomite.	180-400
		NOLICHUCKY SHALE	Shale, dark-gray, grayish-red, olive-green, calcareous; and limestones, oolitic, intraclastic; with some stromatolites, some thin-bedded and fine-grained.	600-1400
MIDDLE CAMBRIAN		**MARYVILLE LIMESTONE**	Limestone, aphanitic to fine-crystalline, medium- to medium-dark-gray; some with oolites, intraclasts, generally thick-bedded.	250-700
		ROGERSVILLE SHALE	Shale, light-greenish-gray, pale-olive with a few beds of siltstone, limestone and dolomite.	100-325
		RUTLEDGE LIMESTONE	Limestone, gray, some argillaceous, mottled, some ribboned or banded, in places with dolomite at the top; in places with interbeds of shale.	115-325
		PUMPKIN VALLEY SHALE	Shale and siltstone, reddish-brown to grayish-red, greenish-gray and olive-gray; with thin sandstones, limestones and dolomites in some places.	100-750
CAMBRIAN		**ROME FORMATION**	Sandstone, siltstone and shale; some rippled, generally with an abundance of primary sedimentary features; gray, brown, orange, yellow, greenish gray and grayish red.	450+ - 1500+; faulted at base.
		SHADY DOLOMITE	Identified by Cattermole from Saprolite in eastern Knox County; saprolite is reddish-brown to greenish-gray clay, siliceous, with banded chert.	

TABLE 2. COMPARISON OF KNOX GROUP STRATIGRAPHY OF BRIDGE (1956) AND HARRIS (1969) AT THE THORN HILL AND LEE VALLEY SECTIONS, GRAINGER AND HAWKINS COUNTIES.



OBSERVATIONS ON THE BIOSTRATIGRAPHY AND STRATIGRAPHY OF KNOX COUNTY, TENNESSEE AND VICINITY

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INTRODUCTION

During the long history of geological investigations in the Southern Appalachians, beginning with Safford (1869), most field geologists have recognized differences, both in the distribution of stratigraphic units and in the lithologic characteristics of the belted eastern and western exposures of Early Paleozoic rocks in East Tennessee. Even so, as a matter of expediency in the construction of generalized maps for one purpose or another, such differences often have been minimized. Following similar procedures, stratigraphers have tended to rely on lithologic similarities in attempts to standardize unit terminology applicable throughout the region.

In recent times, more detailed studies of selected areas within the region have demonstrated: (1) the fallibility of type section definition of units; (2) the widespread stratigraphic distribution and commonly repetitive occurrence of several distinct lithogies within a given stratigraphic sequence; and (3) the obvious intercalation and intergradation of dissimilar rock units previously believed to be chronostratigraphically separate.

Structural grain superimposed on the region as broad to narrow anticlinal and synclinal folds and extensive parallel thrust faults has particularly complicated efforts to establish relationships between these rocks. Moreover, despite the fact that structural detail, through the efforts of Rodgers (1953), Swingle (1961), Milici (1970), and others, constitutes the best developed body of information in the region, structural interpretation on a regional basis has been largely generalized. Region-wide, synchronous, tectonic events are implied in many reports based on such data. Arguments concerning structural interpretation have been concerned mainly with depth of structural roots rather than time (Rich, 1934; Rodgers, 1949, 1950).

Over the years, the recovery and application of paleontologic data coincident with other studies of the East Tennessee section has been the exception rather than the rule. Extensive fossil collections have been removed from these rocks but detailed information has been slow to surface. Few stratigraphic studies in the Southern Appalachians have employed paleontologic evidence as a basis for either chronological determination or paleoecologic analysis except in a general way. Incidental references to specific fossils are scattered in the literature and, for the most part, are difficult to evaluate owing to inadequate locations, incomplete descriptions, or questionable identifications. The results of the singular effort by Butts (1940, 1941) to relate characteristic fossil suites to some of the regional formations have been devalued considerably by what appears to be questionable identification and interpretation of the stratigraphic position of the rock units involved.

To date, the monumental contribution on Middle Ordovician brachiopods by G.A. Cooper (1956) constitutes the sole comprehensive fossil group study pertinent to the region. Based primarily on evolutionarily significant internal shell structures, commonly obscured by misleading and widespread superficial homeomorphy in the group, this study has placed the brachiopod faunas of the region on a sound taxonomic base and corrected misidentifications by earlier workers. Experience has shown that the distribution of many brachiopods is facies-controlled, thus limiting the use of these fossils for chronostratigraphic purposes.

Unfortunately, it is not possible to treat the systematics and biostratigraphy of representatives of other major groups in the region, such as the bryozoans, mollusks, sponges, trilobites, and echinoderms, with the same degree of confidence as the brachiopods. Newer approaches through the study of the microbiota and community analysis of associated fossil assemblages in these rocks, both in the data collecting stage at present, offer distinct possibilities for the future.

Another problem concerns the difficulty involved in making comparisons between the fossil faunas of this region and those of inadequate type areas such as the Champlain and Black River valleys (Twenhofel, et al., 1954) that were chosen as North American reference standards for age determination. This problem has proved to be especially acute for workers attempting to place the Ordovician faunas in Tennessee in proper biostratigraphic position. Unreliable guide fossils, suspected misidentifications, conflicting and arbitrary stratigraphic unit definitions, unrecognized contemporaneity of contrasting facies, and low information density on all sides have all added to the complexity of the problem.

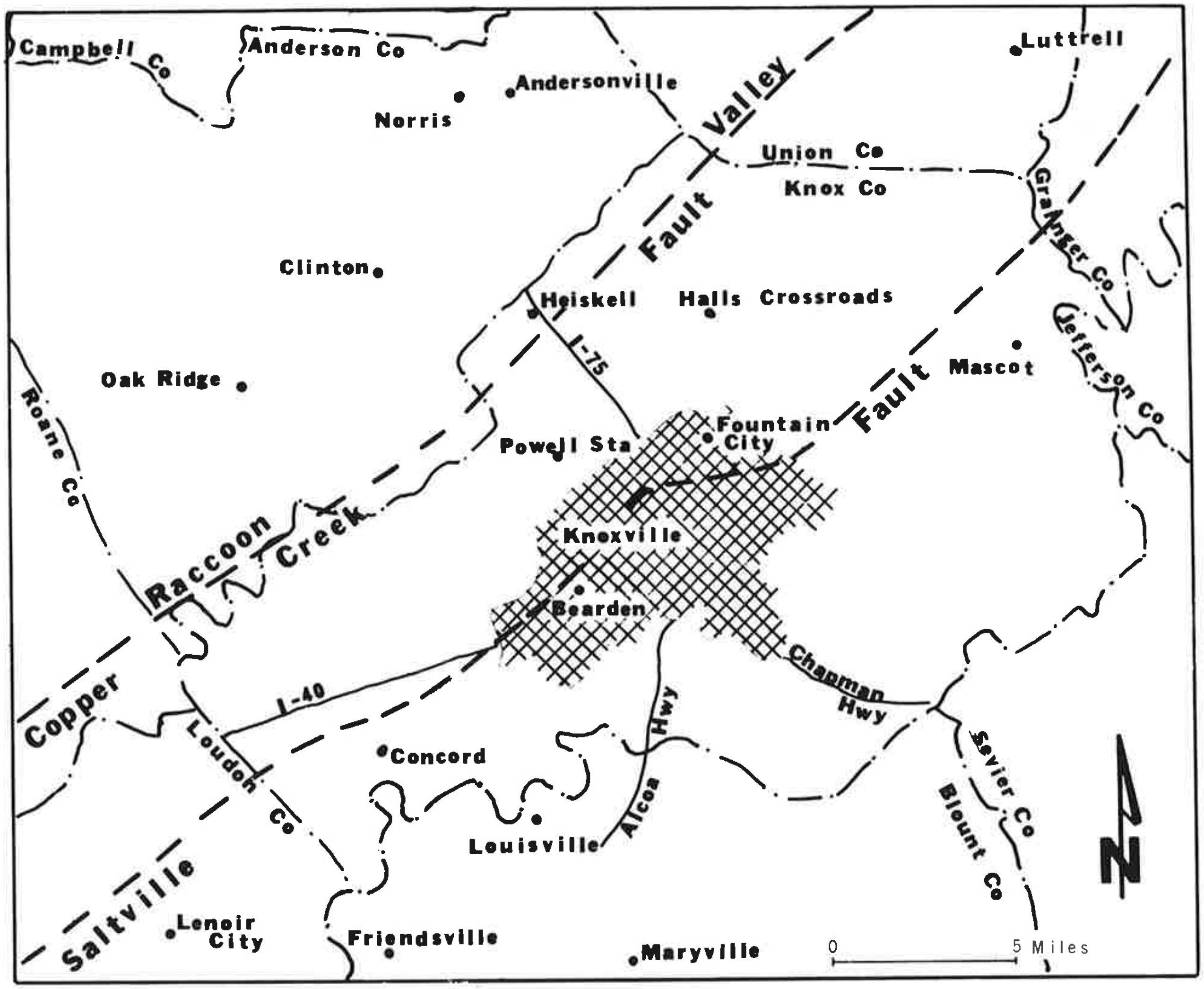

Figure 1. Map of Knox County, Tennessee and vicinity showing location of reference points cited in text.

Because of many of the difficulties cited and despite the definitive work of Wilson (1948, 1949, 1962) on the faunas and stratigraphy of the Central Basin, the few attempts to correlate contemporaneous faunal events from east to west across the state have met with little success. Recently, (Milici, 1969) has traced the long-used Middle and Upper Ordovician stratigraphic units of the Central Basin into Sequatchie Valley, and Milici and Smith (1969) have redefined the stratigraphy at the Chickamauga type area in terms of the same units. Cooper, B.N. (1945), Cooper and Cooper (1946) and Harris (1965), among others, have employed stratigraphic terminology in East Tennessee that was initially developed northeastward in the Appalachian Valley. Serious communication gaps still remain in all directions within the state and region.

Many of the problems cited above must be considered in outlining the main events, as presently known, in the geologic history of the Early Paleozoic in East Tennessee, particularly in developing that history around selected examples from the rocks in Knox County, which is the main purpose of this paper. As many workers familiar with the problems know, the section exposed in Knox County and vicinity (figure 1) incorporates a high proportion of the problems. It is hoped that this review will provide a useful frame of reference for illustrating, emphasizing, and recognizing critical gaps and unresolved questions related to the biostratigraphy of the area.

ACKNOWLEDGMENTS

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BIOSTRATIGRAPHIC PHASES

Despite the several problems cited previously, the broader aspects of the biostratigraphy and the evolution of the biota, as represented in the Knox County area, rocks have emerged. The chronologically successive phases which can be recognized by means of fossils within stratigraphic units are as follows:

- Phase I Shady/Rome through Lower Maynardville formations
- Phase II Upper Maynardville through Copper Ridge formations
- Phase III Chepultepec through Mascot/Newala formations
- Phase IV Lower Chickamauga/Mosheim through Moccasin/Bays formations

As will be developed further, Phases I, III, and IV all have two subphases which are either chronological or geographical in character or both. Phases II and III are the most consistent throughout the area in terms of geographical distribution, and except for the basal sands in the Chepultepec Formation are not clearly separated. As a matter of fact, these two phases taken together, with their restricted biotas and many comparable lithologic features, form a biostratigraphic boundary between the diverse but less advanced biota of Phase I and the diverse and highly developed biota of Phase IV.

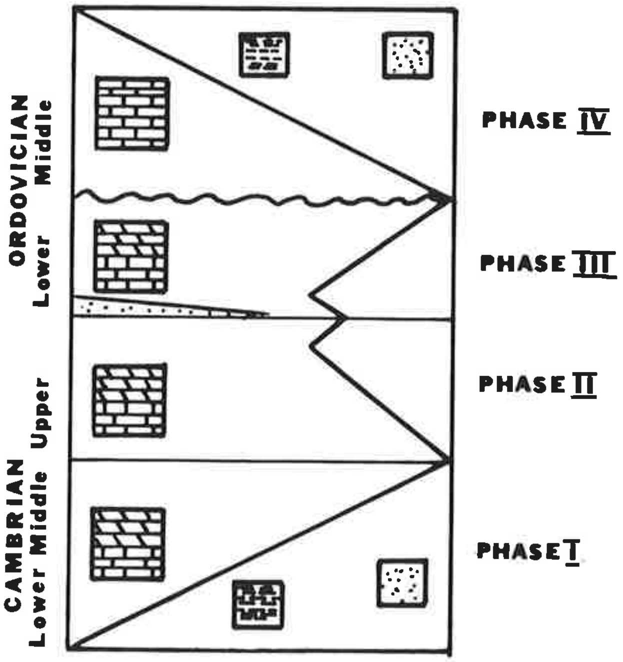


Figure 2. Biostratigraphic phases in East Tennessee.

Faunal diversity in Phases I and IV is directly related to a broad range of environments during essentially transgressive, although oscillartory, intervals. In contrast, Phases II and III represent a long regressive-transgressive interval characterized by a narrow range of biotopes that extended broadly across the sea floor represented by the Valley and Ridge province. The geographic spread of Phases II and III is matched only by the Moccasin/Bays red bed development that terminates Phase IV as included in the present paper. As shown in figure 2, a minor regression appears to approximate the boundary between Phases II and III and marks the base of the Canadian or Cambrian-Ordovician boundary which is defined poorly otherwise.

The earliest faunal relationship to the Central Basin section observed in the east occurs in the upper part of Phase III. A continuation of the gastropod/ostracode-dominated Beekmantown fauna appears in the Murfreesboro. The Murfreesboro fauna, however, as seen in the 70-foot upper portion of the formation exposed in the Central Basin (Wilson, 1949), includes apparently derived gastropod and cephalopod species, a few of which also appear in the lowermost post-Knox formations in the east. The latter and the Murfreesboro both contain the first *Valcourea-Strophomena* brachiopod group members of the Phase IV fauna as well.

In the Chickamauga type area in Georgia, Milici and Smith (1969) mapped 275 feet of Murfreesboro Limestone overlying 250-300 feet of red-mottled shales, limestones, or dolomitic limestones named by them, the Pond Spring Formation. Apparently, the boundary between Phase III and Phase IV of the present paper occurs between the *Ceratopea*-bearing beds of the Knox underlying the Pond Spring Formation and the "Mosheim-like" calcilutite of the lower member of the latter. In the same area, calcilutites bearing *Leperditia* were correlated with the Murfreesboro of Central Tennessee by Cooper, G.A. (1956, p. 55). These same beds were mapped as Murfreesboro by Milici and Smith (1969).

There are four different faunas within Phase I through III. Qualitative distinctiveness, size, and geographical extent would seem to recommend treating them as four phases or stages in biostratigraphic succession. However, the four faunas show little organic connection. The stratigraphic separation is even more pronounced due to the fact that the faunas are bounded by massive, poorly fossiliferous limestones and dolomites that occur in, or comprise entirely, the Shady, Rutledge, Copper Ridge/Conococheague and Kingsport formations. Except for rare trilobites in the Rutledge and Copper Ridge/Conococheague there is little basis on which to establish faunal continuity or phylogenetic relationships across the sedimentary intervals represented by the formations cited.

Fossilization in the upper, predominantly carbonate, Knox portion of the section is highly selective. Secondary silicification in limestone or, more commonly, the formation of internal molds in chert beds associated with dolomites have produced the only fossils present in any degree of abundance. In much of this part of the section recrystallization and dolomitization have obscured, if not eliminated, the morphological detail of the organisms probably involved in the formation of the rock. Subsequent silicification commonly reveals gross features of a few of them.

There is little evidence that solution and reworking throughout most of the Knox were significant contributory factors in isolating the stromatolite-bearing beds in the lower carbonates and the gastropod-dominated faunas in the upper Knox. The specific biota, concentration of dolomites, unique mineralization, and other consistent features favor the treatment of Phases II and III as a single developmental sequence. As such, the sequence is judged to begin and the base of Phase II is drawn in the upper part of the Maynardville Formation.

The upper Maynardville to Mascot/Newala sequence is one of the most widely distributed and persistent features of the entire section exposed in Knox County and throughout the middle belts in East Tennessee. Curiously, the biostratigraphic discontinuity that might be expected between the fauna in the upper part of the sequence and the fauna of Phase IV is not pronounced, if indeed it exists at all, in many places. Certainly there is no evidence of a prolonged, wide-spread biostratigraphic discontinuity coincident with a universally recognizable unconformity despite the fact that such a datum is commonly assumed and entrenched in the literature.

Phase IV, as it developed, resulted in the distribution of a wide assortment of facies across the miogeosyncline. Collectively the Middle Ordovician rocks exposed in Knox County and vicinity serve as a representative sample of these facies. As such, the many problems arising from the interpretation of stratigraphic relationships, the application of diverse unit terminology, and the determination of chronological equivalence of the biota as viewed in regional context all converge in the local section.

In the northeastern part of Knox County, the House Mountain structure (Cattermole, 1966b), an apparent southwestern outlier of Clinch Mountain, exposes a small amount of Clinch Sandstone and other rocks variously mapped as Juniata or Sequatchie (Rodgers, 1953; Hardeman, et al., 1966). All or part of this exposure should be included, logically, in a consideration of the post-Phase IV biostratigraphic development in the region. However, because these rocks constitute only a small fraction of the Knox County section and have provided no conclusive paleontologic information to date, they will not be included in the present survey.

The biostratigraphic range of Phase IV includes fossils recovered from rocks mapped as Martinsburg Shale, also confined to the northeastern part of Knox County. Although the Martinsburg Shale is regarded as stratigraphically higher than the Bays/Moccasin Formation, there is no compelling reason for establishing a separate phase on the basis of the limited Knox County exposures at this time.

PHASE I: SHADY/ROME THROUGH LOWER MAYNARDVILLE FORMATIONS

Compared with the dolomite-dominated and faunally impoverished strata which succeed them, the sandstones, limestones, and shales of the Cambrian Shady/Rome and Conasauga formations contain faunas of contrastingly greater variety and balance. A prolonged clastic episode commencing in the pre-Cambrian distributed a wide range of environments and associated facies east to west across the miogeosyncline.

Coincident with the sedimentary activity, a major evolutionary peak was reached by the trilobites during the interval. The highlights of this organic event are well recorded in the rocks constituting Phase I. The earlier olenellid, dorypygid, and alokistocarid trilobites were succeeded by a host of short-lived ptychoparid species which chronicle the emergence of the basic stock of subsequent trilobite evolution. The stratigraphic occurrences of principal trilobite genera in the Cambrian-Ordovician section exposed in the vicinity of Knox County are shown in table 1. Classification and range information used follows Harrington (1959).

Derivative ptychoparid trilobites occurring in Phase IV illustrate, in sharp contrast, the magnitude of development within the order during the time represented by the stratigraphic section in Knox County. Except for a few solenopleurid and bathyurid species, there is a pronounced phylogenetic and biostratigraphic gap throughout the section comprising Phases II and III.

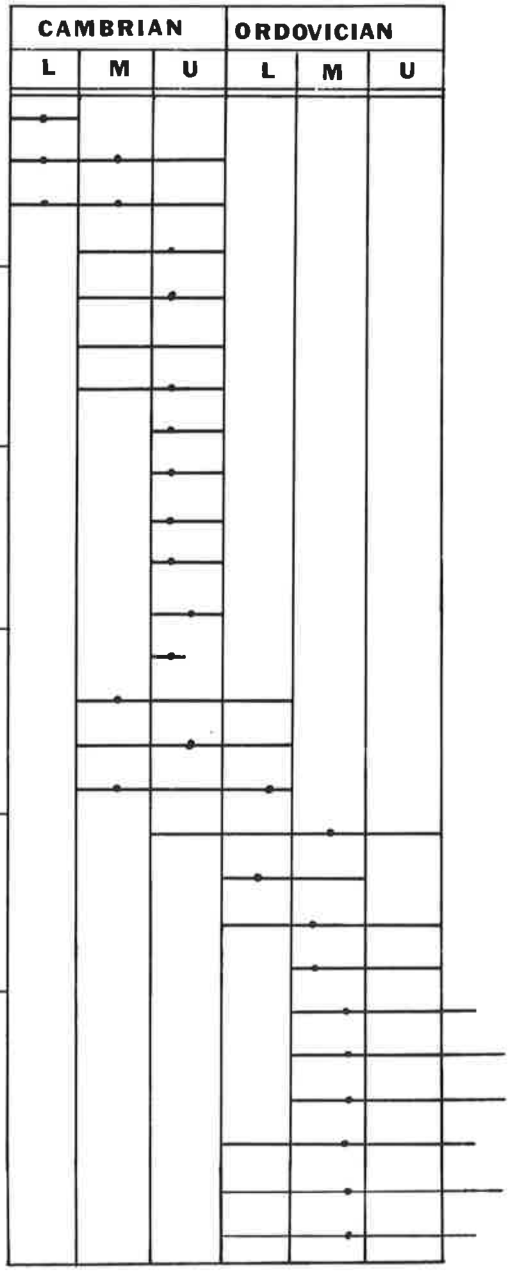
In reviewing the stratigraphic record of a number of the taxa involved in the early history of the trilobites in the Southern Appalachians, there are some discrepancies that require resolution. Both stratigraphic relationships and age determination are involved, either in analysis of the rocks in the local section or in viewing the sedimentary and biologic events in regional context.

Reports of trilobites within the Knox County section and along strike to the northeast and southwest, when compared with known ranges of a number of restricted Cambrian genera and the families to which they belong (table 1), appear to be at variance with the interpretation of the sedimentary units identified with the collection site. Most striking is the apparent indication that parts of the Shady, Rome, and Conasauga are time-related across the lower to upper Cambrian (at least to Dresbachian) stratigraphic interval. Although interpreted otherwise (Rodgers and Kent, 1948), the inter-relationship of the Pumpkin Valley Shale with the Rome below and the Rutledge and Nolichucky formations above can be established on biostratigraphic evidence through mutual sharing of alokistocarid trilobites and because the range of the genus *Solenopleurella* is confined to the Middle Cambrian.

In the Conasauga section exposed in Knox County and vicinity, the Maynardville trilobite fauna (Raymond, 1959) is distributed stratigraphically in an upper (*Aphelaspis*) zone and a lower (*Crepicephalus*) zone. The underlying Nolichucky Shale mainly contains a *Cedaria*-dominated fauna to the exclusion of all Maynardville species. The basal third of the formation features *Modocia elongata* (Walcott).

TABLE I. RANGE AND OCCURRENCE OF TRILOBITE FAMILIES AND GENERA IN EAST TENNESSEE.

Chazyan and Post-Chazyan (1) Knox Group (Beekmantown; Longview-Mascot) (2) Knox Group (Conococheague; Copper Ridge) (3) Conasauga Group (Nolichucky, Maynardville, and Rutledge Formations) (4) Pumpkin Valley Shale (5) Shady Dolomite (6) Rome Formation (7).



Family		Genera
OLENELLIDAE	*	*Olenellus* (6)(7)
DORYPYGIDAE		*Bonnia* (6), *Bonniella* (6), *Olenoides* (6)
ALOKISTOCARIIDAE		*Alokistocare* (4)(5)(7), *Dunderbergia* (4)(7), *Alokistocarella* (5)(7), *Elrathiella* (5)(7)
CREPICEPHALIDAE		*Crepicephalus* (4), *Uncaspis* (4)(7)
KINGSTONIIDAE		*Kingstonia* (4)
ASAPHISCIDAE	*	*Blountia* (4)(7), *Blountiella* (4), *Maryvillia* (4)
MARJUMIIDAE	*	*Modocia* (4)(7)
LONCHOCEPHALIDAE	*	*Glaphyraspis* (4)(7)
TRICREPICEPHALIDAE	*	*Tricrepicephalus* (4)(7)
COOSELLIDAE	*	*Coosia* (4)
PTEROCEPHALIIDAE	*	*Aphelaspis* (4)(7)
SAUKIIDAE		*Tellerina* (3)
RAYMONDINIDAE	*	*Cedaria* (4)(7), *Genevievella* (4)
AGNOSTIDAE	*	*Baltagnostus* (4)(7), *Kormagnostus* (4)(7)
NORWOODIIDAE	*	*Norwoodella* (4)(7)
SOLENOPLEURIDAE	*	*Hystricurus* (2), *Solenopleurella* (4)(7)
ASAPHIDAE		*Isotelus* (1), *Homotelus* (1)
BATHYURIDAE		*Bathyurus* (2), *Jeffersonia* (2)
PLIOMERIDAE		*Pilomerops* (1),
PTERYGOMETOPIDAE		*Pterygometopus* (1), *Calliops* (1)
ILLAENIDAE		*Illaenus* (1), *Bumastus* (1), *Nanillaenus* ? (1)
HARPIDAE		*Eoharpes* (1), *Harpes* (1), *Paraharpes* (1), *Dolichoharpes* ? (1)
LICHIDAE		*Amphilichas* (*Tetralichas*, *Acrolichas*) (1)
ENCRINURIDAE		*Cybeloides* (1), *Cybele* ? (1)
CHEIRURIDAE		*Ceraurus* (1), *Ceraurinella* (1)
RAPHIOPHORIDAE		*Lonchodomas* (1)

* Disputed ranges based on stratigraphic reports

Collectively, the Maynardville-Nolichucky zonation described above parallels the upper Middle Cambrian to lower Upper Cambrian (Dresbachian) trilobite succession in the mid-continent region. The *Cedaria* zone in the Nolichucky Shale and the overlying *Crepicephalus* and *Aphelaspis* zones in the Maynardville are above the Middle Cambrian-Upper Cambrian boundary. Using these zones as time boundaries within the Conasauga to the northeast, it has been established that the *Aphelaspis* zone, 130 feet above the Maynardville-Nolichucky contact in the vicinity of Knoxville, occurs a few feet below the same contact in the Lee Valley section. Further, the *Cedaria* zone, better than 80 feet above the contact between the Nolichucky Shale and the underlying Maryville Limestone in the Knoxville area is less than 15 feet above the same contact in the Thorn Hill section. There is obvious discrepancy between stratigraphic and time boundaries, therefore, in the Conasauga section traced northeastward.

Outside the area of primary concern in the present survey, the reports of Butts (1926, 1940) from rocks of Cambrian age in the eastern belts of the Valley and Ridge from Virginia to Alabama indicate considerable uncertainty as to the relative age of the named rock units from place to place. For example, except for *Olenellus,* all of the trilobites described by Butts as characteristic of the Rome Formation in Virginia are distinctly Middle Cambrian in age. Furthermore, presuming proper recognition of the formation and accuracy in the collection and identification of the fossils, to treat the Rome Formation as exclusively Early Cambrian in age requires extending the Middle Cambrian ranges of three orders of trilobites, well established on a worldwide basis. On the other hand, to regard the Rome as entirely Middle Cambrian in age would amount to an even more unlikely extension of the range of *Olenellus* and another Rome associate from Virginia to Alabama, *Archaeocyathus,* fixed in Early Cambrian time the world over. Rodgers and Kent (1948) separated the formation in Tennessee and re-named the upper part the Pumpkin Valley Shale.

In the view of the writer, there is ample evidence to support a re-casting of the lithologic units comprising the clastic-carbonate section which represents the major part of the Cambrian system in the Knox County area and in both east-west and north-south directions therefrom. As a consequence, it may be possible to establish the distribution and time relationships of the constituents of this lithosomal complex in a much more natural order than the conventional presentation of the units involved.

Scattered occurrences of echinoderm plates and dendroid graptolithinids in shales of the Rome-Conasauga transition further illustrate the diversity of the Phase I fauna as seen in the Knox County area. These few fossils also serve to emphasize the need for information concerning other elements in the fauna.

Except for rare specimens of *Olenellus thompsoni* (Hall), the Rome Formation in many Knox County area exposures has yielded little paleontologic information beyond the trace variety: tracks, trails, "fucoids," possible worm tubes and "nests." Bedding plane surfaces occasionally display *Rusophycus, Cruziana,* and *Diplichnites* track and "nest" types (Seilacher, 1958; Hantzchel, 1962) believed to be associated with trilobite activity.

Few elements of the Phase I fauna as reported elsewhere in the Appalachian region have been found in the Knox County area. The stratigraphic position of many of the fossils, if correctly interpreted, further underscores the need for re-examination of the entire sedimentary complex as noted earlier.

A number of inarticulate brachiopods (*Obolus, Paterina, Wilmanella, Acrotreta*) and the molluscan *incertae sedis, Salterella* and *Hyolithes,* have been recorded from the Rome (Woodward, 1929) (Resser, 1938) (Butts, 1941). Inarticulates referable to at least two of the genera named and *Hyolithes* occur in the *Cedaria* zone of the Nolichucky Shale in the Knoxville area.

The Shady Dolomite fauna appears to be largely restricted to the eastern belts. The brachiopods, *Nisusia* and *Kutorgina,* among the oldest calcareous brachiopods known (Cooper, 1956), and the trilobites, *Poliela, Amecephalina, Prozacanthoides, Zacanthoides, Kootenia, Proliostracus* and *Austinvillia* along with the gastropod *Helicionella* (Butts, 1941) have not been reported in the western belts. The trilobites, *Ptychoparella, Glossopleura, Anoria,* and *Acrocephalops* in the Rome, and *Terranovella, Proagnostus,* and *Oedorhachis* in the Nolichucky, as well as the inarticulate brachiopods in the latter formation, all variously recorded by Woodward (1929), Resser (1938), and Butts (1941), apparently do not appear as far west as the Knox County section.

PHASE II: UPPER MAYNARDVILLE THROUGH COPPER RIDGE FORMATIONS

The stratigraphic sequence above the trilobite-bearing beds of the Nolichucky Shale and lower Maynardville, and below the basal sandstone beds of the Chepultepec Dolomite represents the uppermost part of the Cambrian System in the Knox County area. By comparison with the previous sequence, a very different biostratigraphic interval is embraced by these rocks, consisting of between 950′ and 2050′ (as measured by Oder and Hook, 1950, in northern Knox County and elsewhere) of dark to light gray, laminated limestone and fine- to coarse-grained dolomite with mudstone partings. Within the carbonates, stratified chert lenses and beds provide one of the distinctive features of the sequence which is in many respects remarkably uniform.

Silicification commonly reveals the essential character of parts of the sequence in the form of cryptozoan masses and nodules, large stromatolitic mounds and laminated encrustations in apparent growth position, and shell debris with oolites. The last have been noted along the undulatory upper surfaces of the carbonate beds commonly in contact with mudcracked and crossbedded calcareous siltstone.

The record of graptolithinids in the Phase II fauna (Decker, 1949; Decker and Gold, 1958) has been expanded recently with the discovery of dichotomously branched forms in one of the laminated calcareous siltstone zones in the Conasauga sequence along Interstate 75 northwest of Knoxville. These fossils, currently under study, indicate a period of exposure of the carbonate surface below either to planktonic sediments or to a relatively short period of growth by these organisms. There seems to be little doubt that the strata of Phase II represent carbonate deposition over a wide area during a prolonged period that extended across the Cambro-Ordovician boundary. The general form of the Phase II sequence persists for miles along strike and continues with little interruption into the overlying Ordovician formations of the Knox Group. Apparently, comparable carbonate sequences marginal to geosynclines were under development around the world during the same time interval.

In 1961, Oder and Bumgarner described features in the Maynardville limestone in Jefferson and Sevier counties that they believed represent stromatolitic bioherms. About the same time, a remarkable display of stromatoliths in the stratigraphically higher (Copper Ridge) segment of the sequence was exposed in the channel of the Clinch River diverted during the construction of Melton Hill Dam near the Roane-Loudon county line west of Knoxville. The writer examined the temporary exposure at the invitation of John M. Kellberg of TVA. Five successive developmental cycles could be observed within the benched, ten-foot high exposure which covered approximately 6000 square feet Each cycle consisted of several uniformly thick dolomite layers interbedded with thin, commonly crenulated, chert laminae and was terminated by a very thick bed of chert or chertified dolomite. In one of the sequences there was evidence of incorporation of flat pebbles and other clastic debris into the surface of the upper bed.

Where exposed, the bedding surface of the uppermost bed in each cycle displayed numerous, often crowded, concentrically laminated, stromatoliths referable to *Cryptozoon proliferum* Hall and *C. undulatum* Bassler. The diameter of the stromatoliths ranged from a few inches to more than nine feet. The largest of these was observed in one place to enclose a number of smaller, separately constructed forms. It was also apparent that forms of larger diameter might have been connected to those of smaller diameter in a growth position perpendicular to bedding.

In the regolith of the overlying beds of the Copper Ridge Dolomite at Melton Hill, chertified remains of more complex forms resembling stromatoporoids were recovered but were not observed in growth position. Cryptozoan float specimens are common in the residuum of the Knox Group.

Stromatolithic structures such as *Cryptozoon,* the *"Girvanella"* and pycnostrome masses and oncolites, and various laminated encrustations found in the Cambro-Ordovician section in East Tennessee have long been regarded as direct or indirect evidence of reef or platform building activity of cyanophytalean (blue-green) algae (Fenton and Fenton, 1939; Cloud, 1942; Logan, Rezak, and Ginsburg, 1964). As a consequence of lime deposition or entrapment, and sediment binding, most details of the forms of the organisms involved are commonly destroyed or obscured by the mat-building process, lithification, or diagenesis. Nonetheless, the products of this organic activity provide some insight into the early evolutionary history of an important facies of the marine or marginal marine environment.

The rocks of the sequence constituting Phase II are enigmatic in that they provide little evidence of the continuity of organic groups represented in stratigraphically lower and presumably older rocks, a record also missing from any currently recognized contemporary deposits. The question must be raised, therefore, as to whether seaward facies with which the rocks of the sequence were related in time are not obscured by the traditional stratigraphic view of the relative chronology of the Cambrian strata in the region. Examination of the Conasauga dolomites in the eastern belts has shed little light on the problem to date.

The biostratigraphic break between the Cambrian and Ordovician is much more pronounced than the lithostratigraphic break owing to the essentially uniform character of Knox sedimentation across the interval. The influx of sand near the base of the Chepultepec and the introduction of the well-developed molluscan fauna of Phase III thereafter are probably related events heralding either a major environmental shift or the later development of the same complex begun with Phase II.

PHASE III: CHEPULTEPEC THROUGH MASCOT/NEWALA FORMATIONS

As noted previously, the dolomite-limestone sequence begun in the upper Maynardville was interrupted by an apparently short-term clastic influx represented by well-sorted sandstones at or near the base of the Chepultepec Formation or the Conococheague Limestone as mapped in the southeastern phase of Rodgers (1953).

In the belts to the north and west in East Tennessee, oolitic chert beds, rainprints, ripple marks, and crossbedding, along with the sandstones, mark the somewhat oscillatory transition from the upper Copper Ridge into the lower Chepultepec beds. However, there is neither a pronounced disconformity nor depositional hiatus detectable at this transition.

In addition to citing other regional sedimentary features of the Cambrian-Ordovician boundary, Cummings (1960) has shown that a north and north-western source area provided mineral detritus incorporated in the Chepultepec sands. The lithologic transition and the distinct biostratigraphic change associated with it may be related events taking place toward the close of the Cambrian Period. However, the details of this episode are poorly understood.

The carbonate units succeeding the basal clastics are lithologically comparable to those preceding them. Similarities between the units are even more striking. The general environmental setting as reflected by the physical characteristics of the rocks would appear to have remained fairly constant until the close of the Canadian.

Among all the faunas preserved throughout the Lower Paleozoic section, none is as distinct, homogeneous, and, in many respects unique as the Phase III fauna. Aside from the possibility of selective preservation discussed previously in this paper, the Phase III fauna as presently known stands in striking contrast to the respective faunas of Phases I and II.

Biostratigraphically, the Phase III fauna records important developments in the early history and phylogeny of the predominant gastropods and cephalopods, giving rise to derived forms represented in the Phase IV fauna: Small, slightly curved, ellesmeroceroid cephalopods (*Clarkoceras, Dakeoceras,* and *Levisoceras*), regarded as the root stock of the nautiloids (Moore, *et al.*, 1952), occur in the older Chepultepec fauna. Derivative coiled nautiloids, such as *Centrotarphyceras, Campbelloceras* and possibly *Tarphy-*

ceras, appear in the upper part of the Beekmantown. These cephalopods, in turn, are in marked contrast to the michelinoceroid, endoceroid, and oncoceroid forms in the Phase IV fauna.

Stratigraphically, the gastropod members of the Phase III fauna occur in distinctive zones, broad to narrow in extent. All of the zones are characterized by pleurotomariacean archaeogastropods: (*Sinuopea, Helicotoma, Ophileta,* particularly, in the Chepultepec; *Hormotoma* in the Longview; *Orospira* and *Ophileta* in the Mascot). However, the euomphalaceans, *Ozarkispira* in the Chepultepec and *Lecanospira* in the Longview, and the macluritacean *Ceratopea* in the Mascot are easily the most distinctive forms and clearly separate the upper and lower Beekmantown and the latter from the Chepultepec.

Curiously, only species of *Ophileta* (*O. complanata* Vanuxem in the Chepultepec, *O. solida* Butts in the Mascot) and *Hormotoma* (*H. graciliens* (Whitfield) in the Longview, *H. longispira* Butts in the Mascot) provide any sort of biostratigraphic connection between any two of the three formations containing the Phase III fauna. On the other hand, species of *Ecculiomphalus* and *Helicotoma* (Chepultepec), and *Hormotoma* (Longview, Mascot) and the subulitid *Fusispira* (Mascot) appear to be more closely related to Chazy, Black River, and Trenton species.

The Chepultepec gastropods, the least common and diversified, are mostly flat to low-spired, orthostrophic and dextral pleuromphalaceans. Exceptions are the medium-spired *Sinuopea,* a Cambrian carry-over, and the evolute euomphalacean, *Ecculiomphalus.*

Except for the continuation of the umbilicus-depressed *Ophileta,* the orthostrophic, dextral, pleuromphalacean Beekmantown gastropods are in different low- to medium-spired genera (eg. *Hormotoma, Orospira*). The distinguishing members of this fauna, however, are the hyperstrophic, dextral, euomphalacean *Lecanospira* and the macluritids, all with depressed spires. The latter, along with early subulitids (eg. *Fusispira*), in part at least, form a direct transitional link with the Chazyan gastropods. Early Chazyan faunas contain pleuromphalaceans such as *Eotomaria, Ectomaria,* and *Lophospira.*

Altogether, the biostratigraphic gap with respect to gastropods exists to a far greater extent between the Chepultepec-lower Beekmantown and lower-upper Beekmantown faunas with their pronounced generic distinctiveness than between the upper Beekmantown and Chazyan faunas. In this respect, it is of interest to note that Butts (1941) reported the possible occurrence of a species of *Maclurites* [*M. affinis* (Billings)] in the upper Beekmantown (*Ceratopea* zone) in Virginia and between the lower Beekmantown (*Lecanospira* zone) and the *Ceratopea* zone in Pennsylvania.

Other than gastropods and cephalopods, few invertebrate fossils, none of them common, are known from the Chepultepec-Beekmantown sequence in the Knox County area. Yet to be confirmed are species of the brachiopods, *Syntrophina, Xenelasma,* and *Finkelnburgia* and the trilobites, *Hystricurus* and *Jeffersonia,* occurring in the parallel sequence in Virginia (Butts, 1941).

One of the major unresolved biostratigraphic problems concerns the leperditiid ostracodes said to first occur in the Beekmantown in Tennessee (Ulrich and Bassler, 1923; Cooper, C. L., 1942) and to initiate the evolution of these bivalved crustaceans in the southern Appalachian seas. Ostracodes (*Isochilina, Leperditia*) occur in abundance in rocks in Tennessee regarded as post-Beekmantown by stratigraphers after making an initial appearance in the Murray Shale of the Chilhowee Group of Early Cambrian age (Laurence and Palmer, 1963). Besides the Lenoir, Mosheim, and Murfreesboro leperditiids, species of several other genera (eg. *Drepanella, Tetradella, Coelochilina, Eurychilina*) occur in other Chazy, Black River, and Stones River equivalents, abundantly in some strata. The large scale stratigraphic gap between the first record and the second and the conflicting chronological details of the history of the group merit further investigation.

The more extensive development of the gastropods in contrast to those in the Chepultepec fauna, the comparative advancement of the cephalopods, and the region-wide persistence of the *Ceratopea* and *Lecanospira* zones in the same relative position , combine to set the Beekmantown fauna apart as a separate sub-phase. Although the relative chronology of the two sub-phases would appear to be well established on stratigraphic grounds, direct phylogenetic connections between the two faunas, as pointed out above, are limited.

Recently, Harris (1969) has reviewed the diverse, inconsistent, and commonly imcompatible stratigraphic nomenclature applied to the rocks associated with the Phase III fauna, the upper part of the Knox Group in East Tennessee. As a solution to the problem, that author has proposed abandoning the term Longview as a formational name and has redefined the Kingsport and Mascot formations. While pointing out the importance of algal stromatolites in a reconstituted bipartite division of these rocks, the distinctive fauna of the Longview is relegated to a minor role and the Mascot fauna is not mentioned at all.

In the present writer's view, satisfactory solution of the larger problem of regional relationships within the upper Knox Group is further inhibited by redefinition of stratigraphic units based on lithologic criteria, admittedly variable and limited in application. Of greater significance is the recognition by Harris (1969, p. 10; 16-17) of the exclusiveness of SH-C types of stromatoliths in the lower or re-defined Kingsport subdivision and the predominance of SH-V forms, as classified by Logan, Rezak, and Ginsburg (1964) in the upper or re-defined Mascot subdivision. The principal types of stromatoliths in the Knox Group have been adapted to a region-wide dolomitization model by Harris (1973).

Biostratigraphically, the stromatolithic differentiation noted by Harris may prove to be related to the development of the *Lecanospira* and *Ceratopea* subphases of the Phase III fauna considered to be significant in the present paper. If such a relationship can be established, a more comprehensive paleoecologic model for the Beekmantown interval may emerge.

As noted previously, the first biostratigraphic link with the Central Basin section (Murfreesboro) is in the Phase III fauna or a derivation from it, possibly during a post-Beekmantown pre-Chazyan interval presently obscured either by stratigraphic semantics or natural causes.

PHASE IV: LOWER CHICKAMAUGA/MOSHEIM THROUGH MOCCASIN/BAYS FORMATIONS

General Characteristics

By any standard of comparison, the Middle Ordovician fauna considered here under Phase IV and the stratigraphy of the rocks associated with its preservation are together and at once the most studied for the longest period of time and yet the subject of continuing controversy as first one then another interpretation of their relationships has been offered (figure 3).

It is by no means in an attempt to minimize the complexity of the set of problems involved that the fauna is discussed in this paper under a single biostratigraphic phase. In fact, many of the problems outlined in the beginning paragraphs of this paper are particularly relevant to the phase and the rocks. Notwithstanding, a generalized overview is deemed more appropriate to the scope and objectives of this paper. Historically, examination of the Phase IV fauna began with Safford (1869), Ulrich (1882-1884), and Raymond (1905, 1925). Subsequent studies dealing with different aspects of the fauna are listed by Wilson (1953, 1965).

However the Phase IV fauna and associated rock formations may be subdivided, a number of features characterize the fauna as a whole. Especially noteworthy are the following:

1. Differentiation and proliferation of articulate brachiopods.
2. Introduction of phacopid, lichid, and new ptychopariid trilobites.
3. Appearance of graptoloid protochordates.
4. First record of bryozoans and their rapid differentiation into massive, ramose, and foliate forms.
5. Development of multi-generic intertidal and subtidal associations with the first corals and pelmatozoans and new algal, sponge, and molluscan groups.

Coupled with the introduction of new forms during the Phase IV time interval, faunal associations become increasingly complex, reflecting a greater range of ecologic adaptation. Concommitant delineation and greater restriction of physical and chemical parameters is well displayed by the variability of both lithofacies and biofacies in the section. Whatever the underlying causes, tectonic, organic, diagenetic, or otherwise, the effects have produced a number of stratigraphic problems concerning the relative chronological development of the units comprising the section.

Despite the diversity of environment and organisms, the fossil record of the Phase IV fauna is variable. Representative endemic community assemblages in a single locality are rare in much of the section. Externally, evidence of sedimentary transport, winnowing, and mixing is common. Internally, post-depositional alteration by organisms, differential solution, compaction, recrystallization, and replacement have exacted a considerable toll in many beds. Even so, such evidence could contribute significant environmental information but has not been assembled in most field studies.

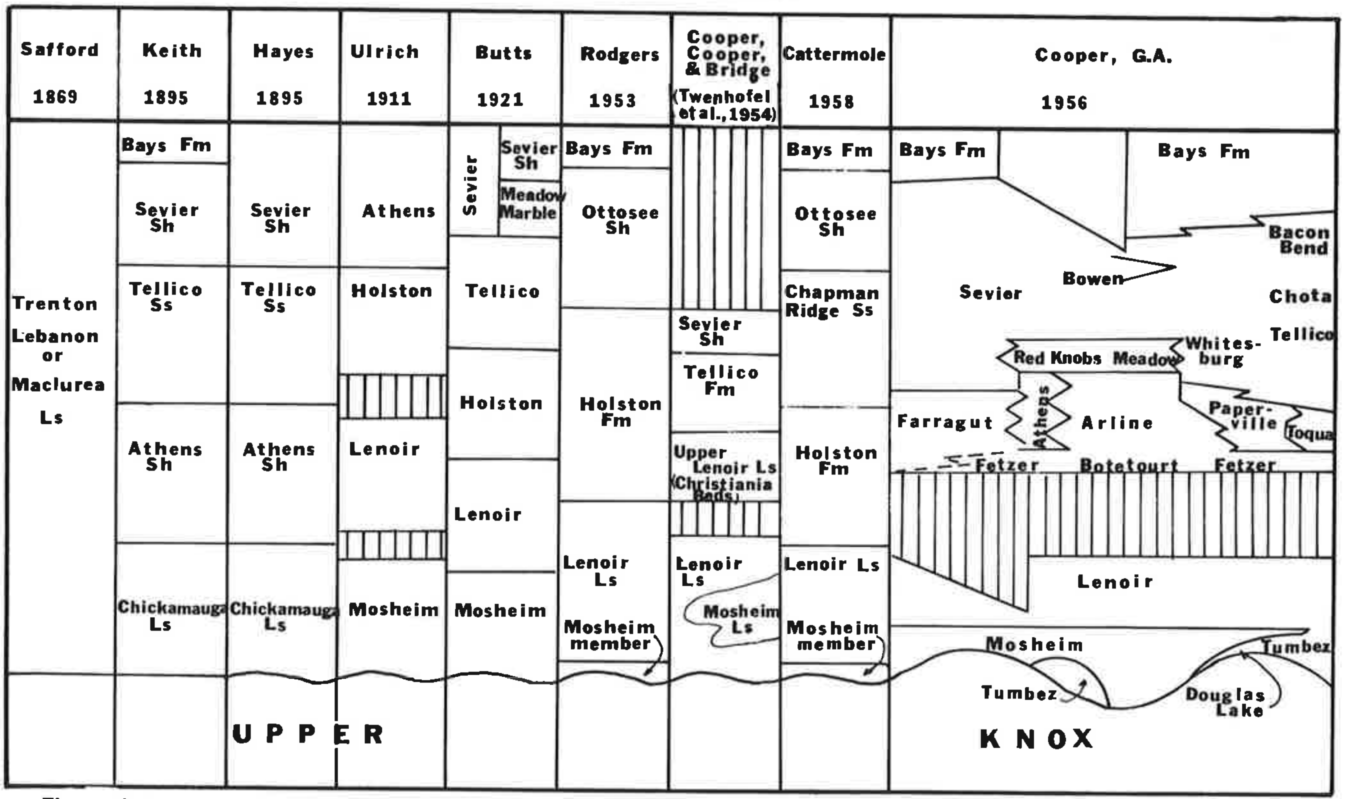


Figure 3. Comparison of Middle Ordovician stratigraphic terminology applied in the middle and eastern belts in East Tennessee.

Phase IV Provinces

Disconformably overlying the light- to medium-gray and tan, fine- to medium-grained dolomites and dolomitic limestones of the upper Knox formations, the several hundred feet of sedimentary rocks comprising the Middle Ordovician section in the Knox County area and vicinity occur in a variety of lithologies, only a few of which are characteristic of one formation or another. The formations themselves are gradational and boundaries based on lithology have been placed arbitrarily.

Over the years, paleontologic data have been used sparingly by field workers owing to the suspicion that fossil distribution was largely facies-controlled. As it has turned out, the imperfections of lithostratigraphic analysis of the section stemmed from the same source of error. Type sections chosen to illustrate the lithostratigraphy proved to be inadequate and many units initially given formational status were reduced in rank as their lithofacies character was recognized. Closer inspection and regional syntheses revealed numerous instances of intergradation and interdigital relationships.

Controversial stratigraphic units of particular relevance to the Knox County section discussed in this paper were originally described under the names Mosheim (Ulrich, 1911), Lenoir (Safford and Killebrew, 1876), Athens (Hayes, 1894), Holston (Keith, 1895, 1896a, 1896b, 1901), Ottosee (Ulrich, 1911), Sevier (Keith, 1895), Bays (Campbell, 1894) and Chickamauga (Hayes, 1891). More recent study of these units by Rodgers (1953), Neuman (1955), Cooper, G.A. (1956) and Cattermole (1955, 1958, 1960, 1966a, 1966b) has demonstrated interrelationships of two or more of these units and has led to revised definitions and interpretations of some of them.

In the western belts, the Middle Ordovician section customarily has been differentiated with a minimum of stratigraphic nomenclature in marked contrast to the variety of unit names applied to the rocks in the eastern belts. Rodgers (1953) employed a system of numbered units to subdivide the major (Chickamauga) portion of the section. Recent mapping (Hardeman, et al., 1966) has followed a three-part stratigraphic division, treating the Chickamauga as a group of undefined formations. The U.S.G.S. (1972) equates the lower division to the Lenoir, Holston, and Ottosee formations of the eastern belts in Knox County. Similarly the Bays Formation and Martinsburg Shale are regarded as representing the Middle Chickamauga Group as proposed by Swingle (1964).

For discussion purposes, the Middle Ordovician rocks of Knox County and vicinity that are exposed in southwest-northeast trending belts mostly on the east-southeast will be considered as belonging to the Blountian province (figure 4A). The similarly oriented belts lying generally to the west and northwest to northeast will be grouped together to constitute the Chickamaugan province. The name chosen for the western province has long been applied to the group of formations that characterize the province. The boundary selected to separate the two provinces is the trace of the Saltville fault. Provincial references will be made in an implied palinspastic or relative paleogeographic sense.

Coarse conglomerates composed of pebbles and cobbles from exposed Cambrian to Lower Ordovician rocks, some in a matrix bearing Middle Ordovician fossils have been recorded from widely separated areas along the eastern flank of the Blountian province (Kellberg and Grant, 1956). A source area to the southeast is believed to have resulted from a southeastern expression of the Chazy-Trenton Taconic orogeny. Kay (1942) and Rodgers (1953) have used the term Blountian to refer to the disturbance.

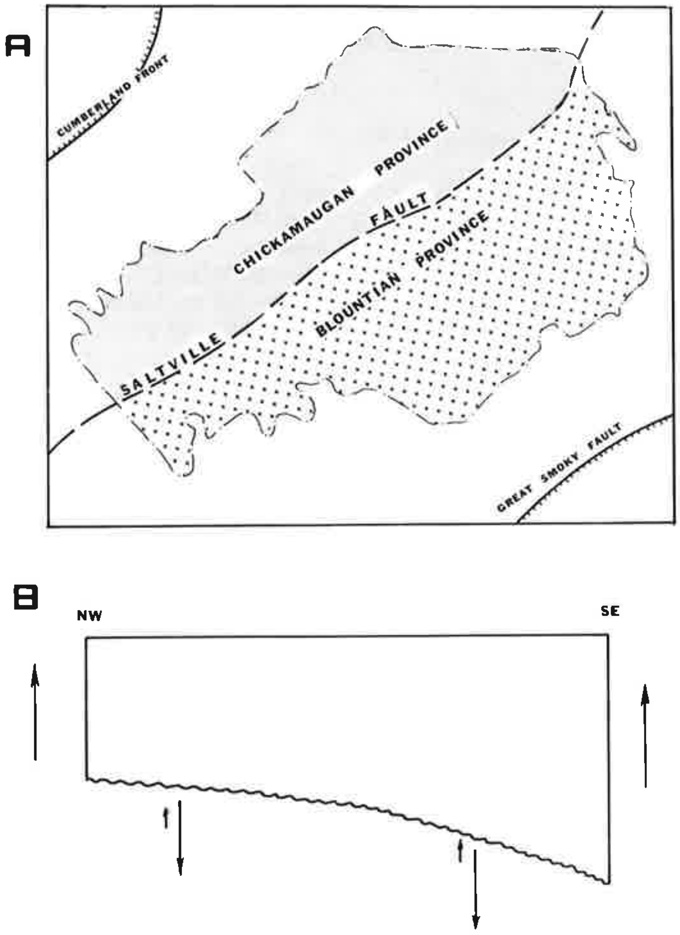


Figure 4. Regional setting of Middle Ordovician faunal provinces, East Tennessee.

Canadian-Chazyan regional uplift westward suggested by structural data (Harris, 1971, p. 738) and a few observations of angularity along the Knox-Chickamauga unconformity (Finlayson and Swingle, 1962) appear to be related to the prolonged exposure of pre-Chazyan rocks in the Chickamaugan province.

Even casual inspection of the lithofacies and biofacies in the intermediate eastern belts reveals numerous examples of areal and stratigraphic discontinuities. It is reasonable to assume that submarine topographic expression of variable degree and origin exercised some control over the distribution and character of these facies. Indirect evidence of exposed terrane lying east and south of the easternmost belts is provided by great wedges of terrigenous clastics (Athens, Tellico/Chapman Ridge, Sevier formations, etc.) which directly influenced the development of the Phase IV fauna in the Blountian province.

Based on present evidence and implications above, it is possible to construct a generalized model for the regional setting of the Phase IV fauna using a set of tectonic boundaries with both areal and chronological connotations (figure 4B). The western boundary, imposed first, exercised control over environments and faunas in the Chickamaugan province. The effects of the eastern boundary, culminating toward the close of the Phase IV time interval, are displayed in the earlier facies in the Blountian province. The subsequent shift of these facies westward occurred later as the western boundary or its erosional remnant was breached or transgressed. Finally, the trans-provincial spread of the Bays/Moccasin clastics progressively terminate the Phase IV episode in a westward direction.

Between the flanking tectonic boundaries, areal parameters and topographic order of suspected intermediate features of the Middle Ordovician seascape remain undefined. A full understanding of the paleobiology of the time will require a much more detailed physical model than can be drawn at present. Ultimately, the thrust of the Saltville fault block brought deformed rocks of the Blountian and Chickamaugan provinces into structural juxtaposition in the vicinity of Knox County.

The Knox Unconformity and the Basal Beds

It has been widely accepted that exposure of the entire sea floor east and west took place following the deposition of the Knox carbonates and a basin-wide unconformity was developed. A number of cross-sectional reconstructions of post-Knox sedimentary relationships in the region (Rodgers, 1953; Twenhofel and others, 1954; Cooper, 1956) invariably illustrate the broad unconformity, literally as a common basal datum. The unconformity thus has been used as a boundary between the lower and middle divisions of the Ordovician System.

Physical evidence for the Canadian-Chazyan unconformity is most convincing in the western or Chickamaugan province where, apparently the period of subaerial erosion was more extensive and relief higher. The basal sediments of the western section are commonly characterized by red beds and by angular fragments of local derivation. Secondary silicification, dolomitization, oxidation of minerals, and other features related to the piezometric profile are common. In several places, some of these features have developed recently with respect to the present erosional surface and can occur within a short distance of ancient analogs. Silicified fossils, molds, casts, and chert are hall-marks of both past and present surfaces.

In the Chickamaugan province represented in the Knox County area the beds at or near the unconformity generally have been referred to simply as the basal Chickamauga formation or designated by lower unit number (Rodgers, 1953). Where an assortment of lithologies reflecting the conditions cited above occur the term Blackford, used as a facies designation in Virginia (Butts, 1940) seems most appropriate to the present writer. The term will be employed in this paper but in the general sense of a magnafacies within which variations have been called Elway, Tumbez, Dot, etc. by various authors.

Within the limits of the present survey, the relative merits of many stratigraphic terms applied to the facies in the area containing the Phase IV fauna will not be considered. In the typical lithologic description of units leading to definition, many past investigators have relied on superficial criteria. As a result, much of this work has contributed little toward comprehending the dynamic aspects of rock genesis and the sedimentary processes and environments involved in their formation.

As a case in point, the commonly basal Mosheim stratigraphic unit of the Blountian province was first described as a limestone formation by Ulrich (1911) and more recently regarded as a calcilutite lithofacies within the Lenoir Formation (Rodgers, 1953; Cooper, G.A., 1956, and others). This unit actually contains as many as five distinct lithologies any of which may extend from a few feet to several hundred yards along strike (Fetters, 1966). Based on the nature and relative amounts of matrix and included components as used in the classification scheme of Folk (1959, 1963), only one of the lithofacies conforms to the medium- to light-gray, fine- to medium-grained, thin- to thick-bedded microcrystalline, styolitic, partially re-crystallized limestone with calcite-bearing vugs ("birdseyes") and sparry stringers described by most authors. This facies, the predominant one in outcrop, often has local concentrations of small cephalopod and gastropod conchs at or near the top of the bed when preserved. Less commonly, a brachiopod shell (probably *Rostricellula*) has been noted.

Another Mosheim facies has thin bands of brachiopod shell accumulations (*Rostricellula, Onychoplechia*) in a micritic matrix. Fragmented echinoderm and bryozoan skeletal debris and rounded, frosted quartz grains in a sparite matrix characterize a third facies. Laterally gradational between fossiliferous facies are relatively narrow zones of unfossiliferous, interlaminated, microcrystalline and sparry calcite layers. Significantly, geopetal structures have been observed in all of the micritic facies, in vug cavities and in association with brachiopod shells and suspected worm burrows.

The lensoid echinoderm-bryozoan biosparite facies may be the only Mosheim facies present above the Knox contact and is sharply disconformable with overlying Lenoir beds. In contrast, directly above the Knox, from one to five feet of thin, reddish-gray, dolomitic siltstones, in some places with mudcracks and small clusters of inarticulate brachiopods constitute a very different facies judged to be penecontemporaneous with the others, in part at least. The *Rostricellula* - *Onychoplechia* biomicrite appears above and below the siltstone facies in places. Locally, angular fragments, some dolomitic, and iron (pyrite) and manganese minerals are seen in this facies at or near the contact with the Knox.

Other variations in the development of the basal beds of the Middle Ordovician which include one or more of the Mosheim lithofacies above have been observed. In the Friendsville area in Blount County, the dominant microcrystalline, often cryptocrystalline, dove gray to white, "birdseye" Mosheim lithofacies underlies coarsely crystalline, fossiliferous, marble-like limestone and overlies gray to pink, medium to coarsely crystalline marble. The latter, in turn, overlies argillaceous limestone with marble interbeds. The marble beds and interbeds contain either abundant brachiopods or crinoid fragments, or a combination of these associated with bryozoans and sponges.

Elsewhere in the same area, the massive, "typical," Mosheim overlies the Knox and the contact is distinct. Small to large gastropods and ostracodes in this sparingly fossiliferous lithofacies contrast sharply with the complex paleontology of the facies described above.

Brecciation, paleokarst collapse structures, mineralization phenomena, clastic inclusions in overlying beds and other features have long been associated with the pre-Chazyan unconformity (Laurence, 1944; Bridge, 1955; Wedow, 1961). The clastic facies of the Mosheim, where it occurs, apparently records the same event. If Mosheim-like rocks appear in the upper Knox, the location of the unconformity is unclear. In places, the post-Knox carbonates may be dolomitized and a lithologic distinction between the Knox and the overlying beds may be difficult to recognize.

In the writer's view, solution of the Mosheim problem is basic to placing other Blountian Province stratigraphic units in proper paleogeographic perspective. There seems to be little doubt that the Mosheim fauna is biostratigraphically close to that of the basal Lenoir Formation where conformable contact is present. Contemporaneity of other deposits lying at or near the Knox-Chickamauga, Lower-Middle Ordovician or Canadian-Chazyan boundary, as it has been called by various authors, has not been established except by common proximity to a real or assumed post-Knox unconformity.

The most enigmatic of the boundary deposits is the Douglas Lake Member of the Lenoir Formation (Bridge, 1955) shown to be a series of depression or sinkhole fillings composed of Knox (Mascot) rubble, conglomerate, bentonite, dolomite, and shale (Laurence, 1944; Caster, 1944 ; Wedow & Laurence, 1967). From conglomerate and dolomite at the Douglas Dam damsite in Sevier County specimens of a merostomaceous arachnomorph (*Chasmataspis laurencii*), a bilvalved crustacean, (*Douglasocaris collinsi*), a foliaceous ctenophoran-like organism (*Cestites mirabilis*), and some trace fossils were described and named by Caster and Brooks (1956). This previously unknown Middle Ordovician fauna has not been reported outside of the discovery site although several investigations into the paleogeomorphology of the erosional surface produced during the Canadian-Chazyan interval have been conducted.

A more pronounced biostratigraphic hiatus between the faunas of Phase III and IV might be expected in places as a result of prolonged subaerial exposure and consequent erosion of the upper Knox terrane. According to Harris (1971, p. 739), two-thirds (or about 420 feet) of the known thickness of the Mascot Dolomite in Tennessee was removed. Compaction, brecciation, weathering, mineralization, and dolomitization of limestone, all believed to be related to a karst surface and an aquifer system developed during this time (Harris, 1969, 1971; Hill and Wedow, 1971) could be expected to produce some gaps and other discrepancies in the biostratigraphic record.

Based on the geographical distribution and interpretations of paleokarst and paleoaquifer phenomena cited above, a number of points relevant to the biostratigraphy and associated paleogeography of the Phase IV fauna in East Tennessee emerge:

1. The best developed features related to an emergent Knox surface appear to be concentrated or lie exclusively west and north of the Saltville fault or in the Chickamaugan Province of the present paper.
2. To the east and south, or seaward of the Knox terrane, penecontemporaneous deposits in the Blountian Province should record a more continuous faunal record in a set of very different facies.
3. The position of strandline with respect to an apparent longer period of exposure of the Knox terrane to the west requires the following contemporaneity of events and deposits:

	West	East
a.	Topographic profile and paleokarst development	Normal marine facies
b.	Diagenetic alteration of the Knox	Continuous sedimentation
c.	Biostratigraphic truncation	Biostratigraphic continuity

Later transgression over the eroded surface to the west would be expected to exhume residuum except where buried and preserved in the topographic lows and collapse depressions, or on the unsubmerged terrane highs. The first marine deposits on the submerged erosional surface would have to be younger to some degree, depending on the length of exposure, than post-Knox deposits to the east. Conversely, the latter would have no precise marine counterpart westward.

Pursuing the comparison further, penecontemporaneous faunas should occur higher in the section in the east than in the west. It follows that biofacies in which the faunas occur would be quite different. Therefore, correlation based on facies-controlled fossils would be impossible to achieve. By the same token, lithologic characteristics developed secondarily as a by-product of diagenesis might appear in rocks of different origin.

For the purposes of the present paper, further examination of the general problems relating to the biostratigraphy of the Phase IV fauna will be confined to an area comprising Knox County and adjacent counties in central East Tennessee. First, the best known and documented component of the fauna, the brachiopods, will be examined in terms of areal and stratigraphic distribution within and between the two provinces. This review is followed by an analysis of the composite Phase IV fauna from the lower part of the stratigraphic section in each province as represented by a selected example or case study.

Brachiopods in Phase IV Fauna

By any measure, articulate brachipods form the most numerous and ubiquitous component of the Phase IV fauna. In Knox County and vicinity, they are represented in many facies in both provinces. From a survey of the Middle Ordovician formations comprising the section, a list of as many as 180 articulate species in 55 genera, as defined, re-defined, or confirmed by Cooper, G.A. (1956) can be compiled from these rocks. Well over sixty percent of the brachiopods are orthids and strophomenids.

A study of the areal distribution of the brachiopods has indicated that the species of 49 of the listed articulate genera, or about 90 per cent, are found exclusively or nearly so in either the Chickamaugan or the Blountian province (table 2). Clearly, the greater diversity occurs in the eastern province, a compounded reflection of thicker section, environmental variability, and, perhaps, a longer, more sustained evolutionary record. A majority of the inarticulate brachiopods occur in the eastern belts as shown.

A number of generic range restrictions are also evident from the same data. If formations and facies in both provinces are grouped into two classes, higher and lower with respect to the stratigraphic position generally agreed on by recent workers, 13 genera with 22 species are confined to stratigraphically higher units (table 2). On the other hand, 18 genera with 31 species are found only in stratigraphically lower beds. Viewing the diversity in the eastern province in stratigraphic context, the greater concentration of articulate genera in stratigraphically lower units is apparent.

Twenty key brachiopod genera define three separate but inter-related dimensional characteristics of the Phase IV fauna:

1. *Glyptorthis, Hesperorthis, Dactylogonia, Multicostella, Rhipidomena,* and *Camarella* are stratigraphically and geographically unrestricted. These genera can be regarded as a chronostratigraphic index group for the Phase IV fauna as a whole.

2. *Leptellina, Valcourea,* and *Onychoplecia* in the Blountian province and *Murinella, Protozyga,* and *Plectocamara* in the Chickamaugan province are geographical indices regardless of stratigraphic position. Adaptation to specific environmental situations which have time-continuity but provincial exclusiveness is implied.

3. *Plectorthis, Macrocoelia, Öpikina, Palaeostrophomena, Rostricellula, Sowerbyites, Oligorhynchia,* and *Oxoplecia* record significant facies relocation during the Phase IV time interval. Occurrences of *Sowerbyites, Oligorhynchia,* and *Oxoplecia* appear to shift from west to east and those of the other genera named change from east to west. These shifts, from a stratigraphically lower position in every case, illustrate the dynamic and migratory character of the Phase IV fauna in part.

TABLE 2. PROVINCIALLY RESTRICTED BRACHIOPOD GENERA, MIDDLE ORDOVICIAN, KNOX COUNTY, TENNESSEE, AND VICINITY

Stratigraphic Position	**Formations & Facies ***	**PROVINCE**	
		CHICKAMAUGAN	**BLOUNTIAN**
Higher	Sevier, Chota, Ottosee, Whitesburg, Red Knobs, Chapman Ridge, Chickamauga Unit 2, Witten, Wardell, Benbolt, Rockdell (Ward Cove), Moccasin, of various authors	Articulates: *Fascifera, Strophomena, Doleroides, Ancistrorhynchia, Zygospira* (part), *Chaulistomella* (part) Total species: 12 Inarticulates: *Schizotreta, Pseudolingula* ?, *Petrocrania* Total species: 4	Articulates: *Pionodema, Skenidioides, Teratelasma, Triplesia, Anisopleurella, Sphenotreta, Cyclospira, Zygospira* (part), *Chaulistomella* (part) Total species: 10 Inarticulates: *Elliptoglossa, Westonia, Paterula, Philhedra, Ectenoglossa, Trematis, Obolus* ? Total species: 13
Lower	Arline, Lenoir, Tellico (restricted), Blockhouse, Lincolnshire, Elway, Mosheim, Dot, Surgener, Chickamauga Unit 1, of various authors	Articulates: *Pionomena, Atelasma* (part) Total species: 2 Inarticulates: *Petrocrania* Total species: 1	Articulates: *Bimuria, Isophragma, Christiania, Orthambonites, Taphrorthis, Ptychopleurella, Phragmorthis, Eremotoechia, Perimecocoelia, Playtymena, Laticrura, Dorytreta, Stenocamera, Apatomorpha, Titanambonites, Atelasma* (part) Total species: 29 Inarticulates: *Schizambon, Siphonotreta, Lingulasma, Westonia, Schizotreta* Total species: 8

*Excluded from consideration is the Holston facies or formation, stratigraphically undefined at present.

Viewed in cross-sectional trans-provincial context (figure 5), the distributional complexity of the articulate brachiopod component in the Phase IV fauna at the generic level is obvious. Relative stratigraphic position of many genera in respective provincial sections has little value in determining time equivalence. Trans-provincial correlation of brachiopod faunas in a collective sense is qualified at best.

Except in very general terms, full equation of provincial sections in a time sense has least support. On the contrary, individually and in combination, the distribution patterns displayed by the brachiopods provide evidence for more plausible options:

1. Most of the Chickamaugan section on the west represents the same time interval as the stratigraphically higher portion of the Blountian section on the east. Thus, the species of *Sowerbyites, Oligorhynchia* and *Oxoplecia* noted above are conceived to be part of a chronostratigraphically younger sub-phase occurring in trans-provincial biofacies. In contrast, the distribution of longer-ranging genera such as *Plectorthis, Öpikina, Macrocoelia, Palaeostrophomena,* and *Rostricellula* with species in both an earlier eastern sub-phase and a later western sub-phase, might be used to illustrate a time-transgressant westward migration of the biofacies to which they were adapted.
2. The lower part of Chickamauga section on the west is older than the lower part of the Blountian section on the east whereas the upper part of the Chickamaugan section is younger than the comparable portion of the Blountian section. In this concept, some trans-provincial occurrences of species within genera are explained as a product of an earlier west to east regressive migration of facies. Later transgression from east to west accounts for trans-provincial distribution of species in the upper part of both sections. Thus the complex distribution of the genera cited above, along with those of *Zygospira, Atelasma* and others, may have dual explanations.

In each province there are several genera which were not involved in the extensive translocations implied, although intra-provincial movement of facies and species should be expected. *Christiania subquadrata* (Hall) in the Blountian province is an apparent example of the latter case. Although this brachiopod has been used (Cooper, 1956) as a stratigraphic index to subdivide the Lenoir Formation of earlier workers, outside the area of redefinition of that formation in Blount County the fossil is known to occur in a lower stratigraphic position. Even so, within the geographical area under discussion in this paper, the *Christiania* fauna remains a useful key to relative stratigraphic position in the eastern province.

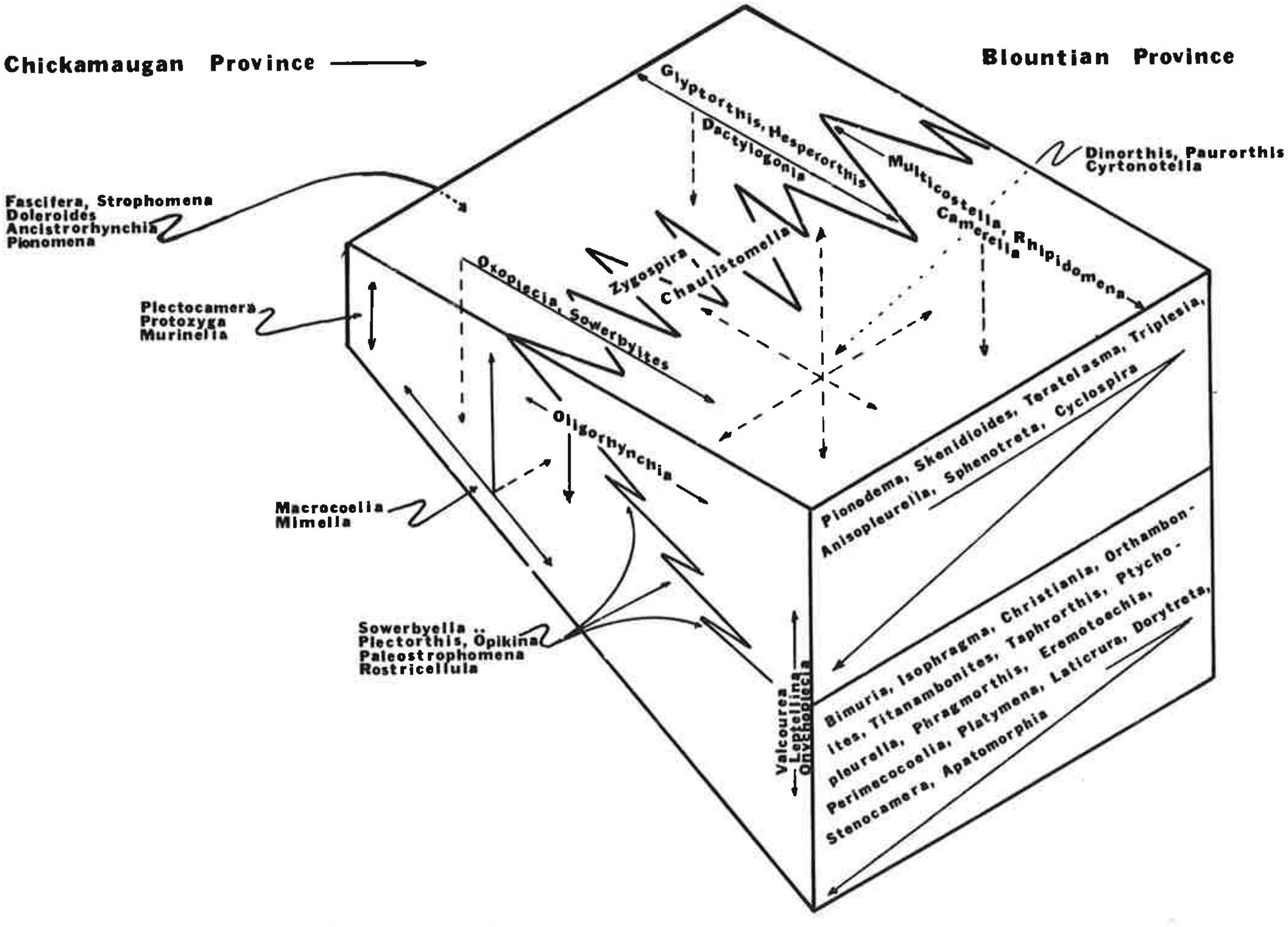


Figure 5. Distribution of Middle Ordovician articulate brachiopod genera, Knox County, Tennessee and vicinity.

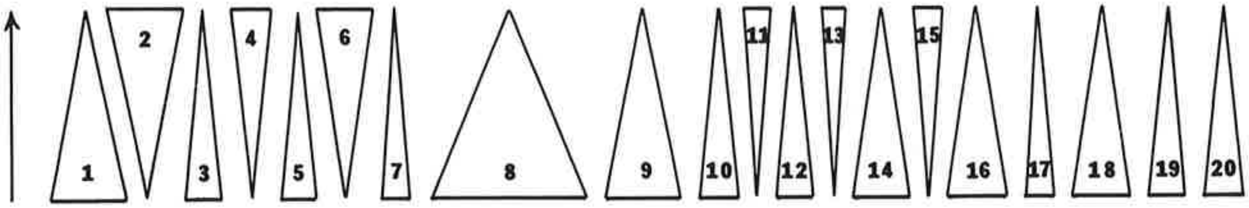
Among several stratigraphically unrestricted genera in both provinces, there are distinct patterns of increase or decrease in species (figure 6). Of nine such genera characteristic of the Chickamaugan province, six show a reduction of species and eight of eleven genera are similarly reduced in the Blountian province. Whatever the underlying causes of reduction, the effects appear to be trans-provincial.

It is at the species level that the distribution patterns of several articulate brachiopods in the Phase IV fauna outline the biodynamic parameters of the fauna in sufficient detail for definitive interpretation. Work in progress (McLaughlin, 1973) indicates that when viewed stratigraphically and transprovincially these taxa can be categorized as follows:

1. Provincially heterotypic genera represented by two or more species in one province, none in the other. Species within these genera appear to form continuous biostratigraphic series, phyletic in character and provincially endemic. Examples of this group are *Doleroides, Strophomena, Fascifera, and Protozyga* in the Chickamaugan province and *Titanambonites, Valcourea,* and *Orthambonites* in the Blountian province.
2. Regionally heterotypic genera represented by two or more species in one province, but commonly monotypic in the other. Where heterotypic and biostratigraphically continuous, the succession of species is considered to be endemic. However, the series may be truncated and separated stratigraphically from migrant species in the same genus. Transprovincial migration of one or more species is believed to account for the diverse distribution patterns of these genera which include *Chaulistomella, Atelasma, Paurorthis, Crytonotella, Plectorthis, Mimella, Oligorhynchia, Camerella, Rhipidomena, Dinorthis, Hesperorthis, Multicostella, Sowerbyella,* and *Öpikina.*
3. Regionally heterotypic genera represented by two or more species in both provinces but occurring within different stratigraphic intervals in each. Because representatives occur higher in the section in the Chickamaugan province, genera of this type such as *Oxoplecia, Rostricellula, Macrocoelia, Dactylogonia,* and *Sowerbyella* are considered to be basically migrant within transgressive facies that moved progressively westward.
4. Regionally and stratigraphically monotypic genera represented by a single species in one province and subphase. Examples of this type such as *Christiania subquadrata* (Hall), *Bimuria superba* Cooper, *Phragmorthis buttsi* Cooper, *Skenidioides costatus* Cooper, *Pionodema camerata* Cooper and *Apatomorpha pulchella* (Raymond) occur primarily in the Blountian province. These brachiopods are judged to be intraprovincial migrants which stand out uniquely in a fauna characterized by heterotypic genera with several species.

A given assemblage sampled from the Phase IV fauna could include a combination of species from two or more categories defined above. It follows that representatives of other faunal groups might be dispersed in a similar manner throughout the area. As viewed stratigraphically and transprovincially (figure 7), the distribution patterns of the four categories of brachiopods, illustrated by the examples shown may serve as a model for the whole fauna.

Figure 7A depicts the stratigraphic distribution of the articulate brachiopods according to their known generic ranges, individually indicated by number, or collectively by capital letter if the range and province is the same. Stratigraphic gaps or diastems in the ranges, and geographic gaps or provincial separation of species within genera are indicated by small letter subscripts.



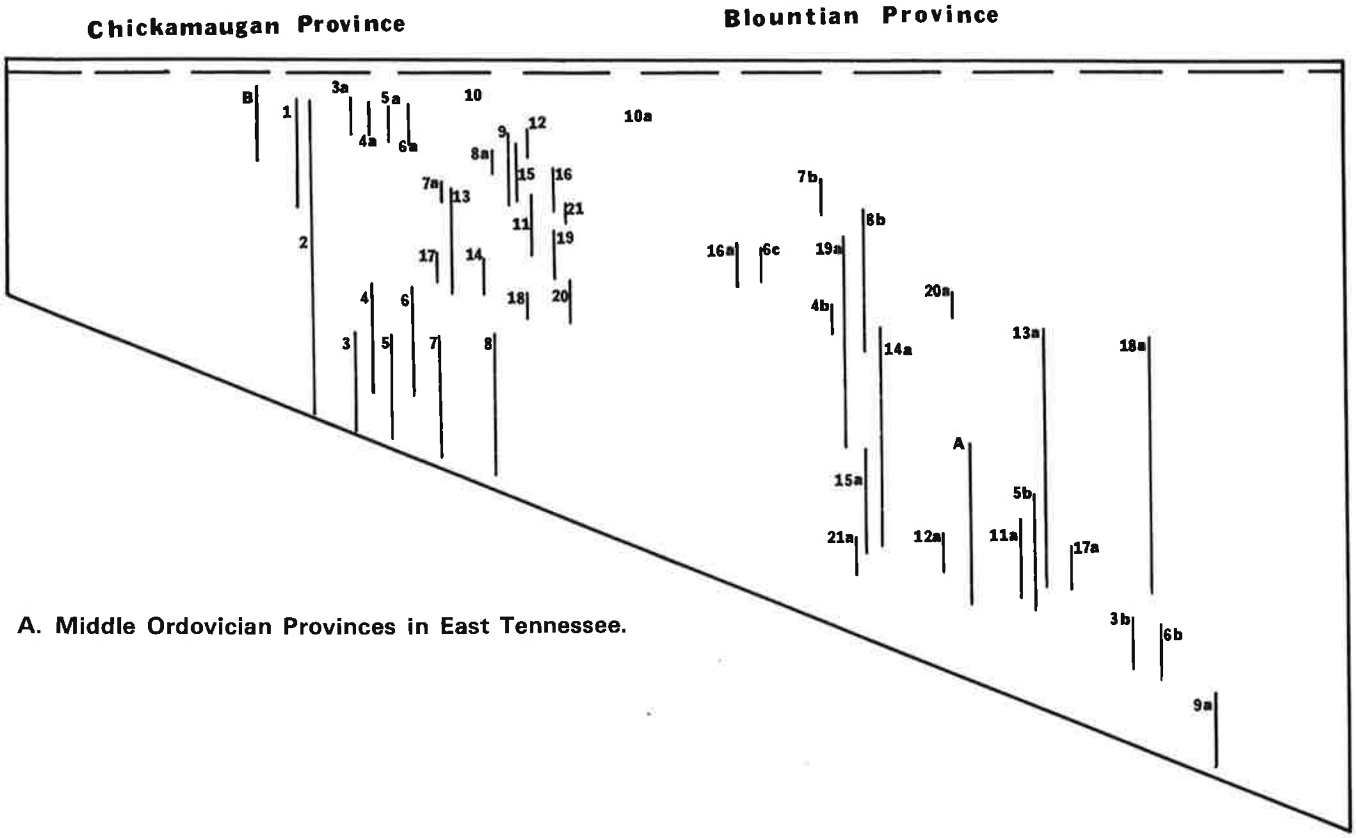
1 Murinella
2 Sowerbyella
3 Macrocoelia
4 Plectocamera
5 Plectorthis
6 Öpikina
7 Dactylogonia
8 Mimella
9 Camerella
10 Dinorthis
11 Oxoplecia
12 Leptellina
13 Glyptorthis
14 Valcourea
15 Oligorhynchia
16 Cyrtonotella
17 Multicostella
18 Paurorthis
19 Rhipidomena
20 Hesperorthis

Figure 6. Relative increase or decrease in species among principal brachiopod genera, Middle Ordovician, Knox County, Tennessee and vicinity.

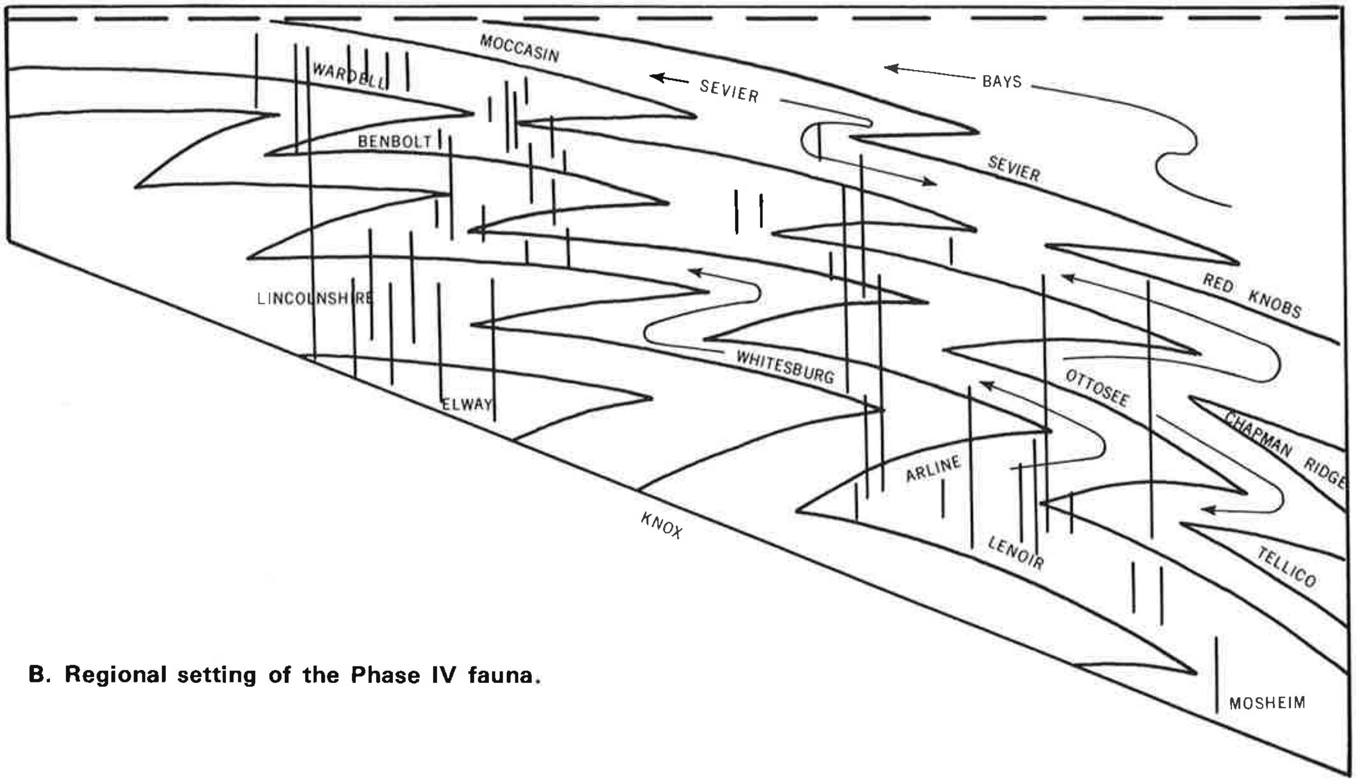
Legend: Circled letters and numbers refer to species described by Cooper (1956).
Unnamed species in some genera not included.

(A) *Leptellina tennesseensis* Ulrich & Cooper
Christiania subquadrata (Hall)
Bimuria superba Ulrich & Cooper
Titanambonites amplus (Raymond)
T. medius Cooper
T. praecursor Cooper
Valcourea obscura Cooper
V. brevicarinata Cooper
Orthambonites angulatus Cooper
O. friendsvillensis Cooper
O. blountensis Cooper
O. neumani Cooper
O. tennesseensis Cooper
(B) *Doleroides irregularis* Cooper
D. regularis Cooper
Strophomena grandimusculosa Cooper
S. inspeciosa Willard
S. medialis Butts
(1) *Fascifera stonensis* (Safford)
F. convexa Cooper
F. subcarinata Ulrich & Cooper
(2) *Protozyga microscopica* Cooper
P. rotundiformis Cooper
P. uniplicata Cooper
P. rotunda Cooper
(3) *Mimella intermedia* Cooper
M. tumida Cooper
M. laticardinia Cooper
M. costellata Cooper
M. globosa (Willard)
M. similis Cooper
(3a) *M. wardellana* Cooper
M. globosa (Willard)
(3b) *M. nuclea* (Butts)
(4) *Oligorhynchia angulata* Cooper
O. subplana Cooper
(4a) *O. bifurcata* Cooper
(4b) *O. inexpectata* Cooper
(5) *Camerella indefinita* Cooper
C. multiplicata Cooper
C. perplexa Cooper
C. costellata? Cooper
C. quadruplicata (Willard)
C. bicostata Cooper
(5a) *C. plicata* (Schuchert & Cooper)
(5b) *C. triangulata* Cooper
C. tennesseensis Cooper
(6) *Hesperorthis longirostris* Cooper
H. biconvexa Cooper
H. multicostata Cooper
(6a) *H. australis* Cooper
(6b) *H. tenuicostata* Cooper
(6c) *H. dubia* Cooper
(7) *Rhipidomena subparallela* Cooper
R. mesleri Cooper
R. tenuitesta (Willard)
(7a) *R. tennesseensis* (Willard)
(7b) *R. filicostellata* Cooper
(8) *Dinorthis holdeni* (Willard)
D. atavoides Willard
D. willardi Cooper
(8a) *D. transversa* Willard
(8b) *D. tenuis* Cooper
D. transversa Willard
D. venusta Cooper
(9) *Rostricellula rostrata* Ulrich & Cooper
R. subtransversa Cooper
(9a) *R. basalaris* Cooper
R. varicosta Cooper
(10) *Zygospira lebanonensis* Cooper
(10a) *Z. mediocostellata* Cooper
(11) *Macrocoelia duplistriata* (Willard)
M. magna (Butts)
(11a) *M. obesa* Cooper
M. plebeia Cooper
(12) *Opikina speciosa* Cooper
O. varia Cooper
O. subplanodorsata Cooper
(12a) *O. glabella* Cooper
(13) *Dactylogonia magna* Cooper
D. magnifica Cooper
D. parva Cooper
(13a) *D. alternata* Cooper
D. geniculata Ulrich & Cooper
(14) *Multicostella semisulcata* Cooper
(14a) *M. plena* Cooper
M. planosulcata Cooper
M. saffordi (Hall & Clarke)
M. robusta Cooper
M. bursa (Raymond)
(15) *Sowerbyella compacta* Cooper
S. socialis Cooper
S. aequistriata (Willard)
(15a) *S. negritus* (Willard)
S. varicostellata Cooper

Figure 7. Legend.



A. Middle Ordovician Provinces in East Tennessee.



B. Regional setting of the Phase IV fauna.

Figure 7. Chronostratigraphic and provincial distribution of Middle Ordovician articulate brachiopod species, Knox County, Tennessee and vicinity.

In figure 7B a dynamic interpretation, essentially transgressive in concept, to account for the gaps in distribution, is superimposed on the range data. Both the distribution patterns and interpretation are related in figure 7B to the relative positions of rock units mapped or discussed by various authors under the names shown. Omission of the name Holston is intentional as is the deletion of unit rank.

Inferences derived from the brachiopod distribution model will serve as a recurrent theme throughout the balance of this paper. Provincial faunas will be examined in the context of their burial sites in the rocks but primary emphasis will be placed on the dynamics of the Middle Ordovician ecosystem in the area as deduced from the remains.

Biostratigraphic Associations in the Blountian Province

Biostratigraphic problems

In the Blountian province, laterally persistent stages in the development of the fauna are a matter of record. Distinctive biostratigraphic zones have been used to determine relative chronostratigraphic position of strata in a given section. However, because of facies changes a zone may grade laterally into another facies or be displaced entirely.

Stratification of sediments and hence zones may imply continuity but successional stages are commonly in discontinuous series and interrupted by facies with recurrent fossil forms or other features. In some sections the succession may be truncated and thus partially represented. In other sections all or part of the succession may be stratigraphically telescoped or, conversely, extended.

Physical causes or controls such as compaction, subsidence, or relief on the initial depositional surface and each subsequent sedimentary interface are assumed to have been responsible to some degree for some sequential variations noted. While the causes and controls of facies may be speculative the effects, as illustrated by the rocks and fossil assemblages, are distributed within the province in a variety of combinations. As a result there is no provincial type section conceivable which could incorporate all of the features as a reference standard. Even partial sections chosen for lithostratigraphic or biostratigraphic purposes have limited areal application.

Many field observations of the Phase IV fauna in both provinces show that related fossil assemblages vary qualitatively from place to place. Beyond the expected variation resulting from local environmental influences and diagenetic alterations, the mixing of temporary migrants with taxa endemic to a particular stage is predictable if inferences previously drawn from the areal and stratigraphic distribution of brachiopod taxa in the fauna are valid.

In the light of the heterogeneous composition of the fauna and the range in variation observed in the continuity of developmental stages represented in the Blountian province, the use of monotypic zones within stages for province-wide correlation must be challenged. Especially suspect are those containing benthonic forms which reflect narrowly restricted environmental conditions that are not necessarily synchronous, let alone normal. As a matter of fact, the repetitive character of many stratigraphic sections in the province attests to the time-transgressance of rock facies and fossils and the respective environments in which they were developed.

By far the most striking aspect of the Phase IV fauna when viewed in stratigraphic context is the internal discontinuity and marked changes in fauna occurring within a relatively short distance both along and across the strike of the rock units. This has led to a superficial isolation of fossil-bearing strata, with intervening gaps providing little if any lithologic and/or paleontologic connection. Thus the biostratigraphy of the fauna is replete with biological unconformities which have been treated as diastems by some workers or missed by others.

Examination of the biological unconformities or diastems over several years by the writer has led to the following observations and conclusions:

1. The biostratigraphic gaps in the fossil record have been used as evidence for the inauguration or termination of specific fossil ranges. The subsequent appearance of index fossils of this type in an obviously lower stratigraphic position elsewhere gave rise to paper unconformities to account for the discrepancy. Neither range extension nor facies translocation was considered a more logical alternative by previous workers.
2. The same biostratigraphic gaps have tended to magnify small differences between members of the same biological lineage. Hence, stratigraphic boundaries became species boundaries. Further, faunal lists compiled in this fashion seem to have been supplied mainly to dignify the definition of a stratigraphic unit which otherwise was described on the basis of even more dubious chronostratigraphic criteria such as allegedly synchronous bedding planes or marker beds.
3. Preoccupation with stratigraphically distributed lineages of certain members of faunas rather than the evolution of the whole biota has resulted in a distorted view of the life of the time. The biased collection and form description of selectively preserved remains of the most obvious or quantitatively dominant members of communities has destroyed the rather elementary but highly significant aspect of function which characterizes all biological systems past present.
4. Emphasis on the stratigraphic distribution of individual forms rather than the communities and ecosystems of which they were a part has obscured the spatial dimension of life as well. In practice, while biofacies were recognized they were fabricated largely into the same time/stratigraphic, uni-dimensional pattern as the rocks and selected fossils. When viewed in the conventional manner, it is clear that many of the sharpest biological unconformities of all exist between assemblages of fossils separated by a narrow stratigraphic interval in the same section. Thus, stratigraphic succession in these cases has no relationship to biological succession in the sense of the environmentalist.

For one or more of the reasons discussed above, an inescapable conclusion based on experience is that much of the past biostratigraphic interpretation of these rocks is quasi-biological at best. Furthermore, because it represents a marriage of convenience between questionable, although time-honored and codified, stratigraphic procedures, re-evaluation is long overdue.

The total effect of the rock-fossil-time parallelism concept used in the past to depict rock and fossil relationships in the area under consideration and, by extension, to reconstruct the geologic history of the region is beyond the scope of the present paper. Instead, better understood sections containing representatives of the fauna will be examined in order to (1) demonstrate the development of the composite fauna in general terms and (2) evaluate the data without the bias implicit in the earlier work. Special emphasis will be placed on Knox County sections because of the primary purpose of this report. However, the provincial variability noted previously and interpretations based on other sections must be considered.

This analysis of the Phase IV fauna will include older data checked in the field or otherwise treated in a generalized, provisional manner. Newer data extracted from recent studies (McLaughlin, 1973, Walker and Ferrigno, 1973) and work in progress will be used primarily as a basis for illustrating more promising and satisfactory approaches to the study of the rocks and the fossils.

Blountian case study: the Lenoir fauna

The inaugural or stratigraphically lower subphase of the Phase IV fauna as developed in the Blountian Province is typically incorporated in light- to medium-gray, finely crystalline, argillaceous limestones traditionally mapped by stratigraphers as the Lenoir Formation in Knox County. Faunal elements of the Lenoir subphase occur in facies, members, tongues and subdivisions of the formation termed Mosheim (Ulrich, 1911), Douglas Lake (Bridge, 1955), Arline (Cooper, 1956), Blockhouse (Neuman, 1955), and Fetzer (Cooper, 1956) within the province. Complete or partial contemporaneity with the Athens and restricted Tellico formations of the older literature has been established.

The subphase is spread out in several sections which measure from less than 500 feet to more than 800 feet, with the thickest sections developed in the Knoxville-Friendsville belt and thinning northwestward. The subphase consists of several stratigraphically arranged faunal zones (Moehl, 1965). The greater number of these zones can be observed in the Friendsville area, which has become, through the studies of G. Arthur Cooper, literally the type locality of the subphase. However, along strike and in other belts a number of variations have been observed although the basic format is similar. The characteristic fossils in the zones arranged in stratigraphic order are shown in table 3. A brief description of the principal features of these faunal zones is given below.

Zones I and II are believed to be genetically related and to represent a compatible assemblage occupying a distinct biotope sufficiently oxygenated and nutritionally supplied to allow a fairly wide range of feeding habits. This biotope includes the several Mosheim facies discussed previously in this paper and over 200 feet of the Lenoir Formation in the thicker sections. To the southeast, however, these zones are contained in an interval about half as thick above the Mosheim, and there two key members of the initial developmental stage, *Rostricellula basalaris* Cooper and *Onychoplecia brevirostris* Cooper are in the Mosheim rather than the Lenoir as they are to the northwest (Fetters, 1966). Furthermore, along with the elimination of many species, there is physical evidence that a considerable part of the record of the fauna has been removed.

The sponges, including a problematical pleosponge-like form, the smaller gastropods, corals, stromatoporoids, stromatoliths, and most of the brachiopods appear to have contributed collectively in a direct or indirect way to building up the substrate over a longer or shorter period of time. Bryozoans apparently played a minor role in this activity. John Stephenson (personal communication, 1972) has recognized in thin-section several members of the construction and producer elements of the base community represented in this assemblage. Species of the algae, *Hedstroemia, Girvanella, Nuia, Vermiporella,* and *Solenopora,* and the bryozoans, *Stictopora* and *Nicholsonella* have been identified up to this time.

The trilobites, *Pliomerops canadensis* (Billings) and *Amphilichas* (*Tetralichas*) *minganensis* (Billings) are judged to be endemic to the community. On the other hand, *Illaenus fieldi* Raymond and the remaining trilobites, the gastropod, *Maclurities magnus* Lesueur, the best known fossil of this subphase, the sponge, *Allosaccus prolixus* Raymond and Okulitch, and the orthocone cephalopods are ubiquitous. Commonly, large numbers of *Maclurites* or orthocone conchs are seen in current-oriented clusters suggesting that they were beached by waves along the margins of the main community mass.

Zone III, which occurs in intervals as thin as 25 feet to over 180 feet in some sections, is characterized by a complete absence of most species found in Zones I and II, and in Zone IV lying stratigraphically above. Only vagrant forms, such as orthocones and a few trilobites, have been found to connect the zones in any kind of relationship. This is an example of the biologic discontinuity discussed previously. Chronostratigraphic succession, either in an evolutionary or environmental sense, across such a gap is inconceivable.

Zone IV, which measures from less than 50 feet to more than 175 feet, has created the most mischief in the annals of Southern Appalachian stratigraphy. Because of the common occurrence of a sharply separated subzone in the lower to middle part of the interval which contains silicified shells of the brachiopod, *Christiania subquadrata* (Hall), the subzone has been used as a marker bed for lateral correlation purposes and for dividing the Lenoir Formation. The upper (and presumably younger) of the divisions, the Arline Formation of Cooper (1956), includes the "*Christiania* zone" as part of its definition.

Christiania subquadrata (Hall) occurs in the upper part of the Athens Formation and in an even lower stratigraphic position to the south. Thus, objections have risen as to the basis and need for subdividing the classic Lenoir rocks. The Athens Formation displaces all of Zone III and most of Zone IV to the south. This formation introduces the first Middle

TABLE 3. FAUNAL ZONES IN THE LOWER BLOUNTIAN SUBPHASE, KNOX COUNTY, TENNESSEE, AND VICINITY

ZONE VII		Brachiopods: *Leptellina tennesseensis* Ulrich & Cooper, *Macrocoelia obesa* Cooper, *Paurorthis* sp. Trilobites: *Illaenus fieldi* Raymond, *Homotelus* sp. Sponges: *Allosaccus prolixus* Raymond & Okulitch, cf *Hudsonospongia* sp., *Hindia* ? Gastropods: *Maclurites magnus* Lesueur, *Liospira* ? Cephalopods: Unidentified orthocones and tarphycerid Bryozoans: *Monotrypa* sp., *Monticulipora* ? Stromatoliths
ZONE VI		Brachiopods: *Bimuria superba* Ulrich & Cooper, *Glyptorthis concinnula* Cooper, *Macrocoelia obesa* Cooper, *Titanambonites* sp., *Orthambonites* sp., *Paurorthis* sp., *Lingulella* sp. Trilobites: *Illaenus* sp., *Homotelus* sp., *Isotelus* sp. Sponges: *Allosaccus prolixus* Raymond & Okulitch Gastropods: *Maclurites magnus* Lesueur, *Trochonemella*?, *Liospira*?, *Holopea*? Cephalopods: Unidentified orthocones Bryozoans: *Monotrypa* sp., *Mesotrypa* ?
ZONE V		Brachiopods: *Bimuria superba* Ulrich & Cooper, *Leptellina tennesseensis* Ulrich & Cooper, *Phragmorthis buttsi* Cooper, *Orthambonites* sp., *Paurorthis* sp. Trilobites: *Illaenus* sp. Sponges: *Allosaccus* sp. Gastropods: *Liospira* ?, *Pleurotomaria* ? Bryozoans: *Monotrypa* sp., *Mesotrypa* ?
ZONE IV	(A)	Brachiopods: *Christiania subquadrata* (Hall), *Dactylogonia geniculata* Ulrich & Cooper, *Isophragma biseptatum* Cooper ?, *Isophragma* sp., *Multicostella plena* Cooper, *Orthambonites blountensis* Cooper, *O. friendsvillensis* Cooper, *O.* sp., *Paurorthis longa* Cooper, *P.* sp., *Phragmorthis buttsi* Cooper, *Platymena plana* Cooper, *Plectorthis compacta* Cooper, *P. transversa* Cooper, *Ptychopleurella globularia* Cooper, *Atelelasma* sp., *Cyrtonotella* sp., *Taphrorthis* sp., *Rhipidomena* sp., *Schizambon subradiatum* Cooper, *S.* sp., *Lingulella* sp., *Conotreta* ? Trilobites: *Illaenus fieldi* Raymond, *I.* sp., *Isotelus gigas* Dekay, *Ceraurus* sp., *Ceraurinella* sp., *Lonchodomas* sp., *Pterygometopus-Calliops* parts. Sponges: *Allosaccus* sp., *Hindia* ? Gastropods: *Liospira* ?, *Raphistoma* ? Cephalopods: Unidentified orthocones Bryozoans: *Monotrypa* sp., *Mesotrypa* ?, *Cyphotrypa* ? Receptaculitid: *Receptaculites oweni* Hall Pelmatozoan fragments
	(B)	Brachiopods: *Christiania subquadrata* (Hall), *Orthambonites blountensis* Cooper, *Valcourea semicarinata* Cooper ?, *Palaeostrophomena* sp., *Sowerbyella* sp.
ZONE III		Trilobites: *Homotelus* sp., *Pterygometopus* ? Cephalopods: Unidentified orthocones

TABLE 3. (Continued)

ZONE II	Brachiopods: *Titanambonites* sp., *Valcourea* sp., *Lingulella* sp. Trilobites: *Pliomerops canadensis* (Billings), *P.* sp., *Amphilichas* (*Tetralichas*) *minganensis* (Billings), *Illaenus* sp., *Ceraurus* sp. Sponges: *Allosaccus prolixus* Raymond & Okulitch, Unidentified "pleosponge" or *Zittelella*-type ?; spicules Gastropods: *Maclurites* sp., *Pleurotomaria* ?, *Raphistoma* ?, *Liospira* ? Cephalopods: Unidentified orthocones Bryozoans: *Monotrypa* sp., fragments Corals: *Billingsaria parva* (Billings), *Tetradium* ? Stromatoporoids
ZONE I	Brachiopods: *Rostricellula basalaris* Cooper, *Onychoplecia brevirostris* Cooper, *Atelelasma variabile* Cooper, *Dactylogonia alternata* Cooper, *Mimella nuclea* (Butts), *Ptychopleurella glypta* Cooper, *Hesperorthis tenuicostata* Cooper, *Valcourea* sp., *Dorytreta ovata* Cooper Sponges: *Allosaccus prolixus* Raymond & Okulitch, *Hindia* ? Gastropods: *Maclurites magnus* Lesueur, *Liospira* ?, *Raphistoma* ? Bryozoans: *Monotrypa* sp., fragments Receptaculitid: *Receptaculites* ? Stromatoporoids, stromatoliths Corals: *Billingsaria parva* (Billings), *Tetradium* ?

Ordovician graptolites, species of *Climacograptus* and *Diplograptus* in particular, into the Blountian province. In the writer's view, this shaley lithosome represents an advance stage of the gradually developing clastic wedge which is to greatly modify succeeding faunas in the province.

In addition to *Christiania subquadrata* (Hall) the Zone IV fauna has a great diversity of brachiopods; many of them are similarly monotypic with a single species (table 3). Given the proper circumstances leading to silicification, a non-biologic process, any of these species, for example, *Bimuria superba* Ulrich and Cooper, might have been chosen to characterize the zone. Recognition of the *Christiania*- associated fauna, however, in its full development as shown here, is important in reconstructing the paleoenvironment to be proposed later in this paper. Within the framework of this paleoecological setting. *Christiana subquadrata* (Hall) becomes a significant paleoecotype.

Compared with Zones I and II, a much more varied biotope is implied by the fauna of Zone IV. The presence of several inarticulate brachiopods is indicative of the range of environments. Crinoidal debris in the zone compares interestingly with similar bioclastic material in the Mosheim facies. Echinoderm fragments, some probably cystoid, occur in Zone I in sections to the southeast below the *Billingsaria-Pliomerops-Valcourea* fauna. It is suspected that each of the biotopes was laterally contiguous in part with a frequently washed growth surface supplying this debris.

Again, there are a number of gastropods, sponges, and receptaculitids, especially *Receptaculites oweni* Hall. The presence of the latter, and other so-called "sponge-like" fossils, provide a clue to one of the unresolved enigmas concerning the Zone IV fauna and many of the spectacular Middle and Late Ordovician faunas elsewhere. As described, these fossil assemblages are biologically imbalanced because the most critical element of all in the supporting ecosystem, the primary producer, has been rarely identified. In recent years, the work of Kesling and Graham (1962), Nitecki (1969), and others has shown that the receptaculitids, most commonly classified as sponges or "sponge-like," are dasycladacean algae. Therefore, the food chain of the Ordovician seas can be extended to include green plants without which there would have been no fauna. The term "fauna" as used in this paper on occasion and in the literature quite generally implies lack of information or failure to recognize this critical point.

The trilobite, *Isotelus gigas* DeKay, is a frequent member of the Zone IV biota as are species of the *Pterymogetopus-Calliops* trilobite complex. Some additional bryozoans occur but not in large numbers and typically as bioclasts. The ubiquitous *Maclurites magnus* Lesueur-*Illaenus fieldi* Raymond-orthocone cephalopod faunule repeats its appearance in Zones I and II, again illustrating the distinct biostratigraphic and biological unconformity that separates comparable, in some cases identical, faunal elements when local sections of rock strata are viewed in stratigraphic context. In the opinion of the writer, it is completely unrealistic to interpret these two disjunct parts of the same ecological continuum as being greatly separated in time. Nevertheless, in the brachiopod-biased, pseudo-biostratigraphic subdivision of the Lenoir Formation by Cooper and Cooper (1946) that seems to be the case.

Zones V, VI, and VII are characterized by a drastic reduction in brachiopods. However, *Bimuria superba* Ulrich and Cooper and *Leptellina tennesseensis* Ulrich and Cooper, among others, maintain a connection with Zone IV. The appearance of *Macrocoelia obesa* Cooper and *Glyptorthis coccinula* Cooper is diagnostic of Zones VI and VII, as is a sponge (cf *Hudsonospongia*). Again it will be noted that many of the taxa are monotypic and several forms are common to most of the upper zones. There is thus a semblance of unity among the three zones which collectively measure well over 200 feet in section.

In the Friendsville area and to the south, the Zone VII fauna underlies and has some forms in common with the Holston Formation or facies which overlies the zone in that direction. However, in the section of the Lenoir rocks exposed along Alcoa Highway in Knoxville, the Holston facies replaces most of Zone IV and all or most of the succeeding zones except for at least two relatively thin beds or orthocones and a few other fossils characteristic of the Zone IV-Zone VII interval. These beds flank and interdigitate with the upper end of the Holston which underlies the northwestern flank of Chapman Ridge. In the prominent cut on the highway, Cattermole (1955) named these beds the Chapman Ridge Sandstone because he did not believe they correlated with the type Tellico of the older literature. The limey beds themselves were regarded as representing the Ottosee Formation, and the lower tongue of the Ottosee was included within the Chapman Ridge. This exercise in stratigraphic dismemberment, characteristic of much of the field mapping of the rocks in the area in recent years, has served no useful purpose except to emphasize that at times and in certain places all of these units, the Lenoir, Holston, Tellico, and Ottosee, are interrelated in some fashion along their contiguous margins. In the case of the cut in question, the marginal relationships may be viewed as follows:

1. The main body of the Holston biohermal mass, seen in cuts opposite the Naval-Marine Reserve station on the highway, is laterally equivalent to most of the Lenoir section observed as Units IV through VII in the Friendsville area.
2. Toward the Chapman Ridge cut and within it, reef flank debris, especially from the surface organisms, trepostome bryozoans, crinoids, and the like, is incorporated in other beds marked by current features, erosional surfaces, beached shells in limey muds, and finally, well-sorted sandstone, at first bioclastic, with some crossbedding.
3. The transition between the biogenic rocks on the one hand and the transported sand body on the other represents the interaction of two distinct environmental regimes which, in the absence of controverting evidence, are penecontemporaneous.

The Lenoir rocks which flank the biohermal mass display carbonate environments and faunal properties related to the position of the mass.

The fauna of Zones VI and VII, and possibly a portion of the fauna of Zone V, is interpreted by the writer as progressively elutriated modifications of the Zone IV fauna, which reflect more specialized or transitional environmental conditions, perhaps ecotonal in nature, marginal to Zone IV. Viewed collectively, all of these zones are believed to be interrelated within a single biotope that was somewhat more complex than the one occupied by the fauna of Zones I and II.

It is concluded from the analysis of all faunal zones that two general biotopes with faunal associates can be recognized. The two biotopes are interrelated both by migrant species in common and general community similarity, but each has features peculiar to it alone. However, these inter-relationships are difficult to determine if they are sought in the traditional chronostratigraphic manner should the lithified representation of one biotope occur in a relative stratigraphic position with the other in the same section. Where this happens, as it does in several sections in the Friendsville area, if only the endemic, and especially monotypic, brachiopods are considered, the differences between biotopes are magnified and the gross analogy between the community organization in each biotope is missed. One would be tempted to define a stratigraphic break on this basis. The distinct biostratigraphic gap or break in genetic linkage between the endemic genera and species in each zone, coupled with an intervening unfossiliferous interval, might lead to the conclusion that selective preservation or undiscovered transitional forms had produced the gap. The writer is unaware of a single case where a gap of this nature has been closed in the sections under consideration here, and such gaps are numerous.

It can not be denied that where all zones are present and the differences noted above considered, a sense of relative age is established. Ignoring the biostratigraphic gaps, an assumption might follow that the total sequence constituted a fairly accurate evolutionary history of the fauna of the time interval involved. Thereafter, using the sequence as a "type section," absence of zones with one or more "chapters" missing might be considered grounds for establishing a case for nondeposition or erosion, with or without physical evidence. On the other hand, presence of a particular species known to occur in one of the zones in the reference section, and in that section having therefore a relative age position, could be interpreted as indicative of the same "chapter" outside the area where the reference section occurred. Such has been the application of biostratigraphy in establishing age relationships between and among the rocks in East Tennessee, and in particular the fossil-bearing strata in the Blountian province of which the Lenoir Formation is a pre-eminent example. Such procedures, cultivated and nourished by highly respected organizations, have about the same chance of success in resolving stratigraphic problems as the lithostratigraphic procedures which use type sections of rocks and "marker beds" for correlation.

Model for the early Blountian subphase

It is here proposed that a more satisfactory model for interpreting age and regional relationships of the Phase IV fauna in the Blountian province should first take into account the fact that the fossils represent once-living organisms, either directly and fairly close to their position of growth or indirectly at some distance away from the growth site. Secondly, the rocks under consideration must be conceptualized as orginating either from sediments that entomb and entrap locally or from those that are carried into the area. Thirdly, both organisms and sediments as products of dynamic processes operating within environmental parameters must be expected to show changes in some manner as the processes or parameters are modified. Finally, there is a finite number of combinations of these variables, so that those recognizable patterns which emerge and are repeated regardless of time and place may be treated as analogous, although not homologous because of random factors such as genetic mutations.

It is further proposed that there are two identifiable and measurable components of such a model, a common base, well established as an irregular surface developed in the upper Knox, and a set of fossils, known to occur in zones qualitatively recognizable in outcrop and in relative stratiform position in several sections. As an alternative to previous interpretations of the relationship between the two components, the writer suggests that the biotopes, as deduced in general terms from the fossils in the zones, be deployed along the common base as shown in figure 8. The relationship as shown is essentially areal in concept and the biotopes are presumed to be contemporaneous at this point in time. There is a reasonable amount of data to show that a number of the fossils found in the reconstructed biotopes do occur at or near the Knox surface regularly or at least once. From the known habits of living organisms of similar form and from the studies of marine sediments and environments of the present time, the biotopes can be placed within a frame of reference that includes a set of laterally disposed shallow water environments.

Evidence from the rocks and the fossils indicate an environmental range from supertidal to subtidal conditions. Orientation with respect to shoreline can be deduced from the fact that one of the zones included within a specific biotope contains lithologic units which indicate subaerial exposure and supertidal development, as well as units with incorporated material derived from an eroded terrane. Distance must remain entirely conjectural inasmuch as the maximum sedimentary thickness measured, approximately 828 feet, in a section depicting the entire range of environment postulated, is a product of post-depositional alteration. However, assuming that foreshortening averaged out along the line of section, relative distances within the range can be projected.

The depositional profile, at first the Knox surface, must have been irregular in order to produce the variations in biofacies reflecting a range of energy conditions. Landward, the rocky shores of the still exposed Knox surface formed the coastline. Topography along this coast would be expected to vary according to the length of time exposure was maintained. It is possible that the discussion of the nature of the upper Knox formations in connection with the Phase III fauna has relevance here. Both emergent and submergent features characterize the Knox contact. More specialized Mosheim/Lenoir biofacies may have been in actual organic connection with those of the upper Knox in places. Physical unconformity would be more pronounced in these cases whereas the biological relationships at the interface would show ecological conformity. Seaward, on the other hand, the physical boundary should be less striking than the biological unconformity.

Farther to the south along the depositional strike, in time the Athens silts and muds appear over a clearly telescoped lower Lenoir sequence. Deposition on a subsided Knox surface is clear from the thickness of the section in that direction as illustrated by Rodgers (1953) and others. Graptolite-bearing offshore (?) currents were unable to breach or circulate among the shelf environments to the north to any

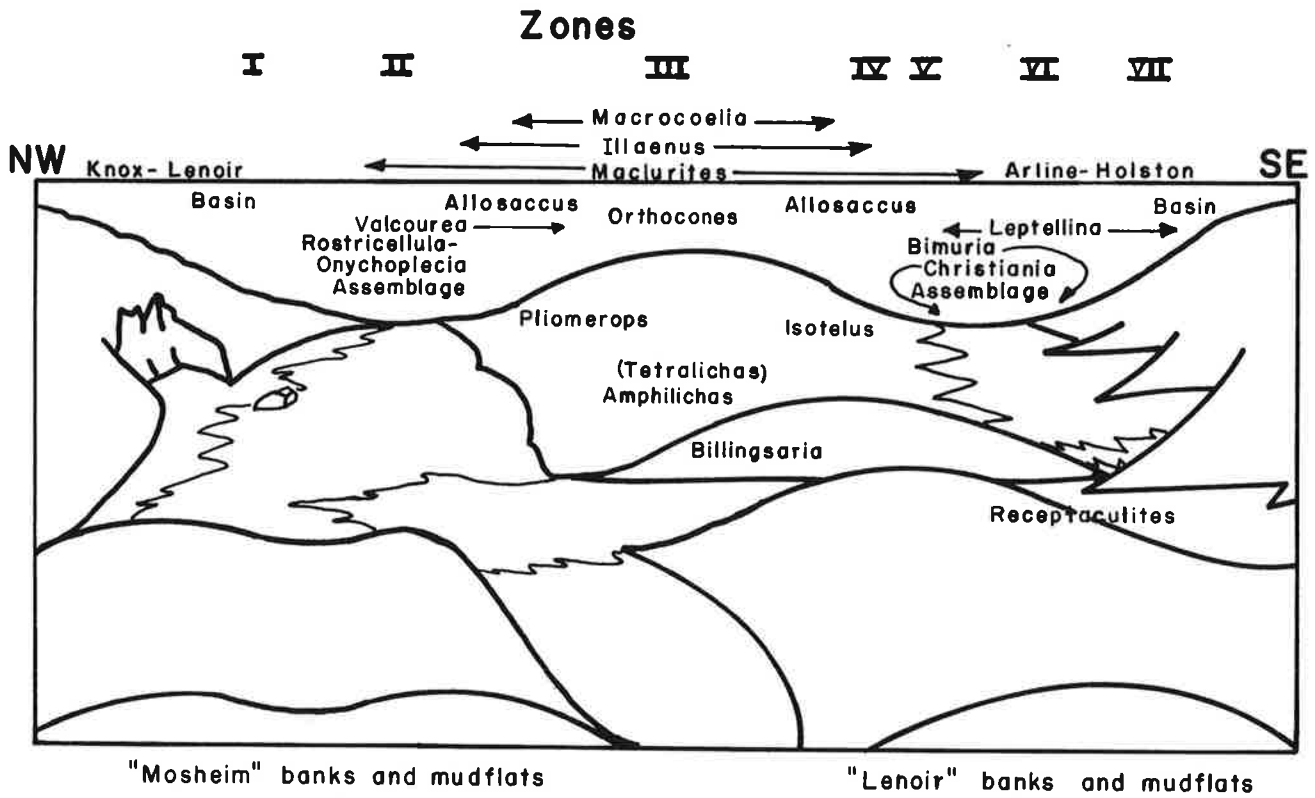


Figure 8. Model for original biotope deployment, early Blountian subphase.

great degree, if scarcity of graptolites (Decker, 1952) in presumed contemporary Lenoir deposits is an indication. Recently discovered conodonts in the Lenoir subphase by Bergstrom (1971) may provide evidence of a periodic connection with the "Athens seaway." Acritarchs and chitinozoans, observed in preliminary studies by Ann Brooke Reaugh (personal communication, 1972) and the writer, are expected to add further insights into this problem.

The stratigraphic position of the more seaward biotope above the more landward biotope (figure 8) in the sections to the north, as in the Friendsville area, mark the initial transgressance of the complex to the north and northwest. It is believed by the writer (McLaughlin 1973) that the pattern of Middle Ordovician stratigraphy and biostratigraphy is set thereupon and continues progressively west and northwestward thereafter. Resultant biofacies lying obliquely to the composite section of the rocks should record the transgressance. Assemblages observed in these biofacies should be ecotypical, that is, composed of compatible species forming communities in comparable biotopes. Community membership will change in time relative to evolutionary development within groups; however the same functions (niches) will continue. Thus, analogs of similar community structure can be traced along the line of transgressance. Walker and Laporte (1970) have shown that basic community patterns established in the Ordovician can be identified in Devonian rocks.

In a given stratigraphic section, transgressive stages separated by biostratigraphic unconformities will appear in number and variety according to the periodicity of transgressance, the number of biotopes developed initially, and the length of time during which the transgressance took place. The degree of transgressance between stages can be measured on the basis of community similarity. In the case of the Friendsville section, the latter is not great. In sum, the stratigraphic break between the stages could be called a paleoecological unconformity. Compared with the physical break of the same name, identification may require detailed field inspection and collection of more specific paleontological information than has been the rule in the past.

The results from the analysis of brachiopod distribution (figure 7) presented first in discussing the Phase IV fauna strongly suggest that the pattern of transgressance is traceable upward and westward through the balance of the composite Middle Ordovician section. If this thesis is correct, then the later Phase IV fauna is shifted in time and place gradually north and westward. Evidence is strong that the fauna and the environments containing it were displaced by an advancing clastic wedge derived from a rising and spreading landmass to the south and east.

The trace of the northwestward advancing shoreline with associated supertidal, intertidal, and subtidal biofacies containing the Phase IV fauna should be discernible for as long as the transgressance continued. Parallel to the trace, lateral continuity along the depositional strike with comparable biofacies will reflect an extension of comparable ecological conditions for longer or shorter distances. The fact that similar faunas, commonly with identical genera and even species, are found from Georgia and Alabama to Virginia is an indication of the regional magnitude of the Phase IV fauna. Ecological continuity of the same proportions must be presumed.

In line with the provincial theme of this paper, the writer believes, further, that the same features described in the discussion above can be used to construct a model for the rocks of the Chickamaugan province. It follows that the stratigraphically higher rocks in that province must become increasingly younger in age westward as a continuously re-established shoreline traces the line of transgressive advance.

The Holston facies problem

In the Blountian province the most enigmatic facies in the composite section is comprised of the partially crystallized, thick-bedded to massive calcarenites or biosparites termed "marble" included in the Holston Formation of Keith (1895, etc.) and the Vestal and Meadow marbles of Gordon, *et al.* (1924). The chronostratigraphic position of these bryozoan-dominated, biohermal growth structures has been the subject of much debate and misunderstanding. Holston-type facies occur throughout most of the stratigraphic sequence in the province. Recently, Walker and Ferrigno (1973) have undertaken a study of this facies to determine the paleoecological significance and chronostratigraphic relationships of this facies in the Middle Ordovician ecosystem.

The obviously sustained growth properties of the Holston facies provide one of the few opportunities in the composite section to establish comparative age relationships across the strike of the section. A remarkable list of bryozoan species in as many as thirty genera has been compiled to date from a thin-section study of the facies by Kenneth Ferrigno (personal communication, 1972; Ferrigno and Walker, 1973). The mostly ramose and encrusting bryozoan fauna is expected to resolve a number of problems concerning the facies. For this reason, the present writer has avoided dealing with the facies in the context of the proposed model discussed previously. However, the fauna involved in its development is part of the Phase IV complex, probably both earlier and later subphases. Indirectly, the bioherm itself for as long as it grew undoubtedly influenced the balance of the Phase IV fauna, modifying the environmental parameters of the fauna from place to place.

Intermittent lenses and relatively thin beds of bioclastic debris largely composed of crinoidal and bryozoan fragments can be traced from the base of the composite section in some places to at least the Ottosee/Chapman Ridge stratigraphic interval. Commonly, the associated rocks in a given section provide little if any evidence of a source for these materials. Angular fragments of Holston-type lithology have turned up in beds as low in the section as the Mosheim facies. All or some of the anomalous occurrences cited recommended the consideration of a laterally disposed Holston-type bioherm as a possible provenance.

It should be recorded that the stratigraphically highest portion of the Holston complex, inexplicably re-named the Red Knobs Formation by Cooper (1956), has produced a limited, apparently superficial, brachiopod fauna consisting primarily of species of *Dinorthis, Oxoplecia,* and *Oligorhynchia.* These species relate to a transgressive stage east to west that probably involved all or part of the Sevier and Whitesburg formations in the Blountian province and Chickamaugan facies on the west. Conceivably, this transgressance was recorded by the brachiopods on the final Holston reef surface which had developed westward along with other facies by this time.

Further consideration and extension of the provincial model in the Blountian province will be treated elsewhere (McLaughlin, 1973). Work currently in progress by Kenneth R. Walker and his students, designed to elucidate and identify many of the important details of community relationships, will contribute greatly toward the construction of a much more accurate version of the model in the future.

Biostratigraphic Associations in the Chickamaugan Province

Stratigraphic considerations

In western Virginia, with several references to Tennessee localities believed correlative, Butts (1940) used the names Murfreesboro, Mosheim, Lenoir, Lowville facies (Lowville-Moccasin Formation), Eggleston, and Trenton for the sequence of Middle Ordovician formations above the unconformity in the upper Knox. Subsequently, Cooper and Prouty, (1943), Cooper (1944), Prouty (1946), Miller and Brosge (1954), and Cooper and Cooper (1946) recognized that Butts' combination of stratigraphic terminology from the Central Basin in Tennessee, the middle and eastern Appalachian Valley in Tennessee and Virginia, and the New York section was inappropriate if not erroneously applied.

However, after satisfactorily demonstrating to many that the rocks of the eastern and western belts were diachronous, the many substitute unit names proposed by the workers cited have had limited application outside of the area of definition. As in the eastern belts, the variation and repetition of lithofacies and biofacies has led to conflicting opinions, and resolution of the original problem is incomplete.

Southwestward into Tennessee, the interpretation and designation of rock units in the coextensive middle to western valley belts northwest of the Saltville fault has followed a different course. There has been a general reluctance to extend usage of eastern terms into the western belts and to inaugurate new terms on the basis of age differences. Rather, following the practice of the early folio mappers, the term Chickamauga, first applied to rocks in the western belts, has been used widely to refer to the whole suite of Middle Ordovician rocks across East Tennessee. In the eastern belts the older formational names were retained for more local reference. Some workers, noting the inadequacy of the original Chickamauga type section of Hayes (1891), have objected to the implied synchroneity of this usage as was done in the case of Butts' extension of eastern belt terms in Virginia.

In the only comprehensive treatment of the lithostratigraphy in East Tennessee on a workable scale, Rodgers (1953) used the term Chickamauga as a general three-part group name for all of the Middle Ordovician rocks in the region and also to designate numbered mapping units in the belts west of the Saltville fault. Collectively, Rodgers (1953, p. 66-67) regarded the Chickamauga rocks as divisible into two major superunits, an uppermost, dominantly medium-grained, dark, crystalline limestone portion with accessory shale beds and a combined lower and middle part mainly composed of fine-grained light-colored, slightly silty limestone with associated limy siltstones. Below the boundary between the two divisions, two bentonites a few feet apart and underlain by greenish chert, form a lithologic datum traceable throughout the western belts. These bentonites appear within the upper 100 feet of the Moccasin Formation as mapped by Rodgers in the eastern part of the province, and in about the same position in Chickamauga Limestone Unit 3 in the belts west and northwest of the White Oak Mountain and Hunter Valley faults (Rodgers 1953, p. 86-89).

Older formational names were maintained with some redefinition by Rodgers in the eastern belts and assumed equivalence to the western Chickamauga units was suggested. However, recognizing the many conflicting opinions and unresolved problems, Rodgers (1953, p. 67) placed greater reliance on correlation within belts rather than belt to belt correlation.

In the easternmost belts northwest of the Saltville fault, the formations mapped by Rodgers (figure 9) as Chickamauga Limestone, unit 1, Chickamauga Limestone, unit 2, and Moccasin Formation, representing the lower and middle subdivisions of the Chickamauga Group, are relevant to the discussion of the biostratigraphy of the Phase IV fauna in that part of Knox County included in the Chickamauga province of this paper.

Elements of the provincial fauna, contained in the Chickamauga units above can be traced along the strike of the belts northeastward into Virginia. From the studies of Hall and Amick (1934), Butts (1940), Cooper and Prouty (1943), Rodgers (1943, 1953), B. N. Cooper (1944), Prouty (1946), Rodgers and Kent (1948), Miller and Brosgé (1954), Cooper and Cooper (1946) and G.A. Cooper (1956), it is evident that the distribution of the Phase IV fauna in the rocks of the Chickamaugan province is distinctly linear in pattern and parallel to major fault traces from the latitude of Knoxville north and west. Major East Tennessee localities related to the mapping units of Rodgers (1953) are shown in figure 9.

Preliminary examination of the same belts to the southwest indicates that the same pattern continues well into Roane County. While a great many details are presently unknown, it must be concluded that the characteristic lineation displayed in the Chickamaugan province has a definite paleogeographic base. Further, extensive lateral continuity of paleoecological parameters governing the distribution pattern must be assumed.

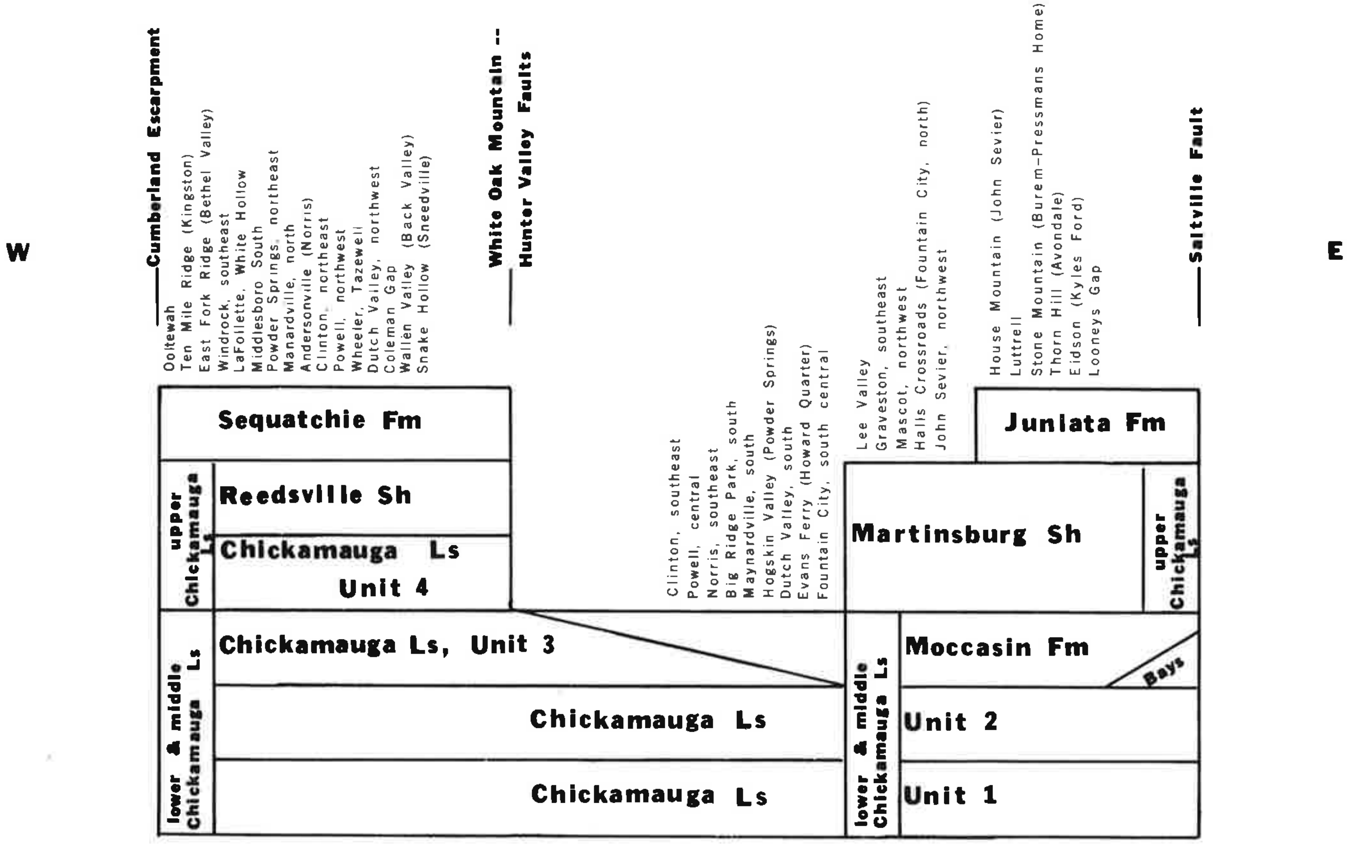


Figure 9. Subdivision of the rocks in the Chickamaugan province by Rodgers (1953) and distribution of sections by quadrangles.

Chickamaugan case study: the Raccoon Valley fauna

LITHOFACIES OBSERVATIONS

In Knox County, some of the best exposures of rocks bearing the post-Knox Phase IV fauna in the Chickamaugan province are located in Raccoon Valley, approximately 12 miles northwest of Knoxville on the northcentral portion of Powell (Station) (T.V.A. 137-SE) quadrangle (figure 1). Raccoon Valley by name and geological character extends from the Bethel Valley (130-NE) quadrangle on the southwest, northwestward across the northwest Lovell (138-NW), southwest Clinton (137-SW), southeast Norris (137-NE), south central Big Ridge Park (146-NW) and southeast Maynardville (145-SE) quadrangles. Through Hogskin Valley, Powder Springs (154-SW) quadrangle, Dutch Valley, Dutch Valley (154-SE) quadrangle, the Evans Ferry section on the Howard Quarter (162-NW) quadrangle, and Clinch Valley on the Kyles Ford (170-SE) quadrangle the same belt can be traced into Virginia.

Important comparable sections containing the earliest Phase IV fauna and associated Chickamaugan rocks can be observed in the belt bordering the Saltville fault on the northwest, which includes the Thorn Hill section, Avondale (162-SW) quadrangle, first described by Hall and Amick (1934), the Lee Valley section, Lee Valley (171-NW) quadrangle, studied by Rodgers and Kent (1948) and the section that crosses the adjoining central Graveston (146-NE) and northwestern half of the Luttrell (155-NW) quadrangles.

Full examination of the lithologic and faunal variation within the Raccoon Valley belt is beyond the scope of the present paper. The Knox County section and extensions along strike southwest to Edgemoor Bridge on the Clinton quadrangle and northeast to Hill Gap on the Big Ridge Park quadrangle will be used primarily as a basis for the discussion to follow. New cuts on Interstate 75 crossing the valley in northwest Knox County have fully exposed both ends of the section, from the disconformable contact with the upper Knox (Mascot) in Flint Ridge on the northwest side of the valley to the fault (Copper Creek) contact with the Rome Formation in Bull Run Ridge flanking the valley on the southeast.

Together with other exposures in cuts on U.S. 25W (Clinton Highway), in adjacent Anderson County, on Tennessee Highway 71-U.S. 441 (Norris Freeway) and along the average N40°E strike of the formations within the portion of the valley included here, a composite section between approximately 1740′ to 1870′ has been examined. The Bull Run Ridge cut in the northwest corner of the Fountain City quadrangle and the Flint Ridge cut in the southeastern corner of Norris quadrangle have provided additional views of the upper and lower contacts, respectively, of the section. Details from measured sections by Harvell (1954), Causey (1956), Fields (1960), and Lomenick (1958) have been incorporated in the analysis of the section given here.

Beginning with Ulrich (1911), the Raccoon Valley section in Knox County has served as a prime source area for information concerning the Phase IV fauna in the Chickamaugan province. The study of brachiopod collections from several locations in the valley, especially between Heiskell and Fleanor Mill, by G. A. Cooper (1956), has contributed significantly to present understanding of this fauna. Primarily on the basis of faunal characteristics, two formations, the Fleanor Formation (Cooper, 1956) and Heiskell Shale (Ulrich, 1911) were defined within the portion of Raccoon Valley considered in the following discussion.

The rocks of Raccoon Valley include a number of contrasting lithofacies none of which is unique to the Chickamaugan province but represent lateral migration of the sedimentary environments responsible for them. Similarly, biofacies reflecting established community organization or allogenic origin are systematically comparable at the group level. Similar patterns recording original spatial deployment of these facies can be observed in both provinces as well.

The biostratigraphic analysis of the Raccoon Valley section presented in this paper is developed around the stratigraphic and areal distribution of four lithofacies groups and associated faunas as follows:

1. Shale, siltstone, and mudstone, gray, buff, yellow, maroon, and green in weathered or unweathered condition. These rocks are argillaceous, calcareous, or mixed in composition and both autochthonous and allochthonous origins are inferred. This lithofacies complex is characterized by its limited paleontology, ranging from none or trace fossils on one extreme to a single group or single species on the other.

2. Thin-bedded, medium-gray to brownish limestones, pure to impure, flaggy, with thin shale or weakly lithified mudstone partings. These limestones exhibit on outcrop a laminated to ribbed appearance, the degree depending on weathering. Fossils on the limestone surfaces are mixtures of locally adapted species, commonly in growth position, and introduced bioclastic debris. Screening of the argillaceous interbeds produces large numbers of small, well-sorted fossils, usually whole brachiopod shells and bryozoan fragments, and ferruginous pellets.

3. Medium to poorly bedded, medium-gray to bluish, argillaceous limestone, internally convoluted, nodular or cobbly where weathered. Buff chert float, in brownish irregular fragments and deep regolith obscure the outcrops. Fossils are numerous but commonly occur in mixed coquinoid assemblages composed of both indigenous and introduced elements.

4. Medium- to thick-bedded or massive and lenticular limestone ranging from very light-gray or blue to darker shades, fine- to coarse-grained to crystalline in texture. Individual varieties display features such as stratiform primary cherts, dark-gray to black, banded, bedded, blocky, or nodular, some jasperoid; calcite stringers, blebs, and birdseyes are common; and some rock has asphaltic odor on fracturing and typically breaks conchoidally. Included among the varieties are fine-grained to aphanitic (vaughanitic) calcilutites and coarser calcarenites and biosparites.

> Finer textured varieties in this lithofacies group are generally poorly fossiliferous with very restricted faunas. Coarser varieties are commonly highly fossiliferous. Secondary, blocky chert and clayey soil comprising the residuum of the latter contain molds, casts, partially or completely silicified shells and other fossils in great variety and abundance. Many of these can be traced through successive stages of silicification from the outcrop into the residuum. Assemblages from these rocks are the most complete and ecologically compatible.
>
> It is evident from the contrasting paleontology that the limestones in this group represent a range of environments. However, unlike the dual character of the rocks in the other lithofacies groups listed, all of these rocks are primarily autochthonous representing inorganic—organic buildups or deposition in place for longer or shorter periods of time. Such lithofacies occur as basal beds in a given sequence or are marginal to other lithofacies when viewed in areal context.

Several transects of the portion of Raccoon Valley examined indicate that the lithofacies complexes grouped above are repetitive and occur in cycles in the approximate order given if complete. These cycles may be truncated from place to place but the relative position of a given lithofacies remains the same from section to section.

The lithofacies groups can be observed to intergrade and interdigitate laterally along strike. Thus, calcarenites lie marginal to: brown-weathering, impure, granular limestone; maroon, red and gray mottled shale and siltstone with thin gray limestones; medium-bedded, dark limestone with dark gray nodular chert; fine-grained, light-gray limestone with dark-gray chert interbeds; and basal conglomerate, red, green, and gray shale and chert beds,. In other cases, cobbly-weathering limestone is overlain by buff-colored shale and both intergrade laterally with calcarenite.

There are a few lithologically and faunally consistent beds of fairly uniform thickness extending for several miles along strike throughout the valley. One of these units, composed of cobbly-weathering limestone grading upward into thin-bedded shale, forms nearly two-thirds of one zone that underlies the southeastern part of the valley. This zone effectively subdivides each section examined by the writer.

BIOSTRATIGRAPHIC ZONATION

Between the Knox contact and the Copper Creek fault, the composite Raccoon Valley section can be separated stratigraphically into four major zones based on recurrent lithofacies cycles and distinctive faunal assemblages. From northwest to southeast, or in proper stratigraphic order, these zones numbered for reference purposes, are described as follows:

Zone I. Lithologically, this zone consists of interbedded light-to dark-gray, thin- to medium-bedded, less commonly massive, fine-grained, slightly argillaceous to pure limestone and green and gray siltstone and calcareous maroon shale. The limestones may contain dark maroon and green shale interbeds, lenses and beds of dark red (jasperoid) to brown chert and blebs and stringers of calcite; the latter is pink in one section examined. Angular chert and dolomite fragments of the Knox mark the unconformity in most places. The basal limestones of this zone may be dolomitic and thin red mud layers and bedded nodular chert may occur in the upper Knox; therefore, in the absence of a marked disconformity or where the contact is covered by residuum, the base of the zone is not easily determined.

The thickness of Zone I appears to vary according to the number of limestone-shale cycles repeated. The zone measures less than 50 feet in one section and over 130 feet in another with relief on the unconformity a probable factor. Wide covered intervals and karst development inhibit precise measurement.

The upper contact with Zone II is likewise obscured but topographically may be marked by depressions filled with soil and chert residuum from both zones. Where the two zones are exceptionally cherty and resistant they form, with the upper part of the Knox, a ridge (Flint Ridge) paralleling the Knox-Anderson county line. To the southwest in Anderson County, prominent spurs and knobs flanking Chestnut Ridge are underlain by these zones. The Interstate 75 cuts through Flint Ridge in northwestern Knox County expose the Knox contact and the lower part of Zone I.

The Zone I fauna in Raccoon Valley is very limited consisting of gastropods (especially *Eotomaria* sp.) and ostracodes. The gastropod fossils frequently occur as molds and casts on the surfaces of blocky chert fragments in the residuum. Resemblance in form and preservation to similar zones in the Mascot elsewhere indicates that in places the biological-ecological unconformity between the top of the Knox and the basal Chickamauga beds is not pronounced.

Zone II. The basal limestones of this zone are comparable to those in the underlying zone with bedded chert, buff and maroon shale interbeds, calcite blebs and stringers. A ten-foot interval of limestone with asphaltic odor on breaking has been observed in one section. As much as half of the zone is made up of buff to red calcareous shale or mudstone with thick beds or massive lenses of relatively pure, bluish-gray limestone, some of it crystalline. The upper 60 feet or so of the zone is commonly composed of argillaceous gray, buff-weathering, fissile shale and mudstone.

Along strike, Zone II is intermittently exposed and is distinguished by changes in lithofacies. The lower beds, as in the case of the upper part of Zone I, are commonly represented only by cherty residuum and soil. Upward in the section large masses of coarse-grained, crystalline limestone stand out in the relief due to the weathering of shaly beds that surround them. Thin-bedded, impure limestones in the upper part of the zone are exposed on washed hill slopes and in ditches.

Owing to generally poor exposure, thickness of Zone II is indeterminate but is believed to approximate between 275 feet and 300 feet. In the Knox County portion of Raccoon Valley, the zone forms a low gap or saddle parallel to Flint Ridge. To the southwest, the zone occurs under low foot slopes on the northwest side of the valley and where less cherty extends out on the valley floor. Red, calcareous mudstones in the zone can be seen along Highway 25-W.

The biostratigraphic break between Zone II and the underlying Zone I is sharp as are several boundaries within the zone. Along the strike of the zone, the red mudstones, sterile except for worm trails and burrow fillings, contrast with highly fossiliferous shale, flaggy, coquinoid limestones and chert-producing, thick-bedded to massive limestones. In one place, the red mudstone has vague *Camarocladia*-like markings.

The lowest well developed assemblages above the Knox occur in this zone. The zone is characterized by stratigraphic increase in number and community diversity. In the upper part of the zone, long exposures of rapidly-weathering biostromal mats and lensoid masses are profusely fossiliferous. Brachiopods typically occur in stratiform beds marginal to lensoid growth mounds. In the lower part of the zone the characteristic ostracodes, gastropods, pterygometopid and bathyurid trilobites, and rare small pelecypods comprise more limited assemblages, perhaps owing to greater environmental restriction. Chert molds and casts and silicified shells, especially those of the brachiopod *Dinorthis holdeni* (Willard) in the iron-stained regolith, provide most of the faunal record in the lower part. The upper part has a prolific brachiopod fauna, notable for speciation within certain genera, especially *Mimella, Oligorhynchia* and *Rhipidomena.*

Zone III. The lower third to a half of this zone consists of a wide assortment of relatively pure limestones, dark- to medium-gray, fine-grained to coarsely crystalline, thick-bedded to massive. Varieties are distinguished by lenses of blocky chert, fluted surfaces, stylolites, ooids, bioclasts, asphaltic odor on fracturing, buff, silty partings, or pink and white calcite stringers and blebs. None of the special features persists for great distances but the limestones, in general, grade upward into nodular or cobbly weathering limestones, interbedded impure argillaceous limestone, and blue to buff calcareous shale at the top of the zone.

Zone III varies in thickness from 450 feet to 500 feet but within the zone lithologic subzones thin and thicken along strike so that the relative proportions of the lithofacies noted vary from southwest to northeast. Buff-weathering calcareous shale with *Dinorthis transversa* Willard in a relatively thin subzone above a dense coquina of *Sowerbyella* shells is a distinctive and consistent feature in the upper part of this zone. The broad belt (ca 200′) of nodular weathering limestone is also conspicuous and persistent.

To the northeast in the Raccoon Valley section on the Big Ridge Park quadrangle, the typical limestones at the base of the zone grade into maroon, buff, and dark gray argillaceous and calcareous shales. In the same section a narrow subzone of "marble-like" pink to red, coarsely crystalline, massive lenticular limestone occurs within the cobbly-weathering limestone zone. Except for these cases, Zone III differs from the overlying and underlying zone which are distinguished by prominent red beds.

Zone III generally underlies the lowest part of Raccoon Valley but more resistant beds may form low ridges flanking both sides of the valley. Although Rodgers (1953) did not differentiate the lower and middle Chickamauga rocks in most of the portion of Raccoon Valley described here, Zone III compares favorably on lithologic grounds to Chickamauga limestone Unit 2 of that author. It is assumed, therefore, that the underlying Zones I and II of the present paper represent Rodgers' Chickamauga limestone Unit 1 as mapped elsewhere in the belt northwest of the Copper Creek fault.

Many of the limestones forming the bulk of Zone III are fossiliferous; calcarenites toward the base of the zone are profusely so. Many of these are cherty, biohermal masses or biogenic mounds or banks, linear in orientation and several feet thick, composed largely of flat and cylindrical branching bryozoans, especially species of *Batostoma* and *Rhinidictya*, assorted echinodermal parts, trilobites, and nitulitids (*Nidulities pyriformis* Bassler). These assemblages are among the most diverse in Raccoon Valley and environmental conditions supporting several trophic levels and maintaining community stability for sustained periods are evident.

Thin bedded limestones with shale interbeds and the limestones of the cobbly-weathering variety generally have more restricted brachiopod assemblages. Compared to the brachiopods in Zone II this element of the total fauna is reduced to about half the number of genera, most of which are represented by one species. Large strophomenids (e.g. *Macrocoelia magna* Butts) forming coquinoid beds with stony bryozoan parts are common.

Zone IV. This zone comprises over half of the Raccoon Valley section, ranging in thickness from about 925 feet to the northwest to nearly 1000 feet to the southwest. Everywhere it consists of recurrent sequences of limestone, mudstone and shale. The number of such sequences, identified on the basis of a concentration of thicker bedded, purer limestones on one end of the sequence and thin or poorly bedded mudstones and calcareous shales on the other, varies from three to six in the valley sections examined.

The limestones commonly occur in thick units of 50′ to 100′ or more and every lithologic variety found elsewhere in the composite section is represented. Thin-bedded flaggy limestones with thin shale or mudstone partings are especially abundant. These limestones weather rapidly and leave a ribbed outcrop pattern. Nodular or cobbly-weathering limestone is present but nowhere in the zone approaches the relative proportion or persistence as in Zone III. Dark-gray to black, bedded chert, calcite veinlets, stringers and blebs ("birdseyes") and thin coquinoid lenses and layers mark many of the limestones and these features recur in each sequence.

The most distinctive feature of Zone IV are single or multiple sequences of maroon, mottled or interbedded red and green, gray and buff, calcareous mudstones and shales. In the Raccoon Valley belt, Rodgers (1953, p. 83) following the usage of Keith (1896b, Morristown Folio) includes all of the red beds and, hence, most of Zone IV of this paper, in the Moccasin Formation. Other authors have subdivided comparable rocks in approximately the same relative stratigraphic position elsewhere and the terms Wardell, Dryden (upper part) (Cooper, 1956), and Witten (Cooper and Prouty, 1943) probably apply to facies included in the lower half of Zone IV.

The red beds are concentrated generally in the upper third to half of the zone but at least one similar concentration occurs within 200 feet of the base of the zone in all of the transects made. In one section, bedded red jasperoid chert occurs near the base of the zone and with the lower red bed concentration and intervening beds in that section recalls the comparable lithofacies sequence seen in Zones I and II.

Zone IV is cut by the Cooper Creek fault accompanied by drag folds in a thick sequence of interbedded gray, red, and buff calcareous siltstone in the Interstate 75 cut through Bull Run Ridge bordering Raccoon Valley on the southeast. The fault contact with the Rome Formation approximates the summit of Bull Run Ridge. Zone IV underlies the northwest slope of the ridge and extends by means of parallel hills and slopes into the valley southeast of the Heiskell school in the Knox County section of the valley. Approximately 175 feet below the fault contact, a 1½ foot bed of greenish gray clay underlain by a chertified gastropod layer is a suspected but unconfirmed bentonite. In the reference section in Clinch Valley used by Rodgers (1953, p. 86) two comparably thick bentonites occur in the upper hundred feet of the Moccasin Formation.

Approximately 313 feet of Zone IV is exposed in the Dry Gap cut through Bull Run Ridge on I-75. This part of the section has been studied in detail by Milici and Walker and they have proposed a model for the depositional environments of these rocks elsewhere in this volume. Aside from the concentration of red beds, the most distinctive feature of these strata is the zonation and repetition of paleontologic characteristics. The more diverse and less disturbed assemblages consisting of bryozoans, brachiopods, trilobites, mollusks, (and in one place, corals) are associated with relatively thick-bedded calcarenites which grade into thinner calcilutites with mud partings. Lithologically similar but finer grained calcarenite grades into algally-laminated, micritic calcilutite and mudstone with fossil fragments, burrows, and calcite blebs or birdseyes. Ostracodes in layers and lenses are consistently and singularly present in the laminated, burrowed units with birdseye structures.

Quantitatively, the cobbly-weathering, argillaceous limestones that succeed the laminated, ostracode-bearing limestones are the most fossiliferous rocks in the section. However, much of the trepostome bryozoan, brachiopod, trilobite, and echinodermal material in these rocks is fragmental and disarticulated, and appears to represent accumulated debris. Such deposits are capped by beds with whole brachiopod valves, cryptostome bryozoans, and cephalopods.

Except for burrows, the mud- or shrinkage-cracked, colored shale and mudstone in single, thin beds or thick sequences of thin beds are unfossiliferous. However, these beds are separated by ostracode layers on occasion.

From their analysis of these rocks based on external and internal characteristics, Milici and Walker have separated the fossil-bearing beds in the upper third of Zone IV into two facies groups, one developed in shallow, semi-isolated, subtidal basins, the other formed in the construction of progradational mudbanks marginal to the basins. The recurrence, variation and specific character of assemblages and lithofacies have been related to the dynamics and fluctuating parameters of the local sedimentary environments responsible for the two facies groups. Relative thickness and completeness of sequences combining both components have been interpreted by Milici and Walker as indicative of areal position with respect to the evolution of a carbonate platform-bay-key complex somewhat analogous to Florida Bay at the present time.

FAUNAL RELATIONSHIPS

The fauna as presently known in the portion of Raccoon Valley examined is tabularized by zones in table 4. It is clear that despite the lithologic similarities upon which the zones were established, each zone is faunally distinct. The relatively few systematic connections between any two zones are marked in many cases by wide stratigraphic gaps in the section.

The limited Zone I fauna may be related to either conditions incident to the initial transgressance of the exposed Knox surface marked by the unconformity, or to conditions marginal to a part of the Knox platform still exposed. Walker and Laporte (1970) regard lepertitiid ostracodes as indicative of supratidal to low intertidal environments. In contrast to the fauna in Zone II which has a large number of taxa and individuals, an intertidal interpretation is favored. In this regard, it is noteworthy that the zone is characterized by maroon and green shale interbeds and along with the ostracodes form a combination of features repeated in the upper part of Zone IV.

As noted in describing the lithologic features of Zones II, the reduced exposure and mixing of residuum make analysis of the zone difficult. From scattered outcrops and residuum a fairly representative sample of the associated fauna has been collected although not complete by any means.

The faunal summary in table 4 shows the sharp biostratigraphic break between Zone II and the underlying Zone I. One might be tempted on the basis of the faunal lists to draw a major stratigraphic boundary between the two zones. However, the basal beds of Zone II contain gastropods and ostracodes comparable to those in Zone I, typically in blocky chert pieces which are bored vertically. Therefore, it is probable that these zones are ecologically conformable in part. The lower beds of Zone II include laminar stromatoporoids and an assortment of small trilobites. Residuum derived from the lower part of the zone contains small, thin valved, silicified orthid brachiopods distinguished by large numbers of individuals. One of these *Dinorthis holdeni* (Willard), has been used to characterize the fauna of this zone in the easternmost belts of the Chickamaugan province elsewhere.

In contrast to the lower monotypic lenses and beds with limited faunal diversity, the fossiliferous strata through the middle part of the zone reflect conditions supporting the speciation in some brachiopod genera and the development of stratiform skeletal communities. Coquinoid beds containing many superimposed layers of large strophomenid brachiopods (e.g. *Pionomena*), again monotypic, or nearly so, with many individuals and shales and muddy limestones with small spiriferid brachiopods such as *Protozyga microscopica* Cooper probably represent low intertidal environments or tidal channels marginal to the better developed subtidal communities. Well-sorted bryozoan fragments and other fossil debris are a common constituent of the strophomenid coquinas and were likely supplied from some low intertidal or high subtidal source.

TABLE 4. FAUNAL ZONES IN RACCOON VALLEY, KNOX COUNTY, TENNESSEE

ZONE IV	(A)	Brachiopods: *Zygospira lebanonensis Cooper* Trilobites: *Calliops* sp. Gastropods: small, unidentified. Cephalopods: *Endoceras* sp. Bryozoans: *Batostoma* sp., *Rhinidictya* sp. Ostracodes: *Leperditia fabulites* Conrad, *L. sulcata* (Ulrich), *Isochilina* sp. Algae: *Solenopora* sp., *Hedstroemia* sp.
	(B)	Brachiopods: *Mimella wardellana* Cooper, *Protozyga* sp., *Glyptorthis irregularis* Cooper, *Rostricellula subtransversa* Cooper, *Murinella muralis* Cooper, *Ancistrorhynchia costata* Ulrich & Cooper Gastropods: *Maclurites* cf *bigsbyi* Hall Bryozoans: *Batostoma* sp., *Rhinidictya* sp., *Prasopora simulatrix* Ulrich, unidentified *Dekayella*-type Receptaculitid: *Receptaculites* sp.
ZONE III		Brachiopods: *Dinorthis transversa* Willard, *Rhipidomena tennesseensis* (Willard), *Mimella globosa* (Willard), *Macrocoelia magna* (Butts), *Protozyga uniplicata* Cooper, *Glyptorthis uniformis* Cooper, *Rostricellula rostrata* Ulrich & Cooper, *Sowerbyella compacta* Cooper, *Chaulistomella brevis* (Willard), *Fascifera convexa* Cooper, *F. stonensis* (Safford) Trilobites: *Illaenus consimilis* Billings, *I.* sp., *Bumastus* sp., *Amphilichas* (*Acrolichas*) *prominulus* (Raymond) Sponges: *Microsporangia* (*Hindia*) *parva* (Ulrich) Gastropods: *Maclurites* sp., *Oxydiscus catilloides* (Raymond), *Kokenospira virginiana* Butts Cephalopods: *Orthoceras* sp., *Gonioceras anceps* Hall Bryozoans: *Rhinidictya* sp., *Batostoma* sp., *Eridotrypa*?, *Nicholsonella*? Nidulitids: *Nidulties pyriformis* Bassler, *N. ovoides* Butts Hydrozoans: *Cryptophragmus* sp. Echinoderms: *Diabolocrinus* sp., *Echinosphaerites* sp., undetermined glyptocrinid.
ZONE II		Brachiopods: *Dinorthis holdeni* (Willard, *Rhipidomena subparallela* Cooper, *R. mesleri* Cooper, *Mimella intermedia* Cooper, *M. costellata* Cooper ?, *M. similis* Cooper, *Oligorhynchia angulata* Cooper, *O. subplana* Cooper, *O. bifurcata* Cooper ? *Pionomena neumani* Cooper, *Multicostella semisulcata* Cooper, *Camerella* sp., *Öpikina* ?, unidentified inarticulate. Trilobites: *Pterymogetopus* cf *annulatus* Raymond, *Bathyurus* sp., unidentified *Isotelus*-type. Gastropods: *Holopea* cf *scrutator* Raymond, *Maclurites* sp., *Eotomaria* ? Bryozoa: *Batostoma* sp.
ZONE I		Ostracodes: *Leperditia* cf *fabulites* Conrad, *Leperditella* ?, *Isochilina* ? Gastropods: *Eotomaria* sp.

Certainly the most distinctive features of Zone II are the red calcareous mudstones and shales that appear in discontinuous outcrop in the upper half of the zone. These rocks are lithologically similar to some of the red beds of Zone IV. In the view of the writer, the model proposed by Milici and Walker in this volume for the upper part of Zone IV may be applicable, in part at least, to the red bed facies and associated rocks of Zone II. Paleontological resemblances between these zones include the common occurrence of similar ostracodes and closely related pterygometopid (*Pterygometopus, Calliops*) trilobites.

The Zone III fauna (table 4) is the most diverse and complex in Raccoon Valley. Although systematically comparable in some aspects, the introduction of new forms, the replacement of community members at the generic and specific level, and the large scale biostratigraphic gaps in generic ranges all combine to distinguish this fauna from the Zone II fauna. Upward in the section, the terminations of many forms sharply differentiate the Zone III fauna from the succeeding one in the area. Some continuity with the Zone IV fauna is displayed by a few brachiopod genera and bryozoans which extend well into the lower part of Zone IV. However, these elements are phased out ultimately and the distinction between the upper Zone IV fauna and the Zone III fauna in general is as pronounced as between the faunas of Zone I and Zone II.

A review of the stratigraphic and geographic distribution of Middle Ordovician articulate brachiopods in the region (figure 7) provides the basis for the following conclusions concerning the Zone III fauna in Raccoon Valley.

1. Both systematic differences and similarities between the faunal zones may be explained as resulting from a mixture of endemic Chickamaugan elements with those which were brought into the area due to westward translocation of environmental conditions favorable to migration. Thus, species of the strictly provincial genera such as *Fascifera, Protozyga,* and *Oligorhynchia,* are associated in the fauna with species of *Rostricellula, Macrocoelia, Sowerbyella,* and *Chaulistomella.* The latter genera all have Blountian relatives each of which is in a lower stratigraphic position in the eastern province.
2. The apparent generic continuity shown by different species of *Dinorthis, Rhipidomena,* and *Mimella* in Zones I and II is misleading. Large scale stratigraphic gaps interrupt the ranges of the species of these genera in the Raccoon Valley fauna. *Dinorthis holdeni* (Willard), *Rhipidomena subparallela* Cooper and *R. mesleri* Cooper of Zone II are widely separated from *Dinorthis transversa* Willard and *Rhipidomena tennesseensis* (Willard) of Zone III.

None of the intermediate dinorthid forms found in other eastern Chickamaugan belts (e.g. *Dinorthis atavoides* Willard, *D. Willardi* Cooper) have been found in the Knox County Raccoon Valley section to date. On the other hand, the biostratigraphic gap between the Zone II and Zone III species of *Mimella* is not as pronounced on morphological grounds as the stratigraphic separation of the species in the section.

The apparent biostratigraphic gaps in the ranges of *Dinorthis, Rhipidomena,* and *Mimella* are accompanied by another distribution characteristic that requires explanation. Each of these genera has species in the Blountian province. Species of *Dinorthis* and *Rhipidomena* are found exclusively in stratigraphically higher beds (with the later Phase IV fauna) in the Blountian province. If these genera originated in the Chickamaugan province, a later regression of facies eastward could account for the reversal of direction in contrast to the overwhelmingly westward transgression exhibited by species of other genera. Species of *Mimella* are found in the earlier Phase IV fauna in the eastern province but all other occurrences are in the Chickamaugan province.

The *Mimella* biostratigraphic gap in the Chickamaugan province may well document transgressive stages involving different species of this genus. On the other hand, it might be argued that the initial translocation of facies was regressive and eastward and that derived species from the Blountian stock of the genus returned westward during a later transgressive phase. Whatever the explanation for the geographical disjunction in the distribution of species of *Mimella, Dinorthis,* and *Rhipidomena*, genetic continuity is required at one or more points in time.

The marked contrast in trilobites between Zone II and Zone III faunas parallels that of the brachiopods. However, the different ptychoparid, especially illaenid genera and previously unrecorded lichid forms, appear to be entirely introduced into the area. Comparison with the Lenoir fauna (table 3) shows a concentration of illaenid trilobites in the upper part of the Lenoir (Arline Formation of Cooper, 1956). Work in progress by the writer and students is expected to show a great proliferation of lichid trilobites in the Blountian province during the time represented by the deposition of the Ottosee carbonates and shales. In this connection, it is of interest to note that both *Dinorthis transversa* Willard and *Chaulistomella brevis* (Willard) and species of the genera *Glyptorthis* and *Rhipidomena* are commonly associated in the Sevier Formation in the Blountian province just as they are in Zone III in Raccoon Valley.

The ecological range of the Zone III fauna is believed to extend from intertidal mudflats which characterize the upper part of the zone to well-developed, more localized, probably subtidal biohermal mounds or biostromal growth forms of some lateral extent in the lower part. Especially abundant and apparently important in the construction of the latter are nidulitids and bryozoans. Echinoderms and small gastropods are found *in situ.*

The cephalopods and larger gastropods in the fauna are usually found as isolated occurrences in more massive cryptocrystalline limestones, or in thin-bedded argillaceous limestones or shales, with or without bioclastic debris. As in other zones, large strophomenids, crinoid columnals, and fragmented bryozoans are common to the argillaceous, nodular or cobbly-weathering limestones.

Shales, siltstones, and thin-bedded limestones with shale interbeds commonly contain single brachiopod species (e.g. *Dinorthis transversa* Willard, *Rostricellula rostrata* Ulrich and Cooper, and *Protozyga uniplicata* Cooper) in very large numbers. These rocks and limited fauna are interpreted as one extreme in the range of environments to which the Zone III fauna was adapted when compared to the multigeneric subtidal communities in the purer limestones at the other extreme. The uppermost part of Zone III is marked by widespread shale and siltstone throughout Raccoon Valley and, it is assumed, a significant reduction in the range of environments described.

As shown in table 4, relatively few Zone III brachiopod genera are represented in the Zone IV fauna. These few, along with the bryozoans and macluritid gastropods, show persistence, or restoration, of some environmental conditions represented in the preceding zone but with obvious limitations. The introduction of red beds is undoubtedly associated with the reduction in fauna.

Receptaculites, now regarded as an algal form, occurs with the Phase IV fauna in the Blountian province (table 3) and in Zone IV in Raccoon Valley. A species of *Maclurites* close to *M. magnus* Lesueur, the familiar gastropod of the Blountian province, is also present in the zone. Here again, the translocation of comparable environments with parallel community organization seems inescapable.

The massive bryozoan, *Prasopora,* in the lower to middle part of Zone IV and the small spiriferid brachiopod, *Zygospira lebanonensis* Cooper, in the upper part of the zone have special significance. These fossils provide a chronostratigraphic index to the changing fauna populating the shallow water carbonate environments of the Middle Ordovician. According to Cooper (1956) *Zygospira lebanonensis* Cooper in Raccoon Valley, and other species of the genus in the Sevier Formation in the Blountian province mark the first record of the genus in the Southern Appalachians. Cooper (1956) places the lower range limit of *Zygospira* near the midpoint of his Wilderness Stage (uppermost Bolarian of Kay).

The lower Zone IV fauna includes representatives of other brachiopod genera, *Rostricellula, Murinella,* and *Mimella,* at or near the end of their range, also in the Wilderness Stage, according to Cooper (1956). On the other hand, brachiopod genera characteristic of the succeeding Trenton communities such as *Dalmanella, Rhynchotrema* and *Rafinesquina* are not represented in the Raccoon Valley fauna so far as is presently known.

The presence of *Zygospira lebanonensis* Cooper in the upper Zone IV fauna takes on added significance as a link with the Lebanon Limestone faunas of the Central Basin where it occurs in outcrop of that formation at Shelbyville, Columbia, Murfreesboro, and Readyville. *Zygospira lebanonensis* Cooper and the closely related *Hallina saffordi* (Winchell and Schuchert), both reported in the literature under the name *Zygospira saffordi* Winchell and Schuchert, are found in Lebanon faunas with *Glyptorthis irregularis* Cooper and *Maclurites magnus* Lesueur, other Zone IV species.

Altogether, the fauna of both Zones III and IV in Raccoon Valley have a distinct "Stones River" aspect. The brachiopod species, *Rostricellula rostrata* Ulrich and Cooper and *Ancistrorhyncha* (*Protorhyncha*) *costata* Ulrich and Cooper, are found in the Pierce and Ridley formations; *Fascifera stonensis* (Safford) and *Glyptorthis irregularis* Cooper are in the Pierce faunas although other species of these genera occur in the Ridley rocks; species of *Mimella* are present in all three of the main fossiliferous zones in Raccoon Valley and in the Pierce/Ridley fauna, but apparently not in the Lebanon Limestone.

While the number of genera and species in common between the brachiopods in the Raccoon Valley fauna and the lower Central Basin faunas is impressive, and these resemblances extend to other groups as well (ostracodes, bryozoans, algae), it can not be concluded that the faunas and the rocks that contain them are correlative. Such procedures have been challenged throughout this paper and would be antithetic to the biodynamic concept of these faunas that the writer has attempted to portray. The common occurrence of *Maclurites* and other facies fossils led Safford and Killebrew (1900) to equate the Stones River Group of the Central Basin to the Chazyan rocks in the Blountian province of the present paper. Ulrich (1939), using other fossils of comparable reliability but excluding the Lebanon Limestone redefined the Chazyan series in correlating the eastern and Central Basin rocks. Raymond (1905), emphasizing differences rather than a limited number of similarities, concluded that the Stones River Group was entirely post-Chazyan and more closely related to the Trenton.

Recognizing the broad similarities among the associated faunas and rocks B. N. Cooper (1945), following Ulrich, assigned the Lebanon and Carters limestones to the Black River Group with implied reference to the New York section. He considered the Murfreesboro, Pierce, and Ridley formations, however, as post-Chazyan or younger than the eastern rocks defined as Chazyan by the early workers.

Wilson (1949) grouped the Carters Limestone with the older Central Basin formations in redefining the Stones River Group but judiciously avoided the trans-Appalachian correlations popular with others. G.A. Cooper (1956) abandoned the Black River term as used by B.N. Cooper but combined the rocks and the lower Trenton of the New York section in his Wilderness Stage.

Based on selected brachiopods. G. A. Cooper (1956) correlated the Five Oaks, Blackford, Lincolnshire, Dryden, and Witten faunas of the Virginia belts, the later or post-Chazyan faunas of the Blountian province, and the Pierce, Ridley, and Lebanon faunas of the Central Basin. However, the basal Stones River or Murfreesboro fauna of the Central Basin is considered to be younger than any pre-upper Dryden Formation in the east.

In the Raccoon Valley section described in the present paper, elements of the Blackford and Lincolnshire faunas are present in Zones I and II and both the Benbolt and Wardell divisions of the Dryden fauna are represented in Zone III and the lower part of Zone IV. Further study may turn up more evidence of the Witten fauna (*Pionodema, Camarocladia, Doleroides*) but at the present time the record is sparse.

It is beyond the scope of the present paper to engage in a lengthy discussion of the relative merits of past attempts to effect correlation of all the Middle Ordovician rocks and faunas of the Southern Appalachians. As pointed out in an earlier section of the paper, resolution of the problem of the age relationships of the basal rocks and faunas in the Blountian province is basic to the solution of all others. In one recorded example, at least, Cooper and Cooper (1946) described a sequence west of Gate City, Virginia where basal conglomeratic beds containing *Rostricellula basalaris* Cooper are below a calcarenite with *Billingsaria.* These rocks with the common brachiopod and coral, respectively, in the Mosheim and lower Lenoir formations in the Blountian Province, underlie beds containing *Dinorthis holdeni* (Willard). The sequence, named the Marcem Formation by these workers, provides some basis for judgment that the lower Zone II fauna with *Dinorthis holdeni* (Willard) must be younger in a relative sense than the first fauna developed on the Knox surface in the Blountian province.

PALEOECOLOGICAL INTERPRETATION

Neither the carbonate petrography nor the internal paleontology of the rocks comprising the bulk for the Raccoon Valley section has been studied in detail. Therefore, only a very generalized physical model is proposed as a frame of reference for the writer's interpretation of the apparent zonal biostratigraphy and stratigraphy of the section discussed in the previous paragraphs.

The association and repetition of rocks and faunas in the section across Racoon Valley requires, in the view of the writer, the following model components (figure 10A):

1. A transgressed shelf or platform composed of the upper Knox formed under an earlier carbonate regime during Phase III of this paper. Harris (this volume) has described this part of the Raccoon Valley section in Flint Ridge and recently has presented a regional intrepetation of the Knox environment (Harris, 1973). For the writer's model, submergence and variable relief including probable abrupt changes of a local nature are the only features of concern relative to the shelf or platform.
2. A set of mostly shallow water carbonate environments migrating west and northwest over the shelf or platform. At least three superimposed sets of such environments are required to satisfy the changes in faunas and rocks. However, it is not implied that parts of these sets are mutually exclusive. As a matter of fact, all the sets are characterized by features in common which may have been shared at points of contact.
3. A source area out of view in the Raccoon Valley model but logically east-southeast of the belt along the depositional strike. Each zone contains lime units with argillaceous fractions and interbeds as well as shales and mudstones, all of which indicate sporadic and repetitive interchanges between clastic and nonclastic sedimentary systems. Source area and system are implied to the right on the model diagram.

Although evidence is strong that the environments represented in the Raccoon Valley section were predominantly shallow water, some accounting for the character and preservation of certain lithologies and the presence or absence of specific faunal elements is necessary. Initial deposition or accumulation below wave base and/or the photic zone is inferred from the thickness of units (e.g. the thick nodular, argillaceous limestone subzone of Zone III), absence of burrows and limited infaunal evidence, planar layering of cherts, and rhythmic characteristics of some calcisiltites and shales (Wilson, 1969; Laporte, 1969). In contrast, lensoid facies, random distribution of silt and clay in lime units, variable or indistinct bedding features, evidence of subaerial exposure, and the higher energetics implied by some very fossiliferous units all relate to conditions at, near, or above wave base or within the photic zone. Without bathymetric speculations or the use of suggestive terminology in vogue among paleoenvironmentalists, it is necessary to consider refinements of the base model to include lower areas marginal to higher areas within the lateral boundaries of the figurative model. One of these, an elongate medial basin of lagoonal configuration, apparently operative during the development of each zone, is included in the model.

The term non-reefal biogenic buildup as used by Griffith, et al. (1969) is preferred for the multigeneric growth mounds and stratified banks that occur in Zones II through the lower half of Zone IV. Some of these, especially in Zone III, are clearly indigenous and the framework organisms, bryozoans, nidulitids, and girvanelloid forms can be recognized even superficially. Others that are thin-bedded, argillaceous, and exceptionally bioclastic resemble shell banks with many layers of strophomenid brachiopods. The growth structure in this type of buildup may be a combination of transported debris and shells or organisms adapted to bioclastic substrates.

Mud-flat facies marginal to buildup facies range from carbonate to argillaceous extremes with mixtures of the two components indicative of the interaction of two sedimentary regimes. Mud-flat facies include unfossiliferous and fossiliferous varieties, the latter commonly characterized by a single species. Burrowed and bedded chert layers observed in at least two zones may be diagenetic relicts of mud-flat facies.

Most distinctive are the red muds and shales in the upper part of Zone II and in two concentrations in Zone IV (figure 10B). These red beds are interpreted by the writer as indicating that conditions comparable to those postulated by Milici and Walker elsewhere in this volume in describing the upper part of Zone IV were repeated a number of times. It is of interest to note further that the colored shales or mudstones of Zone I coupled with the occurrence of similar ostracodes are features in common shared by the upper part of Zone IV also.

Taken together, the cyclical development of lithofacies in each zone, the repetition of lithologically similar zones, and the recurrence of red beds are interpreted as a reasonable basis for concluding that the general model, modified by fluctuating internal parameters, is applicable throughout the Raccoon Valley section. Thus, each zone provides a sample of the operation of the model in sequential order.

Biostratigraphic boundaries between zones, based on temporal species and associations, gaps in generic ranges, and community replacements define the relative chronology of the repeated environmental complex. Zonal boundaries correspond to time boundaries in a relative sense. The boundary between Zones II and III clearly separates two evolutionary stages in the development of Middle Ordovician faunas as observed in the Chickamaugan province. The boundary between Zones III and IV is distinctive in terms of transprovincial migration of species. Further investigation may demonstrate the need for further subdivision of Zone IV to separate the two red bed concentrations and faunas. It is apparent that the "Moccasin" as a rock-stratigraphic unit contains different fossils in different places. In Raccoon

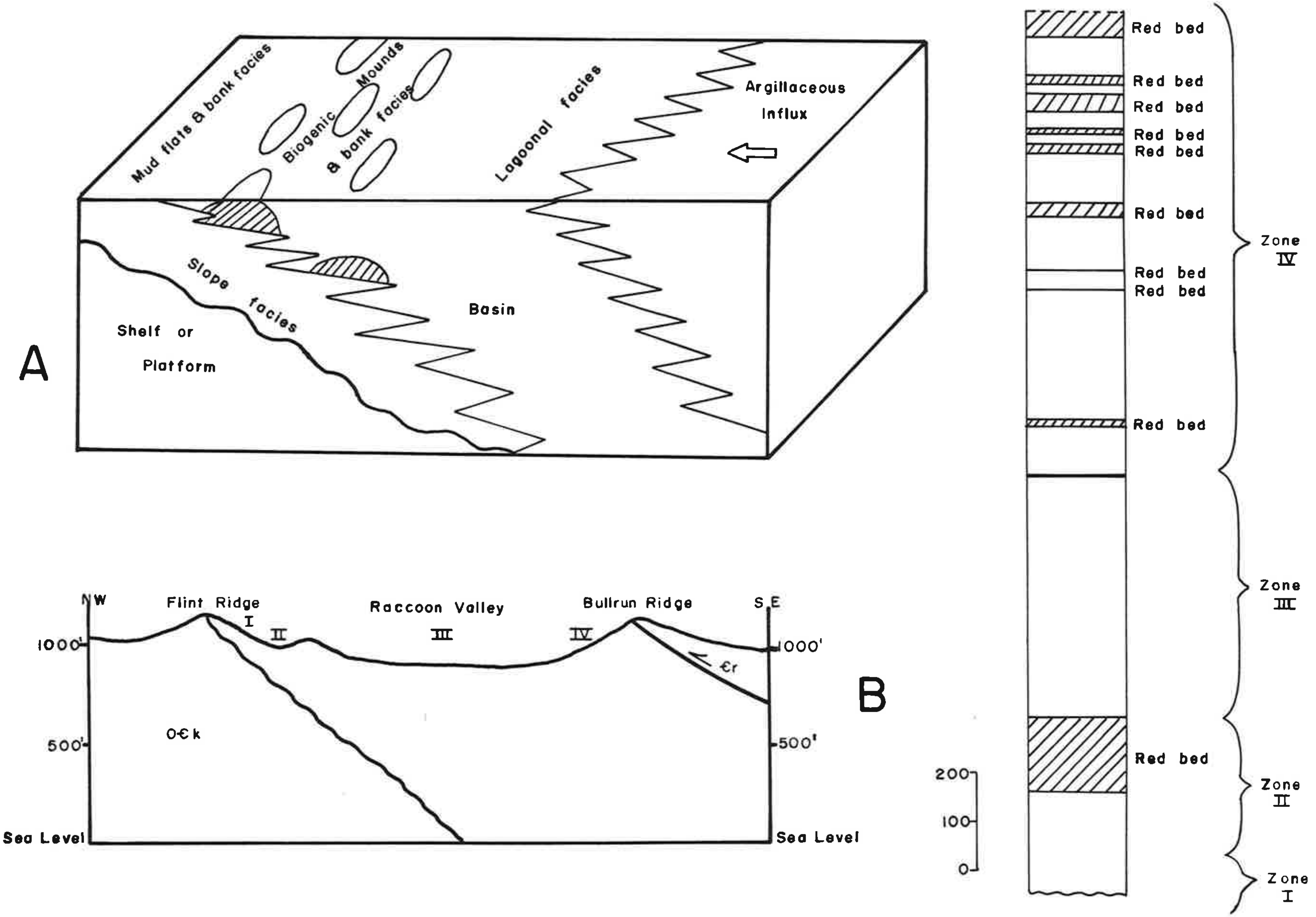


Figure 10. Model for the succession of environments represented in the Raccoon Valley section (A); Zonal subdivision and distribution of red beds in the section (B).

Valley, it is suspected that inclusion of both concentrations of red beds in one biostratigraphic unit is not valid on the basis of faunal differences only partially known at present.

Refinement of the Raccoon Valley model should take into account the coarsely crystalline limestone and calcarenite, pink to red in color noted in Zone III to the northeast. This "marble-like" facies has a variable stratigraphic and/or areal relationship with dark, cherty limestone, calcareous mudstone, or nodular limestone. In the portion of Raccoon Valley examined, the lithofacies is a minor one but is significant in that it adds still another example to the list of lithologies also observed in the Blountian province. If the pattern established in the Chickamaugan province for Lenoir-type and Ottosee-type lithologies is any indication, the marble-like facies can not be the same age as the superficially comparable facies to the east.

In belts between the Saltville and Copper Creek faults northeast and south of Raccoon Valley, marble-like facies of greater extent are well known, as for example at Luttrell in Union County. Work in progress by Walker and Ferrigno (1973) on the "Holston" facies will lead to a better understanding of the temporal and areal relationships of these rocks.

In connection with the model proposed by Milici and Walker (this volume) for the upper part of the Raccoon Valley section, it is interesting to speculate that some representation of a bordering key or reef tract component to their Florida Bay analog may appear after further study of the marble-like facies and the tracing of stromatoporoid and coralline facies along strike. It must be assumed that some barrier or baffle to strong currents would have been necessary for some of the thicker biogenic structures present in the area to have formed.

Sufficient evidence has been compiled from the analysis of the section in Raccoon Valley and work in progress in other areas to predict that many important details of paleoecological value will come from further study of the invariable relationship of certain species or combinations of species to specific lithologies. Speciation within groups appears to vary from facies to facies. Other autoecological implications relate to form, especially between genera and higher taxa of brachiopods, gastropods, and trilobites. Certain forms within taxa are found in one facies, other forms in the same taxon are associated with another facies. Within biogenic structures form of the species appears to be related to position with respect to the internal or external composition of the structure.

AGE OF THE RACCOON VALLEY FAUNA

Based on evidence in hand, it is possible to determine the relative but not precise age relationships of the Raccoon Valley faunas by making the following comparisons with the "Stones River" faunas of the Central Basin as delineated by Wilson (1948, 1949), Bassler (1932, with modifications), and Cooper (1956):

1. The expanded community membership seen in the several biofacies within the Murfreesboro/Pierce/Ridley/Lebanon/Carters lithosomal complex is a reflection of time and evolution within groups already established and environmentally associated at least as far eastward as the Raccoon Valley section. As an example, the greatly enlarged and widespread *Escharopora-Rhinidictya* association of ramose and biofoliate bryozoans in the Lebanon through Carters formations westward are the evolutionary derivatives of the uppermost bryozoan association observed in Raccoon Valley.
2. The same time/space/development relationships can be inferred between the gastropod, trilobite, ostracode, hydrozoan, sponge, algal, and other community associates which invite similar comparisons at the generic to class level, on the one hand, and at the specific level on the other. There are niche replacements and additions in the later western faunas as might be expected, but in the same faunas there are "older" community members (e.g. *Cryptophragmus* cf *antiquatus* (Raymond), *Glyptorthis irregularis* Cooper, *Zygospira lebanonensis* Cooper, *Maclurites magnus* Lesueur, and *Leperditia fabulites* (Conrad) which maintain an ecogenetic linkage with previous developmental stages of the community complex. This list may include, after further study, cephalopods, gastropods, solenoporoids, and camarocladiids.

   In extensions of the Raccoon Valley sequence northeastward in the Copper Creek fault belt (in particular, the Evans Ferry section, Howard Quarter quadrangle, 162-NW), beds containing the Zone III fauna are overlain by others with Pierce and/or Ridley brachiopods *Hesperorthis australis* Cooper, *Doleroides regularis* Cooper, *Opikina speciosa* Cooper and the Lebanon brachiopod *Strophomena grandimusculosa* Cooper. Most, if not all, of these species are believed to provide the same type of linkage as those listed above.

3. The "newer or later" brachiopod members of the western or "Stones River" fauna (e.g. other species of *Öpikina, Strophomena, Hesperorthis, Doleroides,* and most species of *Pionodema* and *Skenidioides*), fulfilling or expanding niches already established in systematically similar communities eastward, are phylogenetic derivations from eastern precursors and provide the increasingly Trentonian "look" of the Central Basin faunas upward in section. In the uppermost Raccoon Valley fauna examined, other records of this impending change in aspect is limited (e.g. *Zygospira lebanonensis* Cooper). The phylogenetic "gap" is too great to regard the known "Stones River" fauna as exactly the same age but must be younger, in the writer's view, than the fauna in the Raccoon Valley section.

   As pointed out in another section of this paper, only the upper part of the Murfreesboro Limestone is exposed in the Central Basin; therefore, this judgment must remain qualified pending study of subsurface sections. The Murfreesboro fauna of record includes a mixture of gastropods and other mollusks of ancient and derived stocks, pterygometopid trilobites and leperditiid ostracodes comparable to the Raccoon Valley forms, and, most significantly, species of

Hesperorthis, Pionodema, and *Strophomena,* brachiopods which elevate the phylogenetic position of the fauna. The "older" elements in this fauna, coupled with lithofacies peculiar to earlier as well as later "Murfreesboro-type" environments, led to misidentification of the formation in the eastern provinces by earlier workers (Butts, 1941, and others). In the same manner "Lenoir" and other lithologies were mistaken for the same formation every time they were seen.

The analysis above is predicated on the seemingly incontrovertible proposition that in a given fauna or representative assemblage there are two components: one older and indicative of the continuing community, environment, or ecosystem; the other, younger and indicative of the phylogenetic level attained at the point in time or place observed. The first component may be represented by a single taxon, genus or species, in an order or larger category. Based on number of individuals preserved, the probability of little trophic competition, adaptation to lower energy environments, or wide tolerance is strong for these organisms. They are represented by facies fossils that cross stratigraphic, provincial, and time boundaries, and are poor although favorite "index fossils" for static correlation but excellent indices for shifting environments. The second component is characterized by a number of taxa, narrower ecologic, geographic or stratigraphic range. Adaptation to highly competitive environments and rapid evolutionary rates under these circumstances make this component of the assemblage a more reliable "tool" for correlation of faunas. Both components are linked genetically with previous developmental stages of the community complex. Viewed in the dual manner described, the combined assemblage, if a fair sample, provides a community-wide analog to the palingenetic principle as applied to individual taxa.

Ecological diversification in the Raccoon Valley fauna is not as broad as in faunas regarded as comparable in age and development. Notably absent or nearly so, are *Tetradium*-type corals, both fasciculate and massive forms. Discovery of these fossils and associated biofacies may come after further reconnaissance along strike or study of the internal paleontology of the units in both the lower and upper zones. Subjacent strike belts westward do contain coral biofacies of "Stones River" aspect. Another part of the Middle Ordovician seascape observed elsewhere that appears to be missing from this particular set of ecological "samples" are the "clam beds" (e.g. *Modiolopsis, Ctenodonta*) which appear in the "Stones River" set and in the succeeding Trenton faunas in the west.

Ultimate correlation of the Central Basin and the Chickamaugan province rocks and faunas will come with the discovery and identification of more fully developed faunas westward, positioned in time and place with one or both of the two elements of the Central Basin complex believed by many not to be facies controlled, the metabentonites and graptolites. Lebanon Limestone graptolites, briefly noted by Safford (1869, p. 286) were literally re-discovered by Hofstetter (1965). A new species or variety resembling *Diplograptus (Mesograptus) multidens* Lapworth was traced over a wide area embracing southeastern Davidson and northeastern Williamson counties and across a strip of quadrangles from the northern Wilson County type locality area south to northern Bedford County (Hofstetter, 1966). George L. Benedict (personal communication, 1972) has traced the Lebanon graptolite fauna into Sequatchie Valley and is engaged in a study of the fossils.

At present there are no greater biostratigraphic and geographic gaps across the Valley and Ridge section and westward to the Central Basin than those between occurrences of graptolites in the Athens Shale and equivalents (Decker, 1952) and the Lebanon Limestone. Similarly, eastward from the Central Basin the areal and regional relationships of the metabentonites are unclear. Metabentonites are known in the strike betls west and northwest of Raccoon Valley. Hopefully, study of these belts in context with a set of community analogs advancing in time and across the strike of the poorly understood formations between Raccoon Valley and the Cumberland Escarpment will narrow the geographic, faunal, and time gaps that still remain.

If the thesis advanced in this paper of shifting environments in space and time, populated by ecotypes and evolving lineages, both realtistically observed at some angle or perpendicular to the standard stratigraphic section, has any merit, then it can be argued that a single reference or type section of the Chickamaugan province suite of rocks is nonexistant. The type section bearing the name used in discussing these rocks, redescribed and reanalyzed by Cooper (1956) and Milici and Smith (1969), furnishes another view in the province of a set of these environments arranged in stratigraphic order. Each of the set as seen in any one place is a part of a developmental phase composed of several parts. If the whole is the sum of the parts, it follows that there are many more parts to examine if the developmental stages are to be understood and placed in chronological order.

SUMMARY OBSERVATIONS

The foregoing review of the biostratigraphy and stratigraphy in East Tennessee, with particular emphasis on Knox County and vicinity, has been designed primarily to identify and illustrate with selected examples certain problematical aspects of the present state of knowledge concerning both rocks and fossil faunas. An attempt has been made to sort out the problems and place them in regional context. The seemingly disproportionate amount of space given to the Middle Ordovician part of the section is by no means a measure of a better understanding of the relationships among the older rocks but, rather, a reflection of the attention given to the problems, if indeed they have been recognized. If interest in one or more of the problems throughout the section is generated by the review, it will have served a useful purpose.

Viewed in the past as a set of biologically independent samples suspended in space and time, the fossil record to this point has provided few satisfactory solutions to the basic problems of correlation. Superficial resemblances of both faunas and rocks have proved inadequate in establishing regional relationships. Based on initial success in other areas, it is apparent that the new directions taken in petrology and paleontology toward synthesis of data and collective interpretation will provide a more natural approach to the solution of the problems.

It is clear that the resolution of many systematic problems both at the individual and community level is fundamental to the determination of age and space relationships. There is little doubt that past efforts have been encumbered by nomenclatural dogma which has had the effect of separating and isolating functional correlatives under the guise of order and classification. This applies to both rock units and fossils. At the other extreme, gross generalizations have led to oversimplification and faulty correlation. An apparent pattern of provincial interchange among Middle Ordovician faunas which has emerged as a result of this survey is due largely to the sound taxonomic data base provided by G. Arthur Cooper's work on the brachiopods in the area. Evidence is strong that as lithologic details are sought with the same precision, external homeomorphy but internal distinctiveness will be recognized among rocks as well as fossils.

If areal and regional relationships are to be established in a more satisfactory manner than in the past, *ex post facto* interpretation of faunas and rocks must be replaced by deductive methods designed to collect information related to the biological and sedimentological dynamics in operation at the time of deposition. Coincident environmental patterns shared by benthonic faunas and sediments may be elusive or obscured owing to incomplete records. Diagenetic effects may be more instructive than faunal remains in some environments.

Faunal analysis no less than lithologic analysis must be comprehensive. Solutions to problems in the area have been sought by means of expedient methods inherently unidimensional in concept and based on too few factors in a complex of many. Differentiation between environmentally and evolutionarily significant components or factors is common to all of the biostratigraphic problems cited in this paper. Recurrent environments with systematically similar but not identical faunas adapted to them can be recognized in detailed stratigraphic sections. As a product of time, evolution, and physiochemical controls, it can be argued that fossil faunas are best viewed as representing a set of community functions. At the species level, function may be time-transgressive as a number of examples show. Thus, the total fauna rather than the individual species or a single group will provide a more reliable basis for correlation.

Despite the several problems discussed, every past effort to relate the rocks and faunas has contributed a share to the sum of data on which more rational interpretations must build. Success in the future will stem largely from synthesis of new information with old data cast in a different way. The fact that stratigraphic and biostratigraphic problems relative to the area and region can be enumerated and discussed as has been done in this paper is a tribute to the contributions made by the numerous workers cited. But as Safford (1869, p. 235) remarked about the Blue or Maclurea Limestone when he examined these rocks for the first time over a hundred years ago, "The fossils . . . have not, as yet, been thoroughly studied."

STRUCTURAL GEOLOGY OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Knox County is in the Valley and Ridge midway between Virginia and Georgia and between the Cumberland Plateau and the Blue Ridge physiographic provinces (Clark, fig. 1). The structure of the county is an integral part of Valley and Ridge structure, and indeed of the adjacent Cumberland Plateau and Blue Ridge. Most structural elements of the Valley and Ridge province are represented in this area, including the Copper Creek, Beaver Valley, Saltville, Knoxville, and Dumplin Valley faults (fig. 1). Several major folds are in the area and the Rocky Valley anticline and Athens syncline extend for several tens of miles beyond the county.

The Knox County area contrasts markedly with the Cumberland Plateau to the northwest. On the Plateau rocks are, for the most part, gently dipping and are composed of Pennsylvanian sediments at the surface. Southeast of Knox County, Blue Ridge rocks are generally metamorphosed and their structure is reflected by complex topography. Knox County terrain is divided by the major thrusts into several northeast trending belts; and unlike those of the Plateau and Blue Ridge provinces, Valley and Ridge strata are folded and faulted in a more or less regular fashion.

The structure of Knox County (and much of the Valley and Ridge) has been determined by detailed areal mapping. There are no deep wells that might contribute subsurface information, but there is a limited amount of geophysical information. Staub and his students (this volume) at the University of Tennessee made gravity maps of the county (pls. 2 and 3) which incorporated some of Watkins' (1964) data. In addition, Watkins (1964) published a regional magnetic map of part of the Appalachians in Tennessee.

Structurally complex areas such as along the Saltville fault in the northwest outskirts of Knoxville and in the areas near Farragut and on Beaver Ridge, can only be interpreted by detailed areal mapping. Mapping is generally done on a 1:24,000 base, but in areas of complexity larger scales are necessary. The map accompanying this report (pl.1) does not show details of the structures, but rather records them in a generalized fashion.

As is indicated on the index on the accompanying geologic map, much of this area has been mapped by the United States Geological Survey, part by graduate students of the University of Tennessee, and part by the Tennessee Division of Geology. Control points and outcrop data are not shown on geologic maps because of scale. Geologic mapping and interpreting of structure requires, in addition to a detailed knowledge of stratigraphy, a study of residual float, soils, and topographic expression of rock units.

It is, of course, necessary to unravel the surface structure before attempting structural interpretations at depth. Mapping of the Valley and Ridge requires observation of all the available outcrops and other pertinent data. Even so, geological mapping performed in the same area by experienced, qualified geologists can result in several interpretations or working hypotheses because of the general lack of outcrops, and because of difficulties encountered in the identification of rocks. In general the structural features outlined on the accompanying geologic map (pl.1) are essentially correct. However, because it is difficult to extrapolate surface structural interpretations to any considerable depth numerous interpretations other than those shown in the cross section of figure 1 can be made for this area. Lack of knowledge of the type of rock that comprises the basement is a major handicap that greatly hinders the usefulness of geophysical data in interpreting structure.

FOLDS

The structural pattern of folds and faults changes in a general way across the Valley and Ridge from the Cumberland Plateau to the Blue Ridge. Rodgers (1953) divided the Tennessee Valley and Ridge into two structural subprovinces, the belt of dominant faulting northwest of the Saltville fault, and the belt of dominant folding to the southeast.

In the belt of dominant faulting most folds are linear and elongate parallel to regional strike. With the exception of the Powell Valley anticline on the Pine Mountain block, and the Lookout Valley, Cranmore Cove, and Cumberland Escarpment anticlines along the Eastern Cumberland Escarpment, large anticlines are virtually absent in this region. Rather, the folds preserved at the present level of erosion are footwall synclines at or near the traces of the major Appalachian thrusts.

In the belt of dominant folding, folds are generally broader than those to the west and their width-to-length ratios are generally greater. Anticlines although not

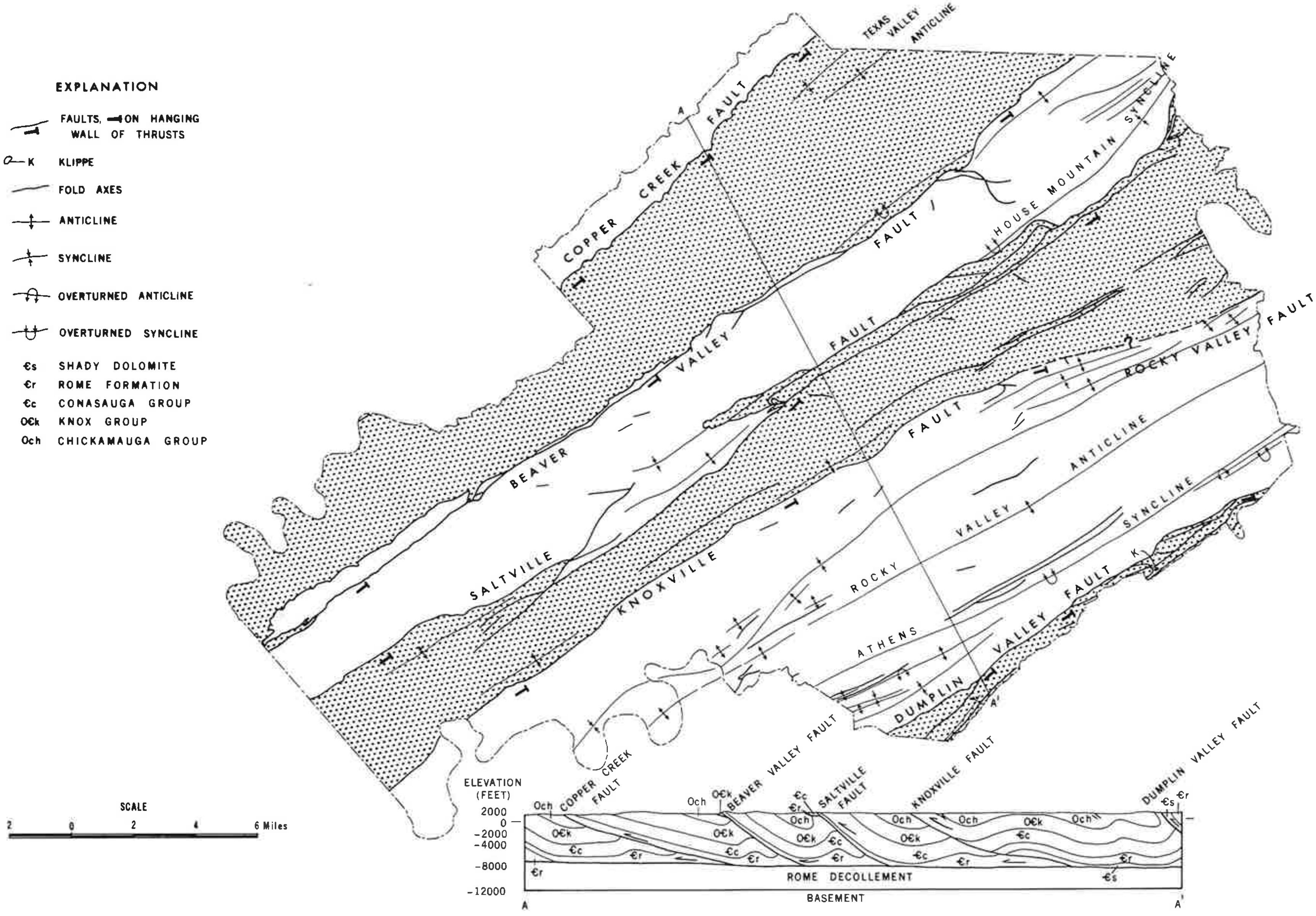

Figure 1. Generalized map of geologic structures in Knox County, Tennessee.

abundant are prominent. Like those to the west, folds in this belt generally trend northeast parallel to regional strike.

The dominant form of deformation northeast of Knox County on the hanging wall of the Pulaski block is folding, but these folds are different in some ways from those between the Pulaski and Saltville faults. Folds of the Pulaski block strike more northerly and are generally more tightly compressed than those to the west; many are overturned and a few are even isoclinal. However, in detail the structural style of the Tennessee Valley and Ridge is poorly known, and is beyond the scope of this paper.

Knox County lies astride the Saltville fault, the boundary between the belt of dominant faulting and the belt of dominant folding. Folds in Knox County range in size from a few inches to tens of miles. Axial lines of the larger folds generally parallel regional strike; however many of the small folds are haphazardly oriented. At the surface synclines are perhaps more common than anticlines; the anticlines are commonly faulted. The folds are generally upright, asymmetrical, and in places overturned. All of the folds plunge, but in most areas the amount and direction of plunge is not constant. Axial planes are usually curved and range from horizontal to vertical or overturned. Commonly, folds, both small and large, are broken by faulting. Many are of the flexural slip variety, and fold type (concentric, parallel, chevron, etc.), tightness, and symmetry are related to lithology. Shale and thinly bedded rocks occur in tight folds, whereas massively bedded rocks form more open folds. However, in places isoclinal folds of small scale are common in the thicker bedded units. For example, folds in the Rome Formation involving thin sandstone and shale beds commonly have their axial portions filled with shale. Similar thickening of shale is undoubtedly developed in axial regions of major folds and abnormal thickening can lead to misinterpretation of stratigraphic thickness.

Non-tectonic folds are known in a few places in Knox County. However, these sedimentary folds (draping of layers over stromatolitic bioherms or reefs) can best be seen along the shores of Norris Lake in Union County in the Copper Ridge Dolomite. When viewed from a distance, the folds appear to be tectonic anticlines and synclines with amplitudes of a few tens of feet. Near Knoxville, however, primary folds are not so well developed and only a poor example of this type of folding is discernible in the stromatolite bioherms in the lower part of Nolichucky exposed along Interstate 75 on the northwest side of Copper Ridge (Field Trip 2, Stop 2).

In the belt of dominant faulting, the Copper Creek thrust block contains three prominent folds—an anticline and syncline in Texas Valley (Benson, 1963) and the Beaver Valley syncline in the footwall of the Beaver Valley fault. The Texas Valley structures are generally symmetrical with vertical axial planes. The folds are about four miles long and a mile wide (width to length ratio of 1:4), and their limbs dip generally 10 to 30 degrees. The folds involve Conasauga strata; the Pumpkin Valley Shale is exposed in the core of the Texas Valley anticline, and the Maynardville Formation is preserved in the adjacent syncline.

The Beaver Valley syncline, which extends along the footwall of the Beaver Valley fault between Halls Crossroads and Graveston, contains the Martinsburg Shale in its core. The structure is overridden by the thrust at each end, is asymmetrical to overturned, and has an axial plane that is steeply inclined to the southeast. The west limb dips about 20 degrees and the overturned east limb 60 to 70 degrees to the southeast (Harris, 1972).

Folds on the Beaver Valley thrust block include structures between Amherst and Lonsdale in central Knox County, the House Mountain syncline, and a number of small folds between House Mountain and the Beaver Valley fault near Corryton. The folds at Amherst involve the Knox and the lower part of the Chickamauga Group. The synclinal structure there is the House Mountain syncline which extends into the area from north-central Knox County under the flap of the Saltville fault. From limited outcrop data this southern extension of the House Mountain syncline is asymmetrical to the northwest, with limbs dipping about 15 and 25 degrees to the southeast and northwest, respectively. Interestingly, the associated anticline is asymmetrical to the southeast, opposite the general asymmetry of the Valley and Ridge, and its southeast limb dips 30 to 35 degrees (Harris, 1972). The anticline at Amherst lies entirely within a re-entrant of the Saltville fault, and Knox is exposed in its core.

The House Mountain syncline is the southwestern extension of the Clinch Mountain syncline into Knox County. The fold preserves the youngest Paleozoic beds in the county and is doubly plunging. Where it is most bulbous it encloses a large mass of Martinsburg Shale. The fold narrows from 2 miles to less than a mile in width in short distances both to the southeast toward Fountain City, where older beds are involved in the structure, and to the northwest where it joins the main Clinch Mountain syncline in Grainger and Union counties.

In general the House Mountain syncline is asymmetrical or overturned to the northwest. The west limb dips 20 to 60 degrees to the southeast, and the east limb dips gently west or is overturned to as much as 50 degrees to the southeast (Harris, 1972).

Between House Mountain and the trace of the Beaver Valley fault near Corryton incompetent beds of the Ottosee are thrown into a number of tightly compressed small folds, some overturned to the northwest. Although the area northwest of the John Sevier quadrangle has not been mapped in detail, a reconnaissance survey indicates that the Holston and Lenoir may extend in an anticlinal structure to near Corryton (pl.1).

The Saltville block lacks large scale folds in Knox County, except for the anticline in the Knox County panhandle near Farragut, and the Park City syncline in the footwall of the Knoxville fault. The anticline at Farragut consists of a core of Conasauga (Maryville, Nolichucky, and Maynardville) surrounded by the Knox. This anticline is broken by numerous small faults at or near the leading edge of the Saltville fault. The structure is long and narrow (5 miles by 1 mile) and its outcrop pattern suggests that it is nearly symmetrical with a vertical axial plane.

The Park City syncline contains a tightly compressed core of Bays which extends northeastward through much of downtown Knoxville (Cattermole, 1958). Both limbs dip 80 to 85 degrees, suggesting that the fold is nearly symmetrical with a vertical axial plane. The main part of the fold is about 5 miles long and perhaps a mile wide. To the southwest the fold axis disappears under the trace of the Knoxville fault. Near Ebenezer the synclinal structure reappears and continues 3 or 4 miles southeast toward Concord. There, rocks as young as Ottosee are in the core of the structure (perhaps with some Bays) and the fold is asymmetrical to overturned to the northwest with a steeply dipping axial plane. Near West Emory the west limb of the syncline dips 45 degrees to the east, and the east limb dips as much as 70 degrees to the west, although beds may be overturned at the Knoxville fault (Cattermole, 1960).

In Knox County the principal belt of folding is on the Knoxville-Rocky Valley fault block, where the axial traces of five major structures occur in a zone seven miles across. There, wave lengths (distances between axial traces) of the folds range from one to two miles. The oldest strata in the region are Knox beds exposed in cores of an anticline along the Tennessee and Holston rivers, the Rocky Valley anticline, and the faulted core of the Stock Creek anticline in the south-central part of the county. The Ottosee commonly marks the cores of synclines, although the Bays and even a little of the Martinsburg Shale crop out in the faulted Athens syncline.

Intricate folding is common around the noses of plunging folds on the Knoxville block, particularly around the Tennessee-Holston River anticline near Holston Hills, and the Rocky Valley anticline in south Knox County. The major folds plunge both to the northeast (Tennessee-Holston River anticline, Stock Creek anticline, Island Home syncline), and to the southwest (Rocky Valley anticline), or are doubly plunging (Athens syncline).

Structures in southeastern Knox County near the Dumplin Valley fault (Athens syncline, Stock Creek anticline) are overturned and more tightly compressed than those to the northwest. Normal limbs dip 40 to 60 degrees and overturned limbs 50 to 80 degrees to the southeast. In contrast, the Rocky Valley anticline and the two folds northwest of it are relatively open with nearly vertical axial planes. Interestingly, the broad flat-topped Rocky Valley anticline is asymmetrical to the southeast; its west limb dips 15 to 20 degrees to the west, and its east limb 20 to 35 degrees to the east (Harris, 1972).

The Dumplin Valley fault block extends across extreme southeastern Knox County where strata from the Rome to the Knox are exposed in a complex of small folds and thrusts. Near Alcoa in Blount County, strata on the hanging wall of the Dumplin Valley fault are in a tight, intricate pattern of folds nearly symmetrical or slighty overturned to the northwest. The limbs are steep, some vertical or nearly so, and axial planes are vertical or steeply dipping to the southeast (Cattermole, 1962).

FAULTS

Although several types of faults (including thrust, gravity, reverse and tear faults) are typical of the Valley and Ridge, the most commonly occuring variety are the thrusts. There are more thrusts in Tennessee than elsewhere in the Appalachians. Generally, they dip to the southeast but some of the larger thrusts are folded so that in places their dip can be in any direction.

Movement along faults ranges from a few inches to many miles, and fault traces extend from a few feet to a few hundred miles. Fault traces are generally irregular because of undulations of the fault plane; however several of the larger faults are relatively straight. Stratigraphic throw can usually be determined from formation thicknesses; however net slip is very difficult, if indeed not impossible to determine. Slices and klippen are along several of the major thrusts, but no windows are known to be present in Knox County.

Surface dips of the major faults are not necessarily indicative of dips at depth. For example, the Saltville fault in local exposures may dip as much as 70 or more degrees at the surface, but where mapped in detail, the gross dip is essentially horizontal or at very low angles to the southeast or northwest. Dips are commonly estimated from the intersection of the trace and topography.

Omission and or repetition of formations is the most important method used to determine the presence of faulting. Some faults may be recognized in outcrop; however such exposures are not abundant. Other faults, principally tear or transverse faults, are commonly inferred from topography and offset contacts. In general, the accuracy of trace location is better along ridges than in valleys or flat-lying areas. Some of the larger faults appear to be single breaks, but others, such as the Dumplin Valley fault are zones of imbrication and anastomosing fault traces. Similarly, disruption and repetition or omission of formations is utilized to recognize the smaller faults associated with the Dumplin Valley zone. In many places slickensides, breccia, gouge, grooves, drag, silicification and mineralization are used to recognize faults, but these phenomena are generally of little use in the Knox County area. Indeed, slickensides and grooves reflect only last movements. For example, small thrusts are known in the county which dip steeply southeast; however, their slickensides indicate movement at right angles or at high angles to the direction of major movement and thus record only the last movement.

The relationship between the dip of faults and lithology has not been systematically studied, but as a general rule faults tend to steepen in the more massive and brittle rocks and to flatten in the thinly bedded shales or shaly limestones. Bedding slip is common in the smaller faults as well as along the major thrusts. Wedging (Cloos, 1964) is a common feature and can be observed in several places in this area.

Five major southern Appalachian overthrust faults traverse Knox County. At a glance each of the faults appears different; this may be the case or it may simply reflect differences in structural elevation. At the present erosional level the Saltville fault appears to be by far the most complicated. In contrast, the Copper Creek fault appears to be the most simple.

The trace of the Copper Creek fault is relatively straight across the northwestern part of Knox County, and the dip appears to be moderate. The fault trace extends many tens of miles nearly straight to the southwest; however, to the northeast in Union County the trace becomes irregular and the low angle nature of the fault is revealed (Benson 1963). Throughout much of its extent this fault appears to be a simple break placing the Rome Formation upon rocks of the Chickamauga Group. This fault is somewhat unusual in that to the southwest there appears to be little change in stratigraphic throw. Movement along the fault appears to have been essentially normal to regional strike. This simplicity, however, does not exist to the northeast where relations are more complex.

In contrast with the relatively straightforward trace of the Copper Creek fault, the next fault southeast, the Beaver Valley fault is much more complicated. The trace of the fault is irregular and slices are evident to the southwest where relations are poorly understood. Klippen mapped in southwest Knox County and beyond illustrate the low angle dip of the Beaver Valley fault (Nalewaik, 1961). Near House Mountain, however, the interpretation shown on plate 1 is questionable and more work needs to be done there. Southwest of Knox County changes in stratigraphic throw are evident where rocks younger than the Rome Formation are thrust over younger rocks.

The Saltville fault extends over 350 miles and is one of the major structural elements of the southern Appalachians. Detailed mapping indicates the structural features are much more complex than shown on the generalized plate 1 and figure 1. Complexities along the fault are evident in Knox County where the fault trace splits and is irregular. It appears that the irregular pattern, especially as shown in the Sharp Ridge area, is due simply to the low angle nature of the fault (Davis, 1970; Penley, 1973). In Knox County where surface relations are complex little is revealed of the nature of the fault footwall. Much of the interpretation of this fault (and others) is based on evidence outside Knox County. For example, to the northeast near Rogersville a prominent reentrant reveals footwall structures that are not exposed locally.

In Knox County, the trace of the Knoxville fault appears to be straightforward. However, to the northeast where it is likely that the Knoxville and Rocky Valley faults join, dips flatten markedly. More work needs to be done in this area to verify the junction of these faults.

The Dumplin Valley fault in southeastern Knox County apparently differs from those mentioned above in that the fault is an imbrication rather than a clean break. Hatcher (1969) mapped this fault zone to the northeast and has described its occurrence in East Tennessee.

The above descriptions of faults in this area are generalized because such things as the mechanics of origin, time and place of formation, stages of development, and chronology of events cannot be drawn from an area as small as Knox County. Haney (1966) for example, (see also Helton, 1967 and Smith, 1968) considered the development of the Saltville fault in Hawkins County near Rogersville, where a reentrant in the fault exposes many footwall structures. Haney described the complexity of development of these faults and associated features thusly:

"1. A fold developed along the present axis of the Greendale syncline during the early phase of deformation. In the study area the fold broke across the anticline or mutual limb, presently concealed under the hanging wall of the Saltville fault, along the Stone Mountain fault.

"2. Folding followed or possibly accompanied the initial break, thus folding the fault surface and hindering further movement along it. As movement became more difficult along the initial break, the fault shifted to a higher elevation, and the second break took place which is now referred to as the Saltville fault. This break, like the initial break, cut across bedding in the area of the reentrant in the trace of the Saltville fault; however, it is thought to be a bedding plane fault southeast of the highly deformed area.

"3. More folding and faulting took place in the Saltville thrust sheet prior to the development of the Town Knobs fault. This is evidenced by the truncation of many small folds and faults existing in Caney Valley.

"4. The Town Knobs and associated faults developed and rode over the structures of the hanging wall of the Saltville fault.

"5. Post-fault folding elevated the area of the reentrant to its present elevation, thus developing the structural high observed in the Greendale syncline adjacent to the fault reentrant, the high as inferred under the hanging wall of the fault, and the syncline to the northeast.

"6. Erosion has exposed the southeast limb of the Greendale syncline, thus causing the reentrant in the present trace of the Saltville fault.

"Stages one and two are the same stages described for the development of the fault block that exists between the Stone Mountain fault and the Saltville fault. The fact that the fault shifted upward and cut across bedding from young to old explains the presence of the Conasauga rocks in the hanging wall along the reentrant. Such an explanation places no limit on the magnitude of the displacement along the Saltville reentrant since the fault is probably the bedding plane type back under Bays Mountain to the southeast. Therefore, the fact that Conasauga lies on Knox along the reentrant does not mean that displacement is only 3,500 feet as was inferred earlier in this report.

"The third and fourth stages are evidenced by the many folds and faults in Canes Valley and the fact that many of these structures project under the hanging wall of the Town Knobs fault. Also, the folds in Stanley Valley may have formed during the development of the Town Knobs fault. The writer believes that the post-fault folding was primarily that of gradual uplift and that the tight folds of Stanley Valley are more likely associated with the development of the Town Knobs fault.

"The fifth stage in the development of the Saltville fault reentrant, post-fault folding, elevated the Saltville fault in the study area to a position of very low dip; in fact in places the fault surface is probably horizontal. Thus, the structural high in the reentrant area is postulated as being caused by post-fault folding. Bumgarner, *et al.,* (1964, p. B112-B115) recognize post-thrust folding in the west New Market area of East Tennessee. The west New Market area is in the same strike belt as the Hawkins County area and is approximately 35 miles southwest. Bumgarner, *et al.* (1964, p. B113) outline the structural history of the west New Market area directly related to the Rocky Valley fault as follows:

'1. Compressive forces acting generally from the southeast formed a pair of asymmetrical folds, that is, a synclinal-anticlinal couple with the common limb near vertical or overturned to the northwest.

'2. Further pressure ruptured the paired folds along the common line, thrusting the anticline north-northwestward over and beyond the syncline.

'3. Continued or renewed compression acting on both upper and lower plates of the fault as a unit, caused further folding along the axis of the Rocky Valley anticline and developed the crossways called the New Market syncline.

'4. A fourth and final stage is represented by zones of high-angle reverse faults that dip southeast. This later faulting also acted on both the upper and lower plates of the Rocky Valley fault as a unit, offsetting the thrust surface as well as lower stratigraphic horizons.'

"The general parallelism of the Rocky Valley thrust surface and the folds in stratigraphic horizons as much as 700 to 900 feet lower is well shown by structure contours on the lower-Middle Ordovician unconformity, the "chert-matrix" sandstone at the base of the Mascot Dolomite, and the "Minus-C" oolite in the Kingsport Formation (Bumgarner, *et al.*, 1964, p. B113). Contours on horizons beneath the thrust surface show similar configurations.

"Byerly (1966) reports evidence of post-thrust folding in relation to the Babbs Knob flap of the Pulaski fault near Greenville, Tennessee. This area is approximately 10 miles east of Rogersville. The flap referred to is in the hanging wall of the Pulaski fault and has been preserved in a post-thrust syncline."

JOINTS

Joints are in virtually every outcrop. The origin of such features is generally ascribed to tensional stresses, but some joints contain slickensides that indicate a small amount of movement parallel to the breaks. Some joints are filled with calcite. Weathering accentuates joints and in carbonate rocks the fractures are solutionally enlarged in many places.

Little or nothing is known about the ages of joints in this area. Those associated with Appalachian structures are probably related to Middle Ordovician to Pennsylvanian deformation. In addition it is likely that joints related to post-orogenic (Mesozoic and Cenozoic) movements may be abundant in this region as they are elsewhere in the Appalachians.

A summary of available data in Knox County is given by Harris (1972). In relatively flat-lying rocks joints are expected to be more regular in direction and dip than in areas of folded and faulted rocks. Since most of the rock units in this area are tilted or otherwise deformed, the joint patterns are random and haphazard. A small outcrop may reveal the relationship between joints and folds, or perhaps the joints may be related to movement along nearby faults. However, when viewed over larger areas joint development is very complex and the origin of these features is obscure. The spacing of the joints ranges from less than an inch to several feet. Similarly, dips of the joints range from vertical to horizontal. Curved joint planes are common especially in the more massively bedded units. Because of the highly variable stresses associated with strongly folded and faulted rocks the precise origin of joints in this area is difficult to determine.

PRIMARY STRUCTURES

Primary or sedimentary structures are common in many rock units in this area; for example in the Rome Formation many structures such as ripple marks, mudcracks, raindrop impressions, swash marks, etc. are preserved (see Harvey and Maher, 1948). Small scale intraformational conglomerate or breccia is common in the Nolichucky Shale and other Conasauga units and conglomerates are abundantly developed along the unconformity at the top of the Knox. Mudcracks are plentiful in the Maynardville and in formations of the Knox Group. Cross bedding is well developed in both the Holston Formation and the Chapman Ridge Sandstone, and many varieties of primary structures are also in younger formations such as the Moccasin and Sequatchie. Of particular interest to structural geologists are the mudcracks and crossbeds which can be used in determining tops of beds.

BRECCIATION

Two types of breccia are common in this area as they are elsewhere in the Valley and Ridge; these are collapse or primary breccias and tectonic or secondary breccias. In Knox County a collapse breccia is well exposed along the abandoned Smoky Mountain Railroad near the University of Tennessee at Neyland Drive.

Because the collapse breccias in the upper part of the Knox play an important role in the Mascot-Jefferson City and Copper Ridge zinc districts they have been studied in much greater detail than the tectonic breccias. Concentrated study of these structures in underground workings by zinc company geologists has resulted in the differentiation of several types, such as fine rock-matrix breccia, coarse rock-matrix breccia, hybrid breccia, rubble breccia, crackle breccia, etc. These have been described in detail by Hill (1969), and sketches of breccia have been published by McCormick and others (1969), Hathaway (1969) and Crawford and others (1969).

The precise origin and time of formation of the collapse breccias is unknown, but may be related to uplift and solution at the end of Knox time.

Tectonic breccias associated with faulting are not the chaotic types that occur elsewhere in the world. Brecciation is commonly found along the major faults in this area, but curiously seems to be greater along planes of minor rather than major faults, and particularly so in areas of imbricate faulting or close folding. Breccias are perhaps more common in the massive brittle rocks where deformation by fracturing is easier than by folding. These breccias generally have larger blocks than those developed in finer grained and thinly bedded rocks.

CLEAVAGE

Cleavage is well developed in Cambrian and older rocks in the Blue Ridge province of the southern Appalachians, but is not restricted to the Blue Ridge in Tennessee, where Valley and Ridge rocks are cleaved in some places. This fracturing is best developed between Knoxville and Bristol, Tennssee, but cleavage is common southward to the

Georgia line. Three types of cleavage have been recognized. Shear cleavage is developed in the footwall beds along the larger faults in many places. A good example of this is on the Norris reservoir in Grainger County, Tennessee, where footwall calcareous mudstones of the Moccasin Formation are highly sheared along the Copper Creek fault. Fracture cleavage is well developed in the calcareous shale beds of the Sevier near Elizabethton, Tennessee. South of Knoxville, near Vonore, the relationship of fracture cleavage to folds is conspicuous in mudstones of the Bays Formation. A third type, herein termed "axial plane" cleavage, is neither fracture cleavage according to classic definitions nor is it slaty cleavage. Axial plane cleavage is best developed in dark-gray, slabby, calcareous siltstones.

In Knox County only a few exposures of cleavage are known. The best example is on Chapman Highway between Locust Hill Street and Redbud Drive (fig. 2). There, argillaceous limestone of the Lenoir Formation is cut by well developed fracture cleavage. The relationship between cleavage and folding (if any) at this locality is unknown. Another occurrence is on the Lovell quadrangle on Campbell Station Road just south of its intersection with Grigsby Chapel Road, where small folds in Ottosee Shale are cut by fracture cleavage. The outcrop is strongly weathered but the relationship of cleavage to folding can be discerned.

STRUCTURES AND LANDFORMS

Landforms are second only to stratigraphy in importance in deciphering structure in Knox County as well as in other areas. This section is not concerned with the origin of topographic features (see Clark, this report) but brief mention is made of the utility of these features. In many areas in Knox County both reconnaissance and detailed geologic mapping is facilitated by a study of topography. This is especially true in areas of poor or no outcrops. For example, the Knox Group can be subdivided into various formations based on topography.

Each formation folded or faulted to the surface generally has a different type of topographic expression. Rome ridges tend to be steep and scalloped in profile (fig. 3) whereas Knox ridges tend to consist of rolling and undulating hills. Distinctive topographic style is present along Flint Ridge northwest of Knoxville where a unique ridge is formed by heavy chert beds in the Chickamauga Group.

Examples of the usefulness of landforms in Knox County are too numerous to count. Offset ridges usually indicate some type faulting even though the fault may not be exposed. Beaver Ridge ends abruptly north of Knoxville where the Rome, Knox, and other units are sharply terminated by faulting. Near the Knox - Loudoun County boundary, slices and klippen associated with the Beaver Valley fault are very conspicuous topographically. Massive sandstone beds of the Clinch are preserved in the synclinal House Mountain in the northern part of the county and account in part for its prominence. Imbricate faulting in the Rome Formation along the Dumplin Valley fault in Knox and Blount counties is topographically expressed. Structural discordance in the Buffalo Ridge area just north of Knox County in Union County is clearly revealed by topography. Harris (1972) suggests that many of the creek and river patterns could be due to jointing.

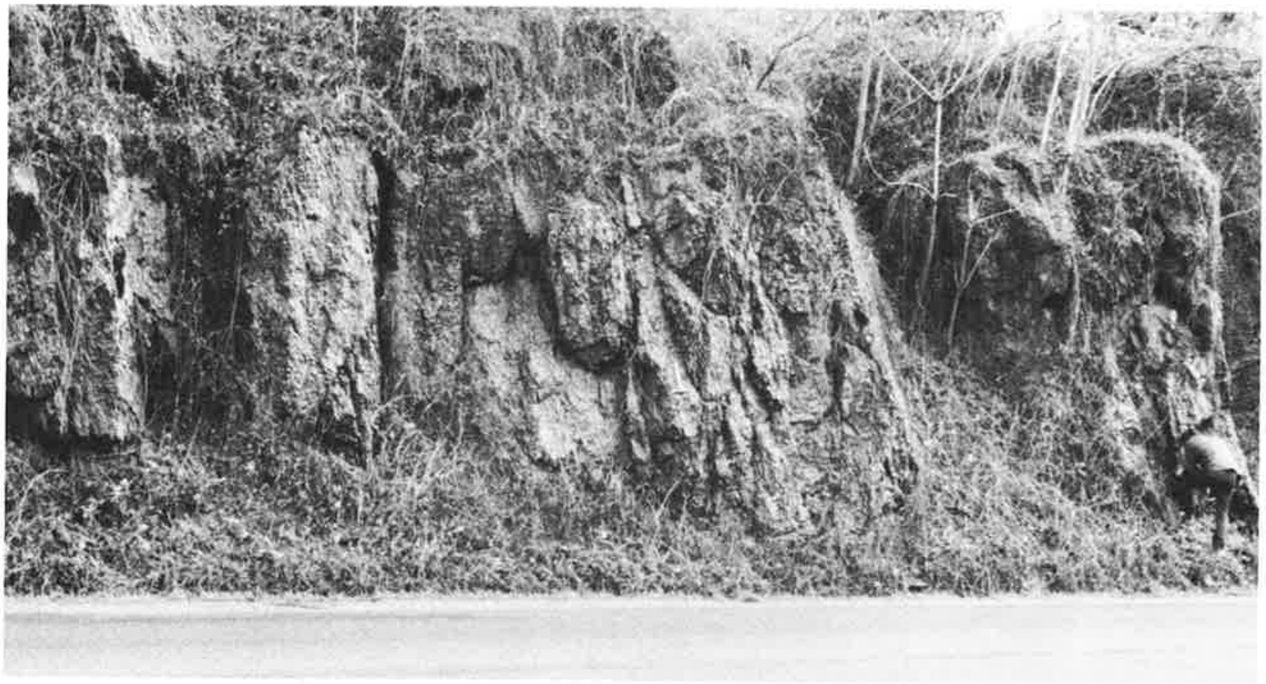

Figure 2. A. Cleavage in the Lenoir Formation on Chapman Highway between Locust Hill Street and Redbud Drive. Bedding is horizontal and cleavage dips steeply to right.

Figure 2. B. Close up of cleavage in the Lenoir Formation showing nearly horizontal bedding and vertical cleavage.

PROBLEMS

Several questions arise concerning the structural features exhibited in Knox County. These questions are not necessarily unique to this area.

1. The universal and oft-asked questions regarding how, when, where and under what conditions did the structures form? Various mechanisms have been proposed as to how the structures originated. These include such things as gravity sliding and stresses of one type or another. The time and sequence of formation of structures poses different problems. Did they originate in one period or multiple stages? Where did the structures form? An appreciable amount of crustal shortening can be demonstrated. What was the overburden or load if any at the time of deformation?
2. What is the origin of cleavage in this area? Is it related to folding?
3. What kind of stresses were involved and what was their distribution, intensity, etc.?
4. What is the role of bedding thrusts as compared to break or strut thrusts?
5. The often asked question of basement involvment in structures, if any.
6. What is the relationship of lithology and structural deformation? What effect, if any, do changes in rock facies have?
7. What is the depth of folding and faulting? Are these features rootless or otherwise?
8. What is the number, the nature, the configuration of thrust sheets now eroded away?
9. How do we interpret the limited amount of geophysical data available in this area?
10. What is the origin of slices? Do they originate from the footwall or hanging wall or both? What role do they play in fold formation?
11. What is or has been the role of high angle, perhaps normal, faulting as is commonly seen in modern geosynclines?

Figure 3. Beaver Ridge, a comby Rome ridge in central Knox County.

12. How do we account for folded fault planes? Is this folding primary or post faulting?
13. What is the magnitude of faulting? What distances have the thrust sheets moved - and what was their rate of movement?
14. What is the relationship of folding to faulting, if any?
15. What is the chronology of deformation? Are the lowest faults the oldest?
16. What is the nature of structures concealed by thrust sheets?
17. What controls the location, spacing, and number of faults?

The above questions are just a few that quickly come to mind when one glances at structural features such as those in Knox County. For a deeper and more thought-provoking discussion of problems, principally those in the Blue Ridge province southeast of Knox County, refer to King (1964a, pages 120-124).

LOCALITIES OF STRUCTURAL FEATURES

A few localities where features of interest can be observed are cited below.

Chapman Ridge, Alcoa Pike

Small drag folds in these cuts may be related to local faulting. Larger folds of 5- to 6-foot amplitude have shale fillings, axial planes are jointed, and the folds show good examples of calcite-filled tension fractures (fig. 4).

Alcoa Pike, across from the Naval Reserve Station (Field Trips 1 and 2, Stop 1)

The Holston exhibits good examples of fracturing and stresses in a massively bedded rock. Bedding is very difficult to determine at a casual glance. The fractures may be related in part to blasting in the construction of the highway but most are due to tectonic stresses. Joints do not have any particular orientation. This is typical of fracturing in both the Holston and in most of the Knox Dolomite.

Chapman Highway, between Locust-Hill Street and Redbud Drive

Good examples of cleavage are shown on either side of the highway. This locality is in the Lenoir Limestone; bedding is not too clear, but it dips gently to the east. The main feature here is a crude fracture cleavage that results in the alignment of the nodules (fig. 2). This cleavage is presumably related to a larger fold of which this is the west limb. The dip is less than 20°. The dip of the cleavage is about 80°. This occurrence is somewhat unusual in that most cleavages develop in more shaly units.

Figure 4. Drag fold in Chapman Ridge Sandstone along Alcoa Pike; note small calcite-filled tension fractures.

Shooks Gap, U.S. 441

The Rome Formation contains many small drag folds generally only a few feet across (fig. 5). Undoubtedly, these folds are related to the Dumplin Valley fault that crops out a short distance to the west. Small faults are present in the cut and beds generally dip to the east. The trace of the main fault, which is not exposed in this locality, is well to the west of the Rome ridge and lies in the adjacent valley near Valley Grove Baptist Church and is a few hundred yards north of the highway.

Broadway, near Interstate 640

Rome sandstone is thrust on Knox Dolomite along the north branch of the Saltville fault contact (fig. 6). Many small drag folds are in the shaly part of the Rome higher up in the cut. The fault plane dips to the southeast at about 50 degrees. Bedding in the Knox Dolomite is nearly vertical, and the Knox is cut by many small fractures. A hundred feet or so to the west of the fault an abandoned quarry is partly in the Knox and partly in the Holston marble. The Holston adjacent to the quarry is badly broken but generally dips to the southeast. The fault is also exposed about a block to the south on US 441, old Broadway, where Rome is thrust on

Knox. Excellent drag folds are exhibited in the Rome east of the fault trace along US 441 (fig. 7). The folds are large, tens of feet apart, with vertical axial planes. To the west around the ridge some of the primary features in the Rome such as ripple marks can be observed in the General Shale shalite pit.

Figure 5. A. The Rome Formation at Shooks Gap. Undulating bedding.

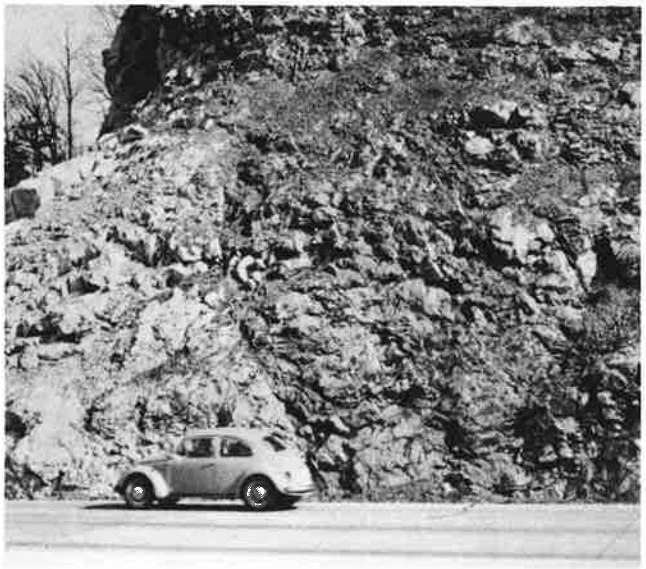

Figure 6. Rome thrust on Knox by north branch of Saltville fault, along Broadway near Interstate 640 on northwest side of Dutch Valley. The Knox is the lighter colored rock on the left side of picture.

Figure 5. B. The Rome Formation at Shooks Gap. Drag fold.

Figure 7. Drag folds in Rome Formation, northwest side of Dutch Valley on Broadway.

Sharp Gap, I-75 North

On the lower level the Rome is thrust on nearly vertical Knox by the Saltville fault. The Knox is well exposed in the quarry just south of the highway. The fault plane dips approximately 70 degrees to the east. Bedding in the Rome dips to the southeast approximately parallel to the thrust. A better exposure of the Saltville fault is a few hundred yards north of the exposure on I-75 on Bruhin Road, where Rome is faulted on upper Knox Dolomite (fig. 8). The Rome beds dip steeply to the southeast and in this cut several drag folds of small amplitude are exposed. The trace of the fault is not exposed but can be located within about 20 feet. The dip of the fault plane here is unknown but it probably is 50 or 60 degrees to the southeast. Fifty feet or so south of the fault trace, the Rome dips 45 degrees to the southeast. In the footwall the Knox Dolomite is almost vertical, although in places the beds appear to be horizontal or dipping slightly to the west. There is much brecciation in this exposure. The Rome Formation is intensely fractured and brecciated and much grooving and slickensiding is in both Rome sandstone and in the Knox. Folding to this degree is unusual in the Knox. These are tight folds, but are not of the flexural slip variety. The folding and anomalous dips are chiefly due to fracturing. A few hundred feet to the west along Bruhin Road a fault is again exposed to within a few feet at the west end of the Knox slice, and appears to be dipping to the west. In the valley a few hundred feet west of this last fault exposure, the Holston marble is in fault contact with the Knox. Holston outcrops are faulted on a minor scale. A few feet to the west the Rome is again thrust on Knox. Sandstone beds in the Rome are dipping to the west.

I-75 at Beaver Ridge

The Beaver Valley fault is exposed in cuts near I-75. The trace of the fault is obscured but can be located within a few feet and Rome is thrust on Moccasin near the top and on the extreme southeast side of the cut. The dip of the fault plane is between 10 and 20 degrees; the dip of the underlying Moccasin is approximately parallel with that of the fault plane. This cut is unusual in that the footwall Moccasin is not deformed.

ACKNOWLEDGMENTS

I would like to acknowledge the valuable assistance of the many graduate students at the University of Tennessee, who through the years contributed their geologic mapping and ideas. The manuscript was reviewed by R. C. Milici and S. W. Maher of the Tennessee Division of Geology, and the former prepared the illustrations.

Figure 8. The Saltville fault at Sharp Gap; Rome (foreground) thrust on Knox.

GRAVITY SURVEY OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

The purposes of this investigation were to prepare and interpret detailed Bouguer and residual gravity maps of Knox County. Watkins (1964) prepared a regional Bouguer gravity map and a magnetic map of much of eastern Tennessee, and some of his data were used by the writers in the construction of the Knox County maps. Watkins (1964) provided 81 data points within Knox County and 117 data points from adjacent counties, mainly along the major highways. An additional 56 data points were acquired between the major highways within Knox County during the current survey.

Eleven stations of the Watkins survey were reoccupied during the current survey so that the probability of introducing artificial anomalies into the results could be predicted. The mean difference in the calculated Bouguer anomaly for the reoccupied stations is 0.05 milligals. On the other hand, the standard deviation of the above difference is 0.34 milligals. These figures suggest that at each station the probability of systematic error is small whereas the chance of random error is relatively large. Therefore, single station anomalies that are less than two standard deviations (0.68 milligals) in value from adjacent stations possess a 5% probability of being artificial, and single station anomalies that are smaller than 0.34 milligals have a 32% probability.

RESULTS

Plate 2 is a Bouguer gravity map of Knox County with the major geologic structural elements superimposed upon it. The most striking gravity feature is the negative anomaly that lies along the southwestern and northwestern boundaries of Knox County. While the trend of the anomaly is generally northeast it is not parallel to the major thrust faults of the region.

Plate 3, the residual gravity map, is based on the error terms of a least squares fit of the data used in preparation of plate 2. On the residual gravity map the various anomalies are more sharply defined than on the Bouguer gravity map.

INTERPRETATION

Watkins (1964) noted the cross-cutting trend of gravity anomalies with respect to the thrust faults. He concluded that the source of the anomalies lies at some depth beneath the thrust sheets.

Because the "wave length" of the anomalies is approximately ten miles, two extreme interpretations are formally correct from a geophysical point of view, and because of the inherent ambiguity of potential data, an infinite variety of possibilities lies between the two extremes. At one extreme elongate, narrow and deep seated density irregularities in the basement complex may be responsible for the observed long wave length anomalies. At the other extreme, elongate but broad and shallow sources for the density irregularities can control the gravitational field strength in precisely the same way. As so often is the case in studies of this nature the truth may lie somewhere between the extremes.

Watkins concluded that variations in the gravitational field strength were primarily related to lithologic variations within the basement complex. However, in this paper we advocate the opposing point of view, that density irregularities lie at relatively shallow depths within the veneer of Paleozoic strata. The sources of these shallow density irregularities are not precisely reflected by the outcrop pattern because low angle thrust sheets have overridden them. Interestingly, even though this interpretation is different from that of Watkins (1964) it leads us to one of his general conclusions, that, as Rodgers (e.g. 1964) has so often stated, basement is not involved in Ridge and Valley thrusting.

King (1964b) noted a large negative Bouguer anomaly within the Blue Ridge province along the Tennessee-North Carolina boundary in a region where the basement complex is at the surface. If these basement rocks extend to any depth, one would expect to find a positive Bouguer anomaly there. Accordingly, King concluded that the basement complex is rootless and is in a low angle thrust block that overlies a great thickness of relatively low density Paleozoic strata. Numerous Paleozoic windows in the Blue Ridge support King's conclusion. Furthermore, Warren (1968) finds no evidence from seismic refraction data that roots exist beneath the Appalachian Mountains.

If the source of the negative Bouguer anomaly lies at shallow depth in the Blue Ridge as King suggests, it seems likely that similar situations exist in the Ridge and Valley.

A shallow source negative Bouguer anomaly in the Ridge and Valley province can be explained thus: thick sections of middle and upper Paleozoic strata lie in synclinal troughs. In places these troughs have been overridden by low angle thrust sheets consisting of Lower Paleozoic strata. In the Valley and Ridge older Paleozoic strata generally consist of far more carbonate rock than do the younger Paleozoic strata, which are chiefly terrigenous shales, siltstones and sandstones. Terrigenous clastic rock is generally less dense than carbonate rock, hence negative Bouguer anomalies should be expected to occur in synclinal troughs—even where the troughs are overridden. By comparison the gravitational field strength would be more positive where anticlines are overridden because their crests contain appreciably more carbonate rock.

Indeed, a spatial relationship between synclinal troughs and negative anomalies appears to exist in the Ridge and Valley. For example, the southwestern end of the Clinch Mountain syncline lies on the nose of a negative anomaly and the extension of this anomaly suggests that the remainder of this syncline lies beneath the Saltville thrust sheet (pl. 3). Furthermore, the southwestern extension of the axial trace of the Newman Ridge syncline, which lies exposed in a broad outcrop pattern to the north of plate 3, passes beneath the Copper Creek and White Oak Mountain thrust sheets; in and near Knox County the projection of that trace is coincident with a large negative Bouguer anomaly.

The above interpretation requires that terrigenous clastic rock in the Ridge and Valley has a low density in comparison to carbonate rock. Gravity profiles across the Rocky Valley anticline (figure 1) and the exposed portion of the Clinch Mountain syncline (figure 2) appear to substantiate our supposed density relationship. A positive anomaly occurs over the Rocky Valley anticline where an unusual thickness of carbonate rock exists. On the other hand, a negative anomaly occurs along the southwest nose of the Clinch Mountain syncline where clastic strata are exposed.

It is possible that broad Paleozoic folds are related to warps in the basement complex. If this is true then perhaps Watkins and we are both correct. However, we would attribute the source of the gravity field to basement structure rather than to basement lithologic variations as did Watkins. If basement structure is related to the broad Paleozoic folds, then it predates the episode of thrusting as Rodgers believes to be the case.

The above interpretation is still rather speculative. A gravity survey through the exposed portion of the Newman Ridge syncline could settle the argument, and we predict that a negative Bouguer anomaly will be found over the center of the Newman Ridge syncline.

ACKNOWLEDGMENTS

The field survey was funded by a grant from Humble Oil Company and a LaCoste-Romberg gravimeter was provided by the Gravity Division, United States Army Corps of Engineers Topographic Command. The Tennessee Valley Authority permitted us the use of data on open file from a previous survey (Watkins, 1964) and they also provided us with the use of a Cal Comp plotter for automatic contouring of Bouguer and residual gravity values. The University of Tennessee Computer Center provided data processing time. We are especially grateful to Christine Haygood, Benjamin K. Bryan and Robert W. Johnson of the Tennessee Valley Authority.

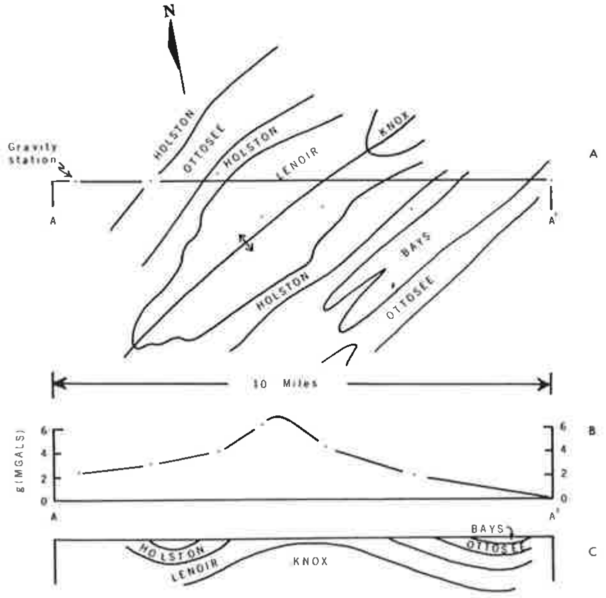

Figure 1. Gravity profile across the nose of the Rocky Valley anticline. A) Geologic map (Rodgers, 1953), B) Gravity profile, C) Geologic section.

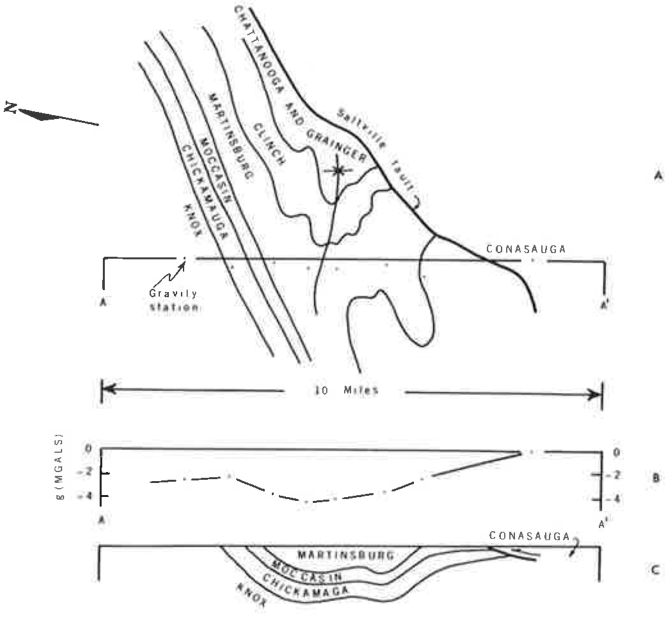

Figure 2. Gravity profile across the nose of the Clinch Mountain syncline, Union County, Tennessee. A) Geologic map (Rodgers, 1953), B) Gravity profile, C) Geologic section.

MINERAL RESOURCES OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Knox County lies wholly within the Appalachian Valley and Ridge province. The outcropping rock sequence ranges in age from Early Cambrian (Shady Dolomite) to Early Silurian (Clinch Sandstone). Folding and imbrication by thrust faults produces a characteristic northeast-southwest belted outcrop pattern with dips chiefly to the southeast. Carbonate strata predominate and probably immediately underlie 55 percent of the surface, shales are estimated to underlie 40 percent and sandstones the remaining 5 percent of the 508 square miles comprising Knox County.

The carbonates are economically important as sources of crushed stone for construction, agricultural limestone, lime, and cement, and are also used for dimension stone. The Kingsport Formation (Knox Dolomite Group) is the principal host for the zinc deposits in Tennessee.

Some of the shales, particularly the Pumpkin Valley and Rome shales of Middle and Early Cambrian age, are quarried for brick and lightweight aggregate manufacture.

The Chapman Ridge Sandstone was formerly quarried and used for dimension and curbstone. This formation overlies the Holston Formation, a calcarenite extensively quarried for marble in the vicinity of Knoxville; therefore, in places, the quartzose Chapman Ridge was removed to quarry the Holston. This Chapman Ridge "overburden" is still used for flagstone in local rock gardens and for rustic decorative purposes. The City quarry of Vulcan Materials, immediately west of Chapman Highway (U. S. 441) in south Knoxville, produces general purpose crushed stone from the Chapman Ridge.

The metropolitan area's silica-sand and gravel supplies are chiefly produced by dredging the Tennessee and lowermost French Broad rivers above Ft. Loudon Dam and transporting the dredged materials by barge to fixed plants on the Knoxville water front.

The only significant production of metallic ores in Knox County, is and has been, zinc ore mining near Mascot on the eastern side of the county.

EARLY MINERAL OPERATIONS

The earliest mineral resource used by the white settlers in the area of Knox County was almost certainly stone. Field stone was collected and built into chimneys, hearths, and door sills. Materials so used included the Knox, Holston and Chapman Ridge formations.

The Holston supplied grave stones in this early period; for example, a marble marker designated William Blount's grave in 1800.

Clays produced at building sites from residual material were apparently used to make brick not long after as the more affluent citizens constructed brick houses. Such clay was also used for stoneware prior to 1820. The 1860 census reports a brickyard in operation in Knox County.

There apparently were several attempts to establish charcoal iron furnaces, all unsuccessful. Records of these forges are scanty, and the enterprises most likely failed because of insufficient reserves of iron ore. Available ores were brown iron hydroxides that occur in residual clays above Knox Dolomite. The reserves in such "banks" range from a few tons to several thousand. In any event, the census of 1820 lists two iron works in Knox County, and the census of 1840 lists two "bar iron forges." None are cited in the 1860 census. Only the general locations of three furnaces are known: Cobb's bloomery at the mouth of Beaver Creek, construction date unknown, abandoned 1853 (Lesley, 1859, p. 204); one on Bull Run mentioned in the Knox County court records for 1825; and one on Flat Creek near the present site of Mascot (East Tenn. Hist. Soc., 1946, p. 352). This last, the "Flat Creek" or "Wills forge", closed about 1856.

Development of macadam road surfaces (1815) and mechanical crushers (by Blake in 1858) greatly stimulated quarrying. However, it was probably not until after the Civil War that mechanical crushers and quarries for raw materials were used in Knox County.

Dimension stone quarries, as already mentioned, were opened much earlier. In 1852 James Sloan opened a quarry in the calcarenite phase of the Chapman Ridge Sandstone.

This quarry is now obscured by the I-40 right of way just north of Caswell Park, about 800 feet east of the overpass across the Southern Railway. This quarry supplied cedar red marble used in the Tennessee and Ohio capitol buildings. Its opening marked the beginning of the marble industry in Knox County. Sloan's quarry was followed shortly by the McMullen or Williams quarry opened in Marble Hill on the north bank of the Tennessee River just northeast of the present Knoxville water plant (Gordon, 1924).

Secondary zinc carbonate and zinc silicate mineralization was found on the west bank of Roseberry Creek, near present day Mascot, about 1856. Mining prior to 1900 was entirely by open pit methods and only oxidized ores were recovered. The first shaft was sunk in 1902 by the Roseberry Zinc Company, and a little zinc sulfide ore was recovered. In 1911 the American Zinc Company of Tennessee acquired properties and developed underground works around Mascot, and in 1913 completed a mill of 1,000 tons daily capacity. The first shipment of sphalerite concentrates was made in 1913.

Cement manufacturing in Knox County began before the Civil War. Joseph Estabrook calcined the Bays Formation for "natural" or "hydraulic" cement (Safford, 1856, 1869; Killebrew and Safford, 1874). Berlen Moneymaker reports the site was on the east side of North Broadway (Tenn. Hwy. 33) opposite Old Gray cemetery. Another such plant using the red Bays mudstone was operated on the southwest bank of the French Broad River adjacent to Cement Shoals. Little is known about this mill, but it apparently post-dates the Civil War and was also operated by Estabrook.

Volunteer Portland Cement Company, now a division of Ideal Cement Company, placed a plant in operaton in 1928. This plant and quarry are north of U. S. Hwy. 11-70 on the east side of Knoxville.

PRESENT MINERAL OPERATIONS

The annual value of minerals produced in Knox County is currently about $24 million. The principal components of this total are zinc (as sphalerite concentrates), cement, limestone, lime, clay (including ground shale), and sand and gravel. The production in dollar value for recent years is shown in table 1.

TABLE 1. VALUE OF MINERALS PRODUCED IN KNOX COUNTY [1]

(Millions Of Dollars)

1951	$14.7	**1961**	$19.6
52	15.1	**62**	18.7
53	12.9	**63**	17.3
54	12.5	**64**	16.3
55	14.5	**65**	16.7
56	15.7	**66**	15.0
57	14.2	**67**	16.4
58	14.2	**68**	18.2
59	16.9	**69**	20.3
1960	16.6	**1970**	23.9

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[1] U. S. Bureau of Mines, **Minerals Yearbooks** 1951-1970

CEMENT

The Volunteer Cement Division of Ideal Cement Company operates its quarry and kiln about a mile north of the I-40 bridge over the Holston River. The Holston Formation supplies high calcium limestone of uniform composition. Shales of the Chapman Ridge and Ottosee formations nearby furnish alumina and iron. Silica in the form of sand is purchased from sources outside the county.

These materials are pulverized in a ball mill and blended to a mixture containing about 5.5 percent shale, 4.5 percent sand, and the remainder limestone. This mixture is slurried in the grinding by adding 40 percent water. The ground mixture may go to storage or to the kiln. The rotating kiln is coal-fired, and its long axis is slightly tilted. The temperature at the hot end of the kiln is approximately 2700° F. The slurry is calcined into clinker which owing to tilt and rotation moves in small pieces through the kiln, and discharges at the lower end. Cooled clinker, now a complex of calcium, aluminum, and iron silicates, is mixed with gypsum and pulverized. The gypsum serves to regulate the setting rate when cement is made into concrete. The final grinding is by ball mills to -325 mesh. At all stages in the process, chemical analyses are performed to insure uniformity and quality of the product. In fact, cement is subject to 18 different specification designations.

Magnesium is perhaps the most critical element in selection of limestone for cement manufacture. Too much magnesium prevents proper setting of the concrete. Specifications for limestone generally used are:

Mg0	3% maximum
Fe	0.5%
Combined Na, K	less than 0.5%
P	less than 0.5%
S	low

The capacity of this plant is approximately 540,000 tons of portland and masonry cement annually.

CLAY AND CLAY PRODUCTS

Knoxville is the site of a very large brick mill. The mill is owned and operated by General Shale Products Corporation and is on the north bank of the Tennessee River 1.5 miles east of the Henley Street Bridge (U. S. Hwy. 441). This plant, the Ollie Coleman Brick Company, was established in 1924, and originally used alluvial and residual clay at the site. Raw material currently used is shale of the Rome and Pumpkin Valley formations quarried at sites on Sharps Ridge, 7 miles northwest of the plant. Care must be exercised in quarrying to avoid contamination by silica sands and limestone. Raw shale is trucked to the plant site. The plant contains a modern automated tunnel kiln, gas fired, that permits close control of temperature and atmosphere. These controls reduce production time, permit regulation of color, and insure uniformity in the product.

Shalite Corporation operates a quarry and plant to produce lightweight aggregates at the Loves Creek water gap through Sharps Ridge north of Knoxville. The quarry is developed in Pumpkin Valley Shale. The shale is fed into a crusher, mixed with pulverized coal and coal breeze, and thence to a traveling grate which traverses through an oil-fired kiln. The sintered shale is sized by screening. The site is served by the Southern Railway and secondary highways. The aggregate is used in concrete slabs, blocks and construction materials.

LIME PLANTS

There are two lime plants operating in Knox County: Foote Minerals quarry and kiln in the Forks of the River district, and Williams Lime Company near Island Home, South Knoxville. Both companies quarry high purity Holston Formation, which is crushed and burned in rotary kilns.

An analysis of the limestone by the Division of Geology yielded:

$CaCO_3$	97.76%
$MgCO_3$	1.20
Insol.	0.54
Iron and alumina	0.44
Phosphorus	.034

Lime was formerly made from the Holston at other sites, e. g. the Knoxville Lime Company quarry in the Forks of the River district, on the Tennessee River near Concord, and at the abandoned quarry off I-40 near Cherry Street.

MARBLE

Marble was used in Knox County from the 18th Century. At first grave markers, lintels, and dimension blocks were obtained from loose fragments in the zone of weathering. The first quarry was developed by James Sloan in 1852, and the second by John Williams not long after.

The Forks of the River district, the principal producing area in Knox County, dates from the opening of a quarry there by the Federal Government in 1872. About 10 quarries have been operated for marble at one time or another in this district. In 1972, dimension marble was produced in the Forks of the River by Appalachian Marble Company and the Tennessee Marble Division of Georgia Marble Company.

The stone is freed by drilling closely spaced holes with a pneumatic powered bar drill. These holes are spaced at about 2.5 inches and wedges are successively driven into them by hand. Great care is taken to distribute the wedging stresses uniformly. The resulting "mill block" averages 7 feet by 6 feet by 4 feet and weighs some 33,600 pounds. It is hoisted by derricks and taken to the mill.

Mill blocks entering the mill are first sawed into slabs by gang saws; the slabs then move to other saws and polishing machines to be variously shaped and finished to the customer's specifications.

Waste marble is used for split face construction, terrazzo chips, and flag stone.

Knoxville has been the milling center for the marble industry of Tennessee for nearly a century. The mills process mill blocks from quarries in Knox and nearby counties, from other states, and from overseas. Architects commonly specify a variety of colors and textures for a particular building and stocks of imported stone allow Tennessee companies to meet such design requirements.

Tennessee marble is a high purity calcarenite containing abundant fossil fragments. The lithology occurs at several stratigraphic levels in the rocks comprising the Middle Ordovician strata. The deposits are regarded as original bryozoan-echinoid reefs and comminuted debris from the reefs. The rocks range in color from grayish pink, to very light gray, to reddish brown depending on the iron content and oxidation state. The rock is generally dense (in the sense of non-porous), and has not been metamorphosed. The calcium carbonate content is characteristically 95 percent or more, silica is generally below 1.0 percent, and iron oxides range from 0.2 to 0.5 percent.

Resistance to penetration by liquids and dirt results in the marble being widely used where biologic sterility is important. Its petrofabrics result in even wear and make it a durable floor surface. Tennessee marble has been used in many major or public buildings throughout the United States, e. g., the National Art Gallery, National Capitol, Lincoln Memorial, National Museum, Morgan Library, GM Building, and Rayburn Library.

SAND AND GRAVEL

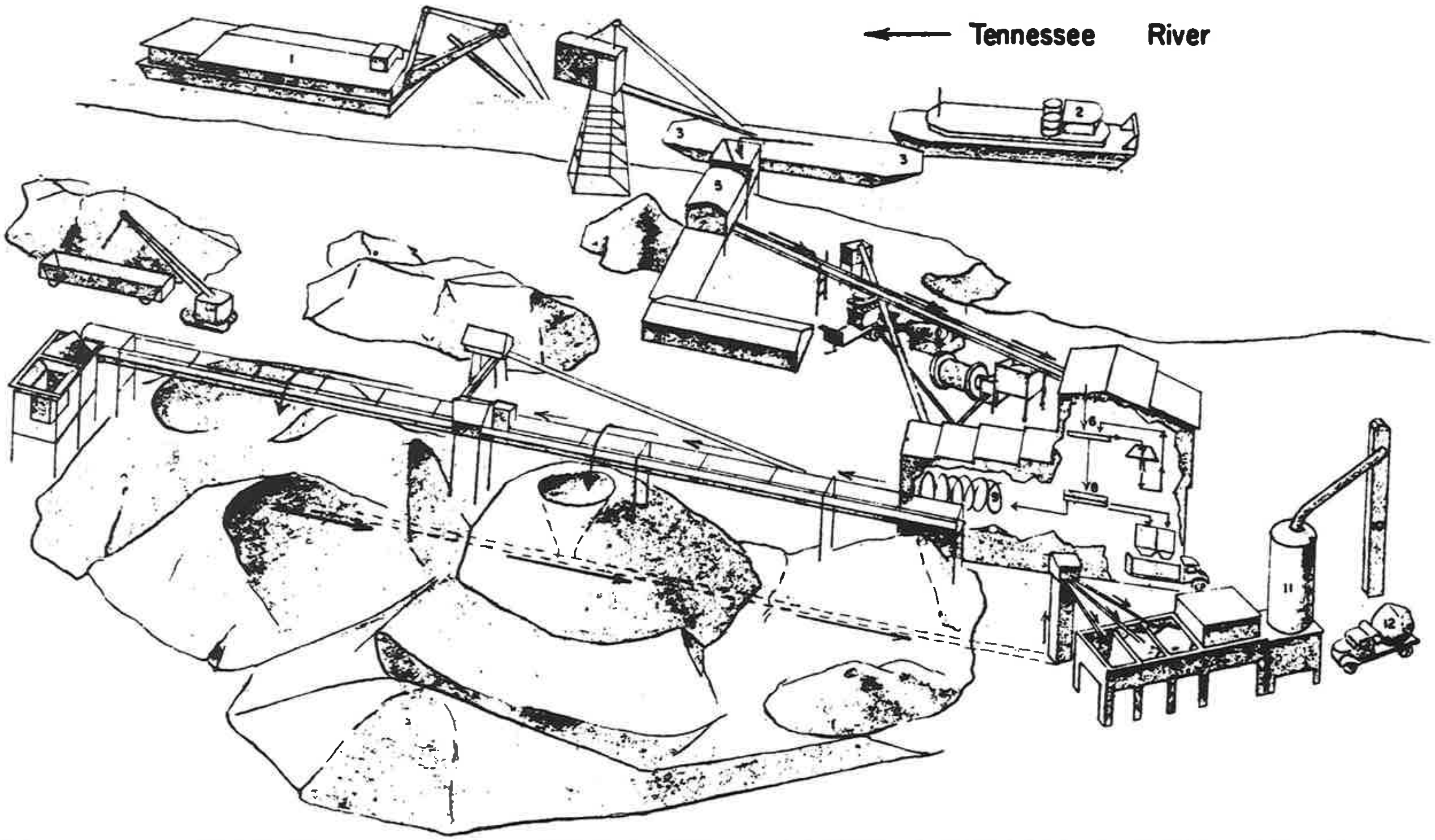
The Holston and French Broad rivers join just east of Knoxville to form the Tennessee. The Holston drainage is chiefly within the Valley and Ridge province, whereas the French Broad system is largely within the Blue Ridge province. This latter river is therefore the carrier of quartzose materials (chert excepted) to the Tennessee above Knoxville. Below Knoxville, Little River and Little Tennessee River are the principal sources of such materials. Prior to the construction of major dams the supply of sand and gravel in the Tennessee was renewed by the spring floods.

The Tennessee (and the lowermost French Broad) have long been the major source of quartzose sand and gravel in Knox County. No production records exist prior to about 1907. The demand for these materials rose particularly as highway construction became important. Whereas in 1907 Knox County produced about 36,000 tons, production from the county is now roughly ten times larger. Most of this is used for construction.

Dredges recover the raw sand and gravel from the river bottom. It is loaded to barges at the recovery site and thus transported to a treatment plant on the river front in Knoxville. Beneficiation includes washing and screening to remove clay and size the material. Most of the product sold is delivered to the consumer by truck. Figure 1 is a flow sheet of the beneficiation plant.

CRUSHED STONE

The map (plate 1) shows that crushed stone has been produced at numerous and widespread sites in Knox County. Many of the abandoned quarries were small short-lived operations opened for particular jobs long ago. Some were originally opened for dimension stone, particularly curbstone and wall and flag stone, and later converted to crushed stone production. Others were opened to extract marble and found to be unsuitable for dimension stone. In earlier times it was not feasible to haul crushed stone any significant distance and small quarries operated concurrently at a number of locations. Larger demand, better transportation routes, large carriers, and standardization of specifications have led to less numerous, but larger, central quarries and mills. Urban growth, while enhancing the market, has restricted the availability of quarry sites.



1. DREDGES (5)
2. TOWBOATS (4)
3. BARGES (14)
4. 21/2 YD. ELECTRIC CRANE
5. 24"X 48" JAW CRUSHER
6. 5'X12' SINGLE DECK SCREEN
7. 4' CONE CRUSHER
8. 5'X14' DOUBLE DECK SCREEN
9. SAND AUGER
10. ELEVATOR
11. CEMENT STORAGE SILO
12. TRANSIT MIXER TRUCKS(25)
13. PEA GRAVEL CIRCUIT

Figure 1.

Knoxville Sand and Gravel Company
Pictorial Flow Sheet

COURTESY KNOXVILLE SAND AND GRAVEL COMPANY

H.A.ORTON

The greatest number of quarries (for crushed and dimension stone, collectively) is in the Holston lithology. As noted, this unit supplies stone of a high calcium carbonate content, and has been and is now used for cement and lime manufacture. The stone is also suitable for agricultural stone and construction aggregate.

The Knox Dolomite contains the second largest number of quarries in Knox County. The Knox is areally extensive, forms ridges whose slopes can be readily developed, and contains construction stone of good quality. Tennessee Highway Department tests of samples from 8 Knox Group quarries showed sodium sulfate losses to range from 0.7 to 1.5 percent and Los Angeles abrasion losses between 13 and 23 percent. The Knox is magnesian and siliceous; analyses from 22 quarries show its content of $MgC0_3$ to range from 5.7 to 33.6 percent, silica to range from 3.0 to 13.4 percent. The magnesium content is desirable for agricultural purposes.

Supplies of crushed Knox come from conventional quarries, but by-product stone recovered in zinc mining and processing at Mascot and Jefferson City contributes a large amount, too.

The Lenoir Formation and its Mosheim Member also are quarried. The Lenoir is an argillaceous unit, slightly siliceous, and generally with thin overburden. The Mosheim Member is not everywhere developed and its thickness ranges widely. This latter rock is a dense calcilutite with "birdseyes" of calcite, slightly magnesian and silty ($MgC0_3$ 3.2 to 6.3 percent, insolubles 1.4 to 3.1 percent). The nodular Lenoir is generally suitable for asphalt and concrete aggregate, although in some instances the Los Angeles abrasion loss is high. The dense Mosheim phase is sounder and suitable for general construction purposes.

The Maynardville Limestone has been quarried at 6 sites in Knox County. This unit is an important source of crushed stone in East Tennessee. It typically presents a scarp slope on the northwest side of Knox Dolomite ridges, contains generally sound rock, and produces good general purpose stone. The Maynardville is typically magnesian limestone (average $MgC0_3$ about 10 percent), and is less siliceous than the overlying Knox (average silica content about 5 percent).

Vulcan Materials operates a large crushed stone quarry in the Chapman Ridge Sandstone less than a mile south of the Henley Street Bridge (U. S. 441). The rock is a very calcareous quartzose sandstone, reddish gray, and somewhat ferruginous. The quarry was opened many years ago for curbstone and building stone blocks. The cost effects of its unusual depth (nearly 200 feet) are offset by its close proximity to the center of Knoxville. The stone is used for construction purposes and road metal.

ZINC

Zinc mining began near Mascot in the mid-nineteenth century and has continued to the present. For many years following its beginnings, the industry produced only zinc carbonate and silicate from residual clay overlying the sulfide-bearing dolomites. Vestiges of these old "carbonate" workings are visible now in the vicinity of Mascot, along Roseberry and Big Flat creeks.

Following exploration and property acquisition in 1911, American Zinc Company of Tennessee developed the Mascot No. 2 shaft and a mill for the recovery of sulfide concentrates. Production began at these facilities in 1914-15. As other mines were developed in nearby Jefferson County, the Mascot mill was expanded to a daily rated capacity of over 5,000 tons per day. Number 2 mine ended production in 1971 and is now being back-filled with tailings. The Immel mine, some 2 miles east of Mascot on the Holston River, was brought into production in 1972. This is the only zinc mine currently operating in Knox County. American Zinc was acquired by American Smelting and Refining Company in 1971.

Zinc occurrences are known to extend west of Mascot to Loves Creek and east of Mascot into Jefferson County. The Mascot-Jefferson City district with 5 operating mines and 3 concentrating mills, is the largest zinc district in the United States.

The New Jersey Zinc Company, The Zinc Mines and Works of U.S. Steel Corporation, and New Market Zinc Company are in adjacent Jefferson County. The first two companies both mine and mill ore in Jefferson County, whereas New Market ore (as well as ore from the Young mine of American Smelting and Refining Company) is milled at Mascot.

The principal mineral is a pale yellow sphalerite, lead-free, accompanied by white gangue dolomite, minor pyrite, and traces of barite, fluorite and galena. The ore occurs chiefly as fillings in brecciated limestone and dolomite developed in the upper part of the Knox Group. The major ore zones are within the Kingsport Formation, a unit of limestone and dolomite some 250 to 300 feet thick. The present concensus is that solution of the limestone beds caused the development of collapse breccia bodies whose open spaces were filled with ore and gangue dolomite by mineralizing solutions.

Mining depths range considerably owing to dip of the ore-bearing units, burial to various depths by post-ore thrust faults, and post-Paleozoic erosion of mineralized zones. The depth of the favorable Kingsport with respect to the top of the Knox Dolomite Group also ranges widely, owing to post-Knox, pre-Middle Ordovician erosion.

The paleo-erosion surface developed in post-Knox time is visible in many outcrops. Perhaps its most impressive manifestations are large paleosink features that may be 200 feet or so deep and over 1,000 feet in diameter. Other features seem to represent stream channels, and some may be explosion pipes. The possible relationships of these erosion features to mineralization in the Kingsport Formation are discussed in Tenn. Div. Geol. Rept. of Inv. 23, and in Economic Geology, Vol. 66, No. 5, 1972. Other geologists (Ridge, J.D., 1972, p. 503-505, 1968, p. B 6-17, for example) do not agree that the erosion surface and mineralization are related.

To summarize: This district is an example of the widely discussed "Mississippi Valley type" ore deposits. There are no obvious igneous sources of the ore minerals, the deposits are low temperature-low pressure, mineralogically simple, in carbonate host rocks, more or less stratiform, etc.

Prospecting methods to delineate the Kingsport Formation involve geologic mapping, drilling into the Kingsport down dip from mineralized outcrops or where mapping indicates it to be below ground level, and use of geochemical analyses of both soils and water to locate zinc anomalies. The principal reserves in the Mascot-Jefferson City district were found by drilling based on outcropping deposits down dip and geologic mapping.

Mining is now entirely underground and is principally from shrinkage stopes opened in ground containing economic grades and tonnages. The ore bodies are irregularly distributed and of various sizes. Crude ore is crushed, screened, and the sphalerite recovered in flotation cells. The sphalerite concentrate is shipped to smelters and zinc oxide plants outside Tennessee. Much of the host rock and carbonate gangue is sold as limestone. Cadmium is recovered as a smelter by-product.

THE SHALITE CORPORATION (LIGHTWEIGHT AGGREGATE)[1]

Shalite Corporation began production of lightweight aggregate in 1950. The quarry and plant are on Mill Road, in the Loves Creek water gap through Sharps Ridge and on the Southern Railway northeast of Knoxville.

Shale is quarried from the Pumpkin Valley Shale of Middle Cambrian age, mixed with solid fuel, and spread on traveling grates in a sintering machine. The mixture is burned at approximately 2400° F, near the incipient fusion point. The result is a chemical reaction that produces gases that form tiny bubbles in the plastic shale. The expanded sinter is cooled, crushed and screened. The sinter is crushed wet to retain the fines.

Plant capacity is 450 tons per day.

TABLE 2. ANALYSES OF THE SHALE AND SINTER

Constituent	Raw Shale	Sinter
Ign. loss	3.2%	3.13%
$Si0_2$	62.3	58.8
$A1_20_3$	17.5	17.5
FE_20_3	6.2	7.2
K_20	7.2	7.5
Mg0	1.2	1.2
$Ti0_2$	.8	.94
Others	1.8	--
Ca0	--	1.0
Na_20	--	0.1
C	--	1.98
S	--	0.00

Shalite's weight in pounds per cubic foot varies with particle size:

TABLE 3. WEIGHT OF SHALITE
(lbs/cu ft)

Size	Damp	Oven dry
Minus 5/8 in. -- plus ¼ in.	43-46	42-46
Minus 5/8 in. -- dust	56-59	58-61
Minus 1/4 in. -- dust	57-60	61-64

Crushing strength is approximately 2,000 lbs. per square inch.

Sodium sulfate soundness (loss in 5 cycles) ranges from 2.08% to 5.5%.

Shalite was used in such buildings as:

State Office Building, Nashville
National Airlines Hanger, Miami
Melrose Hall Dormitory, Knoxville
John Sevier Steam Plant, Rogersville

and for

Prestressed transmission line poles, Florida Power Company
Running tracks at various Knoxville high schools
Septic drain fields
Skid resistant road surfaces
Wall fills for heat insulation.

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[1] Data from, **The Shalite Handbook**

ENGINEERING GEOLOGY OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Engineering geology is the application of geologic data, techniques, and principles to the study of rock and soil materials or subsurface fluids. Such studies are made to assure that geologic factors affecting planning, design, construction, operation, and maintenance of engineering structures and development of ground-water resources are recognized, adequately interpreted, and clearly presented for use in engineering practice.

Some of the main subfields of this discipline are:

1. Foundation investigations for all types of structures, such as dams, bridges, power plants, pumping plants, large buildings, and towers.
2. Evaluation of geologic conditions along tunnel, pipeline, canal, and highway routes.
3. Exploration of sources of rocks, soils, and sediments for use as construction material.
4. Investigation and development of surface and ground-water resources.
5. Evaluation of and recommendations concerning landslide, flood, and earthquake hazards to permit safe development of urban areas.

In Knox County certain phases of engineering geologic investigations are subordinate. For example, it is improbable that any major dam will be built within the county; however, much engineering geologic work was done in connection with the construction of Norris, Douglas, Cherokee, and Fort Loudoun dams in nearby counties. The major emphasis in the future will relate to continued expansion of metropolitan Knoxville and will involve principally foundation studies for large urban buildings; ground water studies, especially those related to identifying and preventing pollution; location of adequate sources of construction materials and insuring that areas containing such deposits are not pre-empted for other uses; evaluation of proposed sites for industrial, commercial, or residential construction, especially in regard to difficulties that might be caused by caves in underlying limestones or dolomites; delineating areas of potential landslide hazard; and, finally, providing geologic expertise to planners so that the best overall utilization can be made of the land surface and the materials underneath.

The following sections briefly summarize exploration techniques, general soil and rock conditions of the county from an engineering standpoint, and major geologic problems that most frequently are encountered in the area. It is hoped that these comments will serve as a useful guide for future detailed studies of specific areas and problems.

GEOLOGIC EXPLORATION

The amount of geologic investigation or exploration that should be made in any specific instance depends on the magnitude and complexity of the project. The judgment of an experienced engineering geologist should be relied on to determine the scope of necessary investigations. For example, an extensive core drilling program could not be justified for a residential or light commercial structure that, in all probability, would be founded on soil. In some instances, a visit to the site, coupled with knowledge of the geology of the area and study of geologic maps of the vicinity, will suffice. Where approximate depth to rock is required or when it is desirable to know if rock exists above a predetermined excavation grade, geophysical techniques such as refraction seismic surveys or resistivity surveys can be utilized at moderate expenditure of both time and cost. For major structures such as high-rise apartment complexes, large office or public buildings, or heavy industrial plants an adequate program of soil sampling and rock drilling usually is required. The number, spacing, and depth of holes cannot be determined arbitrarily. The best procedure is to explore the entire area first with widely spaced drill holes in order to develop the general characteristics of the area and then concentrate exploration in areas of critical loading or where preliminary data suggest that anomalous conditions exist.

In any exploration program it is seldom, if ever, economically justifiable to explore in sufficient detail to discover the exact conditions over the entire foundation area. Much reliance must be put on interpretation of limited data available, and surprises are to be expected after construction has begun. Uncertainties inherent in any exploration program should be well understood by all parties involved.

SOIL EVALUATION

Most small- and medium-sized engineering structures are built on soils; excavations into the underlying rock are required only for foundations for major structures or in areas where soil cover is unusually thin. Probably 90 percent of the structures built in Knox County are founded on soil, and most excavation for road and highway cuts are made in soil.

From a geologic standpoint, soils can be classified on the basis of their origin—residual or transported. Residual soils are those which remain in place directly over the parent material from which they were derived. Transported soils, on the other hand, have been moved from their original point of development and redeposited at another location by agencies such as ice (glacial soils), wind (aeolian soils), water (alluvial soils), or gravity (colluvial soils). Residual, alluvial, and colluvial soils are the only types that occur in Knox County.

From an engineering standpoint, the geologic classification of soils is far from adequate. It does not describe, evaluate, or define the physical properties that are of paramount importance in engineering design. To remedy this situation various classifications have been devised that are applicable to the engineering evaluation of soils. The Unified Soil Classification System, devised by Dr. Arthur Casagrande, is the most widely accepted and has been in general use since 1952. Under this classification all natural soils are subdivided into coarse-grained, fine-grained, and highly organic soils (table 1). Coarse-grained soils are those having 50 percent or less fines by weight; fine-grained soils have more than 50 percent fines. Highly organic soils are identifiable by their black or dark-gray to dark-brown color and sometimes by their fetid odor.

The value of such a classification is that regardless of their origin or occurrence, soils of the same category have the same physical characteristics and engineering properties. For example, a sandy or silty residual soil (SM), overlying the Rome Formation on a hilltop will have essentially the same engineering properties as an SM soil occurring in alluvial deposits on a flood plain. However, several types of soil may be present at different depths at a single location. In an alluvial flood plain deposit, the soil commonly grades from fine silt (MH) at the surface to coarse well-graded gravel (GW) at the base overlying bedrock.

Table 1 relates the Unified Soil Classification System to soils of Knox County, and for each soil type it presents ranges of values for density, permeability, drainage, bearing, and compactibility. These are the parameters most critical to engineering evaluation of soil conditions.

ROCK EVALUATION

The outcrop patterns of 13 geologic formations are shown on the geologic map of Knox County accompanying this report (plate 1). Each unit differs sufficiently from adjacent units to permit recognition of individual formations in the field. As each formation is a distinct geologic unit, each also has characteristic properties relevant to engineering considerations. Table 2 summarizes those properties of each formation that are most critical from an engineering standpoint. More specific details are discussed in the following paragraphs.

Compressive Strength

The values shown in table 2 were obtained for TVA file data on the results of numerous unconfined compression tests on these rock types in the Tennessee Valley region. In practically all instances test specimens were sound, unweathered rock. The range of strengths shown are based on numerous tests of each formation. As an example, the range shown for the Knox (10,000-40,000 psi) is based on 55 tests ranging from a high of 39,300 psi to a low of 11,230 psi. The average value is 25,370 psi. When it is considered that a compressive strength of 1,000 psi is equivalent to 72 tons per square foot, it is immediately apparent that even shales where fresh, unweathered, and confined are capable of supporting all but the heaviest loads that might be imposed by engineering structures.

Modulus of Elasticity

Modulus of elasticity (Young's Modulus) is the ratio of any stress to the resulting strain. In essence, it is the measure of the elastic properties of rocks. For most rocks this modulus commonly exceeds 10^6 psi; thus stresses of 10^4 psi (or 72 tons per square foot) result in strains of less than 10^{-2} in/in, or a deformation of less than 0.01 in/in. This parameter is useful in evaluating response of a rock foundation to shock loads imposed by earthquakes.

The range of values for the modulus of elasticity shown in table 2 was obtained from both static laboratory tests and dynamic field tests made by TVA during foundation investigation programs. This range represents values for sound, unweathered rock. For soils, or partially disintegrated or severely weathered rock, the modulus is below 10^6 psi.

Overburden

Depth of residual material overlying bedrock is controlled by rate of weathering of the rock, rate of overburden removal by erosion, amount of insoluble material in the parent rock, spacing of fractures in the rock, attitude of the rock strata, and topographic slope. Because of these variables which can affect development and transport of the weathering products, it is apparent that only broad evaluations can be made as to depth of residuum. However, in spite of these uncertainties, certain generalizations can be made about residual cover.

In the Knox County area formations with a high sand, silt, and clay content such as the Rome, Pumpkin Valley, Rogersville, Nolichucky, parts of the upper Chickamauga, and Clinch, develop thinner residual cover than the formations with a high carbonate content, such as the Maryville, Maynardville, Knox, Mosheim, Holston, and Chapman Ridge. This is related to effects of chemical solution on limestone and dolomite—the result of organic acids contained in ground water reacting with these carbonate rocks. More soluble limestones and dolomites are affected to a greater degree than less soluble formations and in most places therefore develop a greater thickness of residuum.

TABLE 1. UNIFIED SOIL CLASSIFICATION SYSTEM AS RELATED TO KNOX COUNTY SOILS

Major Divisions		Symbol	Description	Unit Dry Weight lb/cu ft	Permeability ft/min	Drainage Characteristics	Value For Foundations (tons/sq. ft.)	Compaction Characteristics For Fill	Areas of Occurrence in Knox County
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.	125-140	$>10^{-2}$	Excellent	Good bearing (5 to 6)	Good, with rubber-tired or steel-wheeled roller.	Principally at or near the base of flood-plain deposits along major streams; and in high level terrace deposits adjacent to major streams; some very cherty residual clays overlying the Knox could be classified "GC".
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	110-130	--do--	--do--	--do--	--do--	
		GM	Silty gravels, gravel-sand-silt mixtures.	120-145	10^{-3} to 10^{-6}	Fair to practically impervious	--do--	Good, with close control, with rubber-tired or sheeps foot roller.	
		GC	Clayey gravels, gravel-sand-clay mixtures.	120-140	10^{-6} to 10^{-8}	Poor to practically impervious	--do--	Fair, with rubber-tired or sheeps foot roller.	
	SAND AND SANDY SOILS	SW	Well graded sands or gravelly sands; little or no fines.	110-130	$>10^{-3}$	Excellent	--do--	Good, with tractor	Mainly in the upper portions of flood-plain deposits of rivers and major creeks. Some of the residual soils overlying the Rome, Chapman Ridge, and Clinch formations could be classified "SM" and "SC".
		SP	Poorly graded sands or gravelly sands; little or no fines.	100-120	--do--	--do--	Good to poor; bearing depending on density (2 to 6)	--do--	
		SM	Silty sands, sand-silt mixtures.	105-135	10^{-3} to 10^{-6}	Fair to practically impervious	--do--	Good, with close control, with rubber-tired or sheeps foot roller.	
		SC	Clayey sands, sand-clay mixtures.	105-130	10^{-6} to 10^{-8}	Poor to practically impervious	Fair to poor bearing (1 to 3)	Fair, with rubber-tired or sheeps foot roller.	
FINE GRAINED SOILS	SILTS AND CLAYS LL<50	ML	Inorganic silts and very fine sands, silty to clayey fine sands or clayey silts with slight plasticity.	100-125	10^{-3} to 10^{-6}	Fair to poor	Very poor, subject to liquefaction. (< 1)	Good to poor, close control essential, with rubber-tired or sheeps foot roller.	Residual soils over limestones and dolomites are predominantly MH-CH, and ML-CL. The distinction between these depends on whether the liquid limit (LL) is above or below 50 percent.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	--do--	10^{-6} to 10^{-8}	Practically impervious	Good to poor bearing depending on density (1 to 4)	Fair to good, with rubber-tired or sheeps foot roller.	
		OL	Organic silts and organic silt-clays of low plasticity.	90-105	10^{-4} to 10^{-6}	Poor	Fair to poor bearing settlement likely (1 to 3)	Fair to poor, with sheeps foot roller.	Organic silts and clays (OL-OH) are found in slough deposits on floodplains.
	SILTS AND CLAYS LL>50	MH	Inorganic silts, fine sandy or silty soils, elastic silts.	80-100	--do--	Fair to poor	Poor bearing (< 1)	Poor to very poor, with sheeps foot roller.	The upper portions of most flood plain and terrace deposits are mixtures of ML-CL and MH-CH.
		CH	Inorganic clays of high plasticity, fat clays.	90-110	10^{-6} to 10^{-8}	Practically impervious	Fair to poor bearing depending on density (1 to 3)	Fair to poor, with sheeps foot roller.	
		OH	Organic clays of medium to high plasticity, organic silts.	80-105	--do--	--do--	Very poor bearing (< 1)	Poor to very poor, with sheeps foot roller.	Occurs occasionally as pockets of slough clay in flood plain deposits.
HIGHLY ORGANIC SOILS		PT	Peat and other highly organic soils.	--	--	Fair to poor	Unsuitable	Compaction not practicable.	Do not occur in Knox County.

Data from Terzaghi and Peck (1948), U.S. Army (1958), U.S. Bureau of Reclamation (1960), and U.S. Navy (1961).

TABLE 2. ENGINEERING EVALUATION OF KNOX COUNTY ROCK UNITS

Formation	Rock Type	Compressive Strength (psi X 10^3)	Modulus of Elasticity (psi X 10^6)	Range of Depth of Residual Overburden	Weathering Characteristics	Excavation Characteristics (Bed Thickness)	Suitability as Aggregate	Potential Yield for Wells (GPM)
CLINCH	Sandstone	10 - 20	2 - 6	0 - 15	Blocky weathering along joint and bedding planes.	Medium-bedded to Massive, Blocky (4" - 3')	Good, Hard on crushing equipment	Low (1 - 10)
UPPER CHICKAMAUGA	Shale, Siltstone, Interbedded Shale and Limestone	5 - 20	5 - 8	--do--	Moderate near-surface weathering along bedding and joints	Thin-bedded, Slabby to Blocky (1" - 4")	Poor	5 - 500
CHAPMAN RIDGE	Calcareous Sandstone	15 - 30	2 - 6	0 - 100+	Irregular top of rock, near-vertical solution cavities	Medium-bedded, Blocky (4" - 18")	Good Hard on crushing equipment	1 - 100
HOLSTON	Coarse crystalline Limestone - "Marble"	10 - 20	6 - 10	--do--	Irregular top of rock, cavities and sinkholes common	Massive, Blocky (1' - 3')	Good	3 - 500
LENOIR-MOSHEIM	Argillaceous to pure Limestone	10 - 30	5 - 8	0 - 20	Moderate near-surface weathering along bedding and joints	Thin- to medium-bedded, slabby (1" to 6")	Fair, depends on shale content	5 - 50
KNOX	Dolomite & Limestone	10 - 40	6 - 10	0 - 150+	Irregular, pinnacled top of rock, cavities and sinkholes common	Medium-bedded to Massive, Blocky (6" - 3')	Good to excellent, depending on chert content	5 - 500
MAYNARDVILLE	Limestone	10 - 30	5 - 8	0 - 30	Moderate weathering along beds and joints in near-surface 15 - 20 feet of rock	Medium-bedded, Blocky (4" - 18")	Excellent	Moderate (5 - 50)
NOLICHUCKY	Interbedded Shale and Limestone	Shale - 1-5 Limestone - 5-20	2 - 6	0 - 20	Slight weathering of near-surface rock	Thin-bedded, Slabby to Blocky (1" - 10")	Poor	3 - 400
MARYVILLE	Limestone	10 - 20	5 - 8	0 - 30	Moderate weathering, sinkholes common	Medium- to thick-Bedded, Blocky (6" - 18")	Good	Moderate (5 - 50)
RUTLEDGE	Shale and Limestone	Shale - 1-5 Limestone - 5-20	2 - 6	0 - 20	Slight weathering with gradual transition from soil to rock	Thin-bedded to Shaly (1" - 10")	Poor	--do--
ROGERSVILLE	Shale	1 - 5	1 - 5	--do--	--do--	Shaly (¼ - 1")	--do--	Low (1 - 10)
PUMPKIN VALLEY	Shale	1 - 10	--do--	--do--	--do--	--do--	--do--	--do--
ROME	Sandstone and Shale	Sandstone - 20-40 Shale - 1-6	2 - 6	0 - 10	Slight weathering of near-surface rock	Thin- to medium-Bedded, Shale to Blocky (1" - 1')	--do--	--do--

Thickness of residual cover is more uniform over less soluble sandstones, siltstones, shales, and shaly limestones than over more soluble limestones and dolomites. This again is because of the effects of differential chemical solution along steeply dipping natural fractures, which provide avenues of access for percolating acidic waters. As these channels are enlarged both vertically and laterally, the resulting rock-soil interface becomes extremely irregular and pinnacled. As an example, two vertical holes were drilled 10 feet apart to explore the foundation for a bridge pier near Fort Loudoun Dam in an area underlain by the Holston Formation. In one hole sound rock was encountered at a depth of 22 feet, but in the adjacent hole rock was not encountered until a depth of 160 feet was reached.

Weathering

The manner in which a rock unit weathers is controlled by composition of the rock, spacing between partings (bedding planes and joints), its attitude (flat or steeply dipping), and topography.

In general, weathering of rocks that contain a high proportion of insoluble material (shales and sandstones) results in development of a transitional zone of partially decomposed rock between soil cover and solid bedrock. The thickness of this zone may range from 1 foot to several tens of feet, depending on attitude of the bedding and spacing of the bedding and joint planes which provide access for the agents of weathering. Commonly, this transitional zone is thinner over flat or gently dipping strata and thicker over steeply dipping or contorted strata.

Weathering of more soluble rock types (limestones and dolomites) does not produce an intermediate partially weathered zone between soil and rock. Normally, there is a sharp boundary between residual clay and essentially unweathered rock. However, because of differential chemical solution along bedding planes and joints, the configuration of the top of rock is very irregular and pinnacled, and detached blocks of unweathered rock surrounded by residual clay are common.

Excavation

Both ease of excavation and stability of the resulting rock cuts depend not only on depth of weathering but also on orientation of the rock layers in relation to the plane of the cut and on the spacing of bedding and joint planes. In general, cuts in massively bedded rock are more stable than similarly oriented cuts in thin-bedded or shaly rock. However, when failures occur in massive strata larger quantities are usually involved and more damage results.

One common type of failure in rock cuts occurs where strata slope toward the excavation and the slope of the cut is steeper than the dip of the bedding. For example, if rock dips into the excavation at an angle of 30° from the horizontal, a cut slope of 1:1 (45°) would allow an unsupported wedge of rock to slide into the excavation. The simplest method to prevent such a slide is to orient the excavation so that such a potentiality is minimized. If this is not possible, the slope of the excavation should be conformable with the slope of the bedding to assure natural stability. In cases where this is not practical or is not economically feasible, special precautions must be taken. Rock bolting or post-tensioning with special blasting techniques are some methods that can be used depending on the specific circumstances. Such problems emphasize the need for adequate and thorough investigation of a specific site before design and construction.

Aggregate

Two major uses of rock aggregates are in concrete for structures and highways and in asphalt mixes for paving. Although size and gradation specifications for these uses differ, both uses require deposits of sound, durable material available in sufficient quantity and so located that they can be produced and transported economically to the point of use.

As an example, the Clinch Sandstone would provide satisfactory aggregate, especially for use in bituminous mixes. However, in Knox County, the Clinch occurs only in one localized and isolated area near the crest of House Mountain at the extreme northeast corner of the county. Because of its relative inaccessibility and distance from potential markets it is not now economically attractive to develop a quarry in the Clinch.

Evaluation of various formations as sources of aggregate (table 2) is based solely on their physical and chemical properties and does not consider economic aspects. In general, formations that are medium- to thick-bedded or massively bedded are most suitable. Formations with a high shale content should be avoided. Specific quarry sites should be selected only after adequate exploration and consideration of all geologic, economic, and environmental factors involved.

Another source of aggregate which has been and still is being used is sand and gravel dredged from lakes and rivers. Once present deposits of sand and gravel in the Knox County area are depleted this source of aggregate will no longer be available as upstream dams prevent more sand and gravel from accumulating during periods of floods.

Well Yields

There is no area-wide aquifer underlying Knox County which will consistently yield an adequate supply of ground water to wells. Rather, production from wells drilled in Knox County depends on the well intersecting either a large cavity or numerous small interconnecting voids in the rock which can act as conduits for the flow of ground water. For this reason, specific minimum yields from wells at any arbitrary location in the county cannot be predicted accurately. Maximum present yield from a single well in the county is approximately 500 gallons per minute. However, with adequate preliminary geologic and hydrologic investigations, accompanied by some prospecting with test wells, high-yield wells providing a supply of 1 million gallons per day (700 gpm) might be developed at favorable locations within the county.

Yields shown for various formations on table 2 are based on data from Tennessee Division of Geology, Bulletin 58, Part 1. Specific ranges represent data on yields of wells producing from the specified formation in the county. Where either "low" or "moderate" is used, yields are inferred from data on wells in these formations in other areas of east Tennessee.

PROBLEMS AND HAZARDS

It would be impossible, within the scope of this review, to describe all potential engineering geologic problems that might be encountered in Knox County. Each specific site or area has its own individual major or minor problems. However, several common conditions or natural hazards are applicable to many or all areas of the county. Among these are problems of subsidence and drainage and potential hazards of flooding, earthquakes, and landslides.

Subsidence

Land subsidence, whether rapid or gradual, can be vexatious and also costly to control or remedy. The most spectacular form of subsidence is the sudden collapse of the ground surface over a developing sinkhole, which is caused by gradual upward sapping of rock and overburden above an active solution channel in limestone and dolomite. When sapping reaches near enough to the surface to destroy natural support developed in overburden, collapse results. Often the initial surface indication is a relatively small hole a foot or so in diameter which flares outward with depth. Though this is a normal, natural phenomenon that occurs in any area underlain by carbonate rocks, the process can be, and often is, accelerated by either the rapid withdrawal or abnormal influx of ground water. Urban and suburban development frequently alters pre-existing surface drainage patterns and produces a corresponding change in subsurface drainage. In some cases an increased amount of surface runoff draining into a filled or partially filled solution channel will flush out the cavern filling and accelerate development of surface sinks. Conversely, increased surface runoff, which often carries surface debris, can cause an open cavity system which previously had been able to accommodate surface drainage, to become partially or completely plugged and temporarily or permanently flooded. A specific example of subsidence caused by sapping of solution cavities is the recurrent series of collapses that have affected Henley Street in the vicinity of West Main Avenue in downtown Knoxville.

Permanent control of this type of subsidence is practically impossible, as underground solution of limestone and dolomite is one of the inexorable forces of nature. The best preventative measure, especially for large buildings or industrial plants, is adequate preliminary exploration to ensure that active solution channels do not underlie the site. Once an active sinkhole has breached the surface, the best temporary remedy is to fill the void with graded material, starting with large rock at the base, to permit continued drainage and yet provide adequate support by bridging, and then to complete the filling by using successively finer material.

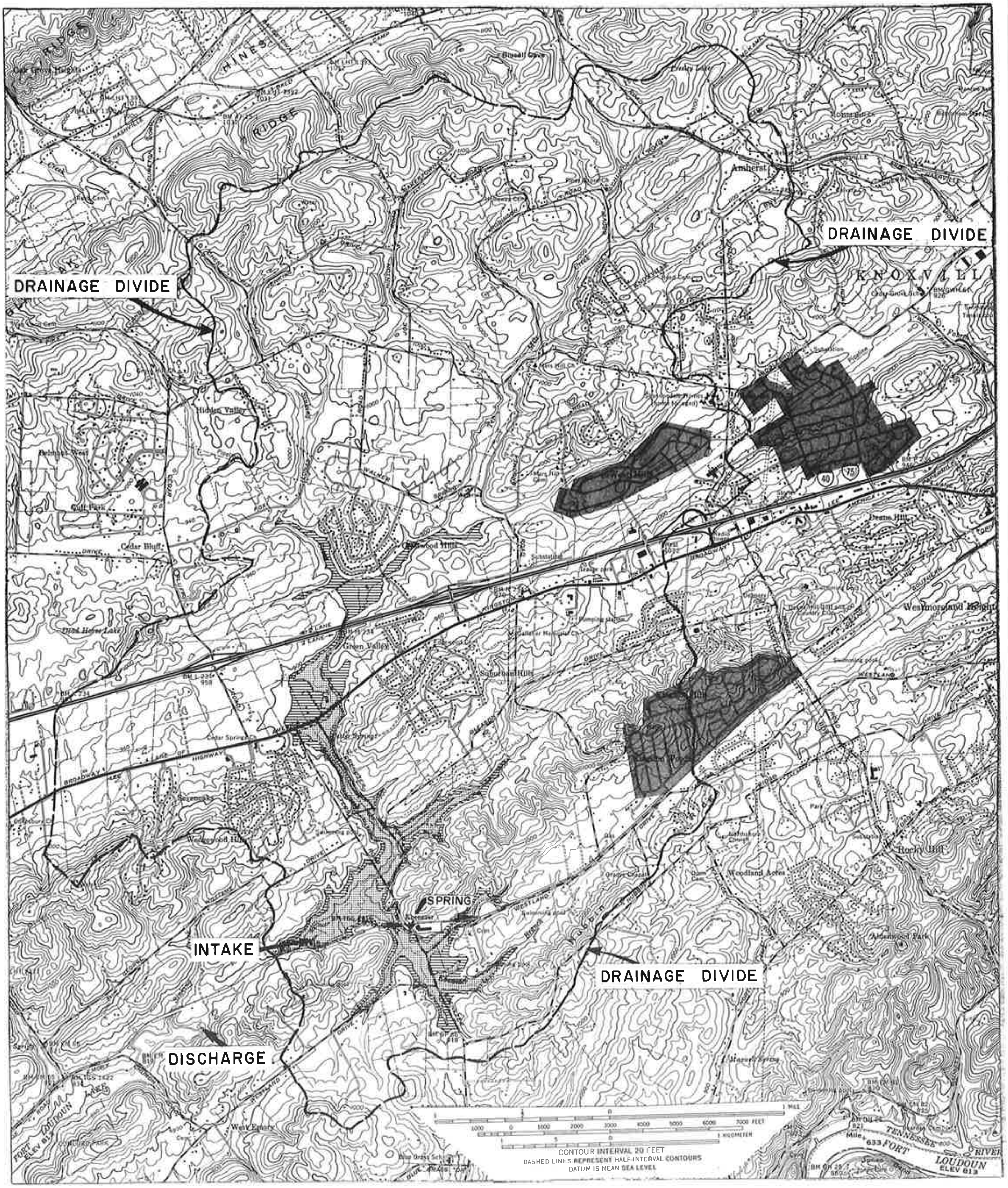
A second type of subsidence is less spectacular than sinkhole collapse but probably causes far more damage to residences and commercial structures in Knox County. This is subsidence caused by unequal compaction or "settlement." Building sites are often prepared by the "cut and fill" method, whereby, in order to level the area, material excavated from higher portions of the site is used to fill lower portions to the desired grade. When a structure is built on such a site so that part is founded on well-compacted, undisturbed material underlying the excavated area and part on less compacted material in the fill area, problems caused by unequal settlement often result. As filled-in material compacts over the years, stresses are set up in the overlying slabs and walls of the building with the result that cracks develop. This annoying problem, which is commonly encountered in many light to medium structures, could easily be eliminated if proper precautions were taken to insure that the building was founded on the same material—either completely in a cut area or entirely on uniformly compacted fill.

A third type of subsidence or ground movement that affects predominantly residential structures is "creep" of the soil on a hill slope. The force of gravity causes soil particles to migrate down slope. The rate of migration depends on various factors such as the steepness of slope, friability of soil, and moisture content. Over the years natural slopes have reached near-equilibrium conditions and rate of creep is minimal. However, when such slopes are developed as subdivisions, changes caused by excavation and grading, increased runoff of surface water resulting from general denudation of the area, and additional moisture introduced locally into the soil from drain fields or from lawn and garden watering all tend to increase the rate of creep. As creep-induced stresses are imposed on foundations and uphill walls of houses, cracks develop. For structures on hill slopes, the best prevention against damage from creep is to reinforce base slabs and uphill walls and to provide adequate footing drainage to relieve hydrostatic pressures.

Drainage and Flooding

One of the most critical problems in areas underlain by limestone and dolomite is contamination of ground water supplies by pollutants introduced into the interconnected cavities which serve as aquifers. Water from surface runoff, septic field drainage, and commercial or industrial wastes commonly drains into the ground water system. Once in an open solution channel system, the water is not filtered as it would be by a sand aquifer. Furthermore, pollutants can migrate over appreciable distances in this essentially free-flowing system. As a result, contamination of ground water in cavernous limestone terranes is commonly widespread, rendering water unfit for human or industrial consumption without costly treatment.

Many of the problems associated with surface and underground drainage are interdependent with the hazards of flooding. Major flooding along the Tennessee River has been reduced almost to nil by TVA impoundments. However, under extreme conditions flooding of areas adjacent to Fort Loudoun Lake could occur. This has been recognized and provided for by county and city flood plain zoning ordinances, which restrict development in these areas. Development on flood plains along major uncontrolled tributary streams in Knox County, such as First Creek, Beaver Creek, and Bull Run Creek, is not yet protected by such zoning restrictions, and flood damages could be incurred in these areas. Data as to probable flood levels and frequency of flooding on major tributaries are available from the Tennessee Valley Authority, Division of Water Control Planning.



▒ - Area affected by 50-year flood.

▓ - Area affected by maximum flood.

Figure 1. Ten Mile Creek drainage basin.

Localized minor flooding, which may be the result of various causes, can account for nearly as much damage and inconvenience as flooding along the Tennessee River or its major tributaries. In the original, undisturbed state, tracts of land can absorb appreciable amounts of rainfall, even in heavy thunderstorms. However, if a tract is subdivided into lots measuring 100 by 150 feet and houses measuring 24 by 50 feet are built on the lots, approximately one-fifth to one-quarter of the area is occupied by houses, and hard-surfaced patios, driveways, and streets. These permit no absorption of rainwater and thereby contribute to increased runoff. As previously mentioned, poorly designed or inadequate drainfields contribute to increased runoff. Not only do these saturate the ground and thereby decrease the amount of rainfall that can soak in, but in extreme cases, as in the West Hills area of Knoxville prior to installation of sewers, they can saturate the ground so completely that there is continuing runoff even during dry periods. If adequate surface and subsurface drainage is not provided by the developers of a subdivision, houses in lower portions of the area or in neighboring subdivisions at lower elevations can be damaged by flash flooding.

An example of potential localized flooding is shown on figure 1. Ten Mile Creek drainage basin has an area of 15.8 square miles and includes all or major portions of the fastest developing subdivisions in Knox County. Drainage from this entire basin flows into an active sinkhole system located approximately 3000 feet west of the intersection of Ebenezer Road and the Southern railroad tracks. From here water flows underground through an interconnected cave system and finally discharges as a spring at the head of the Sinking Creek embayment of Fort Loudoun Lake. With the runoff rate increasing annually as the area develops, a probable 50-year flood would inundate at least the area shown as a stippled pattern on figure 1. If part of the underground cave system should collapse or should become blocked, the additional area shown by the ruled pattern would be flooded before water would flow over the lowest point on the natural surface divide and into Fort Loudoun Lake. Not only would this temporary or permanent flooding cause damage to residential areas and roads, but it would inundate a spring near Ebenezer which is presently being used as a water source for a local utility district. Furthermore, the cave system into which Ten Mile Creek flows is frequently visited by "spelunkers." A severe thunderstorm could cause flash flooding in the cave system that would be disastrous to any group in the cave at the time.

The foregoing may seem to be an extreme example. However, Dead Horse Lake, shown on the map just west of the Ten Mile Creek drainage divide, was formed in the mid-1920's by the blocking of an active sinkhole.

Earthquakes

Although Knox County and surrounding area is not believed to lie within an active earthquake zone, Algermissen (1969) considered seismic activity in the region to be sufficient to classify this area within his Seismic Risk Zone 2. These zones are based on an evaluation of the known distribution and intensities of earthquakes occurring in an area, data on strain release in the United States since 1900, and association of strain release patterns with large-scale geologic features believed to be related to recent seismic activity. Algermissen's map (figure 2) shows zonation for the entire country. By definition, moderate earthquake damage could be expected in Zone 2 that would correspond to an intensity of VII on the Modified Mercalli Intensity Scale of 1931 (table 3). The effects designated for an intensity of VII shock are: "Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars." A shock of this intensity corresponds to one with a Richter magnitude between 5.2 and 5.7 and would have a ground acceleration of approximately 0.1 gravity.

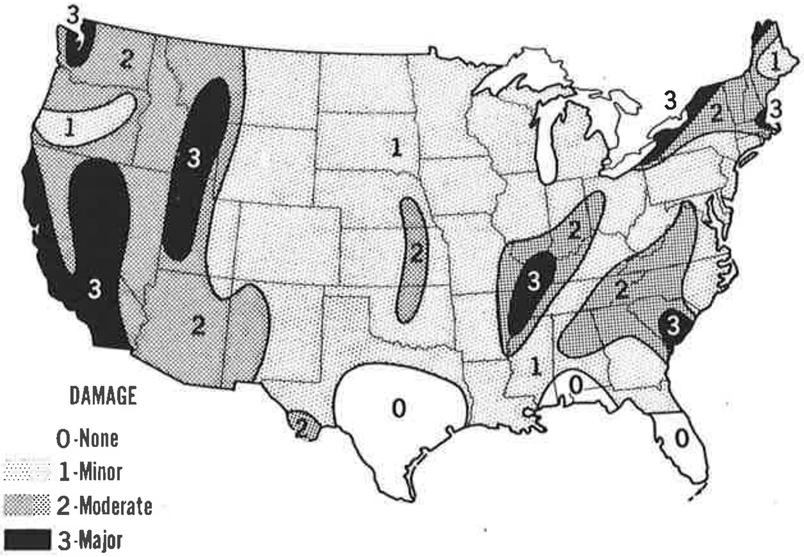


Figure 2. Seismic risk map for the United States.

(S.T. Algermissen, ESSA, 1969)

TABLE 3

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(Wood and Neumann, 1931)

I. Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel Scale).

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII + to IX- Rossi-Forel Scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Ground cracked conspicuously. (IX + Rossi-Forel Scale.)

X. Some well-build wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep-slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale).

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

A detailed analysis of the earthquake history of the area within a 100-mile radius of Knoxville for the past 100 years (1872-1971) shows that 109 earthquakes have had their epicenters within these limits (McClain and Myers, 1970). The following tabulation shows the number of earthquakes in relation to Modified Mercalli Intensities of the shocks:

Modified Mercalli Intensity	Number of Earthquakes
II	20
III	28
IV	26
V	21
VI	12
VII	2

Figure 3 shows graphically the probability of a quake of any given intensity that might occur annually in the 7850-square mile area surrounding Knoxville. Figure 4 shows the epicenters and intensities of historic earthquakes in the area. A graph of the number of earthquakes per year during the past 100 years is shown in figure 5.

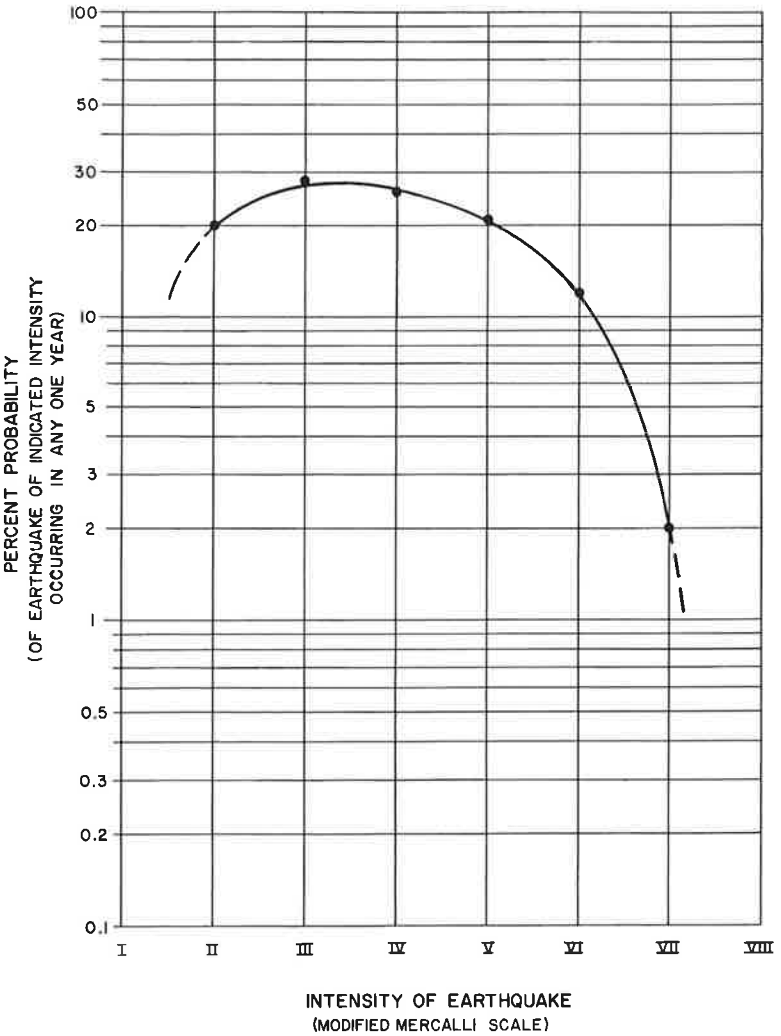
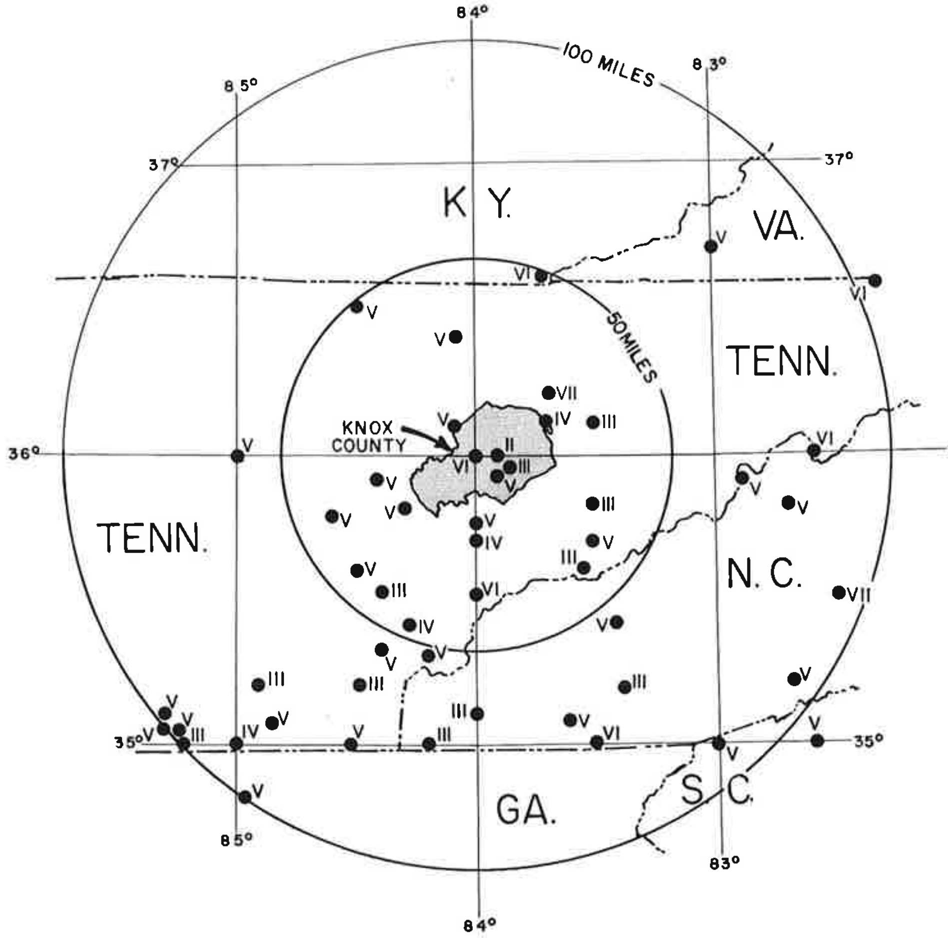


Figure 3. Earthquake probability chart for Knox County.



●V – EPICENTER SHOWING MODIFIED MERCALLI INTENSITY

Figure 4. Location of earthquake epicenters.

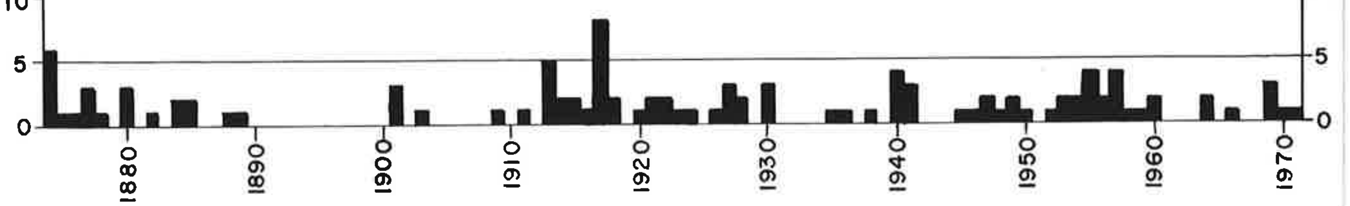


Figure 5. Earthquakes per year 1874-1971.

Landslides

The hazard of major catastrophic landslides of natural origin occurring in Knox County is minimal. Over past millenia, slopes in Knox County and East Tennessee have reached a natural state of equilibrium. However, when this equilibrium is disturbed, either in soil-supported or rock-supported slopes, slides can and do occur if adequate preventive measures are not incorporated into the design and construction of the excavation. Frequently, such slides are the result of misguided attempts to reduce excavation costs and quantities by making cuts as steep as possible. Unfortunately, this philosophy often results in unstable slopes which are subject to partial or total failure by sliding. These failures commonly develop some time after the cut is made, when the material has been weakened by cycles of wetting and drying or frost action.

Several examples of effects of ignoring geologic conditions are evident in Knox County and surrounding areas. In one instance a site proposed for a supermarket on Chapman Highway had to be abandoned when the area was being graded. In this case, a cut into a ridge underlain by folded Chapman Ridge Sandstone resulted in a slope that was so unstable that the project was terminated before the building was erected. Examples of slides caused by roadcuts being made steeper than the natural slope of the rock are in evidence in the foothills of the Great Smoky Mountains, especially along U.S. 441 between Pigeon Forge and Gatlinburg, and on U.S. 129 along Chilhowee Lake. In both these areas bedding and cleavage of siltstones and slates are controlling factors. In areas where these planes dip toward the highway cut at a lower angle than the plane of the cut, slides have occurred. Frequent post-construction maintenance has been required to remove slide debris, and this costly clean-up work will continue to be necessary until the cuts adjust to the slope of bedding and cleavage, at which time they will become naturally stabilized.

An extreme example of the consequences of disregarding geologic factors can be seen on Interstate 40 along the east front of the Cumberland Plateau escarpment between Harriman and Rockwood. Although the underlying geologic structure is complex, many of the major slide areas developed where the interstate alignment crossed colluvial talus deposits filling small re-entrants in the Plateau front. A basic principle in slide control is to remove material (and thereby weight) from the head of the slide and to add weight to the toe of the slide. In traversing the Plateau front the eastbound and westbound lanes of I-40 are separated; the westbound lane is higher on the slope than the eastbound lane. In making side-hill cuts for the westbound lane across the talus deposits, excavated material was dumped over the edge of the cut to provide additional width for the roadbed. This in effect steepened the natural slope and made it less stable. When excavation was made across similar material for the lower, eastbound lanes excess material was removed and used elsewhere for fill, thereby removing weight from the lower area. Major sliding resulted from oversteepening and overloading of the higher areas and removal of material from the toe area. Costly investigations were made and remedial measures were taken with no assurance that a permanent solution has been reached.

These examples serve to point out that any evaluation of a proposed cut not only should consider initial cost of the excavation but also should give equal consideration to damage that might result and remedial or maintenance costs that might be incurred by a failure during the life of the cut.

In general, slopes cut in soil that are steeper than 1 on 1 (45°) are most likely to fail; but failures often occur in flatter slopes cut into saturated, poorly drained, silty soils (ML to MH). The stability of a rock cut depends primarily on the spacing of partings in the rock and their orientation in relation to the cut. Any proposed major cut, whether in soil or rock, requires adequate investigation and judgment to minimize potential development of slides.

SOILS OF KNOX COUNTY, TENNESSEE

BY

RECTOR H. MONEYMAKER

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INTRODUCTION

There are 60 kinds of soils represented on the soil map of Knox County. Each of these, like soils elsewhere in the world, is the product of soil formation. Soil formation begins with the weathering of rocks and the production of parent material. The degree to which a soil develops depends on the nature of the parent material, the relief, and the length of time the parent material has been subjected to the climate and to living organisms. These factors function simultaneously. All are important in the formation of soils but, depending on the location, some are more important than others.

There are wide differences between the soils of Knox County. Parent material, relief, and time account for more of these differences than climate or living organisms.

In the next few paragraphs the five factors of soil formation are discussed in their relation to the soils of the county.

Climate is almost uniform over Knox County. The county has a humid temperate climate. Winters are relatively mild and summers are warm. The amount of rainfall is high (about 47 inches per year). The combination of warm temperatures and abundant rainfall favor the weathering of parent materials, the growth of organisms, and the speed of reactions in the soils. The high rainfall results in a large amount of water carrying soluble and suspended mineral and organic materials downward in the soil. This is part of the reason that many of Knox County soils have pale-colored (leached) surface layers.

Rock, acted on by climate and living organisms, conditioned by relief through time, develops into parent material. Simultaneously, the parent material is being acted on by the same forces and slowly, through many stages, develops into soil. Parent materials of Knox County soils have several sources: limestone, dolomite, shale, sandstone, and sediments of igneous and metamorphic origin brought by streams. Parent material has governed the kinds of minerals in the soils, contributed to soil fertility, helped determine soil texture, influenced the soil-water relationships, teamed with the other factors to determine the relief, and has been a major reason for many of the differences of Knox County soils.

Relief has influenced the formation of soils through its effect on internal drainage, runoff, the rate of erosion, and, indirectly, on plant cover. On many steep slopes, the soil has eroded off about as fast as it formed resulting in weakly developed soils that are shallow to rock. Only a small amount of the rain that falls on these soils percolates through the soil, limiting the kinds and intensities of the processes that occur. Soils in Knox County on steep slopes are well or excessively drained internally; those on gentle slopes range from well drained through poorly drained. Relief has had a bearing on the kinds of soils that have formed and has indirectly helped determine the kinds of organisms in the soils. Many of the differences in Knox County soils can be attributed to relief.

Living organisms have contributed to individual soils in the county but are not responsible for the broad differences between the soils. They have added organic matter to the soil; influenced the gains and losses of plant nutrients; promoted and were involved in physical and chemical changes; contributed to soil structure and porosity; and influenced the development of soil horizons. The native vegetation of Knox County was predominantly hardwoods and mixed hardwoods and pines. Soils formed under hardwoods usually contain only a small amount of organic matter. This is mostly confined to the upper 1 or 2 inches of the surface layer where the soil has not been plowed.

The time it takes for a soil to develop depends on the action of the other factors of soil formation. The length of time the parent material has been acted on by the other forces is reflected in the development of Knox County soils. The Huntington, Etowah, and Cumberland soils, for example, are believed to have developed from alluvium from similar sources, under similar climatic conditions, with similar living organisms, and on essentially the same topography. Huntington soils have developed from recent alluvium and, with the exception of the surface layer, have no distinct horizons. Etowah soils are intermediate between Huntington and Cumberland. Huntington soils are young; Cumberland soils are old.

The soils of Knox County are in several bands, called soil associations, that transect the county in a northeast-southwest direction. Each association consists of several soils in a distinctive pattern. Each normally consists of two or three major soils and a few minor soils. Each association is named for the major soils. Some of these soils are similar but some are very different. A few of the soils are in two or more associations, but the soil pattern and composition of the associations are different. The soils of an association may vary widely in their suitability for use.

Every soil in Knox County can be classified by its properties or characteristics. The same is true of anything being classified whether it be trees, animals, rocks, or whatever. A soil represents a range of properties. Well-defined limits of color,[1] texture, structure, depth, internal drainage, reaction, kinds of horizons (O, A, B, C), and other properties have been set. In the following paragraphs brief descriptions of the soil associations are given. Soil names and many of the properties described in this paper are in agreement with the *Soil Survey of Knox County, Tennessee,* but may not be fully consistent with the current soil classification system.

FULLERTON - BOLTON - CLARKSVILLE SOIL ASSOCIATION

The soils in this association have developed over dolomite. They are on ridges that have relatively broad tops and sides that range in slope from about 12 to 50 percent. Northwest-facing slopes are commonly steepest. The Fullerton soils are the most extensive soils in the association followed in order by Clarksville and by Bolton. These soils are deep and well drained. About one-half of the Fullerton soils and all of the Clarksville soils contain more than 15 percent chert by volume throughout the soil.

The Fullerton soils have brown cherty (or non-cherty) silt loam A horizons[2] and cherty (or non-cherty) yellowish red and red firm clay B horizons.[3] Unless recently limed, these soils are very strongly acid. They are low in fertility and contain only a small amount of organic matter. Kaolinite, dickite, and nacrite make up more than one-half of the clay minerals in the control section.[4]

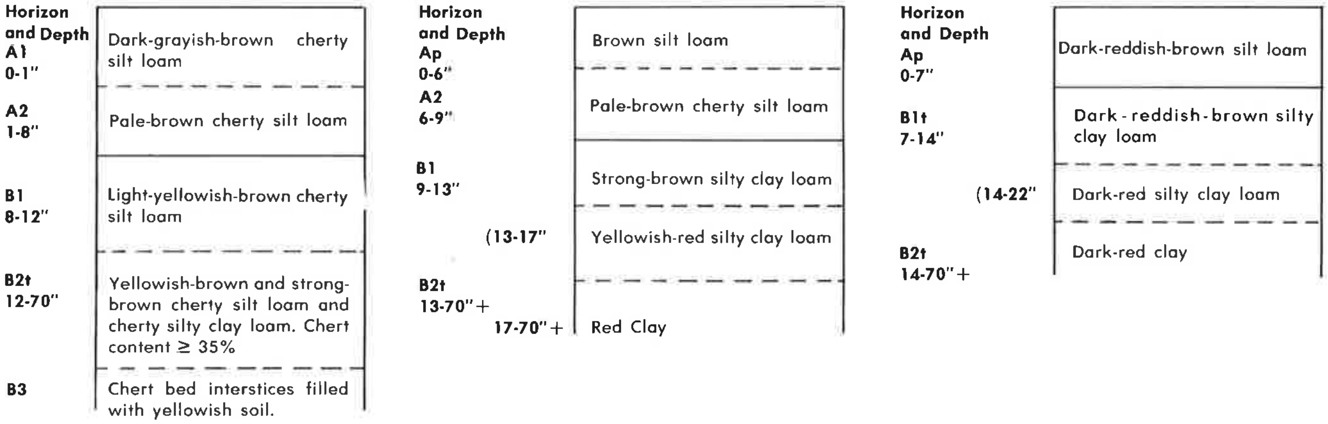
The Clarksville soils contain more than 35 percent chert. They have pale brown cherty silt loam A horizons and yellowish brown and strong brown cherty silt loam and silty clay loam B horizons. These soils are droughty, low in fertility, contain little organic matter, and are very strongly acid. Silica minerals predominate in the .02 - 2 mm size fraction in the control section.

The Bolton soils have dark brown loam A horizons and dark reddish brown or dark red friable silty clay B horizons. These soils are medium to strongly acid and are moderately high in fertility. The organic matter content is higher than in either the Fullerton or Clarksville soils. Bolton soils have siliceous mineralogy.[5]

Minor soils in the association include the Minvale, Tarklin, Etowah, and Greendale. These soils have developed from colluvium or alluvium and are on benches, toe-slopes, and along drainageways.

The Minvale soils resemble the Fullerton soils but have loamy subsoils and siliceous mineralogy. The Tarklin soils are moderately well drained. They have pale brown silt loam or cherty silt loam A horizons and yellowish brown silt loam or silty clay loam (either can be cherty) B horizons. Between 20 and 36 inches in depth, there is a mottled compact layer that restricts the penetration of roots and the percolation of water. The Etowah soils resemble the Bolton soils but on the average do not have dark red subsoils. Greendale soils are in narrow strips along drainageways. They are well drained and have brown silt loam A horizons and dark yellowish brown B horizons. Because they have formed from relatively recent sediments, they do not have strongly developed horizons.

The Minvale, Tarklin, Etowah, and Greendale soils have siliceous mineralogy. Figure 1 illustrates the profiles of the Clarksville, Fullerton, and Decatur soils.[6]



Clarksville cherty silt loam (Developed from residuum)

Fullerton silt loam (Developed from residuum)

Decatur silt loam (Developed from alluvium)

Figure 1. Comparison of the morphology of three soils developed over dolomites and limestones.

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[1] Soil color is determined by use of the Munsell color system.

[2] The A horizon is usually at the surface. It is the zone of maximum leaching (generally speaking—the plow layer or surface layer).

[3] The B horizon is beneath the A. It is the zone of maximum accumulation (generally speaking—the subsoil).

[4] Upper 20 inches of the B horizon (illuviated horizon).

[5] Siliceous mineralogy - 90 percent or more of the minerals in the .02 - 2mm size fraction in the upper 20 inches of the B (illuviated) horizon is silica or other minerals with hardness (Mohs) of 7 or more.

[6] Decatur soils are described in the Decatur - Dewey - Emory soil association.

STONY LAND - TALBOTT SOIL ASSOCIATION

This association occupies gently sloping to hilly valley positions. Outcrops and ledges of limestone are common components of the landscape.

Very rocky land types (Stony Land and Limestone Rockland) predominate but there are sizable areas of Talbott and Colbert soils.

Unless severely eroded, Talbott soils have brown silt loam A horizons. The B horizon is yellowish red very firm clay. The depth to bedrock is variable but the average depth is probably less than 40 inches. Natural fertility and the organic matter content are low. Talbott soils are medium to strongly acid except for a few inches above bedrock. These soils have mixed mineralogy.[7]

The surface layer of the Colbert soils is brown silt loam or yellow silty clay or clay depending on the degree of erosion. These soils are moderately deep to rock, have very firm yellowish brown clay B horizons, are medium to strongly acid, and are moderate in fertility. Clay makes up 60 percent or more of the control section. The soil cracks most years to a depth of 20 inches and cracks are at least .4 inch wide and 12 inches long at this depth. Colbert soils have montmorillonitic mineralogy.[8] Bedrock outcrops are common in areas of this soil.

Limestone outcrops and ledges characterize the Stony Land types and Limestone Rockland. The soil between the rocks is similar to the Talbott and Colbert soils.

Greendale and Lindside soils are along the narrow drainageways and in the bottom of the saucer-shaped depressions. The Greendale soils are described in the Fullerton - Bolton - Clarksville soil association, and the Lindside soils are described in the Cumberland - Huntington association.

Intermingled with the other members of the association are areas of the Sequoia soils. These soils are described in the Sequoia - Litz - Dandridge soil association.

MUSKINGUM - LEHEW SOIL ASSOCIATION

This association consists of soils on long linear ridges that have very steep side slopes and narrow tops.

The Muskingum soils have brown fine sandy loam to silt loam A horizons and yellowish brown loam or silt loam B horizons. Coarse fragments of shale or sandstone make up from 10 to 30 pecent (vol.) of the B horizons. These soils are commonly underlain by light colored sandstone or shale. The Lehew soils typically have reddish brown fine sandy loam A and B horizons. Sandstone or shale fragments make up 35 percent or more (vol.) of the B horizons. Lehew soils are nearly always underlain by reddish sandstone bedrock.

Muskingum and Lehew soils are intermingled in the landscape. Most are less than 36 inches to weathered bedrock. These soils are droughty, low in natural fertility, low in organic matter, and strongly acid.

There are a few areas of Jefferson and Hamblen soils. The Jefferson soils are on benches and toe-slopes whereas the Hamblen soils are along drainageways. The Jefferson soils are described in the Jefferson - Montevallo soil association and the Hamblen soils are described in the Staser - Hamblen soil association.

JEFFERSON - MONTEVALLO SOIL ASSOCIATION

The Jefferson - Montevallo soil association is underlain by shale and occupies valley positions adjacent to the Muskingum - Lehew soil association. Most of the areas are on slopes with gradients of less than 12 percent.

The Jefferson soils have developed primarily in sediments that have washed from the Muskingum and Lehew soils. The A horizon in cultivated areas is yellowish brown friable fine sandy loam; areas in forests have pale brown to dark yellowish brown fine sandy loam. The B horizon is yellowish brown loam or clay loam. Jefferson soils are low in fertility, strongly acid, and contain only small amounts of organic matter. They are easy to work and are permeable to roots, air, and moisture. Depth to bedrock ranges from about 2 to 12 feet. These soils are siliceous in the control section.

The Montevallo soils have developed from shale. They are shallow, averaging less than 20 inches to bedrock. The surface layer is light brownish gray shaly silt loam. Below this is light brownish gray or brownish yellow shaly silt loam or shaly silty clay loam. Shale fragments make up more than 35 percent of this horizon. This horizon grades into weathered bedrock. Montevallo soils are strongly acid, low in natural fertility, low in organic matter, and droughty. They have mixed mineralogy in the control section.

The Leadvale soils are on slightly concave benches, and the Cotaco soils are along the drainageways. The Cotaco soils have dark grayish brown fine sandy loam or loam A horizons; subsurface horizons have matrices of brown and yellowish brown clay loam or loam mottled with gray, yellow, and brown. The Cotaco soils as mapped in Knox County range from moderately well drained to somewhat poorly drained. They have siliceous mineralogy in the control section.

The Leadvale soils are described in the Sequoia - Litz Dandridge soil association.

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[7] Generally, no single mineral makes up more than one-half of the minerals in the clay fraction of the control section.

[8] More than half by weight of montmorillonite and nontronite, or a mixture with more montmorillonite than any other single clay mineral in the clay fraction of the control section.

CUMBERLAND - HUNTINGTON SOIL ASSOCIATION

This association consists of soils in bottomlands and associated stream terraces along the major streams. Most areas are in the bends of these streams and are from a fraction to about 1½ square miles in size. Huntington, Staser, and Lindside soils are on the bottoms whereas the Cumberland, Etowah, and Waynesboro soils are on the stream terraces.

The Huntington soils are young. They have very dark grayish brown silt loam A horizons and dark brown B horizons. These soils are free of gray mottles to a depth of about 36 inches. Huntington soils have high natural fertility and moderate amounts of organic matter. They are well drained, deep to bedrock, and easy to work. The reaction ranges from medium acid to slightly alkaline.

The Cumberland soils have developed from alluvium and are on high terraces. The topography is predominantly rolling to hilly, but there are several areas that are undulating. Typical Cumberland soils have dark reddish brown silt loam A horizons and dark red clay subsoils. Some of the Cumberland soils contain gravels throughout their profiles. The natural fertility is high and the organic content is medium. These soils are medium to strongly acid and are well drained.

The Staser, Lindside, Etowah, and Waynesboro soils occupy considerable acreage in this association. The Staser soils as mapped in Knox County are on the bottoms and are similar to the Huntington soils except the Staser is lighter in color. The Lindside is also a bottom soil but it is only moderately well drained. The surface layer is dark grayish brown silt loam. Below about 15 inches in depth, the dark brown matrix is mottled with gray, yellowish red, and brown. The Etowah are on intermediate terrace positions. They have dark brown silt loam plow layers and yellowish red silty clay loam subsoils. Below 30 inches in depth, the subsoil texture is silty clay or clay in some profiles. These soils are siliceous in the control section. The Waynesboro soils are on high terraces. They have brown (leached) loam A horizons and red and dark red clay B horizons. The upper 20 inches of the subsoil averages about 40 percent clay and from 20 to 50 percent sand. Waynesboro soils are productive but less productive than the soils described above. They are well drained, deep to bedrock, have a low organic matter content, and are strongly acid. Clay minerals in the control section are dominated by kaolinite, dickite, and nacrite.

DECATUR - DEWEY - EMORY SOIL ASSOCIATION

The topography of this association is dominantly undulating to rolling, but there are a few areas that are steep. The soils have developed primarily over limestone (or dolomite).

Decatur soils are similar to Cumberland soils in color and texture and are believed to be of similar origin. They have dark reddish brown silt loam and silt clay loam surface layers and dusky red or dark red clay subsoils. These soils are deep to bedrock, have high natural fertility, and are well drained. The surface layer contains a moderate amount of organic matter. Decatur soils are medium to strongly acid. Kaolinite, dickite, and nacrite are the dominant clay minerals in the control section.

The Dewey soils are similar to the Decatur but do not have the dark subsoil colors. They have dark reddish brown A horizons and yellowish red and red B horizons. The A horizon is silt loam or silty clay loam depending on the severity of erosion. The B horizon is clay. Like the Decatur soils, Dewey soils have kaolinitic mineralogy. These soils are less productive than the Decatur soils.

The Emory soils have developed from sediments washed from the Decatur, Dewey, Cumberland, and Etowah soils. They are in saucer-shaped depressions, along intermittent drainageways, and on toe-slopes. Having developed from recent sediments, they do not have well-developed profiles. The plow layer is dark reddish brown silt loam. The subsoil is dark reddish brown or reddish brown silt loam or silty clay loam. Emory soils are among the most productive soils in the county. They have high natural fertility, are moderately high in organic matter, and are easy to work. They are permeable to air, roots and water. Silica minerals and other minerals with hardness of 7 or more in the Mohs scale dominate the control section. Areas of Emory soils are small and irregular in shape.

SEQUOIA - LITZ - DANDRIDGE SOIL ASSOCIATION

This association occupies valleys that are underlain by shale. It is characterized by low hills that have smooth tops and short moderately steep side slopes.

Upland soils predominate. Sequoia soils are on the broader hilltops and cover more than one-half of the association. Litz and Dandridge soils are on the steeper side slopes, and the Leadvale, Whitesburg, and Lindside soils are along the drainageways.

The Sequoia soils have developed from shale. They range in depth from slightly more than 20 inches to about 40 inches with an average of about 36 inches. The plow layer is dark grayish brown silt loam, and the subsoil is yellowish red or red silty clay. The natural fertility and the organic matter content are low, and the reaction is medium to strongly acid. The B horizon of Sequoia soils has a strongly developed structure. The movement of water through the soil is moderately slow because of the clayey subsoil and the nearly impermeable underlying shale bedrock. Sequoia soils have mixed mineralogy.

The Litz soils have developed from shale parent material. They have light-colored silt loam or silty clay loam A horizons and yellowish red silty clay subsoils. The subsoil contains many soft shale fragments. The depth to weathered shale ranges from about 12 to 24 inches. Litz soils have mixed mineralogy in the control section.

The Dandridge soils have developed from calcareous shale. The A horizon is grayish brown or dark grayish brown friable shaly silt loam or silty clay loam. The B horizon is yellowish brown silty clay and contains more than 35 percent (vol.) shale fragments. Depth to shale is less than 20 inches in most places. The natural fertility is moderate and the organic matter content is low. The reaction ranges from slightly acid to neutral. Percolation rates are high. Dandridge soils have base saturations that exceed 60 percent.

The leadvale soils are on benches. They have developed from sediments washed from uplands underlain by shale. The A horizon is brown silt loam, and the B horizon is yellowish brown silt loam or silty clay loam. At depths of about 24 to 32 inches, there is a layer (fragipan) that restricts the downward movement of air and water and the penetration of roots. Leadvale soils are moderately well drained. They are low in fertility and contain little organic matter. The reaction is medium acid to strongly acid. These soils are siliceous.

Figure 2 illustrates the profiles of the Dandridge, Sequoia, and Leadvale soils.

The Whitesburg soils are along the drainageways among the shale uplands. They have developed from recent colluvium and consequently do not have strongly developed horizons. The A horizon is brown silty clay loam. The B horizon is typically yellowish brown silty clay loam. Below about 16 inches in depth, the soil is mottled with brown and gray. Whitesburg soils are moderately well drained, but small areas of poorly drained soils are commonly intermixed in the landscape. These soils are moderately fertile and slightly acid to neutral. Base saturation is 60 percent or more, and they are siliceous.

Lindside soils resemble the Whitesburg soils in many profile characteristics. They are described in the Stony Land-Talbott soil association.

DANDRIDGE - LITZ - LEADVALE SOIL ASSOCIATION

This association is underlain by shale and is a highly dissected area of hills and knobs with narrow winding tops, steep side slopes, and meandering drainageways.

The Dandridge soils perdominate with lesser amounts of the Litz, Leadvale, Sequoia, and Whitesburg soils. The Sequoia soils are on the milder upland slopes and the Leadvale and Whitesburg soils are on gentle slopes at the base of hills.

This association differs from the Sequoia - Litz - Dandridge soil association primarily in the dominance of the Dandridge soils whereas in the Sequoia - Litz - Dandridge association, the Sequoia soils occupy the larger acreage. This association also is steeper and is probably more eroded.

TELLICO - NEUBERT SOIL ASSOCIATION

This association consists mainly of dark red (dusky) upland soils on steep ridges with narrow intervening hollows. It is underlain by calcareous sandstone and shale. The upland soils are well drained but there are some wet strips of colluvial soils along the drainageways.

The Tellico soils are dominant. Typically, they have dusky red loam A horizons and dusky red clay loam B horizons. In forested areas, the upper 1 to 2 inches of the A horizon is darkened with organic matter. The clay content of the upper 20 inches of the B horizon is more than 35 percent.

The natural fertility and organic matter content are moderate. The reaction is strongly acid except the surface layer is less acid where limed. Tellico soils are permeable to air, roots, and water. They are easy to work, but many areas of these soils are best suited to forest because of the steep slopes. The minerals in the control section consist of less than 90 percent quartz and less than 40 percent of any other single mineral, and the ratio of the percent extractable iron oxide and gibbsite to the percent clay is equal to or greater than 0.20.[9]

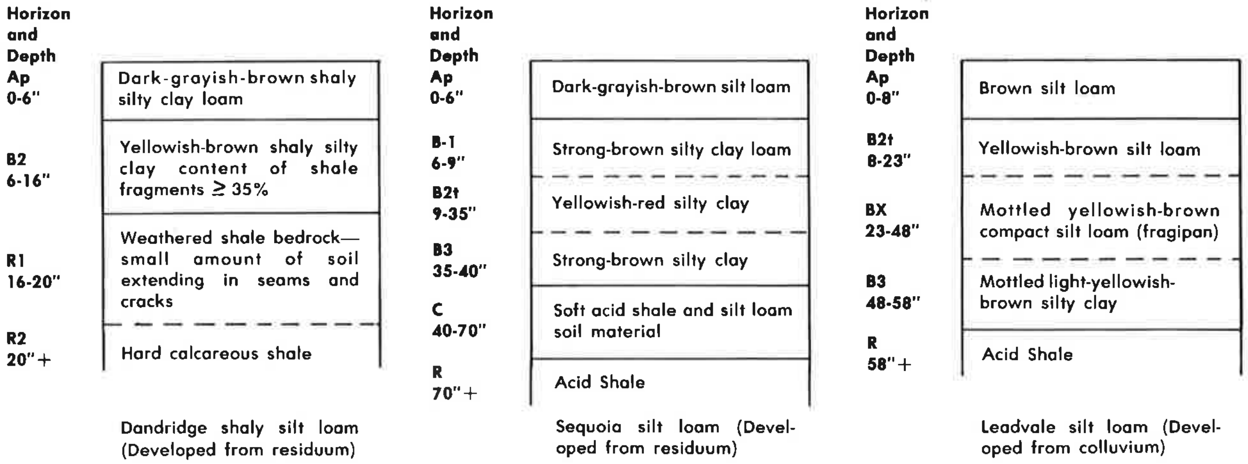

Figure 2. Comparison of the morphology of three soils developed over shale.

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[9] Oxidic mineralogy.

The Neubert soils are alongside the drainageways. They have developed from colluvium washed from Tellico, Alcoa, and Steekee soils. Of recent origin, Neubert soils have no discernible horizons except in forested areas the upper few inches of the A horizon are darkened by organic matter. The soil to a depth of 36 inches or more is reddish brown or dark reddish brown. Typically, the texture of the A horizon is loam and of the B horizon is clay loam. These soils are high in natural fertility and contain a rather large amount of organic matter. The pH is higher than 5.5. Neubert soils are well drained. They are siliceous.

Alcoa soils are on benches and footslopes. They developed from sediments washed from the Tellico and Steekee soils. Their origin is the same as the Neubert soils but they are much older. Most of the Alcoa soils are in the Tellico - Neubert soil association, but some are in the adjacent shale valleys. The A horizon is dark reddish brown loam and the B horizon is dark red clay loam. These soils are well drained. The depth to bedrock exceeds 60 inches. Alcoa soils are permeable to air, roots, and water. Like the Tellico soils, they are oxidic in the control section.

Hamblen soils are alongside the drainageways in close association with the Neubert soils. They are moderately well drained. In this association, the upper 12 to 24 inches of the profile has a reddish cast. Hamblen soils are described in the Staser - Hamblen soil association.

The Steekee series was established after Knox County was mapped. Areas of these soils were included in the Tellico series. These soils are on the steeper slopes of the association. They are reddish in color and loamy in texture. Depth to bedrock is less than 20 inches. There are numerous outcrops. These soils contain more sand than the Tellico and Alcoa soils. They are siliceous. Steekee soils are low to moderate in fertility and are droughty. They are friable and are permeable to air, roots, and water. Their use is largely limited to forest because they are shallow and are on steep slopes.

ARMUCHEE - LEADVALE SOIL ASSOCIATION

This soil association is predominantly hilly and steep. It is underlain by interbedded shale and limestone (or dolomite). The Armuchee soils are dominant. Sequoia soils are on some of the smoother areas, and Leadvale soils are on colluvial positions.

Typically, the Armuchee soils have dark grayish brown A horizons and strong brown and yellow red B horizons. The texture of the surface layer is silt loam except where the B horizon is exposed as a result of erosion. The subsoil is silty clay and contains many shale fragments. The depth to bedrock is generally less than 20 inches, but there are some profiles that exceed this. Outcrops are common in some areas. Armuchee soils are moderate in natural fertility, and the organic matter content is medium. The clayey subsoil and shallowness to rock cause these soils to be droughty.

The Sequoia and Leadvale soils are described in the Sequoia - Litz - Dandridge soil association.

STASER - HAMBLEN SOIL ASSOCIATION

The Staser - Hamblen soil association occupies bottomlands along Bullrun Creek in the northern part of the county. These soils have developed from sediments that washed mostly from soils developed over shales. The Staser soils predominate.

The Staser soils are deep and well drained. They have brown A horizons and grayish brown or dark yellowish brown B horizons. The texture of the A and B horizons is silt loam in most places but is loam and fine sandy loam in other places. The natural fertility of these soils is high, and the organic matter content is medium. The reaction ranges from medium acid to mildly alkaline. Staser soils are easy to work and are productive. They are subject to flooding.

The Hamblen soils are moderately well drained. They have brown silt loam A horizons and yellowish brown and brown silt loam B horizons. The seasonal water table rises almost to the surface during late winter and early spring. There are water-related (gray) mottles within 20 inches of the soil surface. Hamblen soils are high in fertility and medium in organic matter content. The reaction ranges from medium acid through neutral and the base saturation is 60 percent or more. The silt and sand fraction of the control section is dominantly quartz. The amount of weatherable minerals, chiefly feldspars, is less than 10 percent and most commonly is less than 3 percent. The Hamblen soils are easy to work and are productive. The choice of crops that can be grown can be widened by artificial drainage. These soils are susceptible to flooding.

BLAND - CAMP SOIL ASSOCIATION

This association is in a strongly dissected belt in the southeastern part of the county. It is hilly to steep and is underlain by reddish (dusky red) colored shaly limestone and shale.

The Bland soils retain the color of the parent rock. The A horizon is weak red or dusky red silt loam except where erosion has been active. There the surface is silty clay loam. The B horizon is dusky red very firm silty clay or clay. Depth to rock is variable but averages about 2½ feet. Outcrops are common and many areas are severely eroded. The natural fertility is moderate, and the organic matter content is low. The clayey subsoil restricts the percolation of water and causes rapid runoff.

Camp soils are on gentle foot slopes and along drainageways at the base of slope below Bland soils. They have developed from sediments washed primarily from the Bland soils. Typically the surface horizons are weak red to dusky red silt loam; the subsoil is dusky red silty clay loam. In some areas, the soil is lighter in color and increases in clay content with depth. Camp soils have mixed mineralogy in the control section. They are moderate in fertility and, in most places, deep to bedrock. They are well drained and productive. Being on gentle slopes, they are easy to conserve. Most of the areas are small and odd-shaped and do not make up an entire field.

SEQUOIA - LEADVALE SOIL ASSOCIATION

The Sequoia - Leadvale soil association is on undulating to rolling valley floors over shale that is interbedded in places with limestone (or dolomite). The Sequoia soils are on the uplands; the Leadvale soils are on benches and toe-slopes below Sequoia soils.

The soils of this association are described in the Sequoia - Litz - Dandridge soil association.

SEQUOIA - BLAND - LEADVALE SOIL ASSOCIATION

This association is mostly on undulating to rolling valley floors. It is underlain by interbedded shale and reddish argillaceous limestone. The association consists of an intricate pattern of dusky red soils intermingled with light colored soils on the upland; there are strips of colluvial soils along the drainageways.

Sequoia, Bland, Leadvale, and Lindside soils are in this association. The Sequoia and Leadvale soils are described in the Sequoia - Litz - Dandridge soil association. The Bland soils are described in the Bland - Camp association and the Lindside soils are described in the Cumberland-Huntington association.

MONTEVALLO SOIL ASSOCIATION

The Montevallo soil association consists mostly of rolling to hilly Montevallo soils and a few narrow colluvial strips along the drainageways. The association is underlain by shale. The upland soils are shallow to shale bedrock and are poorly suited to farm crops. Much of the association has been cropped at some time but because of the low productivity of the soils has been allowed to revert to forest.

Montevallo soils are described in the Jefferson - Montevallo soil association.

TABLE 1.—GENERALIZED INTERPRETATIONS OF SOIL ASSOCIATIONS
Knox County, Tennessee

Soil association	Kind of underlying rock (association)	Properties of dominant soils in associations						Use suitability of association	Description of association
		Depth in ft to Rock	Developed in	Subsoil texture	Percolation rate min/in	Natural fertility	Flood hazard		
FULLERTON - BOLTON - CLARKSVILLE	Dolomite	5+ 15-30 10+	Residuum Residuum Residuum	Clayey Loamy Loamy and very cherty	45-75 -45 -45	Low Moderate Low	None None None	Woodland, pasture	Pale-colored upland soils on hilly and steep ridges.
STONY LAND-TALBOTT	Limestone	0-3 1½-6	Residuum Residuum	Clayey Clayey	+75 +75	Low Low	None None	Pasture, woodland	Rolling upland soils with many rock outcrops.
MUSKINGUM-LEHEW	Sandstone and shale	1-3 1-3	Residuum Residuum	Loamy Loamy	45-75 45-75	Low Low	None None	Woodland	Shallow soils on steep and very steep linear ridges.
JEFFERSON-MONTEVALLO	Shale	2-12 ½-2	Colluvium Residuum	Loamy Loamy and shaly	-45 +75	Low Low	None None	Pasture, hay	Pale-colored shallow and deep soils over shale.
CUMBERLAND-HUNTINGTON	Limestone and shale	3+ 10+	Alluvium Alluvium	Clayey Loamy	-45 -45	High High	None Frequent	Cropland, hay	Fertile bottomlands and associated stream terraces along major streams.
DECATUR-DEWEY-EMORY	Limestone	4+ 5+ 8+	Alluvium Residuum Colluvium	Clayey Clayey Loamy	-45 45-75 -45	High Moderate High	None None Frequent	Cropland, hay	Deep red soils on broad low hills.
SEQUOIA-LITZ-DANDRIDGE	Shale and limestone	½-3½ 1-4 1-3	Residuum Residuum Residuum	Clayey Clayey Clayey	+75 +75 +75	Low Low Moderate	None None None	Hay, pasture	Pale-colored soils on low hills underlain by interbedded shale and limestone.
DANDRIDGE-LITZ-LEADVALE	Shale	1-3 1-4 4-15	Residuum Residuum Colluvium	Clayey Clayey Loamy	+75 +75 +75	Moderate Low Low	None None Infrequent	Woodland, pasture	Shallow shale soils on hilly and steep topography.
TELLICO-NEUBERT	Calcareous sandstone and shale	2-12 3-20	Residuum Colluvium	Loamy Loamy	45-75 -45	Moderate High	None Frequent	Woodland, pasture	Deep red soils on steep ridges and knobs.
ARMUCHEE-LEADVALE	Shale and limestone	1-3 4-15	Residuum Colluvium	Clayey Loamy	+75 +75	Moderate Low	None Infrequent	Woodland, pasture	Shallow soils on hilly and steep uplands underlain by interbedded limestone and shale.
STASER-HAMBLEN	Shale and limestone	5-35 5-30	Alluvium Alluvium	Loamy Loamy	-45 45-75	High High	Frequent Frequent	Hay, pasture	Well and moderately well drained soils on bottom lands.
BLAND-CAMP	Limestone (shaly) and shale	1-3 2-20	Residuum Colluvium	Clayey Loamy	+75 -45	Moderate Moderate	None Frequent	Pasture, woodland	Dusky red soils on hilly and steep uplands
SEQUOIA-LEADVALE	Interbedded shale and limestone	½-3½ 4-15	Residuum Colluvium	Clayey Loamy	+75 +75	Low Low	None Infrequent	Pasture, hay	Pale-colored soils in undulating and rolling valleys underlain by shale and limestone.
SEQUOIA-BLAND-LEADVALE	Interbedded shale and reddish argillaceous limestone	½-3½ 1-3 4-15	Residuum Residuum Colluvium	Clayey Clayey Loamy	+75 +75 +75	Low Moderate Low	None None Infrequent	Pasture, woodland	Intermingled dusky red and pale-colored soils on rolling and hilly uplands.
MONTEVALLO	Shale	½-2	Residuum	Loamy and shaly	+75	Low	None	Woodland	Pale-colored shallow soils over shale.

+ = more than

= less than

WATER RESOURCES OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Knox County is well supplied with water. Most of the water used in the county is obtained from rivers and streams but ground-water withdrawals are significant. A 1971 water-use survey showed total average daily usage to be 49,370,000 gallons, of which 43,945,000 gallons was from surface water and 5,416,000 gallons was from wells and springs (John M. Wilson, personal communication). This survey showed that industrial water usage totalled 20,110,000 gpd, of which 13, 815,000 gpd was self-supplied, 9,955,000 gpd being obtained from surface water and 3,864,000 from ground water.

PRECIPITATION

Knox County receives an annual average precipitation of about 48 inches. The western part of the county receives about 50 inches; the eastern part about 45 inches. At the McGhee-Tyson Airport Meteorological Station, minimum recorded annual precipitation is 36.0 inches (1952), and maximum recorded is 61.5 inches (1957). Monthly rainfall has been as low as a trace (October, 1963) and as high as 11.74 inches (January, 1954). Rainfall at Knoxville is fairly evenly distributed through the year, ranging from the October average of 2.8 inches to the July average of 5.4 inches. January-March mean rainfall totals 13.3 inches, normally the wettest period of the year, and September-November rainfall totals 9.3 inches, normally the driest period of the year. Heavy storm precipitation can occur in any month. The maximum recorded 24-hour rainfall at Knoxville, 5.08 inches, occurred in September, 1944, in a normally dry month. But hydrologists anticipate flood-generating conditions in February and March as experience shows the generally near-saturated ground surface is coupled with a high possibility of 2- to 4-inch rain storms in these months.

DRAINAGE AND STREAMFLOW

Principal rivers in Knox County are the Clinch, and the French Broad and Holston which join at Knoxville to form the Tennessee. Headwaters of the French Broad are in the Blue Ridge of North Carolina, and the Holston headwaters are in the Valley and Ridge of southwestern Virginia. The French Broad enters Knox County from the east and the Holston enters the county from the northeast. From Knoxville the Tennessee River flows southwestward through the Valley and Ridge towards Chattanooga.

Headwaters of the Clinch River are in the Valley and Ridge and Cumberland Plateau of southwestern Virginia, from where the river flows generally southwestward to its confluence with the Tennessee River at Kingston. The Clinch River forms part of the northwestern boundary of Knox County.

The northwestern third of the county is drained to the Clinch River (Melton Hill Lake) by Bullrun and Beaver creeks. The remainder is drained to the Holston and French Broad rivers and, from Knoxville downstream, to the Tennessee (Fort Loudoun Lake) by many small streams.

Streamflow records of five years or more are available for the Tennessee, Holston and French Broad rivers near Knoxville, Bullrun Creek near Halls Crossroads, and First Creek at Knoxville. Mean flow of Tennessee River at Knoxville for an 81-year period of record is 12,850 cfs (cubic feet per second). Of this, Holston River (3,776 square miles) contributes about 35 percent and French Broad River (5,124 square miles) about 65 percent. Flow of Holston River above Knoxville is controlled by Cherokee Dam, 52 miles upstream, and flow of French Broad River by Douglas Dam, 32 miles upstream.

Annual runoff in Knox County averages about 19 inches; about 29 inches is returned to the atmosphere by evapotranspiration. Of the 19 inches of runoff, an estimated 7-9 inches passes through the ground-water system before being discharged to streams. Some of the characteristics of Bullrun Creek and First Creek, for the period of record at each gage, are in table 1.

TABLE 1. SURFACE WATER CHARACTERISTICS OF BULLRUN AND FIRST CREEKS

Stream	Drainage Area at Gage (sq. mi.)	Mean Annual Runoff (cfsm*)	Peak Flow (cfsm)	Minimum Flow (cfsm)	Annual Runoff (inches)
Bullrun Creek	68.5	1.33	90	0.14	18.1
First Creek	17.2	1.15	72	.06	15.7

*Cubic feet per second per square mile.

Reasons for variations in flow characteristics from stream to stream are complex, but include drainage area, topography, channel characteristics, land use, soils, and geology. These factors influence the rate at which water moves out of the basin. It is reasonable to assume that water storage capacity in First Creek basin, for instance, is greater than that of Bullrun Creek on the basis of higher dry-weather flow and lower flood runoff for First Creek, even though First Creek basin is partly urbanized (which tends to increase runoff), whereas Bullrun Creek basin is rural.

SURFACE WATER QUALITY

The mineral quality of natural water reflects the composition of soils and bedrock over and through which the water moves. In a stream the concentration of dissolved solids tends to increase as flow decreases, that is, as surface runoff contributes less to flow and ground water constitutes a larger proportion of flow. At minimum flow, stream water quality most closely approximates the quality of ground water in a basin. This is partly a function of the length of contact time with minerals of soil and rock of the basin. The following table (from data in TVA, 1972) gives an idea of the range and variation in chemical quality of surface water in Knox County. The extent of effect of man's activities on these quality parameters is unknown.

GROUND WATER

Precipitation that does not run off directly to streams or that is not returned to the atmosphere by evapotranspiration enters the ground-water system where it is stored while in transit to discharge points. Stored ground water is the means by which dry-weather streamflow is maintained. In extended drouth periods, streams draining areas of substantial ground-water storage continue to flow for many days after other streams of comparable size draining areas of little ground-water storage have ceased to flow.

In Knox County most ground water is stored in areas underlain by dolomite, least in areas underlain by shale and sandstone. The significance of dolomite in ground-water storage is reflected in an inventory of large springs in eastern Tennessee (Sun, Criner, and Poole, 1963). Of 63 springs listed as having mean discharges of 500 gpm (gallons per minute) or more, 54 flow from dolomite. Eight of these springs are located in Knox County. Five flow from the Knox Group, three from the Chickamauga Group. The largest, Boiling Spring in eastern Knox County, has a mean discharge of 4180 gpm. This spring's opening is in the Lenoir Limestone within a few hundred horizontal feet of the Lenoir-Mascot contact, and it is probable that most of the water discharged is from the Knox Group.

TABLE 2. CHEMICAL ANALYSES
(Milligrams per liter)

Stream		SiO_2	Fe	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	Dissolved Solids	Hardness as $CaCO_3$	pH
HOLSTON RIVER near Knoxville (3747 square miles; 13 samples 1946-1965)	**Median**	4.3		51	7.7	22	3.5	102	15	60	3.5	244	166	7.6
	Maximum	8	0.04	88	20	26	4.3	164	40	146	5.2	422	261	8.5
	Minimum	1.7		30	3	8	2.8	66	4.4	14	1.4	152	115	7.2
FRENCH BROAD RIVER near Knoxville (5101 square miles; 25 samples 1946-1970)	**Median**	8	.11	15	2.7	10	1.7	44	15	8	1.2	93	52	7.4
	Maximum	12	.52	21	4.3	20	2.6	58	30	32	3.2	143	62	7.9
	Minimum	3.8	.05	12	1.3	8.4	1.2	30	7	1	0	59	39	6.5
BULLRUN CREEK near Halls Crossroads (68.5 square miles; 16 samples 1961-1963)	**Median**	7		44	9			142	7.6	1	1.2	166	152	7.8
	Maximum	8		52	13			170	14	2	2.1	212	184	8.6
	Minimum	5		32	6.5			99	5.1	1	0	112	108	7.5
BEAVER CREEK near Beaver Ridge (72.8 square miles; 10 samples 1960-1961)	**Median**	6		39	8.5			118	11	3	2.8	140	136	7.8
	Maximum	8		44	11			141	22	4	5.3	177	156	8
	Minimum	6		26	5.5			76	8	1	.7	107	88	7.2
FIRST CREEK at Knoxville (17.2 square miles; 8 samples 1967-1968)	**Median**	5.7	.16	58	12	4.6	2.0	216	9.4	7	4.2	196	191	7.7
	Maximum	7.1	.24	61	20	5.5	3.7	222	22	9	4.7	215	201	8.1
	Minimum	3.2	.06	45	6.9	3.2	1.3	143	7.4	5	1.3	152	140	7.1

Most ground water storage in Knox County is in the weathered material over bedrock. The Knox Group is overlain by as much as 100 feet of partly-saturated weathered material, and areas underlain by Knox are drained by spring-fed streams that have substantially higher dry-weather flows than streams draining areas underlain by shale and sandstone.

Although weathered material is the principal ground-water storage reservoir, the permeability of the material is low. Water is transmitted principally through openings in bedrock formed along fractures and bedding planes. The number, size, depth, and extent of interconnection of water-bearing openings determines the ease with which water can be collected from storage in the overburden and transmitted to discharge in springs, streams, or wells.

AVAILABILITY OF GROUND WATER

A reconnaissance of the ground-water resources of Knox County was made in 1949-1950 (DeBuchananne and Richardson, 1956) in which about 300 wells and springs were inventoried and a few quality analyses were made. In 1970 the Tennessee Division of Water Resources field inventoried an additional 500 wells for which partial to fairly complete information is available. The data are from reports by well drillers under provisions of the 1963 Tennessee Drillers Act. In inventories such as these, however, the great majority of wells are used for domestic supply. Domestic wells are drilled to a depth sufficient to supply the few gallons per minute required, and are almost never tested for yield and drawdown.

But since the introduction of the air-rotary method of drilling several years ago, a better estimate of well yield can be made by measuring the rate at which water is blown out of the hole by compressed air than can be made by the older bailer method.

Of the wells inventoried, about 100 were reported to yield 25 gpm or more; 24 were reported to yield 100 gpm or more. The maximum reported yield was 700 gpm. Maximum yield verified by pumping was 500 gpm. Several industries in Knoxville and Knox County are partially supplied by water from wells yielding from 50 to 500 gpm, and springs supply some utility-district water in the county.

Most of the larger well yields are from the Knox Group, but some wells yielding between 50 and 100 gpm are in the Ottosee Shale, a formation evidently sufficiently calcareous to support solutionally-enlarged openings. An evaluation of the ground-water potential of each formation in Knox County is listed by Kellberg (this volume, table 2).

As in most consolidated-rock terrane, prospecting for large-yield wells is difficult because of the areal variability of conditions. Yields of randomly-drilled wells probably will not average more than 25 gpm. But it is believed that a carefully conducted test-drilling program should result in at least one well in three having a yield of 175 or more gallons per minute, if the drilling is under the direction of a hydrologist who is given sufficient latitude in site selection.

GROUND WATER QUALITY

Mineral quality of ground water varies widely from place to place, depending in part on the solubility of minerals with which the water is in contact and the length of contact time. Excessive hardness is the most common natural quality problem in Knox County. Most ground water in the county probably is in the hard range (121-180 milligrams per liter total hardness). The maximum known is 680 milligrams per liter total hardness.

Some indication of ground-water quality in Knox County is given in table 3.

TABLE 3: WATER QUALITY ANALYSES FOR KNOX COUNTY
(Milligrams per liter)

Source		pH	Fe	SO_4	Total Hardness
18 ground-water samples (Wilson and Kernodle, 1971)	**Average**	7.5	.25	3	191
	Maximum	8.0	1.50	10	680
	Minimim	7.0	.00	0	65
12 ground-water samples (DeBuchananne and Richardson, 1956)	**Average**	8.1	.11	12	126
	Maximum	8.5	.15	25	202
	Minimum	7.5	.06	2	88

A prevalent problem in unsewered urban areas in carbonate terrane is that of ground-water contamination by septic field effluent. Where soil and overburden are thin and septic fields are ineffective, unfiltered effluent may have direct access to the ground-water body. In Knox County the potential for this problem probably is greatest in valleys underlain by the Chickamauga Group where closely spaced houses are built in subdivided areas. Fortunately, most of the county now is served by public water supply.

CAVES OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Because they are entrances into the dark subterranean world, caves have long attracted the curious and the adventuresome. A few large caves and caverns which can be easily traversed, and in particular those with extensive dripstone deposits, are of commercial value, and over the years several of these have been developed as tourist attractions along the Appalachian Mountains.

At this writing Caverns of the Ridge is the only commerically developed cave in Knox County, although there are several other caves of equal natural beauty.

To the geologist, caves are more than just curious features because they reveal some of the aspects of landscape formation in regions underlain by carbonate rocks. In addition, caves and their related sinks and springs are important to an understanding of groundwater and its movement; and the recognition of areas of active subsidence and collapse is of considerable importance to those engaged in construction or waste disposal.

The caves of Knox County contain an abundant and varied animal life, as do most of the caves in the Appalachians. The most conspicuous of these, perhaps, is the brown bat which commonly leaves the cave at dusk and may be observed from outside cave entrances.

Animal Life

1. Flatworms
2. Snails
3. Annelid worms
4. Crustaceans
   a. crayfish
   b. pill bugs
   c. isopods
   d. amphipods
5. Arachnids
6. Centipedes
7. Springtails
8. Cave crickets
9. Beetles
10. Flies
11. Fishes
12. Amphibians
    a. salamanders
    b. frogs
13. Reptiles
    a. snakes
    b. turtles
14. Birds
15. Mammals
    a. bats
    b. rodents
    c. raccoons
    d. opossums

Prehistoric human habitation of Knox County caves is of considerable interest to both the archaeologist and to the commercial cave developer. Knox County caves that were probably occupied by Indians include Caverns of the Ridge, Saltpeter Bluff Cave, Paint Rock Bluff Cave, Indian Walk Cave, and Roaring Springs Cave. Of these, Caverns of the Ridge is most widely known for Indian occupation, and it is supposed to have been occupied by the Cherokees. Artifacts such as mussel shells, pottery, and projectile points have been found in the area of the old entrance to Caverns of the Ridge.

In general, Indians did not penetrate deeply into the caverns; their cultural remains, such as charcoal, bones, pottery, and arrowheads are most commonly found in the entrance rooms. There, most remains are buried under rock breakdown and alluvial or colluvial soils.

During the early economic development of the area, settlers were dependent to a large degree on locally derived raw materials. Although most had little or no industrial value, caves with an abundance of organic nitrates (bat droppings) were exploited for those chemicals which were used in the manufacture of gun powder. Nitrate mining in Knox County caves does not appear to have been extensive, however several caves were mined, probably during the Civil War. These include Saltpeter Bluff Cave and Little Saltpeter Bluff Cave in the Concord area and Saltpeter Cave in north Knox County (Moneymaker, 1930).

The purposes of this chapter are to locate the known caves and to discuss certain cavern features and their occurrences.

THE GEOLOGY OF THE CAVES

Knox County topography consists of alternating linear ridges and valleys, some narrow and some broad, but all trending generally northeast, parallel to the regional strike. The ridges are extensively dissected by small streams and it is along the eroded slopes of these hilly areas underlain by carbonate rocks that the caves of Knox County lie (plate I).

The rocks in Knox County are of sedimentary origin. In general, carbonate strata compose a little more than half of the rock units and the remainder are shales, siltstones and sandstones.

Cave development follows the more soluble zones or lines of weakness within the host rocks, and these are generally parallel to fractures such as joints and faults, or to the more permeable zones along bedding planes. Structure on both a regional and local scale appears to control to some degree the development of Knox County caves. On broad, gently plunging anticlines there seems to be an abundance of caves, surface sinks, and depressions. An example of this is in the Marbledale community (plate I) where an anticline is overlain by numerous sinking streams, sinkholes, pits, natural bridges and collapse structures.

Three formations, the Holston Formation, the Knox Group (particularly the Copper Ridge and the Mascot or Newala formations of Cattermole), and the Maryville Limestone, are responsible for much of the cavern development in Knox County. The Holston Formation is one of the more soluble of the formations in the Knoxville area as is evidenced by both the number of penetrable caves per square mile of outcrop (fig. 1) and the number of wells or springs per square mile (fig. 2). The Knox Group is second in number of caves, only to the Holston. However, the outcrop area of the Knox is almost 9 times that of the Holston, indicating either that it is in general less soluble than the Holston or that the cherty residuum generated by solution of the Knox fills most of the solution features.

Caves in the Holston Formation generally are elongate parallel to strike joints, and shorter connecting passages follow joints perpendicular to strike (dip joints). There are no caves developed along bedding in the Holston Formation, mainly because it is relatively homogeneous (i.e. no thick shale interbeds). Of the caves developed in the Holston, about 90 percent have permanent streams. Red clays persist throughout Holston caves, as do thick, sticky mud accumulations. Caves developed in the Holston have a constant high relative humidity, changing water levels, and often "breathe."

Areas where ridges are composed of Holston in stratigraphic contact with the Lenoir (the Lenoir forming a sloping flank off Holston ridges) are most susceptible to extreme cavern development. Examples are the Ten Mile Creek Cave system near Concord and the Keller Bend Cave system in the Bluegrass community (see plate I). Other examples are the Loves Creek caves (north Knoxville), Cruze Cave (south Knoxville), and the Thumping Cave system in east Knox County.

The caves developed in the formations of the Knox Group, the Copper Ridge (lower Knox), Mascot and Newala formations (upper Knox), follow both bedding planes and joints. Where caves are extensively developed in the upper part of the Knox Group (Marbledale area, plate I) they are elongate parallel to joints and are developed latterally along bedding planes. Where caves are in moderately to steeply dipping lower Knox dolostones, solution channels are parallel to both bedding planes and vertical joints.

Dolines and collapse sinks are very persistent throughout areas underlain by limestone. In some strike belts of the Holston Formation extensive underground drainage, numerous dolines, and collapse sinks have been concentrated together forming uvalas. Examples are in the Ten Mile Creek-Ebenezer area in Concord, and in the Lakeview area off Alcoa Highway (plate I).

Numerous sinking creeks called "ponors" dot ridges composed of Holston and Knox limestone and dolostone. Such sinking creeks and natural bridges formed by them are found in the Marbledale community, where caves are developed in the Knox dolostone along the crest of a large anticline (Sheephouse Caves, plate I).

CAVE CLIMATOLOGY

Knox County cavern climatology is characterized by:
- a. a constant yearly temperature
- b. a high relative humidity
- c. total darkness
- d. seasonal inflows and outflows of air
- e. fluctuating water levels.

A constant temperature of about 57° F is found in most Knox County caves throughout the year. The caves have a high relative humidity—commonly around 90-100 percent. In contrast to temperature, humidity changes with seasons, and is highest in late summer and fall. Seasonal inflows and outflows of air are related to differences of air temperature and pressure inside and outside of caves. Caves commonly blow in summer, when internal temperatures are lower than outside air temperatures, and suck in winter, when higher internal air temperatures causes air to expand and rise through vertical cracks, establishing a circulation similar to that of a chimney (Blowing Hole Cave, plate I).

Seasonal wet and dry periods in the Knox County area cause noticeable changes in the water level of many caves. Highest water levels are in late winter and in the spring; the lowest levels occur during middle to late fall. In addition, heavy rainfall generated by storms of limited extent may cause water levels to rise within hours. For example, in the Meades Quarry Cave (plate I) a heavy rain storm in June 1966 caused the water level to rise four feet in six hours. Subsequently, the water level dropped to its pre-storm level over a period of one week.

NOTE: Data on number of wells and springs from DeBuchananne and Richardson, 1956.

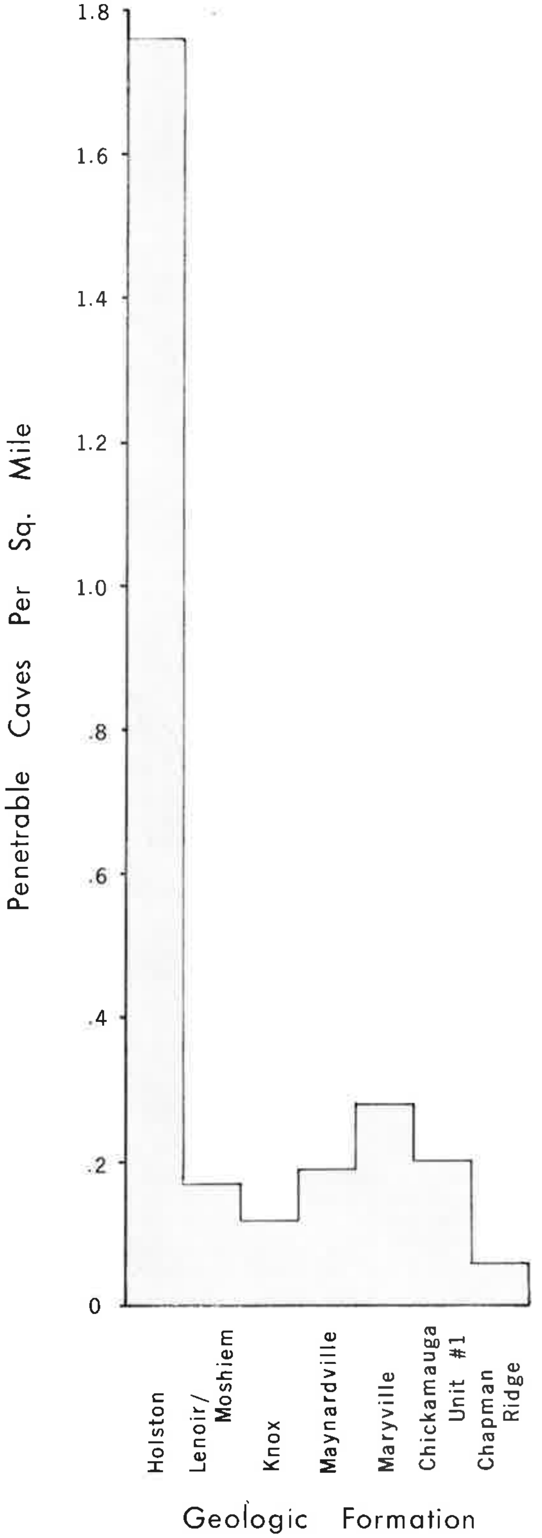


Figure 1. Number of caves per square mile for geologic formations in Knox County.

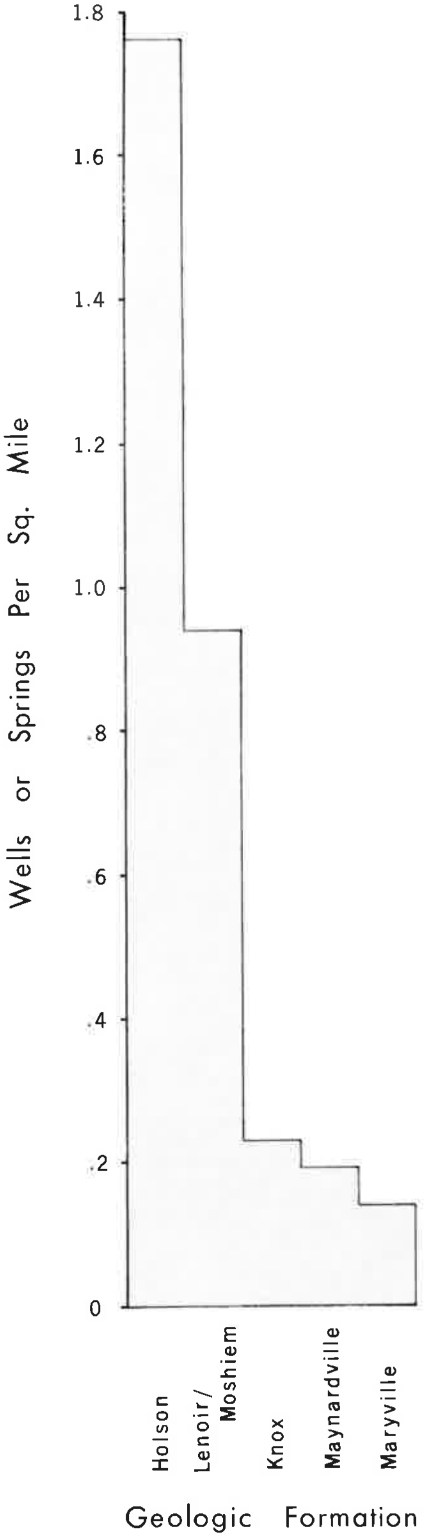


Figure 2. Number of wells or springs per square mile for geologic formations in Knox County.

TABLE 1. MAJOR UNDERGROUND CAVERN SYSTEMS IN KNOX COUNTY[1]

Name	Map No.	Description
Chandler Cave	84	Drains several small streams. Cave stream is not known to break surface again.
Paint Rock Bluff Cave	55	Large stream drains area above Paint Rock Bluff in the Sinking Springs area, and emerges at the Bluff entrance on French Broad River.
Cruze Cave	47	Drains wet weather streams (and city garbage and brush dump). Stream is believed to emerge in several ponds and creeks ½ to 1 mile south of the cave.
Bissell Cave	9	Drains local lake and several intermittent streams.
Heiskell Pit	34	Stream at bottom of pit is believed to emerge from a spring at foot of hill.
Cave Spring Caves	53	Creek drains into Tennessee River.
Meades Quarry Caves	52	Large pond to southeast of quarry appears to drain into the cave system. Main underground stream flows toward Tennessee River (no connection made).
Island Home Cave	51	Drains small area. Stream flows north in cave and siphons.
Ten Mile Creek Cave System	13	Drains large area. Ten Mile Creek sinks into cave system and emerges again in Fort Loudoun Lake.
Rockhill Cave	32	Drains rather large portion of Copper Ridge in Powell area.
Baloney Cave	24	Drains karst area. Stream issues into Fort Loudoun Lake.
Roaring Spring Cave	83	Large stream enters the cave near the ceiling of the entrance room. The stream is believed to emerge at Roaring Spring, 1200 yards SW of the cave and 200 feet lower in elevation.
Carter Cave	78	Stream begins near entrance outside the cave and flows into it.
Caverns of the Ridge	6	Stream drains small area and is believed to emerge in a creek in the nearby community.
Copper Ridge Quarry Cave	86	Stream emerges from cave and drains into a large rubbish and garbage pile before passing into nearby creek.
Scout Ranch Cave	35	The stream inside the cave may emerge at nearby spring. Drains NW side of Copper Ridge in Copeland Road area.
Loves Cave	71	Large stream flows northeastward along strike and probably emerges in a spring near Rutledge Pike and Chilhowee Drive.
Thumping Cave	75	Drains surface stream and overflow from Knoxville Utilities Board water sub-station; water level rises without notice. The stream is permanent and drains into the Holston River.

[1] Cave locations by Harry L. Moore, III; assisted by Ron Downer and Mike Ramey.

UNDERGROUND DRAINAGE

Underground drainage in carbonate rocks is effected either by groundwater percolating through clays and silts that fill connected solution cavities, or is in open channel ways within caves systems.

Sediment in caves may be either residual from the dissolution of carbonate strata or transported alluvial and colluvial material. The amount of fill determines whether a cave is penetrable, and Barr (1961) lists four factors which govern cave penetrability:

a. incomplete filling
b. drying and compaction of the fill
c. subsequent removal of fill by secondary streams
d. a combination of the above.

These factors may apply either singly or in combination to the penetrable caves found in Knox County.

In many Knox County caves subsurface hydrology can be studied directly (table 1). In some areas surface water that is fed into large solution channels which are parallel to strike discharges into nearby rivers and lakes. Two examples are the Ten Mile Creek Cave system at Concord, which has a stream emptying into Fort Loudoun Lake; and Paint Rock Bluff Cave, which has a stream emptying into the French Broad River at Marbledale community (plate I). Most of these solution channels are located along strike belts of limestone (upper Knox to Holston), and underlie high badland knobs generally exhibiting incipient karst topography.

SPELEOTHEMS

Speleothem is a term used for cave mineral deposits of a secondary nature (Moore, 1952). In Knox County an array of speleothems occurs, beautifully decorating some caves.

Most common speleothems are stalactites, stalagmites, and columns (fig. 3) which can be found in almost every cave. Flowstone (fig. 4) and rimstone dams are the next most common speleothems. Less common forms are occurrences of cave coral, helictites, and cave pearls (true oolites) which exist in Rockhill Cave, Caverns of the Ridge, and Meades Quarry Cave, respectively. Also present in Knox County caves are rare speleothems such as anthodites (fig. 5) in Secret Cave and Caverns of the Ridge; oulopholites (gypsum flowers) in Rockhill Cave and Secret Cave; mud craters in Caverns of the Ridge; and "moon-milk" and "white formations" in Meades Quarry Cave. Rockhill Cave contains a greater variety of speleothems than most of the other caves in this area (fig. 6).

Figure 3. Stalagmites, such as these growing upward from a ledge in Rockhill Cave, are common speleothems in Knox County caves.

Figure 4. Massive flowstone of various colors is found along the main joint controlled passage of Rockhill Cave.

Figure 5. Calcite encrusted anthodites from Secret Cave.

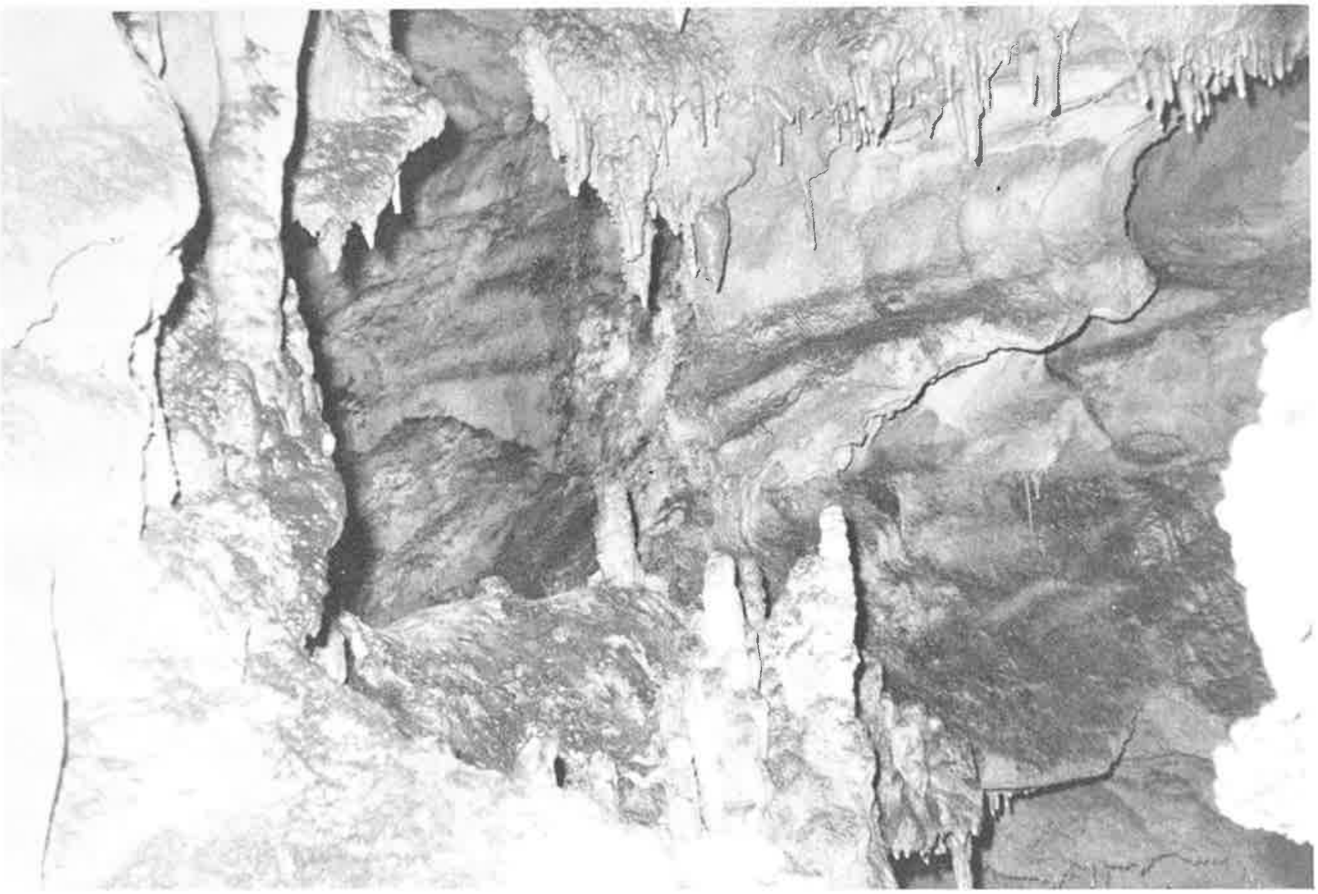


Figure 6. Small formation areas such as the one shown above in Rockhill Cave, indicate groundwater movement in open joints, small fractures, or bedding planes. Water scour marks can be seen on the back wall near the upper right corner of the photograph.

SELECTED CAVE DESCRIPTION

A number of Knox County caves have been described in the geologic literature, including the Cherokee Bluff Cavern (Brooks and Tiedemann, 1958), the Campbell, Cave Spring, Chandler, Cherokee Bluff, Roaring Springs and Ten Mile Creek caves (Barr, 1961, p. 283-287), and the Ball Camp Quarry, Baloney, Bissell, Blowing Hole, Ben Quarry, Carols, Ebenezer, Fox Bone-Three Hole, Grand Caverns (Caverns of the Ridge), Heiskell Pit, Keller Bend, Meades Quarry, Mud Flats, Rockhill, Secret, and Ten Mile Pit (Matthews, 1971, p. 53-59).

Ebenezer Cave is representative of Knox County caves because it shows typical joint-controlled passages lined with formations, and mud-filled interiors.

Ebenezer Cave is part of the Ten Mile Creek Cave system, in which five caves controlled mainly by joints are joined by a subterranean stream flowing along strike. Most of this system developed in the Holston Formation, but some of the cave may be in the Lenoir because of a fault in the area. The cave stream empties into Fort Loudoun Lake. The description is as follows:

Location: Bearden quadrangle, elevation 900 feet.

From Knoxville take 1-40 west to Walker Springs exit. Turn left (south), proceed to Kingston Pike; turn right (west) on Kingston Pike; proceed to and turn left (south) onto Ebenezer Road. Follow Ebenezer Road to the railroad tracks at the steel mill. Walk along the tracks westward through two bends. At the second bend turn left onto a path near a telephone pole. Follow this path for 50 yards to the Ebenezer Cave entrance.

Special Equipment: Change of clothes advised.

Maps: Sketch map by Steffan Ledgerwood and Jim Pope. Other maps compiled by Smoky Mountain Grotto and East Tennessee Grotto. Figure 7 is a map from Tennessee Division of Geology, Bulletin 69.

Register: None presently (several have been placed near the entrance but have been vandalized).

Geology: The cave is in the Holston Formation. The formation is massive, light-gray to light- and medium-pink, crystalline, phaneritic, medium- to coarse-grained limestone. Iron staining is common. The limestones are fossiliferous with brachiopods, crinoid stems and bryozoans, and some are preserved as a fossil hash. Residual soils are medium dark red and are up to 20 feet thick. The formation is commonly well fractured, with joints trending parallel to strike, and weathers to pinnacles of limestone in soil.

Most of Ebenezer Cave has been developed by solution along joints parallel to strike. The cave contains a large stream which descends underground where Ten Mile Creek sinks into a topographically low area (fig. 8).

The entrance to Ebenezer Cave is a small wet-weather stream sinkhole 10 to 15 inches wide and 7 feet high (fig. 9). After entering, the caver must climb over and down 25-30 feet of breakdown which leads to the first large room. The passage parallels strike of the strata and forks about 100 feet from the entrance. The right fork is very muddy and wet, but can be traversed for over 300 feet through several medium-sized rooms connected by crawlways.

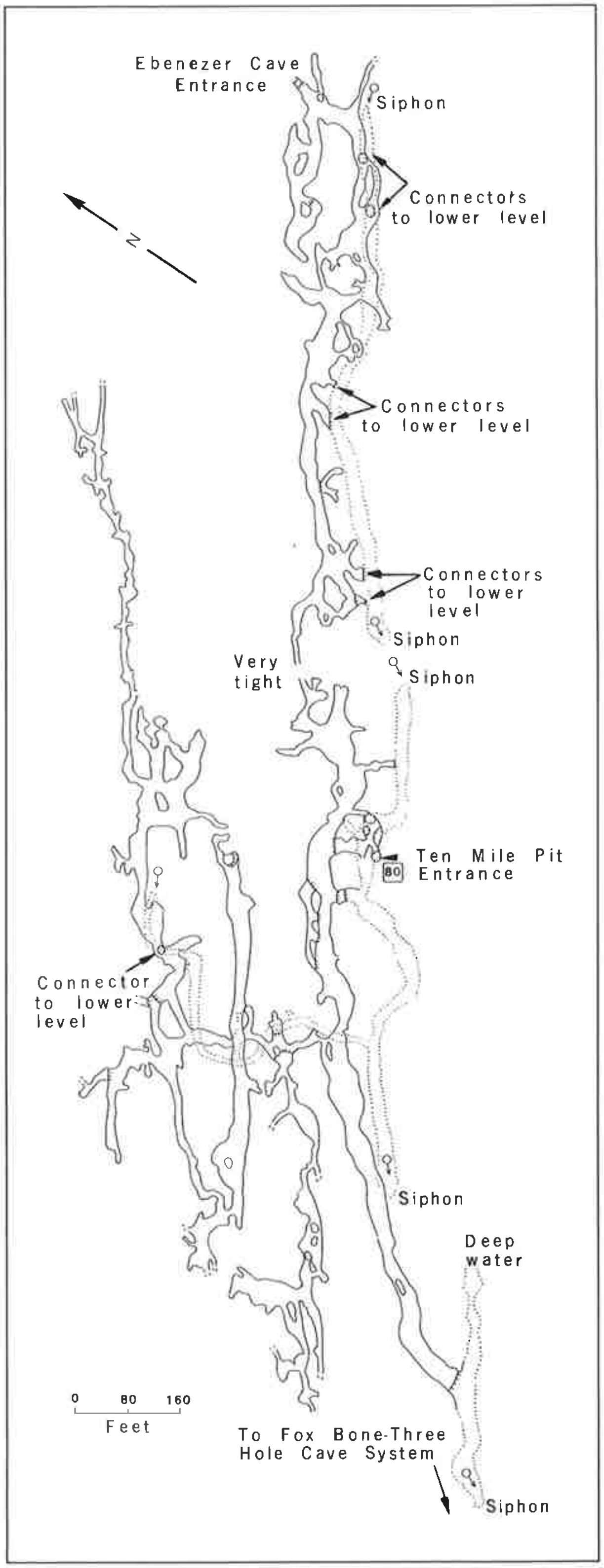


Figure 7. Ebenezer Cave and Ten Mile Pit Cave System. From: Matthews, 1972, Descriptions of Tennessee Caves.

The left fork continues to the main part of the cave which begins as a level-floored chamber about 30 feet high. At the right of the chamber (as one comes from the entrance) there is a 30-foot drop pit connecting this upper level to the underlying stream. To traverse this pit, which is almost as wide as the main passage, one must carefully walk and climb along a narrow ledge to the left of the hole. After traversing the pit, the passage becomes complex. This complex network of passages formed as the result of intense fracturing and jointing. The abundance of dripstone formations appears to have been facilitated by extensive joints which have tapped large amounts of calcium-rich water. A passage leads down to the foot of the pit at the stream's edge. A short distance from the foot of the pit the stream siphons in both directions. A second passage leads up to a third level, and a third leads straight ahead to the Formation Room—"Virgin Room." The Formation Room area consists of several interconnecting passages lined with stalactites and stalagmites all joining to form a high gallery room, itself lined with draperies, columns, rimstone pools, flowstones, stalactites, and stalagmites.

Figure 8. Ten Mile Creek enters the Ten Mile Creek Cave system through the Wagonwheel Cave entrance.

Figure 9. The entrance to Ebenezer Cave (shown in photograph) is along a vertical joint parallel to the strike of the Holston Formation.

A short passage leading to the right from the "Virgin Room" goes to a crawlway filled with small angular pieces of breakdown. This crawlway and chimney were pushed and dug out by the Smoky Mountain Grotto and led to the second entrance of the Ten Mile Creek Cave.

From the formation area the main passage leads along strike into a large gallery devoid of formations. At several points, pits of varying depths lead to the stream passage below. This large gallery, nearly 700 feet long, is devoid of formations except in a breakdown area to the upper left. The breakdown area houses some helictites along a ledge hidden from the main passages. Also in this remote area are "curtain-bacon" formations which have been vandalized. A small hole penetrating the breakdown drops 15 feet to a sand bar in the stream. This stream passage siphons a little farther down but is very large at this point.

An excellent relationship between dipping strata and strike joints can be seen in the long strike gallery toward the end of the walking passage in Ebenezer Cave (fig. 10). Large breakdown areas in this room are the result of stoping of jointed limestone by progressive solution along strike. Also notable are the numerous small pits leading from the upper level to the stream passage. These are probably along nearly vertical joint intersections which were enlarged by solution. Joint patterns are well exhibited at a point midway through the cave. Bedding and fossils can also be seen. Walking passage ends by termination of this gallery into a mud siphon which probably connects with the stream passage.

The entire cave is very muddy and damp to wet, but is a good cave for beginners. Total passages exceed 2100 feet but further penetration is doubtful because all passages end in siphons or tight crawlways.

Figure 10. **This 700-foot long joint controlled gallery in Ebenezer Cave apparently is an abandoned stream passage. At present the active stream passage is several feet below and to the left of this room. This cave is characteristic of the caves in the Holston Formation, i.e. long joint controlled passages, thick mud accumulations and active streams are common.**

THE FIELD TRIPS AT KNOXVILLE

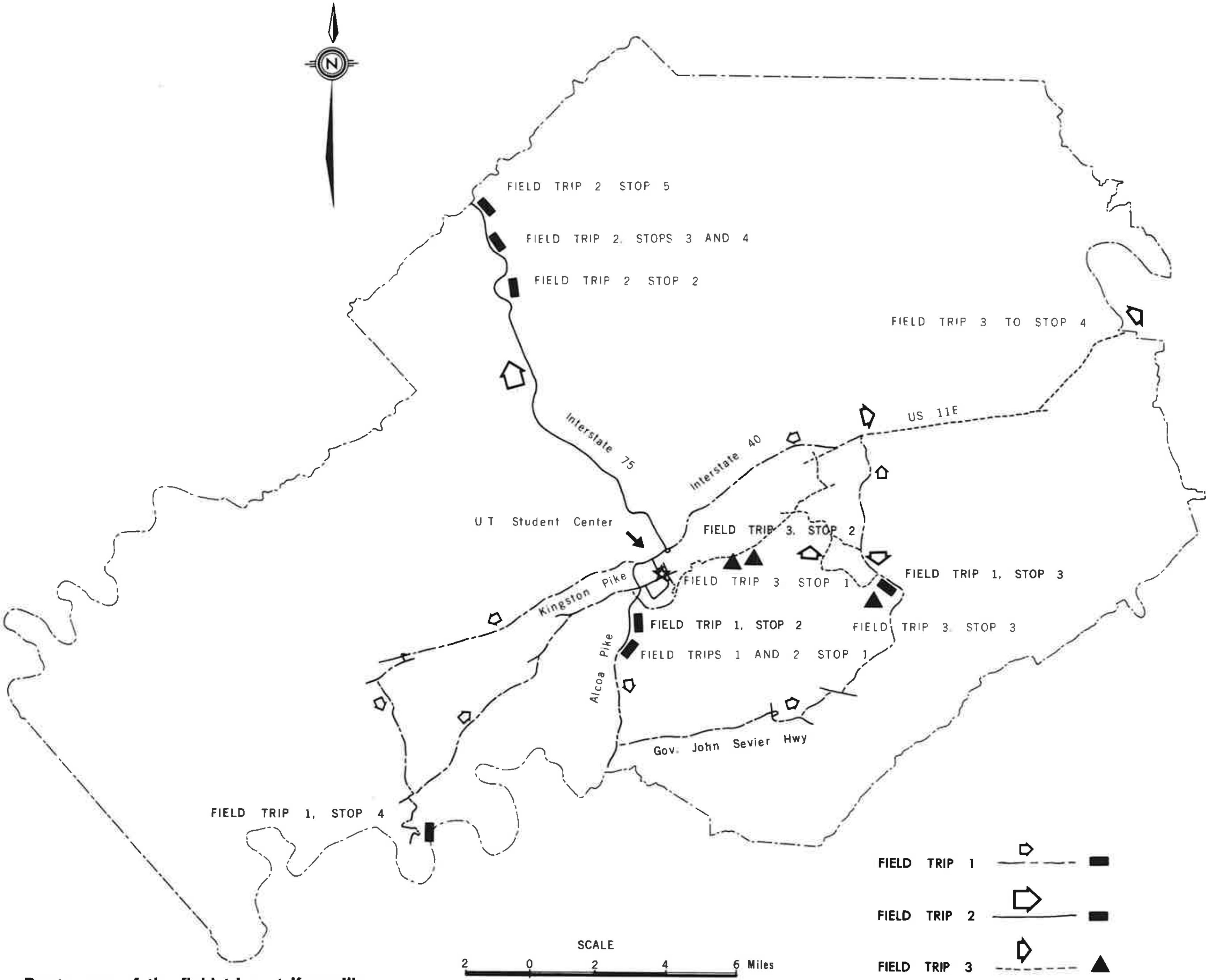
INTRODUCTION

The field trips for the 1973 Geological Society of America Southeastern Section Meeting at Knoxville are designed to show various aspects of the geology and mineral resources in Knox County and adjacent areas. Field trips 1 and 2 illustrate Valley and Ridge stratigraphy and depositional environments in the Rome Formation, Conasauga, Knox and Chickamauga groups.

Field trip 1 is designed for those geologists primarily interested in Middle Ordovician strata, and will visit exposures in the Lenoir, Holston, Chapman Ridge and Ottosee formations. Field trips 1 and 2 have a common starting point at the Holston-Chapman Ridge exposure on Alcoa Pike south of Knoxville. From there field trip 2 proceeds north of the city to visit cuts in the Conasauga, Rome, Chickamauga and Knox along Interstate 75. The trace of the Copper Creek fault, a major Appalachian thrust, is exposed at one of the stops.

Field trip 3 is for those geologists interested mainly in the rock and mineral industries of the area. The trip will visit the mill of the Tennessee Marble Divison of Georgia Marble, General Shale Products Corporation mill, American Limestone Division's newly opened quarry in the Mosheim Limestone, abandoned marble quarries, and the New Market Zinc Mine of American Smelting and Refining Company.

Robert C. Milici
Field Trip Committee Chairman



Route map of the field trips at Knoxville.

FIELD TRIPS 1 AND 2: STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS IN THE VALLEY AND RIDGE AT KNOXVILLE

Interval	Cumulative	ROAD LOG
0.0	0.0	Board buses at Stadium Drive entrance to parking garage behind the Carolyn P. Brown Memorial University Center. Proceed south on Stadium Drive one-half block, turn right (west) on Andy Holt Drive.
0.1	0.1	Intersection, Andy Holt Drive and Volunteer Boulevard. Turn left (south) onto Volunteer Boulevard and follow the street through University of Tennessee campus.
1.2	1.3	Intersection, Volunteer Boulevard and Cumberland Avenue. Turn left (west) onto Cumberland; stay in left lane, proceed under overpass.
0.2	1.5	Turn left (south) onto US 129 and Tenn. Hwy. 73, Alcoa Pike.
0.3	1.8	James E. Karnes Bridge, Fort Loudoun Lake.
0.9	2.7	Knox-Chickamauga contact at University of Tennessee Hospital entrance.
0.1	2.8	Lenoir Formation on left (east) side of Alcoa Pike.
0.4	3.2	Holston Formation, left (east) side of Alcoa Pike. This is Stop 1. Proceed through Stop to Woodson Lane; stay in left lane.
0.4	3.6	Woodson Lane, turn left; turn around at Wye Way Lane which makes an intersection with Woodson Lane. STOP 1; disembark from buses and walk north along shoulder of Alcoa Pike along the outcrop.

STOP 1: HOLSTON FORMATION AND CHAPMAN RIDGE FORMATION - Bryozoan reefs, flanking pelmatozoan calcarenites, and terrigenous silt and sand-flats, at Chapman Ridge, Knox County, Tennessee.

BY

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GENERAL

The purpose of this stop is to illustrate the principal lithologies of the Holston Formation and some of the sedimentary features of the Chapman Ridge. The outcrop (fig. 1) is composed of a series of anastomosing, bryozoan boundstone masses of dark red to maroon fine-grained lime-mudstone which are interpreted as reef-core deposits. The masses are surrounded and separated from each other by crossbeds of white to pink pelmatozoan/bryozoan calcarenite which are interpreted as reef-flank deposits. Several separate cores are exposed in this large outcrop, and each has flank deposits which are clearly associated with it (fig. 1). Particularly notable in the entire outcrop are the irregular dips, a reflection of the variable crossbedding so prevalent here. The variable primary dips and rapid lateral facies changes preclude any meaningful bed by bed measurement of the Holston in this outcrop.

Of special interest is the small reef body at the southern end of the outcrop (see fig. 2A); this is one of the few core masses in the Holston which is of simple shape and small enough size so that all parts of the complex can be sampled in one outcrop. This small reef is generally representative of the core-flank relationships of other Holston reef masses. However, it differs in its small size, separated (nonanastomosing nature, and in the composition of its bryozoan fauna). This small reef is about 8 meters (26 feet) below the top of the Holston Formation; its core is 3 meters (10 feet) thick and 5 meters (16 feet) wide. The associated crossbedded flank deposits dip away from the core and extend to a feather-edge 20 meters (65 feet) north and 10 meters (32 feet) south of the center of the core. Thus, this small reef is asymmetrical with its steeper side facing south. Surrounding this small body are several much larger anastomosing core-flank complexes; the upper core of one of these can be seen at lower left of fig. 2A. The characteristics of the two facies are quite distinct.

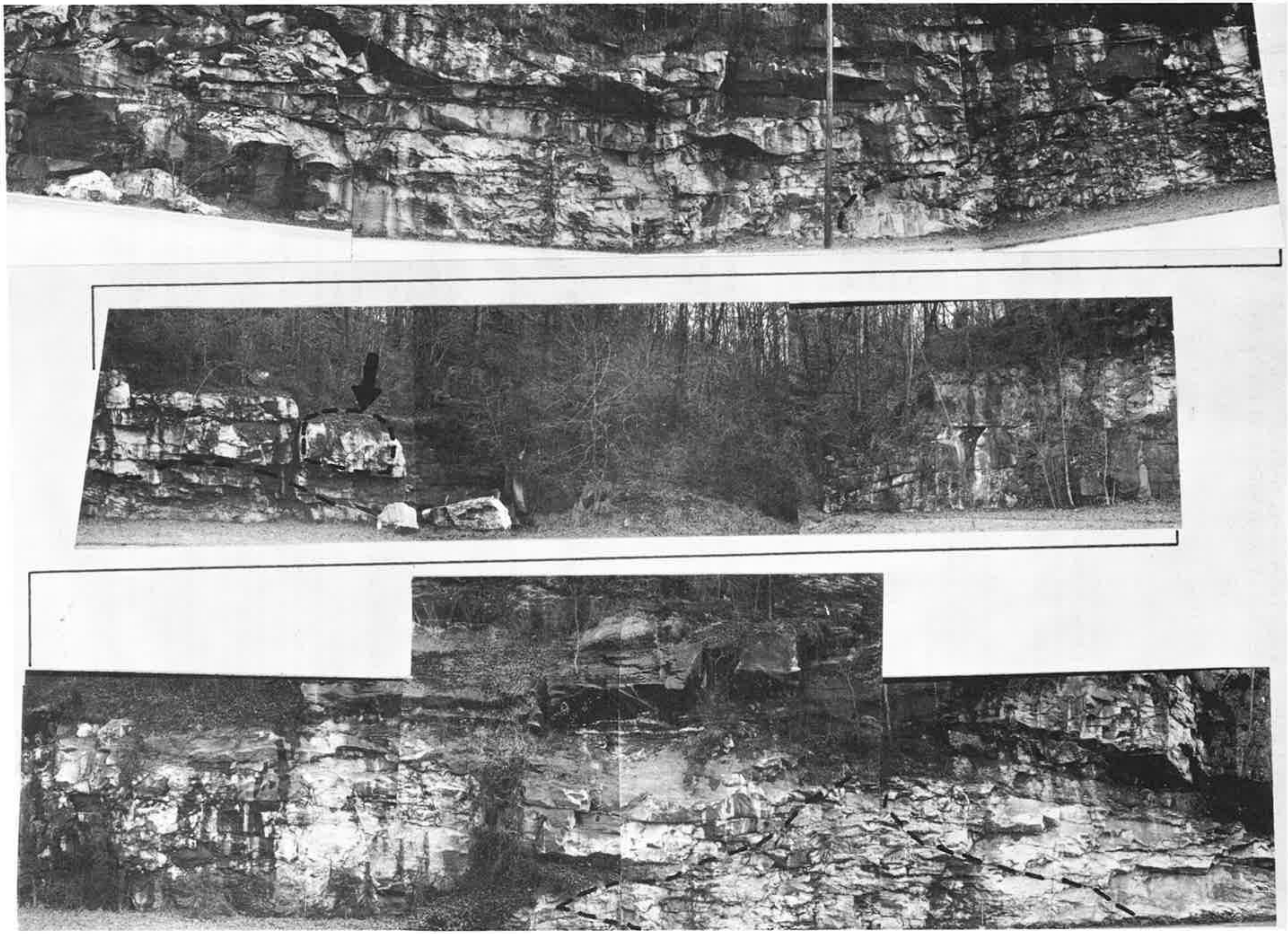

Figure 1. Panoramic view of stop 1 outcrop. North is at upper left, south at lower right. Some (but not all) of the major reef-core masses are indicated. Small reef of fig. 2A is indicated by arrow.

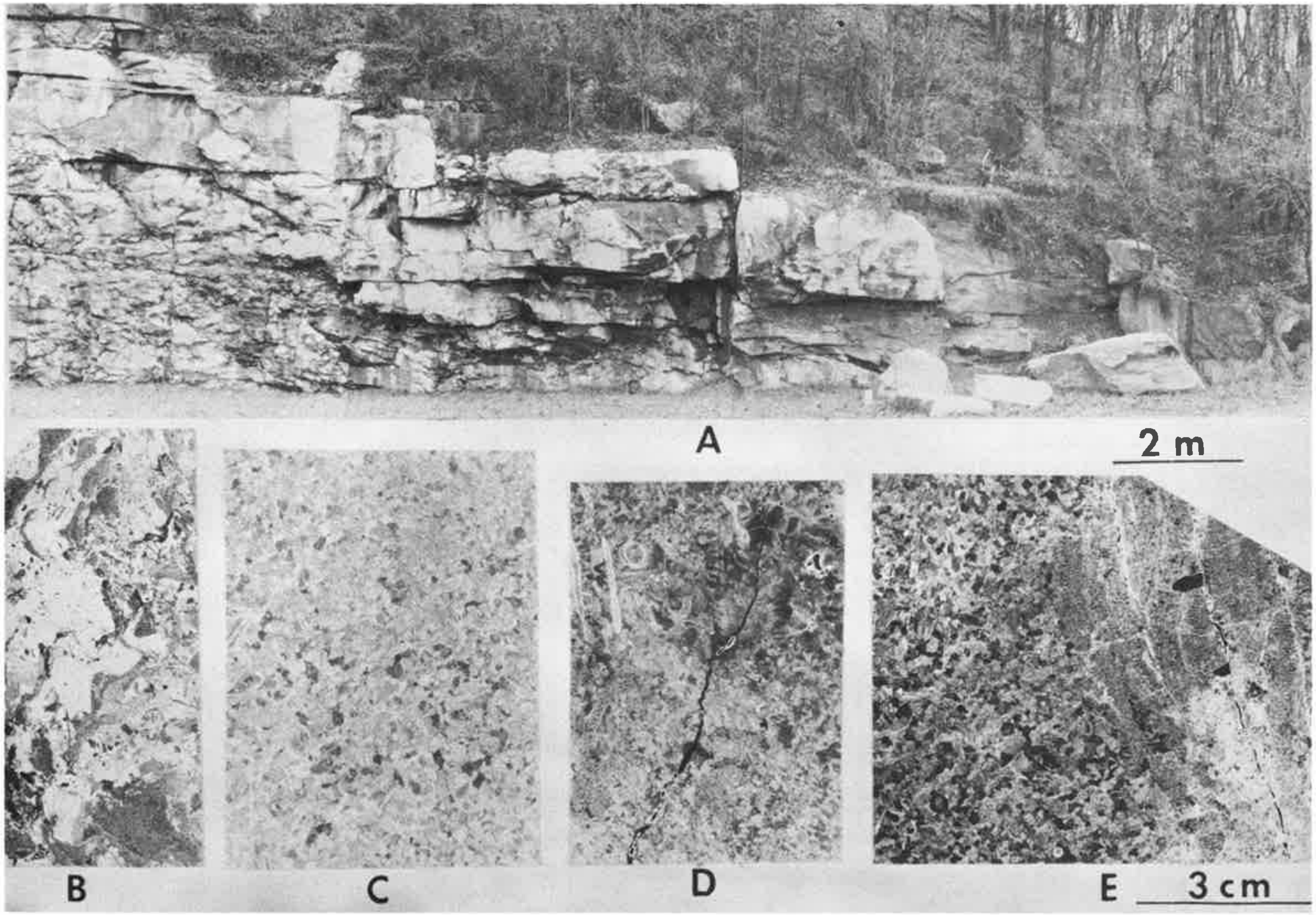

Figure 2. A: Small Alcoa Pike reef mass showing massive core and associated crossbedded flank deposits. B: Negative print of peel showing reef core lithology of Alcoa Pike reef. C: Negative print of peel showing reef flank lithology of Alcoa Pike reef. D: Stromatactis structures (upper right) from center of Alcoa Pike reef (negative print of peel). E: Negative print of peel showing contact between core (right) and flank (left) lithologies on upper wall of Deane quarry. Stratigraphic up is toward top, note orientation of bryozoa with zoecia opening toward left.

CORE FACIES

The core lithology (fig. 2B) is composed of *in situ* incrusting bryozoan colonies, fallen (but otherwise untransported) ramose bryozoans, and occasional stromatactis structures in a fine-grained, reddish mudrock matrix (fig. 3). Except for the in-place incrusting bryozoans which mark former sediment-water-interfaces, the reef core phase lacks sedimentary structures. The matrix is in most instances composed of heavily iron stained micrite (term after Folk, 1959), but some is composed of very small (5-20u) unidentifiable fossil fragments. The rock has a mud-supported fabric, in which a few larger grains "float" in the matrix. There are a few pelmatozoan fragments in the core lithology. Stromatactis structures are common only in the central parts of the core. These features are planar areas of sparry calcite each with a flat base and an irregular top. The calcite filling is composed of bladed or columnar crystals with their long dimensions oriented normal to the base of the structure. Ferrigno (1972) has used the Luminoscope to reveal bryozoan structures in many Holston stromatactis which show no organogenic features under the light microscope. At a few Holston localities, stromatactis structures are common in the core phase and there are only a few unreplaced incrusting bryozoan colonies (see Field Trip 1, Stop 4).

The most common nonmatrix components of the core lithology are bryozoan colonies. Of these, the ramose, bifoliate genus *Stictopora* is the most abundant followed closely by the ramose, subcylindrical genus *Bythopora*. The incrusting genus *Amplexopora* is generally third in abundance, although in several core collections it is the dominant faunal element. Thus, the dominance of core phase fauna by incrusting bryozoan genera which is so marked in most Holston reefs is not so well displayed by this small mass.

One of the most puzzling aspects of the Holston is the distribution of iron oxide among the various facies. The darkest red colors, and presumably the highest iron contents, are usually restricted to the core phase. We originally believed the reef cores could be distinguished at a distance by their red color. This does not hold for many cores, especially lower in the formation, but as a generality is still helpful to us in the field. The flank, on the other hand, is composed of lighter pinks and even whites suggesting a lower iron oxide content (Dale, N.T., 1924, p. 137-138).

FLANK FACIES

The flank lithology is composed of sand-size pelmatozoan debris (27 to 39 vol. percent), subsidiary fallen ramose bryozoan colonies and abraded incrusting bryozoan fragments with sparry calcite cement. Other fossils, chiefly trilobite and ostracod debris, brachiopod valves, and gastropods, compose less than 10 volume percent of the facies. Pale-gray, white, and pinkish colors are most common. This facies is characterized by low angle sets of crossbeds that dip away from the adjacent core. The crossbeds (often laminae) have various but generally shallow dips (apparent dips of 10° to 25°) and are probably not of current origin. Rather, they formed as fallen pelmatozoan debris "slid" or were transported by gentle currents down the flank slope; accordingly, we ascribe a debris-slope origin to the crossbeds. In contrast, cross-lamination in the overlying Chapman Ridge Formation,

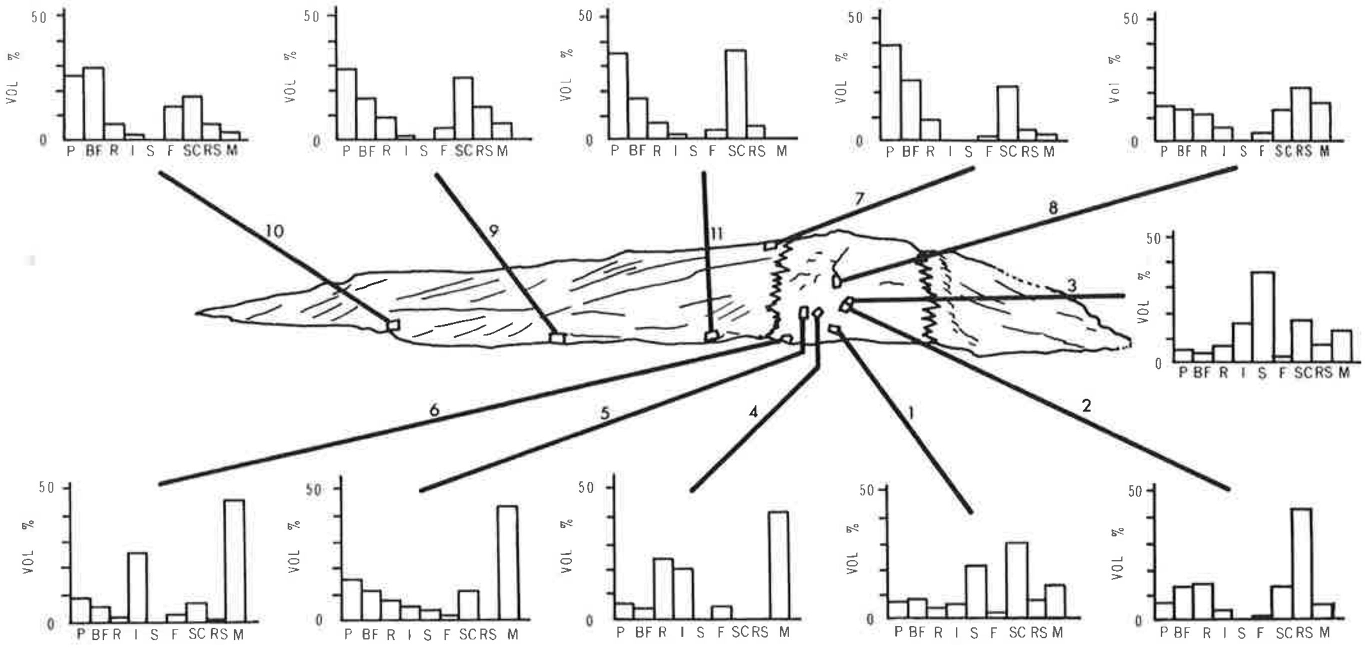

Figure 3. Sketch of small Alcoa Pike reef showing composition of two facies. Samples 1, 3-6, and 8 are core; samples 2?, 7, 9-11 are flank. Components are: P = pelmatozoan debris, BF = bryozoan fragments, R = ramose bryozoa, I = incrusting bryozoa *in situ*, S = stromatactis, F = other fossils, SC = sparry calcite mosaic cement, RS = bladed replacement sparry calcite, M = fine grained matrix.

described below, is of current origin. The flank lithology has a grain-supported fabric with interstices filled with spar which syntaxially overgrows the single-crystal pelmatozoan grains. The cementation process has thus given the rock a pseudo-crystalline texture producing the most impermeable type of commercial Holston Marble. One minor constituent of flank samples warrants special mention; these are a few, small, angular, red mud clasts containing incrusting bryozoans. These mud clasts were eroded from core lithology and their angularity indicates they were lithified when formed. This suggests early lithification of the core facies.

COMPARISON OF HOLSTON FACIES

The core and flank facies differ markedly in their gross composition. Mudstone matrix (M in fig. 3) is virtually absent in the flank, whereas it composes up to 45 volume percent of the core samples. The distribution of interstitial sparry calcite cement is the inverse of muddy matrix. Bladed sparry calcite (RS in fig. 3) is considered here to represent a product of diagenetic replacement, for it randomly cuts across the borders of all other types of grains. In contrast, spar cement (SC in fig. 3) always has an obvious interstitial position and often shows the features of drusy-growth indicating growth by void-filling (Bathurst, 1958). Spar cement syntaxially overgrows pelmatozoan plates as previously noted.

The general taxonomic composition of the two facies differs (fig. 3). The ratio pelmatozoan-debris/bryozoa is about 1/1 in flank samples, but ranges from 1/2 to 1/20 in core samples. Stromatactis structures (S in fig. 3) are abundant near the middle of the core, but absent from flank deposits. There is some evidence of compositional zonation even in this small reef mass (see fig. 3). Pelmatozoan debris (P in fig. 3) decreases in abundance from a high of 39 volume percent in the flank at the core edge to 27 volume percent at the northern feather-edge of the flank. Muddy matrix decreases in abundance upward in the core. Stromatactis is absent in the flanks and core edge but is common in the core center. Incrusting bryozoa are more abundant in the core than in the flank deposits, whereas the opposite is true of ramose bryozoan colonies.

The three-dimensional relationships of larger scale, anastomosing reef masses in the Holston are best exemplified at STOP 4, and a summary of the Holston environment is consequently postponed until the discussion of that stop.

CHAPMAN RIDGE FORMATION

To the south along Alcoa Pike, the Holston reef is overlain by the Chapman Ridge Formation (Cattermole, 1958). The Chapman Ridge shows regular external bedding compared to the Holston. There are approximately 50 meters (175 feet) of this unit at this outcrop; Cattermole has cited a thickness of 190 to 250 meters (600 to 900 feet) for the whole formation. Terrigenous material is abundant in the Chapman Ridge though rare in the Holston; indeed in the upper part of the Chapman Ridge calcareous cemented quartz sandstone is abundant. The bryozoan fauna of the Chapman Ridge is dominated by bifoliate ramose forms, most of which are rather delicate. Boundstone build-ups typical of the Holston are rare, generally very small, and isolated in the Chapman Ridge. The Vestal and Meadow Marbles of Gordon (1924) occur within the Chapman Ridge and Ottosee and represent a temporary return on a moderate scale to the Holston type of reef environment.

The most striking features of the Chapman Ridge in this outcrop are the ubiquitous very small scale sets of cross-laminae (fig. 4). Some of these are actually ripple-drift beds—ripple-marks are common on bed surfaces. In places, abundant fossils, especially bryozoans, brachiopods, and pelmatozoan debris, indicate the marine origin of these sands. Much of the pelmatozoan debris is algally bored and some is algally coated, both features suggesting shallow water deposition. In contrast to the Holston, pelmatozoan debris of the Chapman Ridge is nearly always highly abraded. A few beds of oolite and mudcracked micrites confirm a shallow-water origin for these rocks, and we infer from the sedimentary structures an intertidal or shallow subtidal sand-flat environment of deposition for these sediments, generally similar to beach, swash bar and rippled tidal flat environments described by Kraft, (1971). Some sand units in this outcrop show very gently inclined (less than 10° primary dip), long [greater than 6 meters (20 feet)] crossbeds which are internally laminated (fig. 5). These features are similar to Recent beach foreshore crossbeds. Small channel fills with basal lag deposits of shells probably represent tidal-surge channels.

The intimate relationship between this quartz sand sediment and the reefs of the uppermost Holston (especially well shown at STOP 4) proves the contemporaneity of these facies at the boundary. In fact, the terrigenous sands of the Chapman Ridge were the agents of destruction of the Holston reef tract, acting to smother the prolific growth of

Figure 4. Ripple-drift bedding in the Chapman Ridge Formation at stop 1. Pen gives scale.

incrusting bryozoans which formed the reef-core environment. As the reef was smothered in this area, the reef environment shifted northwestward as evidenced by the younger age of the Holston in the belts north of the Knoxville thrust fault.

Return to buses. Road log for Field Trip 1 continued below. Road log for Field Trip 2 continued on page 138.

FIELD TRIP 1

Interval	Cumulative	ROAD LOG
0.6	4.2	Lenoir Limestone on right (east) side of highway.
0.3	4.5	STOP 2. Intersection of University Hospital entrance road and Alcoa Pike; turn right, stop buses and disembark.

Figure 5. Low-angle crossbeds in the Chapman Ridge Formation at stop 1. Outcrop is about 10 feet high.

STOP 2: THE LENOIR FORMATION—BACK REEF SUPRATIDAL, INTERTIDAL, AND SUBTIDAL SHELF LAGOON FACIES.

BY

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INTRODUCTION

The Lenoir Formation consists of dismicrites, micrites, and biomicrites that were deposited in supratidal, intertidal, and subtidal environments of a shelf lagoon between seaward reefs, represented by the Holston Formation, and a coastline formed by the emerged part of the Knox Dolomite. Dismicrite and micrite are restricted to the basal Mosheim Member of the Lenoir. The Mosheim is mostly covered at this locality but is estimated to be about 24 meters (79 feet) thick. This member will be described and discussed at Stop 3, where a thicker and more complete section is exposed.

The remainder of the Lenoir Formation, known as the main body of the Lenoir, consists almost entirely of biomicrites, and is about 190 meters (617 feet) thick. Differences in these are subtle and so gradational that this part of the formation cannot be readily subdivided in the field. Thin section analysis coupled with field examination has shown that algae (particularly *Girvanella* as oncolites, fig. 6A), tabulate corals (Lichenaridae), sponges *Allosaccus prolixus* and lithistids) and gastropods (including *Malcurites magnus* and conispiral forms) are the most significant criteria upon which to base subdivision of the Lenoir into environmental units. The subdivision based upon these paleontologic elements is given in the measured section below. It should be emphasized that the boundaries delimiting these units are arbitrary boundaries imposed upon a unit in which all constituent particles vary gradually in percentage.

ENVIRONMENTAL INTERPRETATIONS

Unit 1 - Supratidal and Intertidal Mudflat

As mentioned above, a complete discussion of the environmental interpretation for this unit will be given at stop 3, where the Member is well exposed.

Units 2 and 3 - Shallow (0-10 meters, 0-35 feet) Subtidal Backreef Shelf Lagoon

The lower units of the main body of Lenoir contain abundant *Girvanella* (fig. 7). The occurrence of numerous oncolites of *Girvanella* (fig. 6A) is the most reliable criterion for interpretation. Ginsburg (1964) has shown that the formation of oncolites (algally coated grains) is largely restricted to the subtidal environment of Florida Bay. Logan, et al. (1964) have summarized modern occurrences of oncolites and indicated their restriction to water depths of 0-6 meters (0-20 feet). Aitken (1967) has used oncolites to infer a subtidal origin for certain carbonates of southwestern Alberta. Although oncolites can form in the low intertidal zone, their occurrence in the lower Lenoir with abundant corals, sponges, and some pleosponges supports a subtidal interpretation for these rocks.

TABLE 1
STRATIGRAPHIC SECTION OF THE LENOIR LIMESTONE
(MEASURED ALONG ALCOA PIKE, KNOX COUNTY, TENNESSEE)

Unit #	Unit Thickness m (ft)	Cumulative Thickness m (ft)	Description
9	3 (10)	212 (696)	BIOMICROSPARITE, BIOMICRITE, and BISPARITE, gray, weathered brownish-to dark-gray, similar to Unit 7 but with rare *Girvanella* and *Nuia siberica* (fig. 6B).
8	3 (10)	209 (686)	BIOSPARITE, reddish-brown, weathered gray, with abundant sand-size, rounded bryozoans (*Helopora sp.*) and rounded sand-sized pelmatozoan ossicles, and intraclasts, possibly of algal origin. Lithology closely resembles Holston Fm.
7	6 (20)	206 (676)	BIOMICROSPARITE, BIOMICRITE, and BIOSPARITE, gray, weathered to brownish- to dark-gray, massive. Microscopically, contains abundant ramose bryozoan fragments, *Nuia siberica*, and *Girvanella* oncolites; abraded intraclasts and pelmatozoan ossicles, thin wavy, brown laminae, possibly of algal origin, and pellets (5%).
6	52 (171)	200 (656)	COVERED INTERVAL
5	18 (57)	148 (486)	BIOMICRITE, gray to reddish-gray, thick-bedded to massive, with prominent brown to reddish-brown laminations. Megafauna includes an incrusting tabulate coral (Lichenaridae) usually not over 3 cm. in diameter; orthoconic cephalopods, up to 1 m. long, abundant brachiopod and pelmatozoan debris, sponge (?) molds, possibly of *Allosaccus prolixus,* and a stromatoporoid (*Stromatocerium sp* ?), up to 10 cm. in diameter. Microscopically, contains *Girvanella sp.*, and some zones of abundant dasycladacean algae (*Vermiporella* ?) (fig. 6C). Total algae exceeds 10% in some samples. Abundant gastropod fragments are associated with the dasycladacean algae. Algally bored pelmatozoan fragments common (fig. 6D). A few specimens of *Solenopora spongiodes.*
4	70 (231)	130 (428)	BIOMICRITE (fig. 6E), associated with pelletal biomicrite and biomicrosparite, gray, weathers to lighter gray or yellowish brown; thin-bedded to massive, with with brown to yellowish-brown laminations. Megafauna includes brachiopods. (*Camerella sp.*), some lithistid sponges, rare cystoid calyx ossicles. No corals have been observed in this interval. With exception of a thin zone about 31 meters (100 ft) above the base of interval, *Girvanella* and *Nuia siberica* comprise less than 5% of the rock. Where *Girvanella* does occur it occurs as lumps or aggregates of lumps rather than as oncolites. Pelmatozoan debris varies from about 2 to 16% of the rock.
3	12 (39)	60 (197)	BIOMICRITE, light- to dark-gray, thin-bedded to massive, with brown to yellowish-brown laminations. Megafauna includes brachiopods. (*Camerella sp.*), some archeocyathid (ajacicyathid) (?) pleosponge.* Sponges, pelmatozoans ossicles, *Maclurites magnus,* ramose bryozoans, and *Girvanella* oncolites are abundant, although somewhat less abundant than in the unit below. Moehl (1966) has reported the brachiopods *Titanambonites sp.*, *Lingulella sp.*, and *Valcourea sp.* from this interval.
2	24 (79)	48 (158)	BIOMICRITE, light- to medium-gray thin-bedded to massive; with irregular brown to yellowish-brown laminations. Megafauna includes the tabulate coral *Lichenaria sp*, commonly incrusted with the bryozoan *Acanthoceramorporella sp.;* sponges, *Allosaccus prolixus*, and rare *Receptaculites sp.;* trilobites, particularly *Pliomerops canadensis;* gastropods, *Maclurites magnus*; incrusting and ramose bryozoans, and pelmatozoan ossicles. Microscopically, up to 15% of the rock is composed of algae, (*Girvanella* and *Nuia siberica*). Oncolites of *Girvanella*, up to 1 cm. diameter are visible on weathered surfaces (fig. 6A).
1	24 (79)	24 (79)	DISMICRITE AND MICRITE, light- to medium-gray, very compact, thick-bedded to massive, sparingly fossiliferous with concentrations of conispiral gastropods. Poorly exposed here. This is the Mosheim Member of the Lenoir Formation.

*Perhaps the most interresting faunal element of the Lenoir is a heretofore undescribed form closely resembling an ajacicyathid pleosponge (Figs. 6F and 6G). Although the published ranges of archeocyathid pleosponges is Lower and Middle Cambrian, the organism in question exhibits a porous inner wall surrounding a central cavity, a micrite filled intervallum, rod-like parieties, and an outer wall. These features as well as size of the organism suggest the classification of this fossil with the *Archeocyatha.* The organism is tentatively rejected as a dasychladacean algae, which it superficially resembles, because of absence of primary branches in cross-section and any structures resembling "cortical cells."

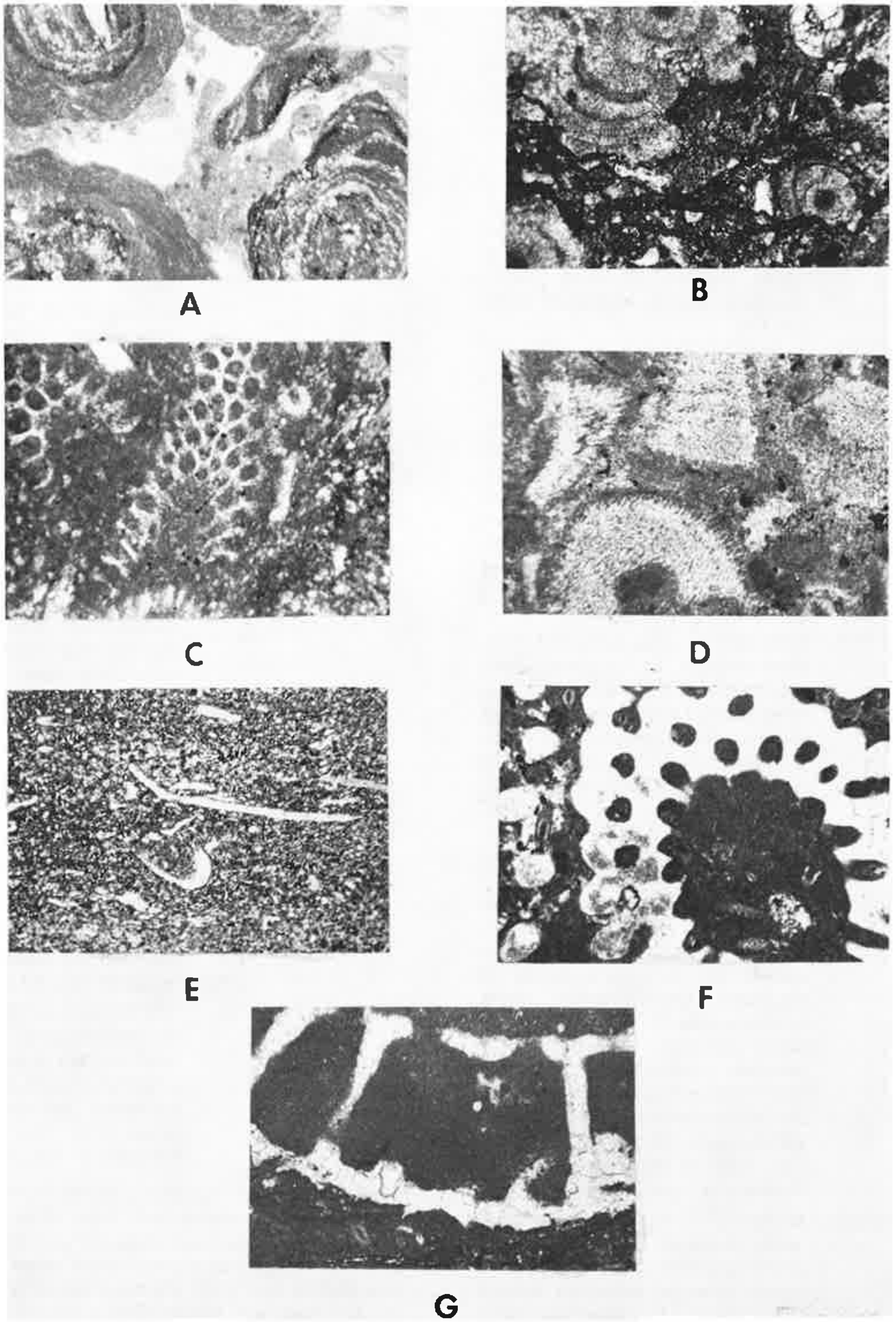

Figure 6. A: *Girvanella* oncolites surrounded by sparry calcite from the lower, "cobbly" Lenoir (X23).
B: *Nuia siberica* grains from the "cobbly" Lenoir (X58).
C: Dasycladacean alga (*Vermiporella sp?*) from the "cobbly" Lenoir (X58).
D: Algally bored pelmatozoan grains which are characteristic of the Lenoir Formation (X58).
E: Biomicrite of unit 4 of the Lenoir Formation on Alcoa Pike (X15).
F: Oblique section of pleosponge (?) present in unit 3 of the Lenoir on Alcoa Pike (X15).
G: Transverse section of pleosponge (?) in the Lenoir Formation (X15).

Wilson (1969) has commented that "boundinage" structures which characterize nodular limestones such as the Lenoir are the result of differential compaction of clay and lime mudstones in water quiet enough to allow accumulation of fine-grained sediment. Such differential compaction mitigates against the early lithification that is so common in mudflat carbonates and thus suggests a subtidal environment.

Other evidence supports the inference of very shallow-water deposition for these rocks. The high percentage of micrite in the Lenoir (50-80%) suggests that even the slightest current activity would make the water turbid. By restricting penetration of sunlight, such turbidity would make efficient photosynthesis difficult below a depth of 10 meters. Abundance of algae of various types suggests that the sediment-water interface was above this depth. The presence of a large suspension feeding population (corals, sponges, and bryozoans) indicates sufficient current activity to provide adequate circulation of nutrients for these organisms.

Unit 4 - Deeper (10-20m., 35-70 feet) Subtidal Backreef Shelf Lagoon

This unit generally contains less *Girvanella* (fig. 7) than the unit described above. Where present, *Girvanella* nearly always occurs as lumps or aggregates of lumps rather than concentrically laminated oncolites. Sponges are rare in this interval and no corals or *in situ* bryozoan colonies have been observed. *Nuia siberica* (fig. 6B), pelmatozoan ossicles (fig. 6D), trilobite debris and other transported faunal elements occur in about the same percentage as in the unit below. The most abundant indigenous organisms of this unit are brachiopods. Shaly laminations are usually thicker and more continuous and the "boundinage" appearance discussed above is more prominent on weathered surfaces. The decrease in percentage of *Girvanella* as oncolites, and absence of an indigenous shallow subtidal fauna (e.g. sponges, bryozoans, and corals) may indicate that this unit represents a deeper subtidal deposit (10-20 meters, 35-70 feet, water depth). That this unit represents water depth not far below that which could support abundant algae growth is evidenced by the occurrence within the unit of some zones that contain abundant *Girvanella.* The absence of suspension feeders and presence of thicker argillaceous laminations suggests quieter water conditions. Absence of oncolites suggests that the agitation required for formation of these coated grains (Logan, *et al,* 1964) was not present in the environment, again indicating quiet-water conditions.

Units 5 and 7 - Shallow (0-10 meters, 0-30 feet) Subtidal Backreef Shelf Lagoon

Unit 5 is distinguished by a return of *Girvanella* oncolites, sponges (*Allosaccus prolixus*), stromatoporoids, and tabulate corals (Lichenaridae). The rocks of this unit are very similar to those of units 2 and 3, in that constituent particle and faunal composition is nearly the same (fig. 8). The interpretation of this unit as a shallow subtidal deposit is based on the same reasoning that was presented in the discussion of units 2 and 3. The occurrence in this unit of orthoconic cephalopods may reflect the proximity of this environment to the seaward Holston reef environment, which would have provided these predators with an abundant supply of food. Unit 7 is considered to represent the same environment as unit 5. Exposures of unit 7 are poor but thin section study shows that its constituent particle composition is nearly the same as Unit 5 (fig. 8).

Dasycladacean algae are common in thin sections from units 5 and 7. Samples with abundant dasycladacean algae also show abundant gastropod debris. Perhaps the snails fed on the algae leading to this biotic association. The abundance of algae probably reflects a return to a shallow-water, well-sunlit environment.

Unit 8

This unit is composed of intraclastic biosparite consisting largely of pelmatozoan grains (47%), and *Helopora sp.* fragments (19%). Intraclasts are well rounded and consist of micrite. All constituent particles are well rounded, and about the same size (½ mm in diameter). Compositionally the unit is very similar to the calcarenites of the Holston Formation and is interpreted as a shallow-subtidal (0-10 meters water depth), near-reef sand. The rounding of all grains, their sorting, and absence of fine material suggest higher current velocity for this environment than any other one represented by the Lenoir. Unit 8 has a maximum thickness of 3 meters (10 feet) and represents a tongue of Holston lithology intercalated with Lenoir rocks. This relationship thus shows the contemporaneity of Holston and Lenoir environments.

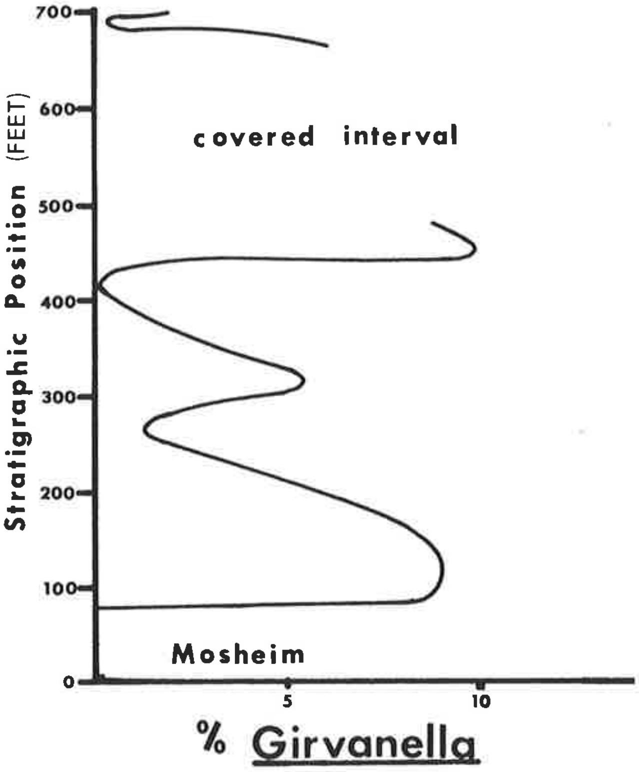

Figure 7. **Variation in the abundance of *Girvanella* (alga) as a function of stratigraphic position in the "cobbly," upper Lenoir Formation on Alcoa Pike.**

Unit 9

This unit, which is poorly exposed, contains a mixture of Holston faunal elements (bryozoans, pelmatozoan grains) and Lenoir faunal elements (*Nuia siberica*, rare *Girvanella*, and dasycladacean algae). The biomicrite of unit 9 probably represents a transition from Lenoir backreef environments to Holston reef environments. Patches of biosparite in this lithology suggest clearer water and more agitated conditions expected in a near-reef lagoonal environment.

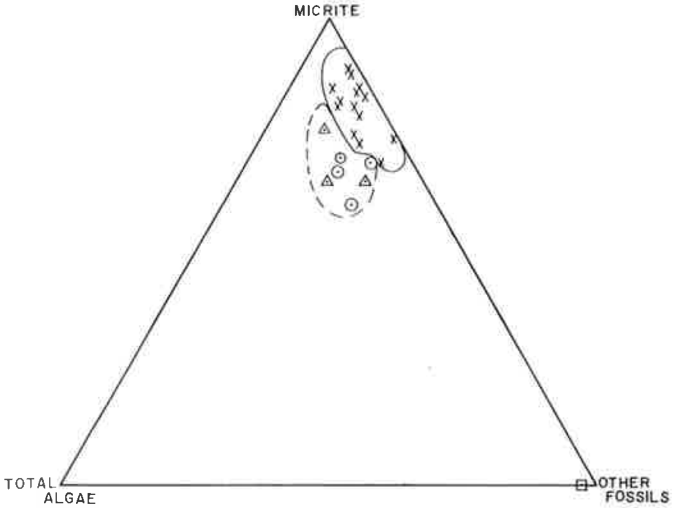

Figure 8. Composition of thin-sections from the "cobbly" Lenoir on Alcoa Pike. Open circles = samples from lower, "cobbly" Lenoir; X = samples from middle, "cobbly" Lenoir; triangles = samples from upper, "cobbly" Lenoir; closed circle and square are from uppermost beds transitional to Holston Formation.

Interval	Cumulative	ROAD LOG
0.2	4.7	University Hospital parking area, buses turn around.
0.2	4.9	Re-enter Alcoa Pike, turn left (south).
1.1	6.0	Chapman Ridge Formation on right (west) side of highway.
0.5	6.5	Chapman Ridge Formation on left (east) side of highway.
1.8- 2.1	8.3- 8.6	Ottosee Shale exposed along highway; move to left lane.
0.1	8.7	Turn left (east) onto Governor John Sevier Highway.
0.3	9.0	Ottosee Shale exposed along highway. These outcrops contain abundant ramose bryozoans and some marble lenses.
1.6	10.6	Limestone beds in Ottosee are exposed on right (south) side of road.
0.3	10.9	Limestone beds in Ottosee are exposed on left (north) side of road.
0.3	11.2	Intersection, Governor John Sevier Highway and Martin Mill Pike; proceed straight on Governor John Sevier Highway.
0.8	12.0	Deeply weathered outcrop of Ottosee Shale on left (north) side of road.
0.3	12.3	Outcrops of Ottosee limestones along highway.
1.2	13.5	End Governor John Sevier Highway, turn right and proceed to stop sign at bottom of exit ramp.
0.2	13.7	Intersection, Governor John Sevier Highway access ramp and Neubert Springs Road. Turn left (south).
0.2	13.9	Intersection, Neubert Springs Road and Tipton Station Road, turn left (east).
0.8	14.7	T-intersection, Tipton Station Road and Abner Cruze Road; turn left (north) onto Abner Cruze Road.
0.4	15.1	Intersection, Abner Cruze Road and Dick Ford Lane; bear right on Abner Cruze Road.
0.7	15.8	Ottosee Shale on left.
0.2	16.0	Intersection, Abner Cruze Road and Chapman Highway; turn right (southeast) on Chapman Highway and move to left lane.
0.3	16.3	Intersection, Chapman Highway and Governor John Sevier Highway; turn left (north) onto Governor John Sevier Highway.
0.1	16.4	Ottosee Shale exposed along road.
0.6- 2.3	17.0- 18.7	Ottosee Shale exposed along road.
0.3	19.0	Holston Formation and Chapman Ridge Sandstone exposed along right side of road. The marble unit contains abundant ramose and incrusting bryozoans.
0.1	19.1	Marble unit on left side of road.
1.3	20.4	Dr. J. H. Gammon Bridge across French Broad River. Knox Dolomite is exposed in Paint Rock Bluff northeast of bridge.
0.1	20.5	STOP 3. Entrance to American Limestone Division's Forks of the River quarry. Knox Dolomite and Mosheim Member of the Lenoir Limestone are exposed in roadcut on left (north) side of road.

STOP 3: THE MOSHEIM MEMBER OF THE LENOIR FORMATION—SUPRATIDAL AND INTERTIDAL MUDFLATS

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INTRODUCTION

The Mosheim Member of the Lenoir Formation consists of intraclastic dismicrite, (fig. 9A), intrasparite (fig. 9B), and micrite (fig. 9C). At Stop 3 the Mosheim has a thickness of about 55 meters (180 feet) and probably is thicker here than elsewhere in Knox County. The Mosheim characteristically ranges greatly in thickness over short distances. For example, approximately 1.5 miles east of this stop the Mosheim is missing and beds of the main body of the Lenoir Formation directly overlie the Knox Dolomite (Cattermole, 1955). Unlike cobbly Lenoir beds, the Mosheim is sparingly fossiliferous, and its fauna is restricted to gastropods (high-spired and low-spired), ostracods, and rare trilobite fragments. There are some algal grains (*Hedstroemia sp.*) fig. 9D, and some micrite intraclasts are algally laminated. Clasts of Knox in the Mosheim near the basal contact demonstrate the disconformable relationship between the two units.

The Mosheim, like the overlying Lenoir beds, is not readily subdivided at this particular locality. Moreover, although units of similar lithology may be found at several localities, they are commonly arranged in a different stratigraphic sequence at each locality. The occurrence of sparry calcite inclusions (birdseyes), and to a lesser extent the shape of these inclusions are the most useful criteria which can be used to subdivide the Mosheim into environmental units. Although the main purpose of this stop is to see the Mosheim Member, cobbly beds of the main body of Lenoir at this stop are similar to those at Stop 2.

ENVIRONMENTAL INTERPRETATIONS

Units 1, 2, and 5 - Supratidal to Intertidal, Mudflat

Units 1, 2, and 5 consist of intraclastic and pelletal internally laminated dismicrite. Only Unit 1 contains clasts of Knox Dolomite. The micrite to spar ratio in these units is 2 or 3/1. Intraclasts, composed of micrite and pelmicrite, and pellets comprise up to 50% of the rock in some samples. Spar, usually constituting around 25% of samples, occurs almost invariably as inclusions known as birdseyes. This spar fills original voids for it exhibits drusy growth (Bathurst, 1958). Samples also contain some grains of *Hedstroemia sp.* (fig. 9D) and some intraclasts that appear to be algally coated. Staining shows that dolomite is very rare.

Two types of birdseyes occur in these units: 1) isolated bubble-like birdseyes a few millimeters to a few centimeters in diameter, and 2) isolated interlaminar, planar birdseyes, tens of microns thick and several millimeters long. Both types have been described by Shinn (1968), who observed them in Recent supratidal and intertidal sediment of Florida Bay and Persian Gulf. They do not occur in subtidal deposits of these localities.

According to Shinn, cavities in which these birdseyes developed are the result of entrapment of gas bubbles in sediment and also shrinkage cracking of sediment by desiccation. Because of the physical similarity of birdseyes in the Mosheim to those described by Shinn, a similar origin and environment is inferred.

In addition to birdseyes these units of the Mosheim are characterized by a fauna restricted to ostracods and gastropods, and by fine-grained sediments. A limited fauna and fine-grained sediment imply restricted marine conditions where variations in salinity would preclude an open marine, stenohaline fauna. These units are internally wavy laminated and individual laminae are separated by thin planar birdseyes described above. The role of algae in formation of this internal lamination is uncertain for no algal cellular structures have been identified, but the ultrathin and wavy nature of these laminae suggest the algal origin of these structures.

Modern carbonate tidal flats described by Shinn, Lloyd, and Ginsburg (1969) provide a Recent analogue for these units as well as for others of the Mosheim. Units 1, 2, and 5 demonstrate many characteristics of supratidal and intertidal carbonate mudflats.

1. High pellet and intraclast content.
2. Thin, wavy laminae (probably of algal origin).
3. Fauna limited to euryhaline taxa.
4. Birdseye structures of desiccation origin.
5. Association with burrowed nonlaminated sediment (Unit 3).

On the basis of the evidence that exists, the deposits are interpreted as intertidal or supratidal carbonates. Without additional information about the three-dimensional geometry of these deposits, we cannot determine whether these facies represent islands and banks or a large coastal mud-flat.

Unit 3 - Intertidal Pond (?)

These units consist of nearly 100% micrite, with some articulated ostracods and a few scattered dolomite rhombs. Thin sections show burrow mottling. Other sedimentary features are lacking. The unit weathers to a mottled gray and yellowish gray. The yellowish color may reflect ferroan dolomite content because stained slides show a small percentage of scattered dolomite rhombs. Environmental interpretation of these units is uncertain, but the subtidal pond environment described by Shinn, Lloyd, and Ginsburg (1969) is a reasonable Recent analogue on the basis of the limited evidence.

TABLE 2

STRATIGRAPHIC SECTION OF THE LENOIR FORMATION (MEASURED ALONG GOVERNOR JOHN SEVIER HIGHWAY).

Unit #	Unit Thickness m (ft)	Cumulative Thickness m (ft)	Description
9	11 (36)	113 (367) **LENOIR FORMATION**	BIOMICRITE, light- to medium-gray, medium-bedded to massive. Although not as fossiliferous as unit 5, megafauna includes some tabulate corals (Lichenaridae?), brachiopods, and pelmatozoan ossicles. Wavy laminations surround limestone nodules which yield a cobbly rubble upon weathering. Very similar to unit 5. Thin sections from this interval are composed of biomicrite with wavy, yellowish-brown laminations. Small percent of quartz restricted to these laminations. *Nuia siberica,* sponge spicules, trilobite fragments, and pelmatozoan ossicles are abundant in these samples. A few *Girvanella* oncolites.
8	11 (36)	102 (331)	COVERED INTERVAL
7	22 (71)	91 (294)	BIOMICRITE, light- to medium-gray, thin-bedded, with shaly laminations. Megafauna includes colonies of *Monotrypa* (up to 3 cm. in diameter), tabulate corals (Lichenaridae), trilobites (*Pliomerops canadensis*), sponges (*Allosaccus prolixus*), and at the top of the interval pleosponges (?) of the type described at stop 2. Thin sections of this interval are composed of *Nuia* biomicrite, *Girvanella* oncolite biomicrite, and pelmatozoan biomicrite. *Nuia* comprises up to 35% of some samples.
6	13 (42)	69 (223)	BIOMICRITE, with some micrite, medium-light to medium-gray, thin-bedded to massive, mostly covered at this locality. Residuum contains blocks with abundant *Girvanella* oncolites and *Maclurites magnus.* At top of unit, micrite closely resembling the Mosheim occurs as a lens. Other abundant fossils from this unit are ramose bryozoans, brachiopods and pelmatozoan debris.
5	38 (126)	56 (181) **MOSHEIM MEMBER**	DISMICRITE, medium-dark-gray, thick-bedded to massive, weathers light gray to dark gray; locally abundant conispiral gastropods. Similar to unit one, but with some thin beds of laminated intrasparite similar to unit three.
4	0.6 (2)	18 (55)	INTRASPARITE, gray, medium-bedded to massive, evenly laminated, stylolitic. Thin section study of this unit shows it to be composed of numerous sand to silt-sized angular and elongate micritic intraclasts. Some thin laminae are composed of micrite. Intraclasts are surrounded by sparry calcite, and are oriented with their long axes parallel to bedding.
3	1 (3)	17 (53)	MICRITE, gray, massive, weathers to mottled light gray and tan. Unit contains some grayish-pink internally laminated clasts, possibly of dolostone. Unit dismicritic at top.
2	15 (48)	16 (50)	DISMICRITE, very compact and stylolitic, gray, massive, usually weathers to light gray. Gastropods are very common in some zones. Both high-spired and low-spired forms are present. Thin section study of this unit shows it to contain mumerous intraclasts and microscopic interlaminar birdseyes (10-150 microns thick and several millimeters to several centimeters long). Micrite portion of this unit as well as the micrite in unit 5 shows grumose texture.
1	0.6 (2)	0.6 (2)	DISMICRITE CONGLOMERATE, gray to yellowish-gray, massive, with numerous subangular to subrounded silt- to cobble-sized clasts of Knox Dolomite.

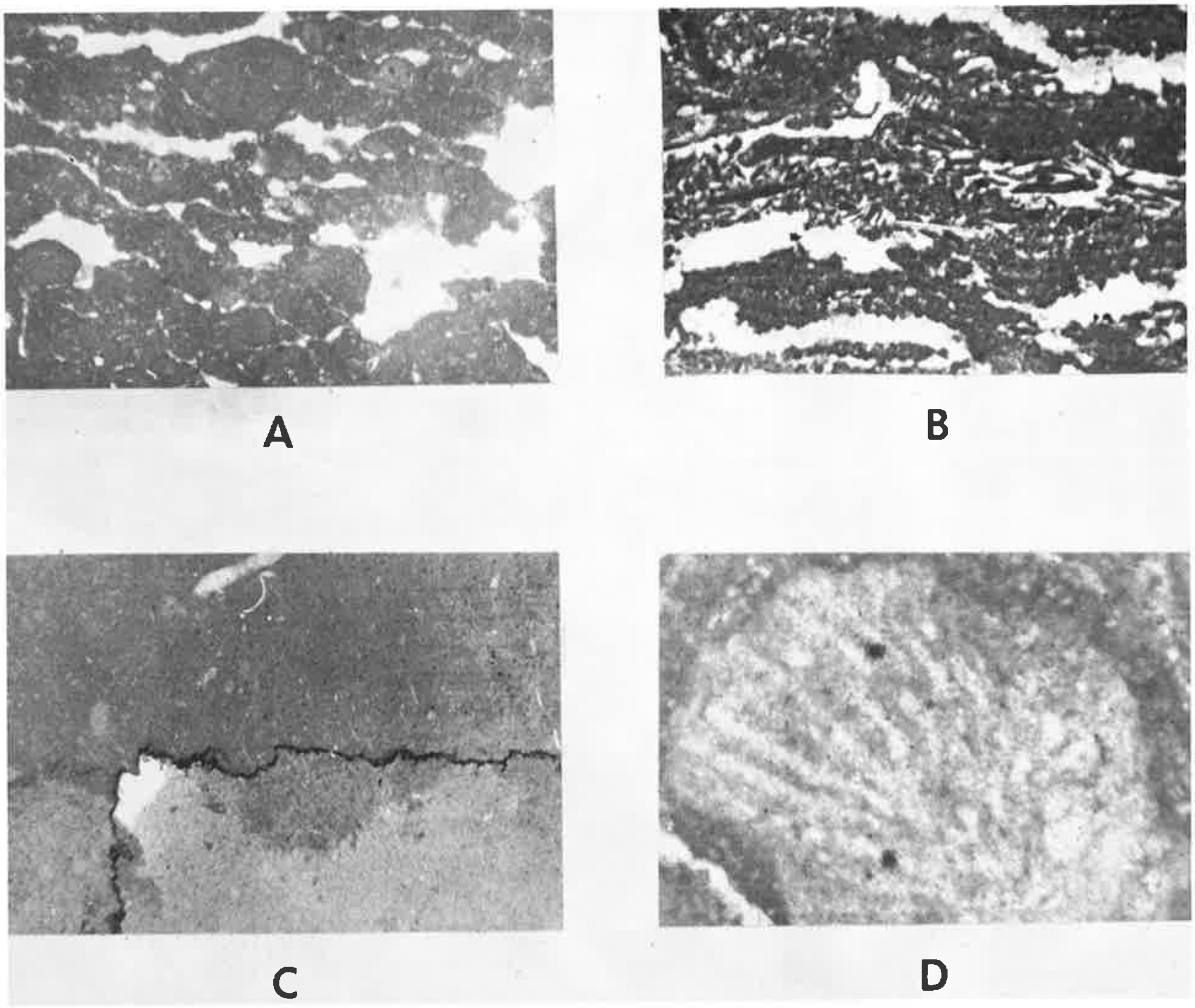

Figure 9. A: Intraclastic dismicrite with planar and bubble-like birdseyes from Mosheim along John Sevier Highway at stop 3. (X23).

B: Intrasparite from unit 4 of the Mosheim Member at stop 3 (X21).

C: Burrow-mottled micrite from unit 3 of the Mosheim Member at stop 3 (X15).

D: *Hedstroemia sp.* (codiacean alga) from Mosheim Member of Lenoir Formation.

Unit 4 - Low Intertidal, Algal Mudflat

Unit four is an intrasparite characterized by subangular to subrounded elongate or elliptical intraclasts of micrite. Laminae of micrite commonly separate thicker laminae of intrasparite. Intraclasts are oriented with their long axis almost parallel to bedding. Samples contain some spar areas which superficially resemble interlaminar birdseyes. These, however, appear to be spar fillings of original voids beneath tabular intraclasts and not voids formed by desiccation. They are, thus, not the type of birdseyes studied by Shinn (1968). Samples also show wavy laminations. This unit is a tabular deposit approximately 2 feet thick. A few thin beds of this lithology occur in unit 5 (see measured section).

An environmental interpretation can be inferred from the evidence in the rocks. Photomicrographs of recent intertidal and supratidal algal laminated sediment (Griffith, Pitcher, and Rice, 1969) are strikingly similar to photomicrographs of this unit. The clearly washed nature of this deposit and the absence of desiccation features suggest that it was deposited where current activity was greater and where the depositional surface was rarely subaerially exposed. The environment tentatively postulated for this unit is an intertidal flat low in the tidal zone. The wavy lamination is the product of sediment trapping and binding by blue-green algal mats. The birdseyes could be filling voids caused by growth expansion of these mats and may not then be of desiccation origin.

Using the evidence summarized for STOPS 2 and 3 an environmental model can be constructed for the Lenoir Formation. This model is shown in figure 10.

Interval	Cumulative	ROAD LOG
0.2	20.7	Lenoir Limestone exposed on right (south) side of road.
0.3	21.0	Intersection, Governor John Sevier Highway and Asbury Road; proceed straight on Governor John Sevier Highway.
1.7	22.7	Intersection, Governor John Sevier Highway and Strawberry Plains Pike; proceed straight on Governor John Sevier Highway.
0.7	23.4	Ottosee Shale on left (north) side of highway.
0.2	23.6	Holston Formation on left (north) side of highway.
0.2- 0.3	23.8- 23.9	Lenoir Limestone on right (south) side of highway; Holston River on left.
0.5	24.4	Lenoir Limestone and Knox Dolomite on right side of road.
0.4	24.8	Intersection, Governor John Sevier Highway and Interstate 40 (under construction).
0.6	25.4	Intersection, Governor John Sevier Highway and U.S. 11-E turn left (west) on U.S. 11-E.
0.2	25.6	J. Will Taylor Bridge over Holston River; move to right lane.
0.7	26.3	Intersection, U.S. 11-E and I-40 access ramp; turn right and enter I-40.
1.4	27.7	Holston Formation, reef core and flank facies on left (south) side of Interstate.

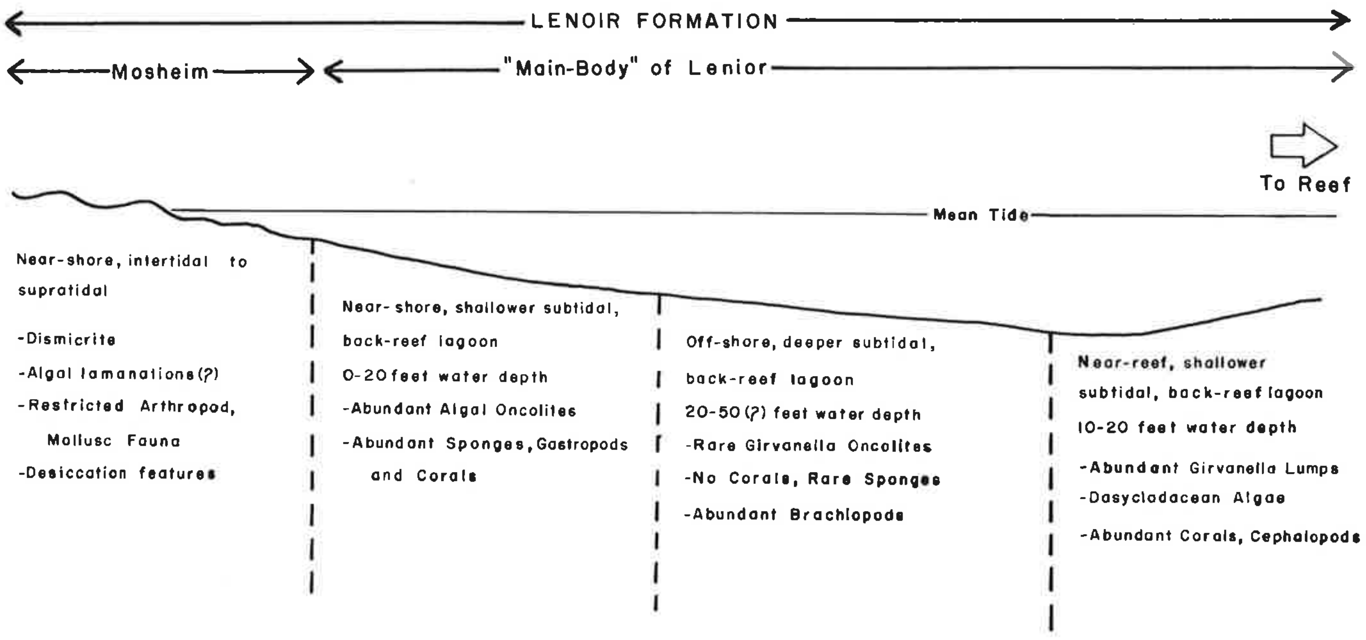

Figure 10. Environmental model for the Lenoir Formation.

Interval	Cumulative	ROAD LOG
1.1	28.8	Holston Formation, reef core and flank facies, on right (north) side of Interstate.
1.2	30.0	Holston Formation on right (north) and Ottosee on left (south) side of Interstate.
0.4	30.4	Ottosee is exposed along Interstate at Cherry Street exit.
10.5	40.9	Exit 379, Walker Springs Road; exit from Interstate.
0.2	41.1	Turn left (south) onto Walker Springs Road at top of ramp.
0.1	41.2	Intersection, Walker Springs Road and Kingston Pike; turn right (west) and move into left lane.
1.0	42.2	Intersection, Ebenezer Road and Northshore Drive; turn right (west) on Northshore Drive.
3.7	45.9	Intersection, Kingston Pike and Ebenezer Road; turn left (south) onto Ebenezer Road.
0.2	46.1	Intersection, Northshore Drive and Keller Bend Road; turn left (south) onto Keller Bend Road.
0.2	46.3	Lenoir Limestone on right side of road at lake.
0.1	46.4	Intersection, Keller Bend Road and Tedford Drive; bear right on Keller Bend Road.
0.1	46.5	Lenoir Limestone on right (west) side of road.
0.2	46.7	Lenoir Limestone on right (west) side of road.
0.2	46.9	Gravel road entrance to Deane quarry on left; Holston Formation on hill at right of road; turn left down gravel road.
0.2	47.1	STOP 4. Deane quarry.

STOP 4: HOLSTON FORMATION - An insight into the three dimensional relationships between reef-core and reef-flank facies.

BY

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GENERAL

Approximately the upper one-half to two-thirds of the Holston Formation is exposed in the inactive Deane marble quarry. The area to be studied is high in the central part of the quarry, and the participants are cautioned to move about the area with due care. Near the top of the quarry a series of horizontal platforms are separated from one another by irregular steps or low vertical walls (figs. 11 and 12), so that about 20 meters (70 feet) of fossilized reef masses are exposed in a three dimensional array. As at STOP 1, reef-core facies is associated with crossbedded calcarenite, but here the cores are interconnected, anastomosing masses. The relative proportion of core and flank deposits in the outcrop (fig. 12) is similar to the proportion of bound-masses and debris in modern reefs (Ladd, 1971). Individual cores stood as much as 3-6 meters (10-20 feet) above adjacent sea-bottom as determined by tracing individual crossbeds downward away from the cores.

Vertical depositional interfaces at the edges of reef cores are evidence that core material was lithified at the time of deposition by the binding activity of incrusting bryozoa (fig. 2E and 12B). A few angular intraclasts of core rock in adjacent flank deposits also indicate early lithification of the core. We conclude that the cores were hard structures which may have been wave resistant, and thus can be termed biohermal reefs in the terminology of Nelson, *et al.*, 1962. As in the reefs at STOP 1, the incrusting bryozoa of the cores at Deane quarry functioned both as framework-builders and as sediment-binders in the construction of these reefs.

In three dimensions, the core lithology forms a network through the mass of the Holston, with individual arms of core up to 3-6 meters (10 to 20 feet) in diameter. The spaces between core masses, which are up to 10 meters (32 feet) in diameter, are filled by complexly crossbedded pelmatozoan calcarenite.

CORE FACIES

There are two types of core lithologies at this locality; one is rare and the other abundant. On the lower wall of the exposure (fig. 11) a stromatactis-dominated core is exposed. (See discussion of stromatactis structures under STOP 1.) This core is composed of replaced incrusting bryozoa (stromatactis) near the top, but lower in the core unreplaced incrusting colonies are abundant. On either side of this core, crossbeds of pelmatozoan calcarenite dip away from the core at high angles, indicating the minimum height of this mass was about 15 feet above the adjacent sea bottom. At other localities larger cores are dominated by stromatactis, some as large as 3 meters (10 feet) high and 7 meters (24 feet) wide. These are composed of alternating stromatactis and red-mud layers. Stromatactis cores are rare and did not differ in origin from other types of Holston cores, but only in

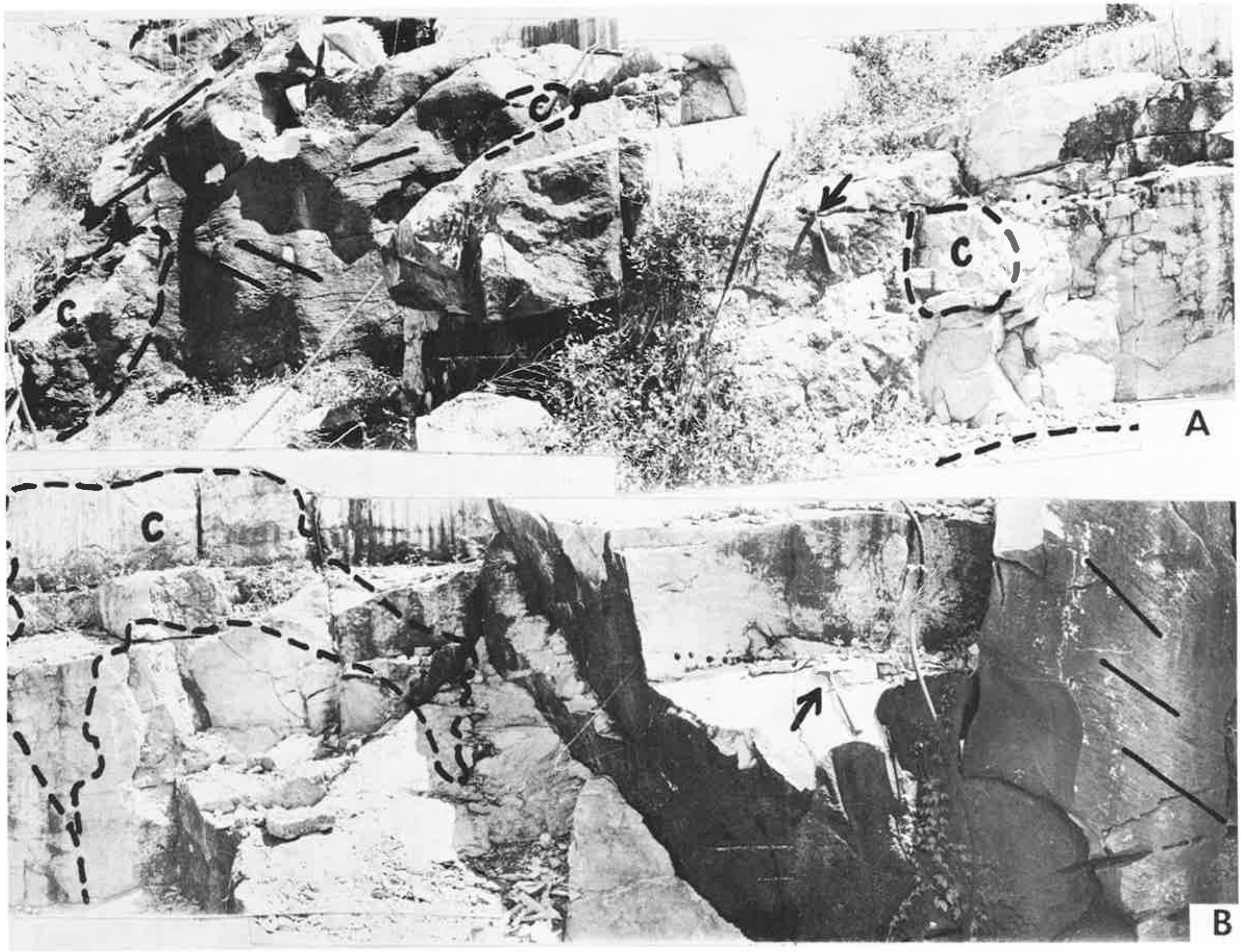

Figure 11. Photomosaic of lowermost stromatactis reef at Deane quarry (stop 4). Lower photo fits to left of upper photo. Hammers give scale. Reef core facies are surrounded by dashed line, and selected crossbed dips are indicated.

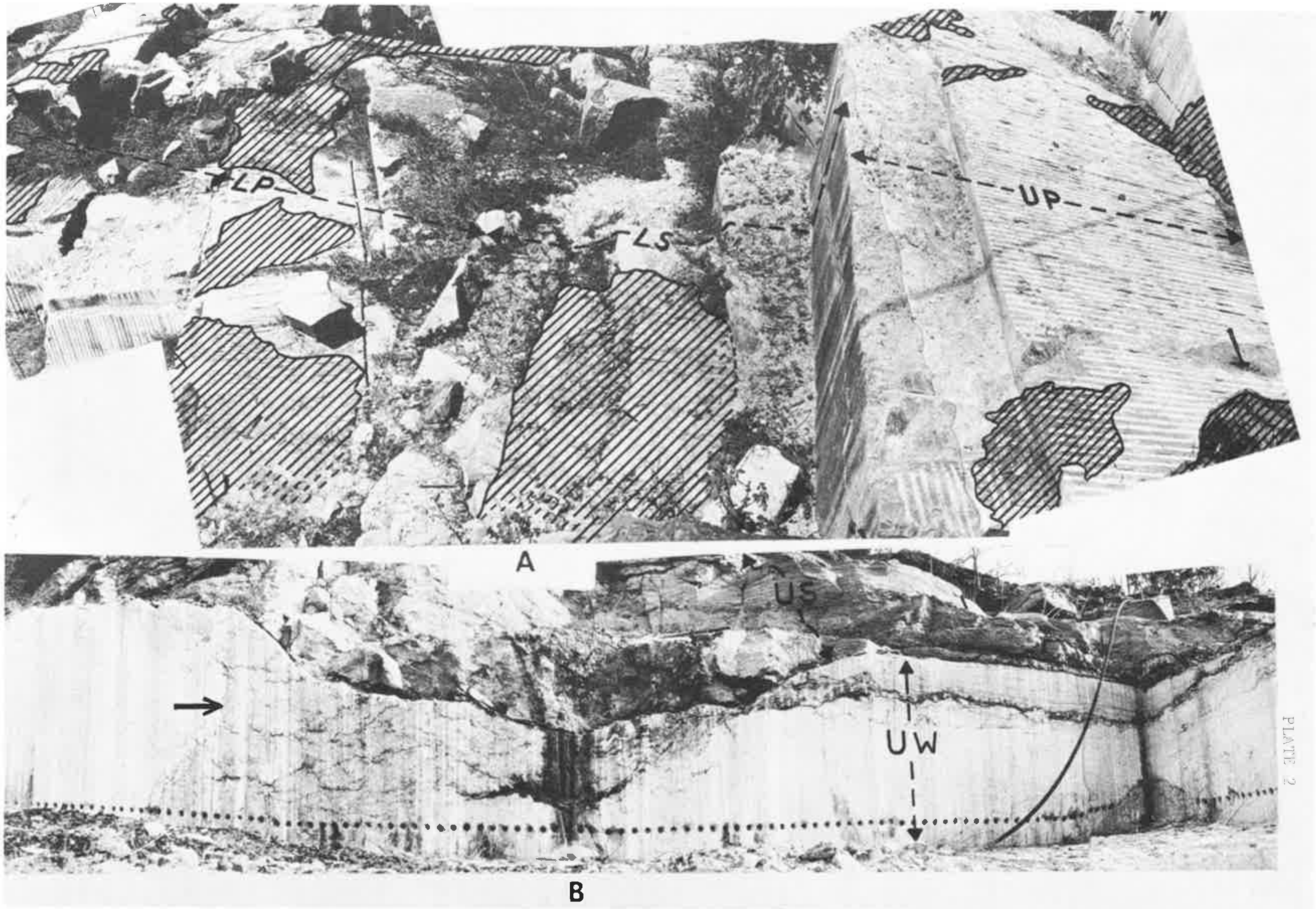

Figure 12. A: Photomosaic looking downward into Deane quarry showing lower platform, lower steps, and upper platform levels. Cross-hatched areas are core lithology, intervening areas are flank deposits. At extreme right is base of upper wall shown in B below. Hammers give scale.

B: Upper wall and upper steps of Deane quarry. Note vertical contact between core and flank facies at arrow. Along this contact incrusting bryozoan zoecia open to the left indicating verticality of the core sides in life. Height of wall on left side of photo about 5 feet.

the diagenetic processes which altered the original incrusting bryozoa to form the stromatactis structures.

The more common core type at STOP 4 (fig. 12) differs compositionally from that of the Alcoa Pike masses (fig. 13, compare fig. 3). Fine-grained matrix composes a uniformly high percentage and spar cement is uniformly low in rocks of Deane quarry cores (fig. 13). In contrast, both of these components are more variable in the Alcoa Pike core (fig. 3). The ratio pelmatozoa debris/bryozoa ranges from 1/6 to 1/20, but is usually greater than 1/8 in the Holston cores at Deane quarry (fig. 13), and is thus higher than in the cores on Alcoa Pike. At Deane quarry, incrusting forms dominate core faunas comprising 80-100% of the bryozoa, and nonbifoliate (subcylindrical) ramose forms are not abundant, although the latter types dominate the Alcoa Pike reef.

The core bryozoan fauna at Deane quarry is largely composed of incrusting forms with *Batostoma* the dominant genus and *Monotrypa* and *Mesotrypa* as co-subdominants. The fauna consists of 19 genera, 10 of which are incrusters (of the 11 most abundant, 9 are incrusters). *Stictopora,* a genus which characteristically takes a bifoliate ramose growth form, is common but often exhibits a contorted incrusting growth habit. Systematic changes in the fauna occur from level to level in Deane quarry, and we can recognize three separate bryozoan core communities, 1) a lower-level *Batostoma* - *Monotrypa* - *Mesotrypa* - *Constellaria* - *Stictopora* - *Diplotrypa* community, 2) a middle level *Batostoma* - *Bythopora* - *Monotrypa* - *Stictopora* - *Amplexopora* - *Hemiphragma* community, and 3) and upper-level *Nicholsonella* - *Mesotrypa* - *Bythopora* - *Batostoma* - *Constellaria* community. Many of these genera occur in adjacent flank deposits, but genera which occur in both facies generally take an incrusting growth form in cores and a ramose growth form in flanks.

Nicholsonella is very abundant in the uppermost levels of the quarry. This genus nearly always shows granular, replaced wall structure suggesting an original unstable (aragonitic?) mineralogy (McKinney, 1971). The marked shift in faunal composition corresponds with the transition into the overlying quartzose sandstones of the Chapman Ridge Formation. Although the Chapman Ridge is thin at the Deane quarry site, the presence of current bedding and terrigenous clastics suggests a higher sedimentation rate than for the Holston limestones. Lagaaj and Gautier (1965) showed that sedimentation rates control modern bryozoan distributions to some extent, so that the change in fauna between the Holston and Chapman Ridge may reflect in part a change in this environmental factor.

Several important features of Holston cores are well illustrated in the upper levels of the quarry. On the uppermost sawed face of the quarry, a core-flank contact is well exposed (fig. 12B); it is marked by the change from grayish red core lithology in the center of the wall to pale pink or white flank lithology on either side. To the left incrusting bryozoan colonies grew on the vertical contact with zoecial openings facing the flank, indicating that there was some relief on the core sides (fig. 2E). Near the center of this wall are several roughly horizontal solution surfaces within the core (fig. 12B) for which we have no certain explanation.

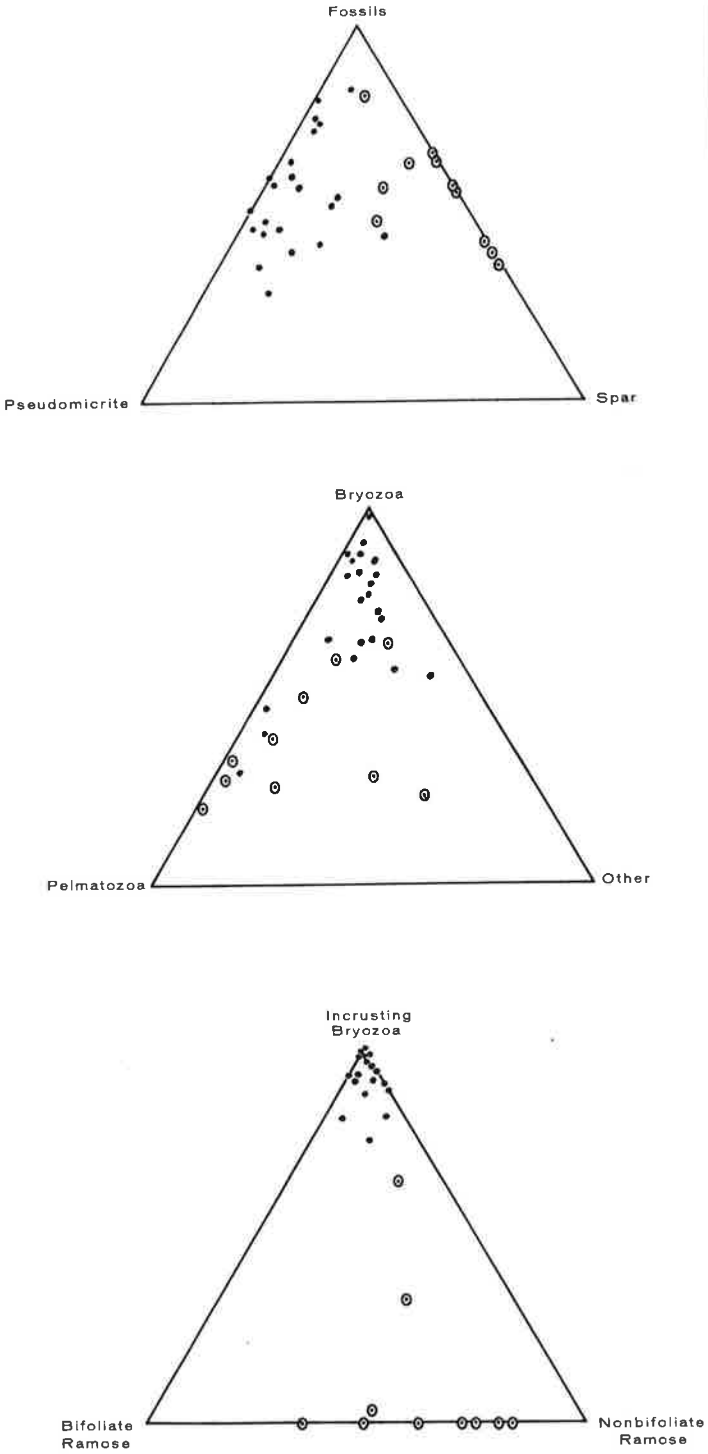

Figure 13. **Composition of samples of Holston facies in Deane quarry. Dots = core facies, open circles = flank facies.**

At the top of the quarry the tops of several cores are exposed. These are surrounded and covered by calcareous Chapman Ridge sandstones, and mark the smothering of the Holston environment at this locality. That Holston and Chapman Ridge lithologies are contemporaneous is obvious in these exposures. Indeed, in these uppermost outcrops lithologies similar to those of the Holston, Chapman Ridge, Lenoir (?), and Ottosee formations are complexly interbedded. The quarry is capped by shales of the Ottosee Formation.

FLANK FACIES

As in the core lithology, flank deposits at Deane quarry differ from those of the Alcoa Pike reef at STOP 1 (compare fig. 13 with fig. 3). Pelmatozoan debris is in higher percentages (19-78 vol. %, mean 46 vol. %), and incrusting bryozoans are virtually absent from Deane quarry flank deposits. In addition, the ratio pelmatozoan debris/bryozoa, which is about 1/1 at STOP 1, is generally greater than 3/2 in Deane quarry flank deposits. Interstitial spar cement is more abundant and mud is nearly absent in the quarry flank phase. Thus, the flank and core facies are much more clearly separated in composition at Deane quarry than in the small reef on Alcoa Pike.

The flank bryozoan fauna consists largely of ramose growth forms. *Stictopora,* a bifoliate ramose genus, dominates the fauna and *Calopora,* a nonbifoliate (subcylindrical) genus, is the main subdominant. The nonbifoliate (subcylindrical) genera *Bythopora*, *Batostoma*, *Hemiphragma*, *Helopora*, and *Eridotrypa* comprise most of the remaining fauna. The total fauna consists of 21 bryozoan genera, 17 of which have a ramose growth habit.

One of the more important features of the Holston shown at this locality is the clear predominance of flank lithology (skeletal debris) over core lithology (boundstone). The former composes 75-80 vol. % of the Holston mass. Ladd (1971) has recently emphasized the great preponderance of skeletal debris over framework-builders and sediment-binders in modern reefs. The Holston has a similar composition.

ENVIRONMENTAL SUMMARY

The exposures in Deane quarry are typical of the bulk of the Holston Formation that we have studied; thus, an interpretation of the environment for this locality would apply to the major part of the formation. A reasonable environmental inference can be made from the physical and biological evidence. At any one time, the environment was composed of domal areas populated by complex communities composed of incrusting bryozoan colonies. At times these grew upward more rapidly than sediment accumulated in intervening areas, and in places developed vertical margins incrusted by bryozoa. The bryozoan colonies acted as sediment-binders and framework-builders in the construction of the reefs which had the ecological potential of being wave resistant. Thus, these masses fit the definition of biohermal reefs (Nelson, *et al* 1962).

Adjacent to the raised boundstone masses, and perhaps on them as well, lived a dense thicket of pelmatozoa (cystoids and some crinoids). As these animals died and their external skins decayed, columnals and calyx plates were liberated and fell downslope to accumulate in crossbeds. A diverse ramose bryozoan fauna lived on these flanking slopes and contributed their colonies to the accumulation. The living cores stood as much as 5 meters (16 feet) above adjacent intercore areas and the flanks reached slopes of as much as 40 degrees (mean 28 degrees).

Of all the important ecological factors cited by Schopf (1969, p. 237) for bryozoans, only turbulence could vary appreciably over the short distance between the Holston core and flank subenvironments. Stack (1936) noted that incrusting colonial forms tend to dominate in areas of turbulent waters while ramose forms indicate quieter conditions. The distribution of growth forms in the Holston suggests that the difference in turbulence between adjacent areas of core and flank subenvironments was sufficient to restrict the growth forms almost completely to one or the other environment.

The individual core masses of the Holston are smaller than other Ordovician reefs previously described (e.g. Pitcher, 1964, 1971; Rowell and Krause, 1972), but the

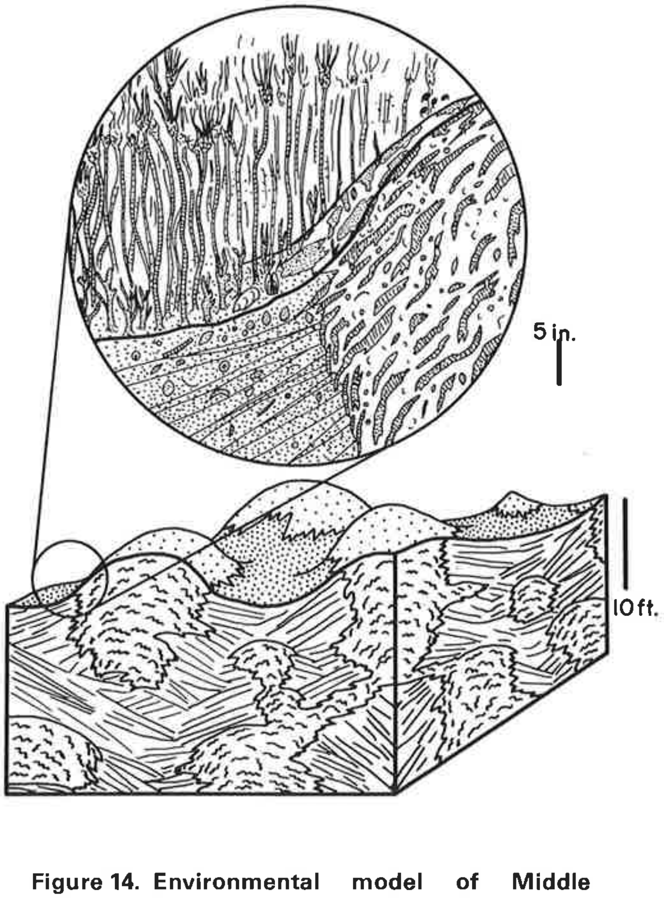

Figure 14. Environmental model of Middle Ordovician rocks of eastern Tennessee.

Holston cores are not separate and distinct bodies as are the other reefs. Instead, as they grew upward, the Holston cores formed an anastomosing network through the rock body, eventually building a great mass of related facies. In this way, the individual cores are analogous to large colonial coral-red algae masses in modern reefs, and the flanks are analogous to the skeletal debris accumulations between those more tightly bound masses. From this view-point, the individual Holston core masses are not by themselves reefs; the greater mass composed of anastomosing core and intervening debris comprises the actual reef. This environmental model is shown in the block diagram of figure 14. If this view is correct, then the Holston reef is a single genetic unit up to 100 meters (325 feet) thick and at least 40 kilometers (25 miles) long. This length is based on reconnaissance to date and certainly represents an under-estimate, for we know these facies extend northeast and southwest of our study area. In any event, such a reef mass represents the largest early Paleozoic reef tract reported to date; indeed it is comparable in size to some modern barrier or fringing reefs (e.g. Maxwell, 1968).

AGE OF THE HOLSTON

We append a short discussion of the age of the Holston Formation here because the bryozoan assemblages present yield correlations widely at variance with earlier assignments. Twenhofel *et al.* (1954) in the Ordovician correlation chart assign an Upper Chazyan age (Llandeilo Series of the British type Ordovician) to the Holston. Based largely on the brachiopod faunas of overlying and underlying units, G.A. Cooper (1956) assigned his Red Knobs Formation (= Holston + Chapman Ridge of this report) to the upper Porterfieldian Stage (= lower Caradocian Series of British type-section). Our preliminary data on bryozoan faunas suggest and even younger age for the Holston. The presence and abundance of *Amplexopora superba, A. conferta, Batostoma lanensis, Monotrypa undulatus*, and *Mesotrypa regularis* suggest correlation of the Holston with the upper Black River Group or lower Trenton Group of New York state. Such an assignment would indicate an upper Wilderness age for the Holston (= Middle Caradocian Series of the British type-section).

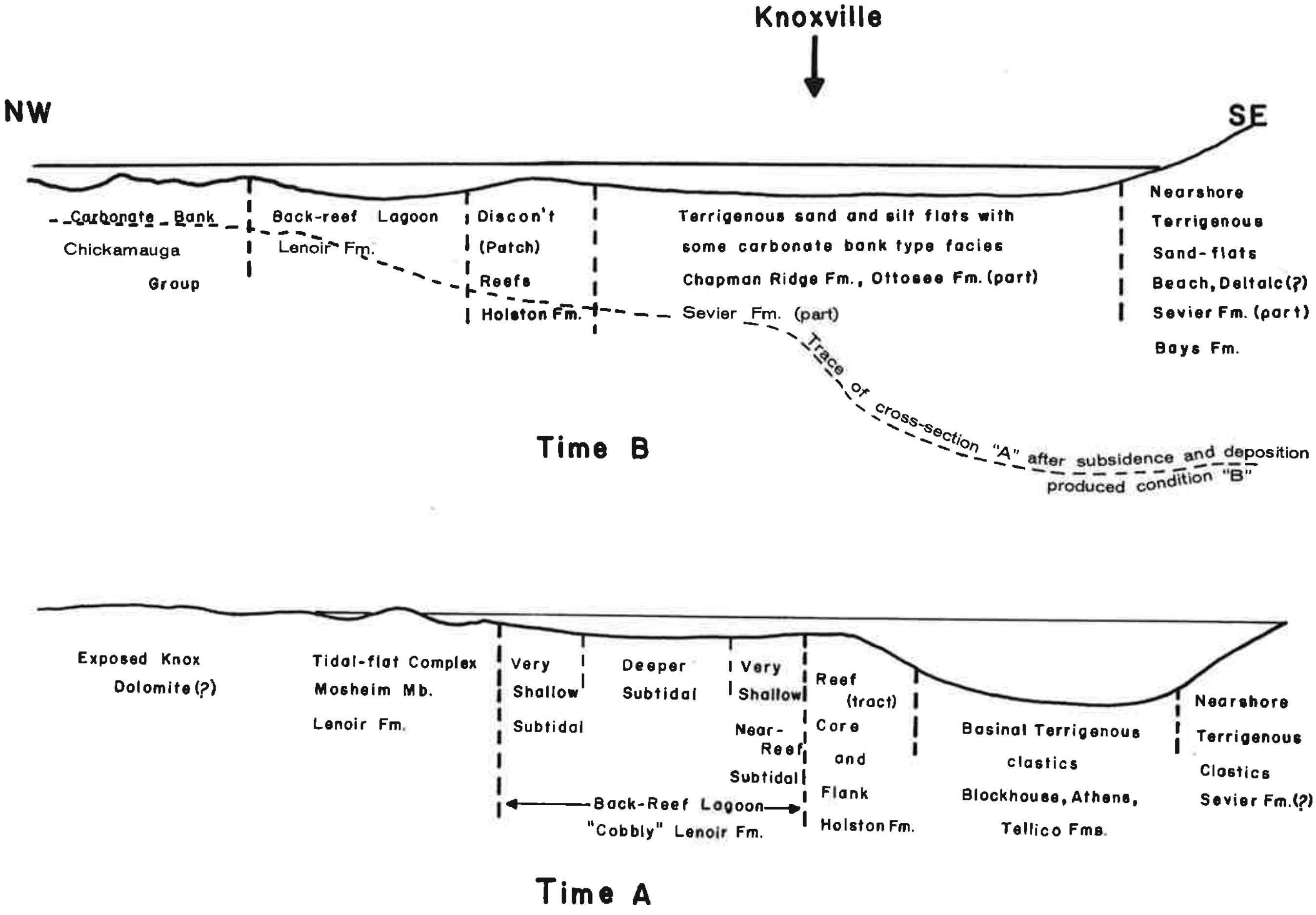

Figure 15. Regional environmental model of Middle Ordovician rocks of eastern Tennessee.

REGIONAL ENVIRONMENT

The rocks examined on this field trip represent parts of a complex regional facies pattern. The environmental pattern from northwest to southeast at the onset of Holston reef development is shown in the lower part of figure 15 and the pattern during early Chapman Ridge time is shown in the upper part. Although this model is based in part on preliminary data, it takes into account the environmental studies of the Lenoir, Holston, and Chapman Ridge formations reported above, and similar studies of the Blockhouse, Tellico, Chota, and Sevier formations of belts farther southeastward.

The research reported herein was supported by NSF Grant GA 35834 to Kenneth R. Walker, Department of Geology, University of Tennessee, and by funds from the Department of Geology, University of Tennessee, Knoxville, Tennessee.

ROAD LOG

Interval	Cumulative	
1.0	48.1	Return to Northshore Drive; turn right (east) onto Northshore Drive.
2.4	50.5	Quarry in upper Knox on right (south) side of road; upper part of this quarry shows interbedding of Knox and Mosheim lithologies, suggesting uninterrupted deposition of these units.
3.4	53.9	Intersection, Northshore Drive and Lyons View Drive; turn right (east) onto Lyons View Drive.
1.7	55.6	Intersection, Lyons View Drive and Kingston Pike; turn right (east) onto Kingston Pike.
1.9	57.5	Intersection, Kingston Pike and Neyland Drive; turn right (south) onto Neyland Drive.
0.7	58.2	Cherokee Bluff on south side of lake is composed of the Knox, Lenoir, Holston and Chapman Ridge formations.
0.9	59.1	Upper Mosheim and lower Lenoir exposed on left (north) side of Neyland Drive. The Lenoir contains abundant *Macluritie*s *magnus* and a zone of *Lichenaria sp.*
0.1	59.2	Intersection, Neyland Drive and Lake Loudoun Drive; turn left (north) onto Lake Loudoun Drive.
0.2	59.4	Intersection, Lake Loudoun Drive and Stadium Drive; turn right onto Stadium Drive.
0.4	59.8	Intersection, Stadium Drive and Andy Holt Drive at U.T. Student Center; end trip.

FIELD TRIP 2

Interval	Cumulative	ROAD LOG
0.5	4.1	Holston Formation on right (east) side of highway.
0.3	4.4	Lenoir Formation on right (east) side of highway.
0.2	4.6	Knox-Chickamauga contact.
0.6	5.2	James E. Karnes Bridge, Fort Loudoun Lake. Proceed on US 129 on overpass over Tyson Park to I-40, I-75. Stay in right lane.
1.2	6.4	Division of routes. Stay in right lane I-40 East, I-75 North to Knoxville, Lexington. Stay in right lane through downtown Knoxville.
1.2	7.6	Exit on I-75 North to Lexington, Ky., US 25-W; proceed north on I-75 toward Sharp Ridge.
2.7	10.3	Sharp Gap, stay left. Sharp Ridge has Rome thrust on Knox; the Knox is in turn thrust on Chickamauga.
0.3	10.6	JCT I-640; continue on I-75 North; abandoned quarry on left (west) side of road is in Knox.
0.4	11.0	Shattered Knox on left (west) side of Interstate.
3.3	14.3	Beaver Ridge. Rome is thrust on Moccasin on right (east) side of highway. The fault is about half way up the hill, near the top of the cut.
0.7	15.0	Emory Road exit, Exit 27; continue on I-75.
2.6	17.6	STOP 2: Depositional environments in upper Conasauga lagoon-fill sequences along I-75 at Copper Ridge, Knox County, Tennessee.

STOP 2: DEPOSITIONAL ENVIRONMENTS IN UPPER CONASAUGA LAGOON-FILL SEQUENCES ALONG I-75 AT COPPER RIDGE, KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Conasauga strata exposed along I-75 on Copper Ridge may be divided into several categories (fig. 16):

1. Stromatolite bioherms
2. Thin, irregularly bedded algal limestones
3. Shale and cobbly limestone units
4. Banded argillaceous limestones
5. Calcarenites, some oolitic
6. Washover beds of intraclastic and oolitic limestone
7. Limestones and dolomites with desiccation features.

Depositional environments of these ancient rocks can be interpreted by comparing their structures with those of modern sediments, and by deducing processes from the character of the rock where precise Recent analogues are lacking.

In general, strata at this exposure are a mixture of terrigenous and calcareous materials. The abundance of fine-grained rock indicates that most of the deposit was formed in an environment protected from the full force of ocean currents and waves, such as in a lagoon or interior carbonate platform.

Recent shallow water mud deposits are common in protected near shore environments, both in coastal lagoons (Kraft, 1971) and in lagoons adjacent to carbonate islands (Newell and Rigby, 1957, p. 26) although muds do not always indicate continuous low energy conditions. For example, Scoffin (1970) has shown that subtidal algal mats greatly inhibit erosion of fine sediments, so that they remain undisturbed under currents 5 times greater than those required to move sand.

The abundance of terrigenous sediments and the regional facies distribution of the Conasauga indicate that the depositional setting at this stop is one of coastal lagoons, generally between a shoreline to the west and carbonate banks to the east. The general change from interbedded terrigenous and calcareous strata at the base of the exposure to limestones at the top reflects a shift from depositional sites within lagoons to environments closer to the carbonate platform, i.e., marine transgression. Strata at this stop are in three coarsening-upward sequences that represent filling of lagoons; each sequence consists of interbedded shales and limestones that are capped by oolitic calcarenite beds.

STROMATOLITE BIOHERMS

Near the base of the section two algal stromatolite bioherms, each 4 to 5 feet thick, are in irregularly bedded and rippled micrites interbedded with thin shale beds and partings (beds 1-6). The stromatolites are in more or less continuous beds, but interareas between boundstone colonies are marked by deposits of shale and limestone debris. Except for thin irregular shale partings and some areas of intraclasts and oolites the boundstones are massive, but they do contain remnants of structures presumed to be of algal origin. Upper surfaces of the biohermal beds are undulating and individual colonies are convex upward.

Microscopically, the stromatolites are burrowed micrite and pelletal micrite, some with algal laminations and interlaminar birdseyes. Intercolony areas are dolomitized pelletal intramicrite.

Desiccation features such as polygons, shrinkage cracks, fenestral structures and tepees are lacking; and this combined with the grossly unlaminated nature of the stromatolites, suggests that these rocks were of subtidal origin, similar to subtidal stromatolites described by Gebelein (1969) and Neuman, Gebelein and Scoffin, (1970, p. 296).

IRREGULARLY BEDDED ALGAL LIMESTONES

Irregularly bedded micrites and shales in the lower part of the section are associated with the stromatolite bioherms. The irregular bedding is unusual in current-deposited strata and that suggests that these micrites are algal boundstones. Furthermore, some intraclasts associated with these beds may be analogous to those Recent carbonate pebbles which form when subtidal currents rip up sediments bound by algal mats (Gebelein, 1969, p. 56).

Microscopically these rocks are algally laminated burrowed micrite. Associated current laminated beds are biopelsparite and biomicrosparite; some of the sedimentary laminae are crossbedded, and some rocks contain small ostracods.[1]

Ripples, intraclast zones and a thin zone of oolitic calcarenite below the lower stromatolite bioherm suggest deposition under gentle to moderate currents. In contrast, formation of Recent subtidal stromatolites is enhanced by currents sufficient only to transport sediment, but not fast enough to ripple sand (Gebelein, 1969, p. 64). From the foregoing it is clear that the relatively thick fossil bioherms are indicative of lower energy conditions than are surrounding beds of thin irregular and rippled or cross-laminated micrites.

SHALE AND COBBLY LIMESTONE

Shale ranges from partings in limestone to units up to 13 feet thick. The rock is commonly greenish gray, but some is gray, olive gray, brownish gray or grayish red. All of the thicker shale units contain gray limestones in thin beds, cobbles, lenses, or nodules, and some of these contain fossil fragments. Some of the interbedded limestones are rippled; others contain intraclasts and oolites.

The thicker shale and cobbly limestone units are interpreted to represent periods of relatively quiet water deposition of terrigenous and calcareous muds in lagoons. Intraclast zones (discussed in another section herein) represent episodes of higher energy deposition, probably related to storms.

In general the relative amount of shale in these fine-grained units decreases upward so that argillaceous, cobbly-weathering limestones become the dominant type of lagoon fill in the upper half of the section. This change is interpreted to represent a shift in the site of deposition from within lagoons containing an abundance of terrigenous material, seaward to where lime muds are the dominant component.

Microscopically, the cobbly limestones (beds 63, 65, part of 66, and 68) are micrite and pelmicrite that is interbedded with algally laminated fine-grained dolomite. Some of the rock contains trilobite fragments; others have sediment-filled shrinkage cracks.

BANDED ARGILLACEOUS LIMESTONE

Four units of banded argillaceous limestones are in the upper part of the section (69, 71, 74, and 76), and they range from about 8 to 28 feet thick. In general these units are composed of mud or silt-sized gray limestone with numerous 0.1 foot-thick bands of olive-gray argillaceous limestone. In some places the banded limestones grade upward into calcarenite, reflecting a winnowing of the sediment by faster currents. In other places banded argillaceous limestones contain thick interbeds of oolitic calcarenites.

The banded argillaceous limestones are interpreted to be a continuation of the trend established in the shale and cobbly limestone sequences, and their lithology reflects the progressive decrease of terrigenous clastics upward in the section. The fine grain size of these strata indicates that they, too, were deposited under relatively quiet water conditions, and their banded nature perhaps reflects the action of tidal currents, with ebb currents contributing fine terrigenous muds that appear (microscopically) to have been bound by algal laminae. The fine grain size, relatively low amounts of terrigenous material and position in sequence suggest that these strata were deposited on a subtidal carbonate platform, on the seaward side of a lagoon that was being filled with both terrigenous and lime muds.

Microscopically, the banded limestones are micrite, intraclastic biopelsparite, pelsparite, intrapelsparite and intramicrite. In general the units contain dolomitized algal laminae; some are burrowed, and some algal laminae contain drusy spar-filled interlaminar birdseyes. Fossils consist of trilobite and ostracod fragments.

CALCARENITES AND OOLITIC CALCARENITES

Calcarenites and oolitic calcarenites are in three main zones in this section, and each represents the climax of a coarsening upward lagoon-fill sequence. These coarser grained and oolitic limestones are interpreted to have formed from shoal-derived materials that were swept generally landward into lagoons by flood tides, somewhat analogous to Recent interior platform deposits of the Bahamas.

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[1] Tentative identification of ostracods is based upon microscopic study of thin sections.

In Recent environments such as in the sand belt along the margin of the Bahamian platform, ooids commonly form in shoaling waters because turbulence generated by waves and currents is sufficient to keep grains separated and moving (Newell and Rigby, 1957; Ball, 1967). The Bahamian marine sand belt (Ball, 1967) is parallel to the break in slope separating the Bahama Bank from deeper water of the Florida Strait. Intermittent high energy events, such as storms, direct marine oolitic sands toward the platform interior in spillover lobes, some 300 feet long and 1500 feet wide. Deposits such as these are in many ways similar to the washovers associated with terrigenous barrier island deposits.

Ooids have also been described from channels between cays (Newell and Rigby, 1957, p. 54) where to-and-fro movement of water is sufficient to keep grains moving, and from within the Bimini Lagoon by Bathurst (1970). The occurrence described by Bathurst (1970, p. 62-66) is unusual because ooids are forming in an environment of little or no wave-formed turbulence, but where only tidal currents wash the sediments.

Oolitic sand bodies or bores are also abundant in the interior platform of the Bahamas. There, oolitically coated grains extend into the bank as much as 50 kilometers from the bank margin, and in places bores of, " . . . nearly pure oolitic sand extend several kilometers into the bank wherever the bottom is very shallow and tidal flow is unobstructed and vigorous (Newell, Purdy, and Imbrie, 1960, p. 484)."

At STOP 2 the lower sequence is capped by two relatively thick oolitic calcarenites, with some intervals of shale (beds 22 to 28). Fresh cuts in the rock appear massive, but well developed crossbeds are evident along weathered joint surfaces on the bench above the highway. The crossbeds are in high angle sets, and there is some indication of bimodal dip directions, indicative of tidal currents.

The upper part of the middle sequence consists mostly of limestone (beds 39 to 54). In general, limestones in the interval 39 to 45 contain few ooids, whereas the upper part of the sequence is oolitic (beds 47 to 54). The rock is commonly rippled, and contacts with overlying and underlying shale beds are concordant; i.e., there is no evidence of channeling. Some of the beds contain intraclasts in thin zones, and these are commonly restricted to the base or lower part of the beds. Fossils are in broken fragments.

Similarly, the upper part of the upper sequence contains two zones of oolitic calcarenites. The lower one (75) is within the argillaceous, banded limestones, and the upper (77, 78) is between the subtidal banded limestones and laminated limestones which are interpreted to be intertidal.

Ooids in these beds could have been formed in tidal channels but because lower contacts of the calcarenite bodies are conformable with the underlying sediments this interpretation is rejected. Rather, these ooids probably formed in carbonate shoals seaward of the lagoons, and this type of oolitic sand body is interpreted to be a tidal delta, or bore, which was built into the lagoon by oscillating but persistent tidal currents—in contrast to the episodic introduction of the single beds of intraclasts and ooids into the lagoon by storms.

Microscopically, oolitic units are intraclastic oosparite, oomicrite, oolitic biosparite, and oolitic intrapelsparite. Some ooids are internally recrystallized; others exhibit well developed radial structures. Intraclasts are micrite, some oolitically coated, some *Girvanella* lumps, pelmicrite, and pelsparite. Oolitically coated grains and grapestone aggregates are common, and that is additional evidence that the sediments were deposited in other than turbulent shoal environments. For example, Newell, Purdy and Imbrie (1960, p. 484) noted an abundance of grapestone aggregates and superficial ooids in interior platform deposits of the Bahamas. Enchinoderm, trilobite and ostracod debris is common.

Other calcareous sand bodies are composed of a mixture of biopelmicrite, biomicrite, biosparite, biopelsparite and intrapelsparite with echinoderm, trilobite and ostracod fragments, and micrite and pelsparite intraclasts.

In summary, these limestone beds apparently were deposited under conditions somewhat analogous to Recent platform interior deposits of Bahamas. The few conglomerates may represent the reworking of the sediment by occasional storms or other periods of fast tidal currents, and oolitic sediments were probably introduced onto the platform from nearby shoal environments.

WASHOVER BEDS

Single beds of intraclastic and oolitic limestones that are several inches thick represent episodic interruptions of the lagoonal environment and introduction of foreign material. Intraclasts are of diverse origins and some, which contain dolomite rhombs, may have formed in intertidal environments. Beds containing ooids are interbedded with intraclast zones, or are in single beds several inches thick interbedded with calcareous shale. The thin oolitic and intraclastic limestone beds have sharp top and bottom contacts and the upper surfaces of these beds are commonly rippled, with wave lengths of a few feet. These beds are conformable with overlying and underlying strata, i.e., they are not channel fills. For this reason ooids in the single thin beds are interpreted to have formed in shoal environments seaward of lagoons, and they were then washed into lagoons and mixed with other debris during storms or during other periods of unusually fast tidal currents.

Microscopically, the washover beds are fossiliferous intrasparite, intrapelsparite, intraclastic pelletal biosparite, and intraclastic biopelmicrite. Larger intraclasts are tabular, but rounded. Intraclasts are micrite, pelmicrite, pelsparite, and intrapelsparite; some are algally laminated. Some washover beds contain ooids and grade into oosparite. Fossils are large trilobite fragments, and echinoderm and ostracod debris.

Washover conglomerates are abundant in the lower part of the section and some units (beds 29 to 38) are composed almost entirely of interbedded shale and limestone. Intraclastic limestones in these units are the best examples of episodic storm deposits at this exposure, and represent periods of high energy deposition in the generally protected lagoon, when clasts were torn from adjacent carbonate rock and washed into deeper water nearby.

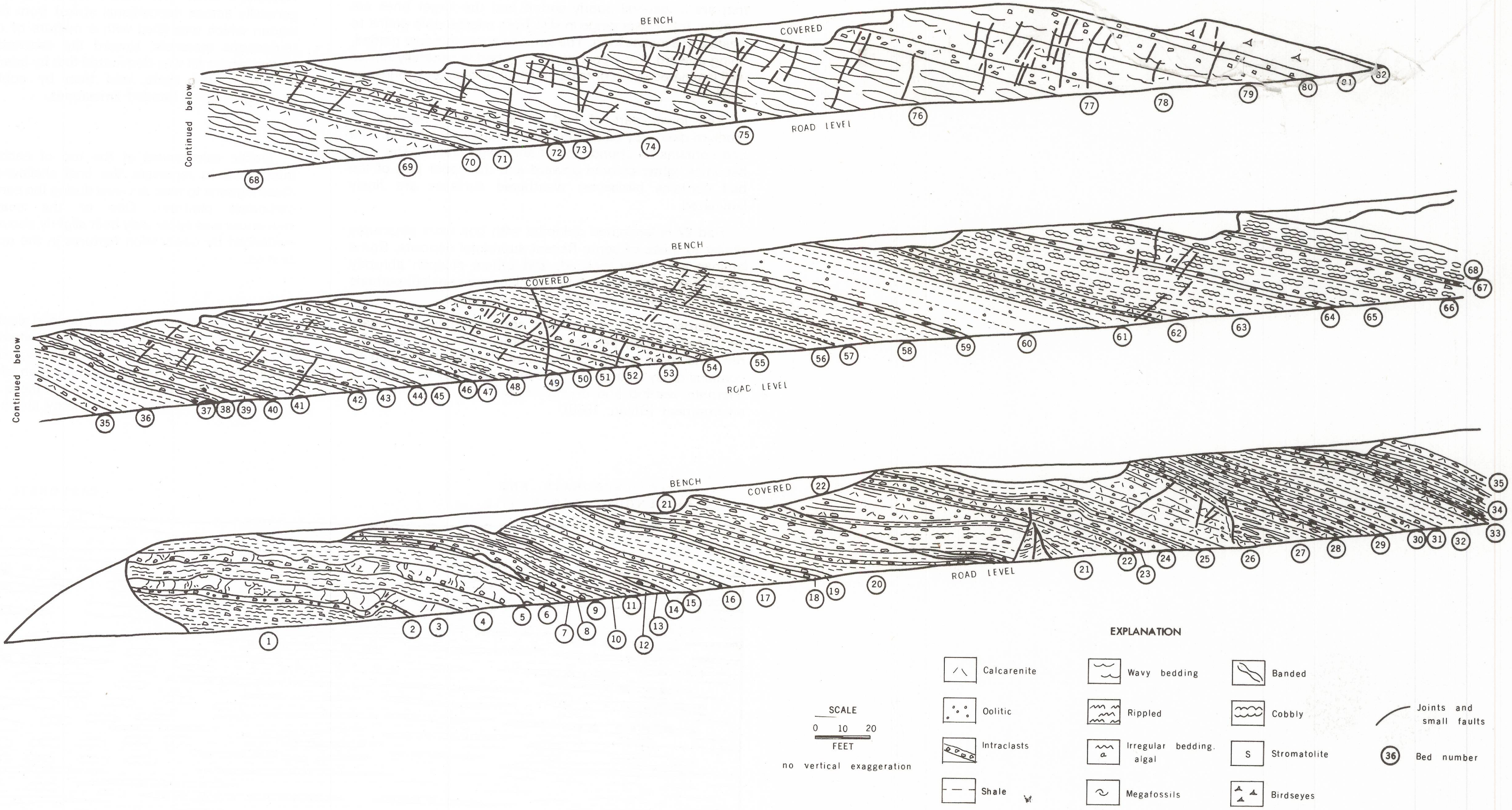

Figure 16. Conasauga lagoon-fill sequences.

CARBONATES WITH DESICCATION FEATURES

Beds at the top of the section exhibit structures similar to those which have been related by others to subaerial exposure and desiccation (beds 80 to 82). Laminated light-gray limestones, dolomites with tepee-like structures and soft sediment deformation features are in the lower part of bed 80. These beds contain an abundance of intraclasts that are in general poorly sorted and the larger ones are angular. Intraclasts range in size from microscopic grains to clasts 2 or 3 inches long. The laminae are commonly graded, fining upward. The upper part of the bed is generally not as well laminated, but contains small intraclasts and shrinkage cracks.

The lower part of bed 81 is mottled medium- to medium-dark-gray calcisiltite that is massively bedded. The bed contains an abundance of shrinkage cracks. The rock becomes lighter colored upward and the upper part of the bed contains birdseyes; weathered surfaces are finely laminated.

Bed 82 is laminated dolomite with box work structures similar to those of some Recent supratidal deposits. Some laminae are gently inclined, and others steepen abruptly before being truncated. A few laminae are crinkled, perhaps rippled, with wave lengths of an inch or so.

Microscopically, these beds are intrapelmicrite, algally laminated micrite, pelmicrite, intrapelsparite, and intramicrite. The rocks are dolomitized, or partly so, and bed 81 contains drusy laminated birdseyes which may be related to alternate wetting and drying of sediment in an intertidal environment (Shinn, 1968).

THE LAGOON-FILL MODEL

The lagoon-fill model (fig. 17) was constructed from the 3 coarsening-upward sequences at this stop. The stratigraphic section at this exposure is interpreted to represent the horizontal distribution of depositional environments (Walther's law). The model represents a cross section generally across depositional strike) from the interior of a lagoon which was filled with a mixture of carbonates and terrigenous materials, toward the seaward edge of the lagoon where fill was dominated first by interbedded cobbly limestones and shale, and then by cobbly limestones and argillaceous, banded limestones.

Oolitic calcarenites at the top of each sequence are interpreted to represent the final shallow-water filling of these lagoons to near sea level during the construction of the carbonate platform. One of the coarsening-upward sequences was apparently built slightly above sea level, as is evidenced by desiccation features in the upper part of the section.

Stromatolites and irregularly bedded algal limestones are in protected parts of the lagoon, where there is an abundance of fine sediment. Episodic deposits of washover conglomerates interrupted sedimentation of the characteristically muddy lagoon fill, and these are generally interpreted to represent high energy storm deposits.

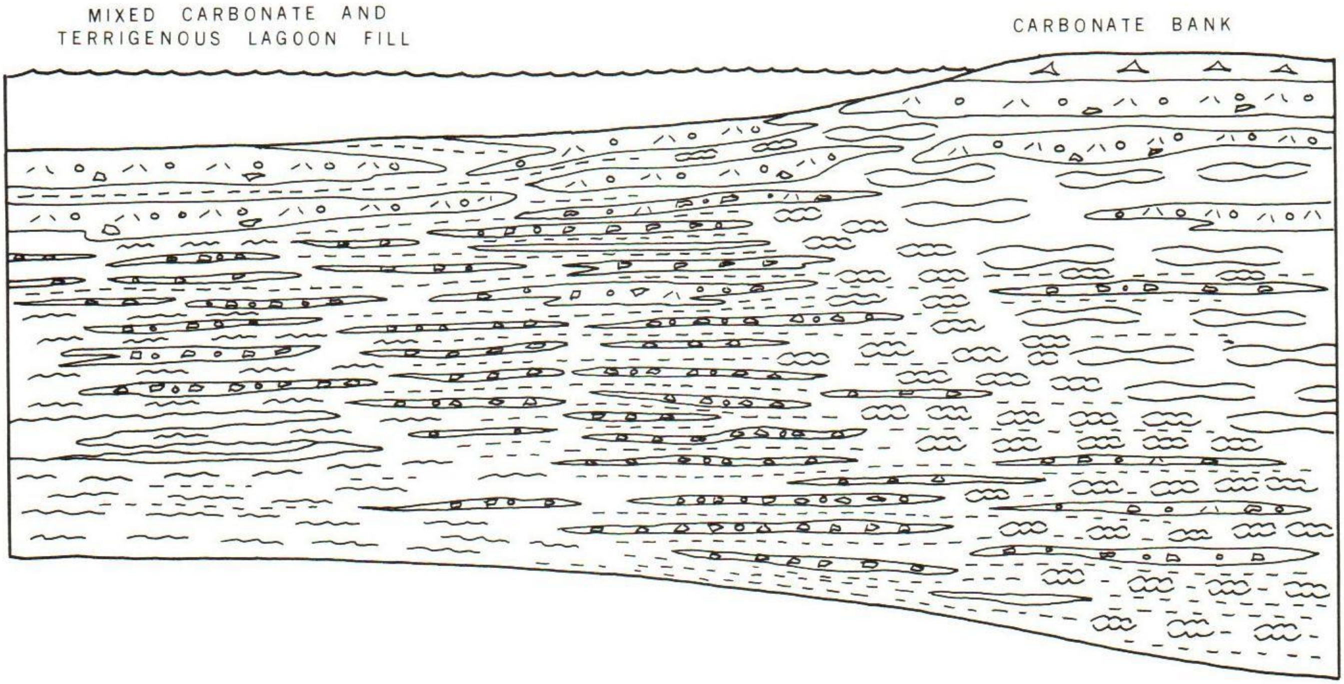

Figure 17. Generalized diagram of Upper Conasauga lagoon-fill model.

STOP 2

NOLICHUCKY AND MAYNARDVILLE FORMATIONS ALONG I-75, COPPER RIDGE CUT, KNOX COUNTY, TENNESSEE

MEASURED SECTION

Bed No.	Thickness (feet)	Description
82	1 +	Dolosiltite, light-gray, laminated; some laminae are crenulated, inclined or crossbedded. Some of the weathered beds show box work structures.
81	7.5	Calcilutite, medium-light to medium-dark-gray, irregularly bedded to massive, with abundant birdseyes in the upper part, and shrinkage cracks in the lower part; upper part is finely laminated on weathered surface.
80	5.2	Calcisiltite, medium-light- to medium-gray; interbedded with dolosiltite, light-olive-gray; with abundant angular rip-up clasts; laminated in lower part, with tepee-like structures; laminae are graded; shrinkage cracks at top.
79	9.8	Calcilutite to fine-crystalline limestone, medium- to medium-dark-gray; some beds with abundant small intraclasts in upper half; becomes darker and faintly laminated, light olive gray in lower half; bedding wavy; with scoured base.
78	9.0	Calcisiltite to finely crystalline limestone, medium-dark-gray, dolomitic; bedding wavy, with ooids in lower part.
77	4.8	Calcisiltite to calcarenite, fine-grained, generally oolitic; with abundant small intraclasts in lower part, wavy bedded.
76	28.3	Calcisiltite, medium- to medium-dark-gray, with some calcilutite and some finely crystalline limestone; generally banded with argillaceous limestone, light-olive-gray; bands generally less than 0.1 foot.
75	7.0	Calcisiltite, medium- to medium-dark-gray, oolitic at top and bottom; banded, with light olive gray beds in middle.
74	12.0	Calcilutite, medium-gray, banded, with argillaceous limestone, light-olive-gray; bands generally are less than 0.1 foot.
73	4.3	Shale, dark-greenish-gray, with lenses up to 0.1 foot of calcisiltite, medium-gray, burrowed (?), with shell fragments.
72	1.4	Calcarenite, fine-grained, medium-dark-gray, oolitic.
71	8.5	Shale, dark-greenish-gray, with a few thin beds, cobbles and lenses of calcilutite and calcisiltite, medium-gray, upper part; lower part is banded argillaceous calcilutites, as above.
70	1.4	Shale, dark-greenish-gray.
69	14.7	Calcilutite, medium- to medium-dark-gray, argillaceous and banded, some lenticular, nodular or cobbly with calcarenite, fine-grained, medium-dark-gray in upper 3 feet; shaly in lower 3 feet; shale is medium gray with lenses of calcilutite up 0.1 foot, with traces of pyrite and trilobite fragments.
68	8.1	Calcisiltite, medium-gray, argillaceous, wavy bedded, upper 2.3 feet, with fossil fragments; interbedded, calcilutite, medium-gray and shale, calcareous, greenish-gray, beds 0.05-0.2 foot, cobbly, lower 5.8 feet.
67	1.0	Shale, medium-dark-gray.
66	7.0	Interbedded, calcilutite to calcisiltite, medium- to medium-dark-gray, and shale, medium-dark-gray, cobbly, beds 0.05 to 0.2 foot, with ooids and trilobite fragments at base.
65	8.2	Interbedded and cobbly as 66, but more shaly; limestone interbeds range from calcilutite to finely crystalline limestone, some contain intraclasts, with fossil fragments.
64	1.0	Calcilutite to calcisiltite, medium-gray, rock pebble conglomerate.
63	13.2	Shale, medium-gray; weathers olive gray, upper 1.2 feet; interbedded, shale, as above, and calcilutite, medium-gray, cobbly, beds about 0.1 foot thick.
62	2.7	Calcisiltite to calcarenite, fine-grained, medium-gray, some iron stained, some fossil fragments, with interbeds of shale, medium-gray (fresh), olive-gray (weathered), with calcilutite toward base.
61	4.2	Calcilutite to calcisiltite, with partings of shale, medium- to medium-dark-gray, irregular or wavy bedded, beds 0.05 to 0.5 foot.
60	13.5	Shale, medium-gray (fresh), greenish-gray (weathered); with lenses of calcilutite, fossil-fragmental, medium-dark-gray, upper half; lower half is calcilutite to calcisiltite, with partings of shale, with traces of pyrite.
59	0.8	Calcisiltite, medium-gray, fossil-fragmental, with rip-up clasts.
58	9.0	Interbedded, calcilutite to calcisiltite, medium-gray; and shale, olive-gray to greenish-gray, rippled and flasered, with traces of pyrite.
57	3.0	As above, but with slightly more shale and more nodular.
56	3.6	As above, but more shaly.
55	9.5	Interbedded, calcilutite to calcarenite, fine-grained, medium-dark-gray; and shale, as in 58 nodular, rippled.

Bed No.	Thickness (feet)	Description
54	1.1	Calcarenite, fine-grained, medium-dark-gray, some oolitic, with shale partings.
53	5.5	Calcarenite, fine- to medium-grained, medium-dark-gray, some oolitic, with fossil fragments, with irregular fragments of calcisiltite, olive-gray, 1 foot long and 0.05 foot across.
52	1.9	Interbedded shale, medium-gray (fresh), greenish-gray (weathered); and calcilutite to calcisiltite, medium-gray; beds lenticular, rippled.
51	2.7	Calcarenite, some oolitic, medium-grained, medium-gray, fossil-fragmental, some fragments altered to siderite.
50	2.5	Shale, medium-gray (fresh), greenish-gray or olive-gray (weathered), with lenses of calcilutite to calcisiltite, medium-gray, rippled.
49	3.0	Calcarenite, as in 51, with iron-stained ooids and shale partings.
48	4.0	Shale, medium-gray, greenish-gray or olive-gray, with thin lenticular interbeds of calcilutite, medium-gray, rippled.
47	2.9	Calcisiltite to calcarenite, fine-grained, medium-gray, some finely oolitic, wavy bedded, with fossil fragments.
46	1.4	Shale, medium-gray, with a few thin beds and lenses of calcisiltite, medium-gray.
45	3.5	Calcarenite, medium-grained, medium-gray, with fossil fragments, wavy bedded.
44	1.9	Interbedded shale, medium-gray; weathers greenish or olive gray, and calcilutite to calcisiltite, medium-gray, lenticular, some rippled.
43	6.5	Calcarenite, fine- to medium-grained, medium-gray, wavy bedded, rippled, with shale partings, with small rip-up clasts at base.
42	0.6	Shale, medium-gray, weathered, greenish-gray, light-olive-gray, with a few thin lenses of calcisiltite, medium-gray.
41	7.2	Calcisiltite, medium-gray; with small fossil fragments; with partings of argillaceous calcilutite, yellowish-orange, rippled.
40	1.8	Interbedded shale, weathered, greenish-gray, olive-gray, and calcilutite, medium-gray, in very thin beds, rippled.
39	3.0	Calcarenite, medium-grained, medium-gray, with numerous rip-up clasts, some ooids and fossil fragments, wavy bedded, shale partings toward base.
38	2.0	Shale, with interbeds of calcilutite to calcisiltite, as in 40, but less limestone.
37	2.0	Calcisiltite, medium-gray, wavy bedded, with shale partings, fossil fragments, and rip-up clasts near base.
36	9.1	Shale, medium-gray (fresh), greenish-gray (weathered), with thin lenses and flattened nodules of calcilutite, some with fossil fragments.
35	2.0	Calcisiltite to calcarenite, fine-grained, medium-gray, with rip-up clasts; shale interbedded at top; upper limestone bed is oolitic contains fossil fragments.
34	11.0	Shale, medium-gray (fresh), greenish-gray (weathered), with interbeds of calcisiltite to calcarenite, fine-grained, with abundant rip-up clasts (0.5 to 0.9 foot), some ooids and fossil fragments and with some thin lenses of calcilutite, medium-gray.
33	1.2	Calcarenite, fine- to medium-grained, medium-gray, with rip-up clasts, fossil fragments.
32	5.6	Interbedded shale as above, and calcilutite, as above in thin beds, lenses and flattened nodules, rippled.
31	1.9	Interbedded calcilutite to calcarenite, fine-grained, oolitic, medium-dark-gray, and shale, as above, beds 0.1 to 1 foot, wavy, with some rip-up clasts.
30	2.3	Calcisiltite to calcarenite, fine-grained, medium-dark-gray with some shale partings, with rip-up clasts at base.
29	9.0	Shale, medium-gray (fresh), greenish-gray (weathered), with several thin beds of calcisiltite, medium-gray containing abundant rip-up clasts, some ooids and fossil fragments.
28	1.7	Calcarenite, fine- to medium-grained, medium-gray, with abundant rip-up clasts, fossil-fragmental, with some shale partings.
27	1.7-2.6	Shale, medium-gray (fresh), greenish-gray (weathered), with a few thin lenses of calcilutite, medium-gray.
26	10.5	Calcarenite, fine- to medium-grained, medium-gray, fossil-fragmental, oolitic, with a few thin interbeds of shale, beds wavy.
25	5.4	Shale, medium-gray (fresh), greenish-gray (weathered), with a few irregular interbeds of calcarenite, fine-grained, oolitic, fossil-fragmental, with rip-up clasts.
24	2.8	Calcarenite, fine- to medium-grained, medium-gray, with abundant ooids, rip-up clasts at base, with fragments of trilobites and brachiopods.
23	1.0	Shale, as in 25, with interbeds of calcisiltite, medium-gray, fossil-fragmental.
22	2.5-10±	Calcarenite, as in 24, crossbedded, with shale partings.
21	10.6	Shale, greenish-gray; weathers olive-gray; 1.5 feet thick at top. Calcilutite, thin-bedded, medium-gray; with interbeds of shale, greenish- gray and medium to thick beds of calcarenite, fine-grained, with ooids, intraclasts, some

Bed No.	Thickness (feet)	Description
		rippled; 4.7 feet in middle. Shale, medium-gray (fresh), greenish-gray or light-olive-gray (weathered); with a few thin lenses of calcilutite, medium-gray, 3.9 feet in lower part. Calcarenite, fine-grained, medium-gray, oolitic, with rip-up clasts at base, 0.9 feet at bottom of bed 21.
20	3.8	Shale, brownish-gray, olive-gray, greenish-gray, and grayish-red, weathered.
19	1.3	Calcilutite, medium-light-gray, very thin to thin-bedded, rippled; with partings of shale, with some rip-up clasts.
18	0.8	Calcilutite to calcisiltite, medium-light-gray, with rip-up clasts.
17	7.5	Shale, greenish-gray, brownish-gray, olive-gray; with lenses and beds of medium-gray calcisiltite, up to several inches thick; with traces of pyrite, birdseyes.
16	1.3	Calcarenite, fine-grained, medium-gray, oolitic, with undulating upper surface.
15	6.2	Calcilutite, medium-light-gray, rippled, in thin, irregular beds; with traces of pyrite; 0.7 feet at top. Shale, greenish-gray, 0.6 feet. Calcilutite, medium-light-gray, rippled, 0.9 feet. Shale, greenish-gray, 4.0 feet at base.
14	0.4	Calcirudite, medium-gray.
13	0.6	Calcilutite, medium-light-gray, very thin-bedded (0.02 to 0.05), rippled.
12	1.9	Calcilutite, as above, rippled, but beds 0.03 to 0.1 foot thick; irregularly bedded, with some birdseyes.
11	2.6	Calcilutite, medium-light-gray and shale, greenish-gray, in thin irregular beds.
10	1.2	Shale, weathered, olive-gray.
9	2.8	Calcilutite to calcisiltite, some argillaceous, irregularly bedded, rippled and banded with shale partings, with small intraclasts, upper bed oolitic.
8	1.5	Calcarenite, fine-grained, medium-gray, oolitic; with traces of pyrite.
7	0.7	Calcilutite, medium-light-gray, rippled, beds 0.05 to 0.1 foot; with small intraclasts.
6	4.8	Upper 2 feet calcilutite, medium-light-gray, rippled, beds 0.02 to 0.03 feet with shale partings, a few ooids and birdseyes; grades downward into shale, light-olive-gray, with interbeds of calcilutite.
5	4-5	Calcilutite, medium-gray, mottled, light-gray, stromatolite beds—stratiform, but domal on top; with rip-up clasts at base, with ooids and intraclasts.
4	4.6	Interbedded calcilutite, medium-light-gray and shale, light-olive-gray, beds 0.02- 0.05 feet; with abundant intraclasts, irregularly bedded, rippled.
3	4.2	Stromatolite bed, as in 5; with traces of pyrite.
2	1.2	Calcarenite, fine-grained, medium-dark-gray; with abundant rip-up clasts, oolitic.
1	20±	Interbedded calcilutite and shale as in 4, very thin, irregularly bedded, rippled; with thin rip-up zones.
0	0.7	Calcarenite, fine- to medium-grained, medium-dark-gray, oolitic.

MICROSCOPIC DESCRIPTION

Bed No.	Description
82	MICRITE, algally laminated, intramicrite and pelmicrite; with drusy laminated birdseyes, some dolomitized.
81	INTRAPELSPARITE, with dolomitized algally laminated micrite; intraclasts are pelmicrite and pelsparite, very poorly sorted.
80	INTRAPELMICRITE, algally laminated micrite and pelmicrite, partly dolomitized, with a few well-rounded micrite intraclasts; possible soft sediment deformation feature.
79	PELLETAL INTRASPARITE, intraclasts well-rounded, mostly micrite, some pelmicrite and pelsparite; with a few ooids.
78	INTRAPELSPARITE, some oolitic; with some *Girvanella* micrite lumps; possibly micro-cross laminated; with a few echinoderm and trilobite fragments.
77	PELSPARITE, with a few well-rounded small micrite intraclasts.
76b	INTRAPELSPARITE and intrapelmicrite, algally laminated, burrowed (?); irregular drusy spar-filled birdseyes, some interlaminar birdseyes; intraclasts are small well-rounded micrite; with a few dolomite rhombs.
76a	INTERBEDDED, micrite with a few shell fragments, and argillaceous fine-grained, algally laminated dolomitized micrite.
75b	INTERBEDDED, algally laminated, fine-grained dolomite and micrite; micrite layers partly replaced by large irregular areas of fine-grained dolomite; the dolomite lithology, surrounded by microstylolites, forms pseudointraclasts.
75a	MICRITE, algally laminated, fine-grained and dolomitized; with a few trilobite fragments.

Bed No.	Description
73	BIOMICRITE, with abundant trilobite fragments and a few ostracod valves; the few original voids under fossils are filled with dolomite; with a few pellets.
72	OOMICRITE, oolitic micrite and pelmicrite with a few trilobite fragments; with intraclasts of micrite and pelsparite; with areas of contorted algally laminated fine-grained dolomite; various lithologies are separated by stylolites.
71	DOLOMITIZED MICRITE, argillaceous, algally laminated (?), and micrite cobble; with a few ostracod valves.
69b	INTRACLASTIC biopelsparite and pelsparite, current laminated, with a few thin algally laminated fine-grained dolomite laminae; fossils are trilobite and ostracod fragments; intraclasts are small well-rounded micrite (may be micritized fossil fragments).
69a	MICRITE, with some partly dolomitized algal laminae.
68	MICRITE, faintly laminated, burrowed; burrows are selectively dolomitized, some dark areas of fine-grained dolomite.
66	INTRACLASTIC BIOSPARITE, with some biopelsparite; intraclasts are micrite, fossiliferous intrapelsparite with ooids; and biopelsparite; there are two forms of *Girvanella;* most intraclasts are algally coated by *Girvanella;* few *Girvanella* lumps are irregular in shape and mantled, suggesting they were soft when deposited.
65	MICRITE, with shrinkage cracks, some sediment filled; overlain by algally laminated fine-grained dolomite.
64	INTRACLASTIC PELLETAL BIOSPARITE; fossils are trilobite fragments and rounded echinoderm fragments in about equal numbers, with a few ostracods; intraclasts are micrite and algally laminated pelmicrite-pelsparite commonly with dark alteration rims, and some biopelmicrite.
63b	MICRITE and algally laminated fine-grâined dolomite, with a few micrite intraclasts; laminae drape over intraclasts; with very few trilobite and ostracod fragments.
63	MICRITE and pelmicrite, some algally laminated, and impure algally laminated fine-grained dolomite, with a few trilobite fragments along some laminae.
62	INTRACLASTIC PELSPARITE in thick irregular laminae; intraclasts are pelmicrite separated by very irregular algally laminated fine-grained dolomite layers; with some small mound-shaped features; the few fossils are trilobite fragments.
61	INTERLAMINATED pelmicrite and pelsparite, and biopelsparite; vertically burrowed current laminated units are eroded; the surfaces are covered by algally laminated dolomitized pelmicrite; intertidal to supratidal (?).
60	FOSSILIFEROUS BIOPELSPARITE, current laminated; pellets are probably of intraclastic origin or are micritized fossil fragments; intraclasts are mostly pelmicrite and abraded grapestone grains; with a few small ooids; fossils are large trilobite and ostracod fragments (0.1-0.5 inch).
57	INTERLAMINATED pelsparite and pelmicrite; some pelsparite is fossiliferous (trilobite and ostracod fragments) and algally laminated; some thin, very thinly laminated intervals are carbonaceous and dolomitized.
56	MICRITE
55b	MICRITE, and fossiliferous intrapelsparite; the micrite is burrowed, burrows are selectively dolomitized; eroded, upper surface of micrite was probably hard ground (boring and overhanging ledges); intraclasts are well-rounded micrite, some faintly laminated, laminated pelmicrite and pelsparite with dolomite crystals; fossils are trilobite fragments.
55	INTERBEDDED, pelsparite and biopelsparite; with intraclasts of pelsparite, a few recrystallized ooids, some replaced by dolomite crystals; some of the pellets in the biopelsparite may be well-rounded micritized fossil fragments; fossils are large trilobite fragments.
54	OOLITIC BIOSPARITE, coarse-grained, with intraclasts of pelmicrite; grapestone aggregates are common; fossils are algally bored echinoderm fragments; trilobite and ostracod (?) fragments.
53	FOSSILIFEROUS OOSPARITE; with common grapestone aggregates, ooids are superficial; with a few pelmicrite and micrite intraclasts, some dolomitized; fossils are mostly echinoderm debris, with a few trilobite fragments.
52	INTRAPELSPARITE, intraclasts are current cross-laminated pelsparite and are imbricated; fossils are green (?) algae (one specimen); echinoderm fragments and trilobite fragments.
51	FOSSILIFEROUS INTRAPELSPARITE; intraclasts are micrite, pelmicrite, pelsparite and biopelsparite; pellets in matrix may be small micritized fossil fragments; fossils are rounded echinoderm fragments, trilobite fragments and a few ostracod valves.
50	FOSSILIFEROUS INTRAMICROSPARITE grading up into intrasparite; intraclasts are laminated pelmicrite and pelsparite; fossils are rounded echinoderm plates and trilobite fragments.
49	FOSSILIFEROUS OOSPARITE overlain by fossiliferous biosparite with ooids, and then by biomicrite with ooids; ooids are recrystallized; intraclasts are oolitic biomicrite; with a few glauconite (?) impregnated echinoderm fragments and dolomite rhombs.
47	INTRACLASTIC OOLITIC BIOPELSPARITE; fossils are mostly echinoderm debris, with trilobite fragments, some replaced by dolomite, with unidentified bipartite fossils; intraclasts are pelsparite and pelmicrite, many grains are stained black.

Bed No.	Description
45	INTRAPELSPARITE, with a few oolites and fossil fragments; pellets may be micritized, well-rounded small fossil fragments; intraclasts are pelsparites, some laminated, some intraclasts are the same lithology as the matrix; upper part is dolomitized biopelmicrite separated by thin algally laminated dolomite; fossils are ostracod and trilobite debris and a few echinoderm fragments.
44	PELMICRITE interlaminated with pelsparite; pellets may be micritized well-rounded small fossil fragments; fossils are trilobite and echinoderm debris.
43	INTRACLASTIC BIOMICRITE and biopelmicrite with stringers of intrasparite; with a few rhombs of dolomite; intraclasts are micrite, dolomitized micrite and pelmicrite and are very small and well rounded; fossils are echinoderm and trilobite fragments with a few ostracod valves.
41	INTRACLASTIC BIOPELSPARITE AND BIOPELMICRITE, partly dolomitized, with a few recrystallized ooids; intraclasts are micrite, some dolomitized; with trilobites, ostracod valves and rounded echinoderm fragments.
39	BIOMICRITE with lenses of biosparite, with a few small micrite intraclasts, a few ooids and some areas of pellets; with a few dolomite crystals; fossils are echinoderm plates, trilobite fragments and a few ostracod valves.
37	FOSSILIFEROUS INTRACLASTIC BIOPELMICRITE; some of the matrix is dolomitized; intraclasts are micrite, algally laminated pelsparite; fossils are trilobite and echinoderm fragments in equal amounts, with a few ostracod valves.
35	INTERBEDDED, fossiliferous intrapelsparite and fossiliferous intrasparite; intraclasts are micrite and dolomitized intramicrite; fossils are trilobite and ostracod fragments; intraclasts are well rounded.
33	FOSSILIFEROUS INTRAPELSPARITE, grades upward into oosparite; intraclasts are micrite and pelsparite; fossils are trilobite fragments, mostly small, and algally bored echinoderm fragments.
30	FOSSILIFEROUS INTRACLASTIC OOSPARITE, with thin partings of argillaceous dolomite; intraclasts are micrite, oomicrite, recrystallized pelmicrite; fossils are large trilobite fragments and well-rounded echinoderm fragments with micrite envelopes.
29	FOSSILIFEROUS INTRASPARITE and intrapelsparite; intraclasts are intrapelsparite, algally laminated intrapelsparite, algally coated micrite grains with dolomite rhombs, and micrite; fossils are large trilobite fragments (0.5 inch), ostracod valves and echinoderm plates.
26	FOSSILIFEROUS INTRACLASTIC OOSPARITE, ooids are internally recrystallized; some of the intraclasts are oolitically coated; some microspar clasts (up to 1-inch) are partly dolomitized fossils are trilobite fragments, many coated with calcite, ostracod valves and echinoderm fragments.
25	VERY FOSSILIFEROUS INTRAMICROSPARITE, intraclasts are pelsparite or pelmicrite (up to 1-inch), some algally laminated; fossils are abundant echinoderm fragments, with some trilobite and ostracod debris; most of the fossils are well rounded.
22	INTRACLASTIC OOSPARITE and oomicrite, with a few small scattered rhombs of dolomite; most ooids recrystallized; fossils are echinoderm debris; some intraclasts are mantled with ooids.
21b	FOSSILIFEROUS INTRASPARITE, intraclasts are well sorted, rounded, some are coated with calcite, with superficial ooids; fossils are echinoderm debris, large trilobite and a few ostracod fragments.
21a	INTRACLASTIC OOSPARITE, ooids are superficial; intraclasts (up to 1-inch) are sparry pelmicrite, intrasparite, sparry intramicrite and biointrasparite; some intraclasts are coated with calcite; fossils are abundant echinoderm fragments.
19	FOSSILIFEROUS INTRAPELSPARITE, intraclasts are algally laminated pelmicrite, pelsparite, sparingly fossiliferous biomicrite; large intraclasts are tabular but rounded; fossils are echinoderm, ostracod and trilobite fragments.
18	FOSSILIFEROUS INTRASPARITE, overlain by intraclastic biopelmicrite; fossils are echinoderm, trilobite and ostracod debris; intraclasts are well-rounded micrite, pelmicrite and pelsparite.
17	INTRACLASTIC BIOPELSPARITE, pellets are possibly small intraclasts, the large intraclasts (up to 1.5 inch) are intramicrite and pelmicrite; fossils are echinoderm and trilobite fragments.
16	INTRACLASTIC OOSPARITE, spar is very fine grained; intraclasts are well rounded and are composed of intramicrite, some grains are algally coated; fossils are trilobite and ostracod fragments and echinoderm plates.
15	MICRITE, some faintly laminated; with U-shaped burrow.
14	INTRAMICRITE, some with poorly developed irregular laminae; with patches of dolomite rhombs; extensively burrowed; intraclasts are well rounded.
12	MICRITE and algally laminated micrite, horizontally burrowed.
11	INTRASPARITE, with intraclasts of fossiliferous (very small trilobite and ostracod fragments) pelmicrite; overlain by laminated crossbedded biomicrosparite and then by biopelsparite; the intraclasts are platy and contain spar-filled desiccation cracks.
9	PELLETAL OOMICRITE, ooids well rounded, recrystallized; with a few intraclasts of algally laminated micrite, with patches of iron-stained dolomite; fossils are a few trilobite and ostracod fragments.
8	INTRACLASTIC OOSPARITE interbedded with intraclastic oomicrite; ooids are recrystallized; intraclasts are rounded micrite; with grapestone grains and a few areas of pelsparite.

Bed No.	Description
7	ALGALLY LAMINATED MICRITE with unlaminated micrite intraclast, horizontal burrows filled with spar.
6	LAMINATED BIOMICROSPARITE (calcisiltite), some cross laminated; with shrinkage cracks.
5	MICRITE, some dolomitized; with a suggestion of algal laminations, with horizontal burrows.
4	ALGALLY LAMINATED MICRITE with a few small burrows, patches of dolomite.
3	PELLETAL MICRITE, algally laminated with interlaminar birdseyes, algal laminae are irregular; intercolony area is selectively dolomitized pelletal intramicrite, burrowed.
1	INTERBEDDED, ostracod biopelsparite and biopelsparite (calcisiltite) with sedimentary laminae.

Interval	Cumulative	ROAD LOG
1.0	18.6	Rutledge, Rogersville, Maryville interval. The Conasauga Group is composed of interbedded shale and limestone formations in southeastern Knox County; but limestone is replaced by shale to the northwest. In the Bullrun strike belt the Rutledge, Rogersville and Maryville are commonly mapped together because the limestone formations are thin and interbedded with shale.
0.3	18.9	Bullrun Valley; strike belt of Pumpkin Valley Shale.
0.3	19.2	Pumpkin Valley Shale in cuts on right (northeast) side of Interstate.
0.1	19.3	Rome Formation.
0.1	19.4	STOP 3: The Rome section along I-75 North, Raccoon Valley, Knox County, Tennessee.

STOP 3: THE ROME SECTION ALONG I-75 NORTH, RACCOON VALLEY, KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

The Rome sequence exposed on the eastern side of I-75 N. consists mainly of beds of quartzitic sandstone, quartzite, and shale. More than 50% of the sequence is made of quartzite, while the remainder is hematitic shale, siltstone and glauconitic sandstone. The thickness of this section is about 113 meters. Primary sedimentary and organic structures are abundant, represented mainly by ripple marks and casts of worm burrows. The great variety of colors in the Rome Formation is one of its most characteristic and easily recognizable features. Typical colors are reddish gray, brownish yellow, tan, and light gray to dark greenish gray.

The lower contact of the Rome in this section is a fault on Ordovician limestones. Several thrust faults and associated drag folds complicate parts of the sequence. The faulting together with the lack of fossils and marker beds, makes it difficult to determine the true thickness of the Rome Formation or how much of the formation is absent or duplicated.

The abundance of iron oxide and glauconite in the strata suggests that both oxidizing and reducing conditions may have existed sporadically within the environment during the deposition of the formation. The iron oxide content, presence of ripple marks, organic structures and shallow, small scour channels (30 cm wide, 15 cm deep) suggest an intertidal to shallow neritic environment. Glauconite, indicating reducing marine conditions, is found in situ mixed with sandstone, especially in the Pumpkin Valley at the top of the sequence; while in other parts of the section it is found in laminations with micro-crossbedding suggesting that it has been transported from a reducing environment to a shallow oxidizing environment.

RELATIVE SCALE OF BEDDING TERMINOLOGY

Term	Thickness in Metric Units
Massive	+ 180 cm.
Very thick bedded	120 - 180 cm.
Thick bedded	60 - 120 cm.
Medium bedded	15 - 60 cm.
Thin bedded	5 - 15 cm.
Very thin bedded	1 - 5 cm.
Laminated	2 mm - 1 cm.
Thinly laminated	less than 2 mm.

Color reference: **Rock Color Chart** distributed by the Geological Society of America, New, York, 1963.

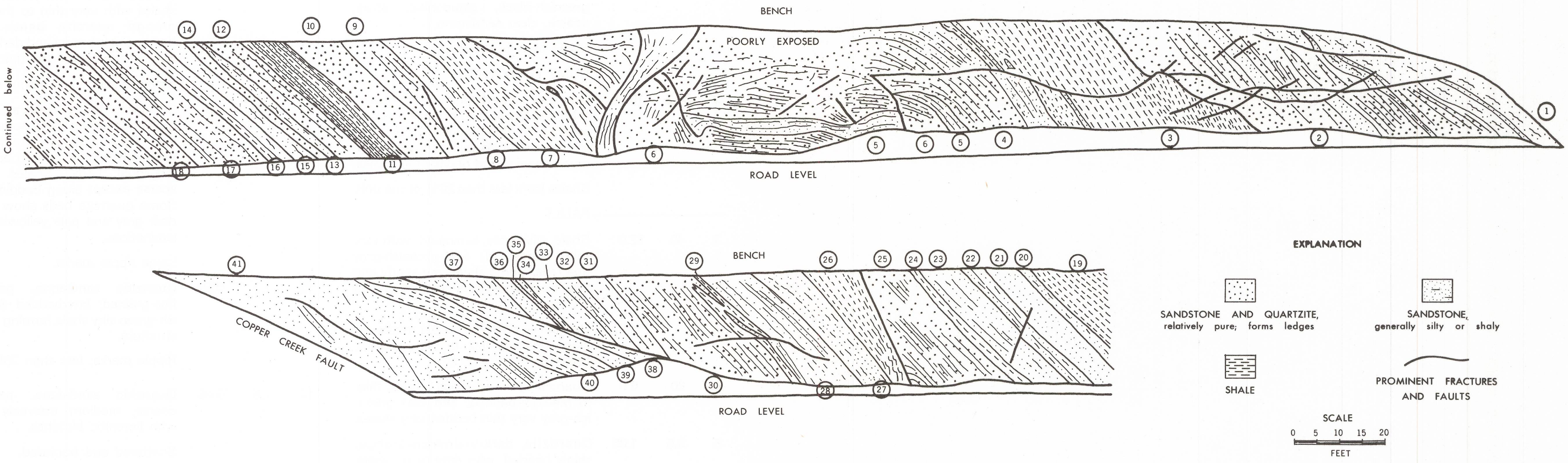

Figure 18. The Rome Formation at Diggs Gap.

ROME SECTION, I-75 NORTH, HALF MILE SOUTH OF RACCOON VALLEY EXIT

MEASURED SECTION (FIG. 18)

Unit	Thickness (feet)	(meters)	Description
			PUMPKIN VALLEY SHALE
1	100	30	Shaly sandstone, thin-bedded, grayish-brown; interbedded with dark-yellowish-orange laminations of quartzitic sandstone and laminated grayish-red friable shales. Unit grades into greenish-black, glauconitic, shaly, coarse, clear sandstone. Some beds burrowed.
			ROME FORMATION
2	34.2	10.25	Quartzitic sandstone, pale-brown, thick bedded at the bottom becoming medium to thin bedded at the top; interbedded with thin dark-yellowish-orange shales and grayish-red shales. Shales form less than 20% of the unit.
			FAULT
3	40	12.0	Shale, olive-gray, laminated; with very thin bands of light-greenish-gray quartzite. Some shales are sandy and friable becoming dark greenish gray at the top. Unit partly covered. Ripple marks are clear on exposed bedding planes. Shale more than 60%
4	20	6.0	Quartzite, pale-yellowish-brown, thin- to medium-bedded; and dark-greenish-gray very thin bedded silty shales.
5	3.5	1.05	Quartizite, dark-yellowish-orange, thinly bedded; with little or no shale.
6	7.3	2.2	Quartzite, greenish-gray, thin-bedded; with brownish-gray beds. Beds badly shattered and fractured.
7	21.6	6.5	Shale, greenish-gray, laminated; interbedded with thin bands of quartzite and greenish gray laminated glauconitic coarse sandstone. The greenish gray shale grades into grayish red laminated shales. Drag folds due to thrust faulting.
8	8.3	2.5	Quartzite, dark-yellowish-brown, very thin, evenly bedded; interbedded with laminated dark-greenish-gray silty shales.
9	6.0	1.85	Quartzite, medium- to thin-bedded, greenish-gray fractured and shattered.
			FAULT
10	8.3	2.5	Quartzite, dark-yellowish-orange, thick-bedded at the bottom, becoming evenly thin bedded at the top with dark-greenish-gray bands. Badly fractured. Quartzite shale less than 10%.
11	6.6	2.0	Shale, greenish-gray, laminated; interbedded with dark-yellowish-brown shales with very thin to thin grayish orange quarzite bands. Shales become pale brown and dark greenish gray at the top of the unit. Ripple marks; shale about 60%.
12	6.0	1.8	Quartzite, light-bluish-gray, thin- to medium-bedded; in some places very light gray and mottled pale yellowish orange bottom and top of individual beds. Shales relatively sparse except along bedding planes. Some quartzite beds show very thin dark gray and pale yellowish orange laminations. Large ripple marks.
13	1.7	0.50	Quartzitic sandstone, pale-brown, fine-grained; interbedded with grayish-green silty shale forming flaser-like structure. Ripple marks; less than 20% shale.
14	1.5	0.45	Quartzitic sandstone, pale-brown, coarse, medium unevenly bedded; with limonitic blotches. Shattered and fractured.
15	4.2	1.25	Shaly sandstone, pale-brown, thinly bedded; becoming thicker at top of the unit; interbedded with laminated dark-greenish-gray sandy shales. Ripple marks and micro-crossbedding in troughs of ripple marks.
16	4.8	1.45	Quartzite, grayish-orange, very thinly bedded; with light-greenish-gray silty shales at the bottom. Silty shale full of burrows, unit has ripple marks.
17	10.6	3.2	Quartzite, pale-brown, thick bedded at the bottom becoming medium to thin bedded at the top; interbedded with very thin dark greenish gray silty shales. Ripple marks. Shale less than 10%.

Unit	Thickness (feet)	(meters)	Description
18	7.0	2.40	Quartzite, dark-greenish-gray, thick- to medium-bedded; interbedded with laminated light greenish gray shaly fine- to medium-sandstone. The shaly sandstone laminations are between bedding planes of the quartzite.
19	15.0	4.50	Shale, dark-yellowish-brown, silty, laminated; with medium-bluish-gray sandy shale bed 20 cm. thick at the bottom of the unit. Unit contains very thin evenly bedded light bluish gray quartzite. A few very thin beds of greenish-black, coarse glauconitic sands are present. A thick bed of grayish-yellow shaly siltstone contains abundant burrow casts. Small scale crossbedding in the glauconitic sands. Burrow casts. Approximately 50% shale.
20	1.6	0.50	Quartzite, dark-gray, very thin bedded; interbedded with shaly fine- to medium-grained sandstone. Quartzite bands show clear laminations of pure quartzite and greenish-black glauconite.
21	5.3	1.60	Quartzite, pale-brown, very thin to thin unevenly bedded; mottled greenish black at the top and bottom of the beds; and interbedded with laminated dark-green shaly sands. Ripple marks.
22	2.6	0.8	Quartzite, greenish-gray, medium-bedded; with dark yellowish orange blotches on the surface. Quartzites are interbedded with greenish-gray very thin bedded to laminated shaly medium-grained sandstone.
----------	----------	----------	FAULT
23	6.0	1.80	Sandstone, shaly, greenish-gray, fine- to medium-grained; interbedded with shaly siltstones and shales; badly weathered; some horizons are burrowed. Quartzitic sandstone, medium- to thick-bedded, nodular. Approximately 10% shale.
24	2.8	0.85	Shale, grayish-red, flaky, friable; interbedded with pale red thin quartzitic fine sandstone at the top. 50% shale.
25	15.0	4.50	Quartzite, grayish-red, thin- to medium-bedded; interbedded with dark-greenish-gray laminated shaly sandstone. A few laminations of greenish-black coarse glauconitic sandstone.
----------	----------	----------	FAULT
26	10.0	3.00	Shale, grayish-brown, friable; laminated with very thin bedded dark greenish gray quartzite; with greenish-gray sandy shales at the bottom of the unit. Drag folds. Approximately 80% shale.
27	5.3	1.60	Quartzite, pale-yellowish-brown, thinly bedded; interbedded with hematitic laminated silty shales; some quartzite beds are dark greenish-gray.
28	12.6	3.80	Quartzite, thick-bedded, moderate-greenish-yellow; with thin beds of siltstone and dark-greenish-gray, fine- to medium-grained glauconitic sandstone. Medium- to thin-bedded quartzites are greenish gray with a darker greenish gray weathered surface.
29	2.3	0.70	Shale, grayish-brown, friable, thin-bedded; interbedded with thin quartzitic fine sandstone. Approximately 60% shale.
30	15.0	4.50	Quartzite, pale-brown, medium- to thick-bedded; interbedded with very thin dark greenish shales. Less than 10% shale.
31	5.0	1.50	Quartzitic sandstone, grayish-red, fine-grained, thick, hematitic; interbedded with laminated flaky grayish-red friable shales. Flute marks, ripple marks and hematitic shaly nodules. Shale about 30% of unit.
32	4.6	1.40	Sandstone, greenish-gray, medium-bedded, fine-grained with reddish surfaces. Greenish-gray shale at the top.
33	6.6	2.00	Quartzitic sandstone, greenish-gray, thin- to medium-bedded; with dark-greenish-gray shale at the bottom.
34	1	0.3	Sandstone, shaly, grayish-red, fine- to medium-grained.
35	0.5	15	Quartzitic sandstone, dark-greenish-gray, thin-bedded.
36	3.3	1.00	Quartzitic sandstone, dark-yellowish-brown, medium- to thin-bedded.

Unit	Thickness (feet)	(meters)	Description
37	10	3.00	Sandstone, shaly, grayish-brown, medium-to thin-bedded, hematitic.
----------------------------			FAULT
38	2.6	0.80	Quartzitic sandstone, brownish-gray, thin-bedded; with laminated grayish-red shales at top of the unit. About 40% shale.
39	3.5	1.05	Quartzite, light-bluish, medium to very thin bedded; mottled greenish gray with dark greenish gray thinly laminated micaceous shale.
40	5.3	1.60	Shale, greenish-gray, laminated friable at bottom of unit overlain by laminated grayish-red shales interbedded with laminated dusty blue-green glauconitic quartzitic sandstone.
41	30	9.00	Sandstone, shaly, fine- to medium-grained, greenish-gray to medium-bluish-gray; sandstone is interbedded with quartzitic sandstone and shales of various colors; bedding is not clear due to distortion. Unit distorted by folding and faulting. It is jointed and fractured.

STOP 4: DEPOSITIONAL ENVIRONMENTS—MUDBANKS AND "LAKES"—IN THE MOCCASIN FORMATION, RACCOON VALLEY, KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

Depositional environments in the Moccasin Formation are similar in many ways to environments in the upper part of the Mascot Formation (STOP 5). The lithologies of the Moccasin and Mascot are different and reflect major differences in the depositional basins; i.e., the Mascot apparently was deposited in hypersaline lagoons, whereas the Moccasin was deposited in lagoons more open to the sea. The formations have many sedimentary features in common, however, and these indicate that the same processes were operative in both of the major environments.

Both Mascot and Moccasin were interpreted in terms of mudbank-"lake"[1] environments similar to those of Recent deposits in Florida Bay. Florida Bay is about 600 square miles of very shallow water (less than 10 feet deep) between the southern tip of Florida and the northern Florida Keys. The sediments in the Bay are almost all calcareous; in contrast, those of the Moccasin contain much more terrigenous clay and silt. Depositional environments in Florida Bay were described by Ginsburg (1956) and summaries were compiled by Ginsburg (1964) and Scholl (1966). There, mudbanks are laterally anastomosing bodies, mostly subtidal, that are separated by deeper (10 feet) subtidal basins locally called "lakes." Where washed by tidal currents the subtidal regions contain an abundance of shelly sediment.

About 320 feet of the Moccasin are exposed at STOP 4. The lower beds of the formation are covered, but were cored nearby. The upper part of the section is missing because Rome is thrust over the Moccasin by the Copper Creek fault. The strata may be grouped into two main types, the very fossiliferous gray limestones and the sparingly fossiliferous greenish-gray, yellowish-gray and grayish-red lime mudstones. The fossiliferous limestones are assigned to "lake" facies, and mudstones are representative of mud-bank deposits (fig. 19).

"LAKE" DEPOSITS

"Lake" facies include: 1) biosparite and biopelsparite, some interbedded with shale; 2) interbedded biomicrite and biosparite; and 3) nodular and cobbly weathering micrite interbedded with shale. The strata are thin to medium bedded and have irregular bedding surfaces. Where calcarenite is interbedded with finer grained rock, small cut and fill structures are abundant. The rocks are fossiliferous with an abundance of brachiopods, bryozoa, and ostracods. Trilobite fragments and pelmatozoan debris are common in some rocks; others are characterized by a pelecypod-gastropod fauna.

In some "lake" beds fossils are abraded; in others they are not, thus indicating that conditions ranged from quiet waters to at least moderate currents. Interbedded micrite and calcarenite is indicative of fluctuating conditions, perhaps seasonal, perhaps tidal. Intraclasts zones attest to

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[1] Shallow semi-isolated subtidal basins (Ginsburg, 1956; Scholl, 1966).

episodes of faster currents that were probably generated by storms. Some of the clasts were derived from the immediately adjacent beds, but others are characteristic of mudbank facies and are evidence that the mudbanks and "lakes" were contemporaneous.

Nodular and cobbly micrites interbedded with shale are commonly at the top of "lake" sequences just below mudbank deposits. Strata such as these probably formed where wave and current activity winnowed fine material from the flanks of subtidal mudbanks; these sediments were then washed into quieter waters nearby where they mixed with "lake" derived lime muds.

MUDBANK DEPOSITS

Where fully developed, the progradational mudbank environment is characterized by an ascending sequence of 5 types of strata: 1) laminated mudstone facies, 2) green mudstone facies, 3) red and green mudstone facies, 4) red mudstone facies, and 5) red shale facies. Each facies is diagnostic of a specific part of a mudbank, and the sequences represent the construction and the lateral migration of the banks over adjacent "lake" deposits.

Laminated Mudstone Facies

The deposits at the base of the mudbanks are characteristically evenly laminated to thin bedded clay and silt-sized limestones, but some beds are rippled. Some beds contain intraclasts, and others have lenses or nodules of dark-gray chert similar to the chert in "lake" deposits below. Microscopically, the rock is well laminated, with thin layers of clay separating layers of broken fossils. The fossils, which are well sorted pieces of trilobites, ostracods, bryozoans, and brachiopods, make up as much as 15 percent of the rock. These fragments apparently were swept from "lakes" by tidal currents and washed onto nearby lower parts of mudbanks. Some clay laminae are in wavy, irregular, and anastomosing films; in contrast with the more regular sedimentary laminae, these are interpreted to be of organic origin, possibly algal. In that case the wavy laminae represent periods of relative quiet waters when algae could grow and bind the previously deposited shelly sediment.

Green Mudstone Facies

The green mudstone facies is similar to, but not nearly so well laminated as, the laminated mudstone facies. The rock is argillaceous lime mudstone with interbeds of relatively pure calcilutite and beds are up to 0.5 foot thick. Microscopically, the rock ranges from intrapelsparite to intrapelmicrite, some with layers of ostracod biopelsparite, brachiopod biomicrite, and burrowed, algally laminated micrite. In general, "lake" -derived fossil fragments in these units are smaller both in number and size than in the laminated units below. The burrowed and poorly bedded mudstone, the small fossil fragments, and the position in sequence of the unit indicate that this facies represents sediment that accumulated higher on the mudbank and in generally quieter waters than laminated units below.

Red and Green Mudstone Facies

Next in sequence are units characterized by red and green coloration. Argillaceous greenish-gray and grayish-red lime mudstones are interbedded with less argillaceous gray limestones. Zones of ostracods are common. Some beds are laminated, some contain intraclasts, and others contain well developed shrinkage cracks. In general, the amount of limestone decreases upward, and some of the limestone beds contain birdseyes.

Small calcite-filled birdseyes are generally horizontally aligned. Larger ones, some one-quarter inch across, are more randomly distributed, indicating that they formed by filling of gas bubbles which were large enough to migrate upward through the soft sediment (Kendall, 1969).

Microscopically, the units are algally laminated pelmicrite with crinkly horizontally distributed birdseyes, and ostracod biosparite to ostracod biomicrite with a few trilobite and pelmatozoan fragments. Intraclasts are algally laminated. Burrows are common; some are horizontal and others are vertical.

The position in sequence, coloration, birdseyes, burrows, and general lack of mud cracks suggests a shallow subtidal to low intertidal origin for these sediments. Horizontally aligned crinkly birdseyes may be related to alternate wetting and drying of sediment as in an intertidal environment (Shinn, 1968), or may fill voids caused by growth expansion of algal mats. Vertical burrows are characteristic but not confined to intertidal and shallow subtidal sediments, and horizontal burrows are suggestive of subtidal deposits (Walker and Laporte, 1970, p. 93).

Red Mudstone Facies

The red mudstone facies and the overlying red shale facies are the most oxidized and least calcareous sediments in the sequence. The mudstones are grayish red and greenish gray; some are laminated, some contain intraclasts; and some are mottled. Except for a few relatively pure ribs of calcilutite, bedding is poorly defined and uneven. Shrinkage cracks are abundant, and although some of the cracks were open and filled with sediment from above, most are hairline fractures. Microscopically, the rock is laminated pelmicrite with a few short vertical burrows, and laminated dismicrite with horizontally distributed birdseyes.

Because of the oxidized nature of the sediment, position in sequence, horizontally distributed birdseyes and abundant shrinkage phenomena, this facies probably accumulated in very shallow subtidal, intertidal or low supratidal environments on the top of mudbanks.

However, in mudbank-"lake" environments depth-related terminology has little meaning. For example, the water over Recent Florida Bay mudbanks is generally very shallow, with depths from a few feet to a few inches. Rarely do these mudbanks have supratidal components and those that do are more common toward the head of the Bay. Even there, supratidal regions are small in area where compared with the subtidal area of the banks. Florida Bay mudbanks inhibit water circulation so greatly that tidal ranges are restricted from a foot or so to only a few inches. Salinity fluctuates from below normal to well above normal and similar salinity fluctuations may have been responsible for the formation of the shrinkage cracks so prevalent in the upper Moccasin beds (Donovan and Foster, 1972).

Red Shale Facies

The red shale facies consists of about a half-dozen beds in this exposure, each a foot or less thick. The beds are very even and concordant with adjacent mudstone beds. One is associated with well-developed shrinkage cracks in the beds below, and another contains a few intraclasts of more calcareous mudstone.

The red shale facies is interpreted to represent very fine deposits which accumulated on the banks where they were protected from waves and currents by the slope of the bottom. Ginsburg (1956, p. 2403) showed that this process was responsible for the distribution of sand and mud-sized particles on mudbanks in Florida Bay.

THE MUDBANK - "LAKE" MODEL

The mudbank-"lake" model for the Moccasin was constructed from vertical sequences at Stop 4 (fig. 20). The lower part of the section, where both "lake" and mudbank facies are thick, is considered to be a subenvironment marginal to a more open carbonate platform. Thinner "lake" and mudbank facies at the top of the exposure are interpreted to represent bay-interior subenvironments. However, the abundance of fossils in "lake" deposits throughout the Moccasin suggests that all of the rocks were deposited in the tidal exchange zone, with little or no reduction of circulation in the bay interior.

Ginsburg (1956, p. 2400) divided Florida Bay into subenvironments based upon differences in hydrography and circulation-salinity across the Bay. Depth variations there are much smaller than thickness variations in the Moccasin, and circulation-salinity variations across the Bay are prominent. These differences, together with the difference in relative amounts of terrigenous sediments show that Florida Bay environments are not precisely analogous to those of the Moccasin, but in the writers' opinion they are close enough to make a valid comparison.

MIDDLE ORDOVICIAN SECTION, I-75, RACCOON VALLEY, KNOX COUNTY, TENNESSEE

SECTION MEASURED ALONG INTERSTATE

Bed No.	Thickness (feet)	Lithology
		THRUST FAULT
31	1.3	CALCISILTITE, medium-gray, grayish-red, mottled, silty; weathers yellowish gray, one bed, even, irregular,[2] with ostracods, birdseyes, shrinkage cracks.
30	3.6	CALCISILTITE, silty, argillaceous, mottled, yellowish-gray, greenish-gray and grayish-red; with scattered ostracods, fossil fragments and birdseyes in non-red rock; shrinkage cracks.
29	3.9	CALCISILTITE, silty argillaceous, medium-gray; weathers yellowish gray, beds 0.4 to 0.7 feet, even, irregular, some laminated; with shrinkage cracks, birdseyes, and scattered ostracods.
28	17.3	INTERBEDDED, CALCILUTITE to CALCARENITE, coarse-grained, and shale, medium-gray; weathers yellowish gray, light gray or greenish gray; beds ½ to 6 inches, even, irregular, some cobbly weathering; calcarenite beds with abundant fossil fragments, (bryozoans, etc.). The more argillaceous beds tend to be laminated.
27	4.0	CALCILUTITE to CALCARENITE, coarse-grained, medium-gray; with thin beds and partings of calcareous shale, medium-gray, very fossiliferous (brachiopods, bryozoans, cephalopods) beds about 1-inch, cobbly weathering.
26	8.5	CALCILUTITE to CALCISILTITE, medium-gray; weathers yellowish gray, very argillaceous or silty, beds 1 to 2 feet, even, irregular; with numerous birdseyes, ostracods.
25	4.4	CALCILUTITE to CALCISILTITE, medium-gray, generally laminated; with ostracod beds up to 0.05 foot; weathers shaly.
24	1.6	CALCILUTITE to CALCARENITE, as bed 22 below.
23	1.2	CALCARENITE, coarse-grained, medium-gray, very fossiliferous (brachiopods, etc.).
22	3.6	CALCILUTITE to CALCARENITE, very fine grained, medium-light- to medium-gray; beds 0.05- 0.1 foot, uneven, cobbly weathering; with ostracods, bryozoans, brachiopods; with partings of calcareous shale, medium-gray.
21	10.0	CALCISILTITE, silty, argillaceous, medium-light-gray; with some layers of calcilutite, beds 1 inch to 1 foot; weathers yellowish gray; some beds with birdseyes and elongate calcite blebs.
20	1.2	CALCILUTITE to CALCISILTITE, medium-light-gray, argillaceous, fossiliferous (brachiopods); beds about 0.1 foot thick, uneven.
19	24.0	MUDSTONE, calcareous, and CALCISILTITE, silty, argillaceous, medium-light-gray, greenish-gray, grayish-red; beds 0.1 to 1 foot, even, irregular; colors become more subdued upward; some beds laminated, some with ostracods; birdseyes abundant in upper part.

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[2] Even and uneven refer to short distance changes in bedding thickness that are less than or greater than 10 percent of the average bed thickness, respectively. Regular and irregular refer to the absence or presence of smaller scale features on bed surfaces.

Bed No.	Thickness (feet)	Lithology
18	0.4	SHALE, weathered, greenish-gray and grayish-red.
	19.0	CALCISILTITE (very calcareous mudstone), argillaceous, silty, medium-light-gray, grayish red in upper foot; weathers yellowish gray, some laminated, some with intraclasts, ostracods; with a few partings of calcareous shale up to 0.05 feet; beds around 1 to 2 feet thick, even, irregular, with birdseyes.

SECTION MEASURED ALONG FIRST BENCH

17	0.0-0.3	SHALE, weathered, yellowish-gray.
	6.0	MUDSTONE, greenish-gray and grayish-red, calcareous, generally as below.
	0.4	SHALE, grayish-red, generally as below.
	3.0	MUDSTONE, calcareous, grayish-red, generally as below.
	0.5	SHALE, grayish-red, as below.
	7.5	MUDSTONE, calcareous, grayish-red, some greenish gray, generally as below.
	0.4	SHALE, as 0.7 feet below.
	7.3	MUDSTONE, calcareous, grayish-red and greenish-gray, generally as 19 feet below.
	0.7	SHALE, calcareous, grayish-red.
	19.0	MUDSTONE, calcareous, grayish-red and greenish-gray; with some ostracod layers, some laminated, some mottled (burrowed) some with intraclasts; some with mudcracks, and shrinkage cracks, beds 0.5- 1 foot, even, irregular.
16	8.5	MUDSTONE, calcareous, laminated, medium-light-gray; weathers light gray or yellowish gray; with numerous thin zones (up to 0.2 feet thick) of ostracods; beds 0.5 to 1 foot, even, irregular; ostracods fill mudcracks near middle.
15	16-17	INTERBEDDED, calcilutite, argillaceous, medium light gray, and shale, weathered, yellowish gray to dusky yellow, beds 0.05 to 0.5 foot, even, irregular, some laminated, with lenses of ostracods.

SECTION MEASURED ALONG INTERSTATE

14	1.5	CLAY, medium-gray to greenish-gray, deformed; with chertified gastropod bed at top; bentonite (?).
13	8.7	CALCILUTITE to CALCARENITE, fine-grained, medium-gray; beds 0.05 to 0.5 feet, even, irregular; with fossil fragments (bryozoans, brachiopods), intraclasts.
12	2.0	INTERBEDDED, calcilutite, medium-gray, and shale, greenish-gray, cobbly weathering, fossiliferous.
11	15.3	INTERBEDDED, mudstone, shale, and calcilutite as in 7 and 9 below; with numerous intraclasts; measured to highest red bed.
10	3.5	INTERBEDDED, calcisiltite, and shale, medium-gray; beds 0.1-0.2 feet, even, irregular, with abundant bryozoans.
9	7.6	INTERBEDDED, as 20.0 feet below; some well-burrowed; calcilutite bed with fossil fragments and intraclasts at top, with some shrinkage cracks.
8	1.0	SHALE, mudstone, grayish-red, greenish-gray, calcareous; with intraclasts.
7	20.0	INTERBEDDED, mudstone, calcareous, greenish-gray, grayish-red, and calcilutite to calcisiltite, light- to medium-light-gray, some laminated, some with birdseyes, some with intraclasts, beds 0.05 to 0.1 foot, even, irregular.
6	10.0	INTERBEDDED, calcilutite, medium-light-gray and greenish-gray, and mudstone, calcareous, medium gray, generally as below but not as well laminated; laminated beds to 0.5 foot, with a few beds of calcisiltite to fine-grained calcarenite, with some intraclasts.
5	15.0	CALCILUTITE to CALCISILTITE, medium-light-gray to greenish-gray; some beds laminated, some with intraclasts; with lenses and nodules of dark-gray chert up to 2 inches across; micrite beds up to 0.2 foot, even, irregular; with a few poorly developed shrinkage cracks, some beds rippled.
4	34.0	CALCILUTITE to CALCARENITE, fine-grained, medium-light- to medium-gray; beds 0.05 to 1.0 foot, even, irregular, some with greenish-gray splotches; generally fossiliferous (brachiopods, bryozoans, etc.); some zones with intraclasts; with irregular lenses of dark-gray chert up to 0.2 foot across throughout the bed; fossil-fragmental calcarenites are interbedded with micrite; with some cut and fill.
3	6.2	CALCARENITE, fine- to coarse-grained, medium-light-gray, bioclastic; with a few interbeds of shale, as below; some beds crossbedded (gently).
2	3.0	INTERBEDDED, calcilutite and shale, light-olive-gray, cobbly, some of the limestones are rippled.
1	18.0	INTERBEDDED, calcilutite to calcarenite, coarse-grained, medium-light-gray and shale, weathered, yellowish-gray to dusky yellow, beds 0.02 to 0.3 foot, uneven, extremely fossiliferous (brachiopods, bryozoans, gastropods, ostracodes), finer grained limestone beds tend to be thinner bedded, cobbly weathering; a few beds with small intraclasts.

BASE OF SECTION

MICROSCOPIC DESCRIPTION

Bed No.	Description
31	DISMICRITE, faintly laminated, with vertical burrows (?).
30	DISMICRITE, laminated, with horizontal crinkly birdseyes, some burrowed, with a few small intraclasts, several ostracod shells.
29	MICRITE, faintly laminated, with dismicrite-filled vertical crack.
27	MICRITE, with a bed of ostracod biopelsparite and large cryptostome bryozoans.
26	DISMICRITE, poorly laminated.
25	MICRITE with algal laminae, vertical burrows; bed of ostracod biopelsparite grades upward into brachiopod biomicrite with treptostome bryozoans.
24	MICRITE, with faint vertical burrow.
23	BIOSPARITE with patches of micrite, ostracods, pelmatozoan debris, bryozoa, intraclasts of biomicrite.
22	MICRITE, with very thin laminae.
21	DISMICRITE, algally laminated, with pellet-filled vertical birdseye.
20	OSTRACOD PELSPARITE, laminated, with a few bryozoans.
19	OSTRACOD BIOMICRITE, laminated, horizontally distributed birdseyes, micro-tepee structures, laminated intraclasts; rock is a micro-breccia.
18	MICRITE, slightly dolomitic.
17	PELMICRITE, grumose texture, probably burrowed, some laminated vertical burrows, few intraclasts.
16	OSTRACOD BIOSPARITE interbedded with micrite, laminated, some algal, with ostracods in vertical crack.
15	MICRITE, finely laminated.
13	BRYOZOAN-TRILOBITE PELSPARITE with *Hedstroemia* (green alga).
11	PELMICRITE and DISMICRITE, laminated, with vertical burrows; some birdseyes are small horizontally distributed, others are vertically aligned.
10	BRYOZOAN BIOPELSPARITE, with trilobite fragments, ostracods; bryozoan-trilobite fauna.
9	OSTRACOD BIOPELSPARITE lense in laminated pelmicrite; algally laminated with horizontally distributed crinkly birdseyes; trilobite, pelmatozoan fragments, vertical burrows.
7	PELMICRITE, algally laminated, with horizontal and vertical burrows, fossil fragments, fine birdseye, *Solenopora*? (red alga).
6	INTRAPELSPARITE with patches of intrapelmicrite, pellets are intraclasts, fossil fragments, some algal laminae, glauconite is in pellets; with horizontal burrows.
5	ALGALLY LAMINATED MICRITE, 10 to 15 percent broken fossil fragments (trilobite, ostracod, bryozoan, brachiopod); with algally laminated intraclasts; dolomite rhombs are in small amounts and are concentrated in the laminae.
4	BIOMICRITE, fossils unabraded, molluscan-bryozoan-brachiopod fauna, with trilobite fragments. Some fossils are filled with spar.
3	BIOPELSPARITE, fossils abraded, intraclast with mollusk shell, *Hedstroemia*; bryozoan-brachiopod fauna; several intraclasts are argillaceous micrite.
2	MICRITE, laminated; small pellets of dolomite in micrite matrix; some laminae are micro-ripples, others contain features suggestive of algal filaments.
1	BIOSPARITE, with some pellets, shells oriented convex upward, spar-filled below; shells poorly sorted, generally unabraded; bryozoan-brachiopod fauna; with intraclasts of argillaceous micrite.

ROAD LOG

Interval	Cumulative	
0.4	19.8	Exit 117, Raccoon Valley Exit; leave Interstate for lunch stop.
0.3	20.1	Head of ramp; turn right (east) on Raccoon Valley Road.
0.1	20.2	Lunch Stop. Fossil collecting from Chickamauga in stripped area on left (north) side of road. Return to Interstate 75 North.

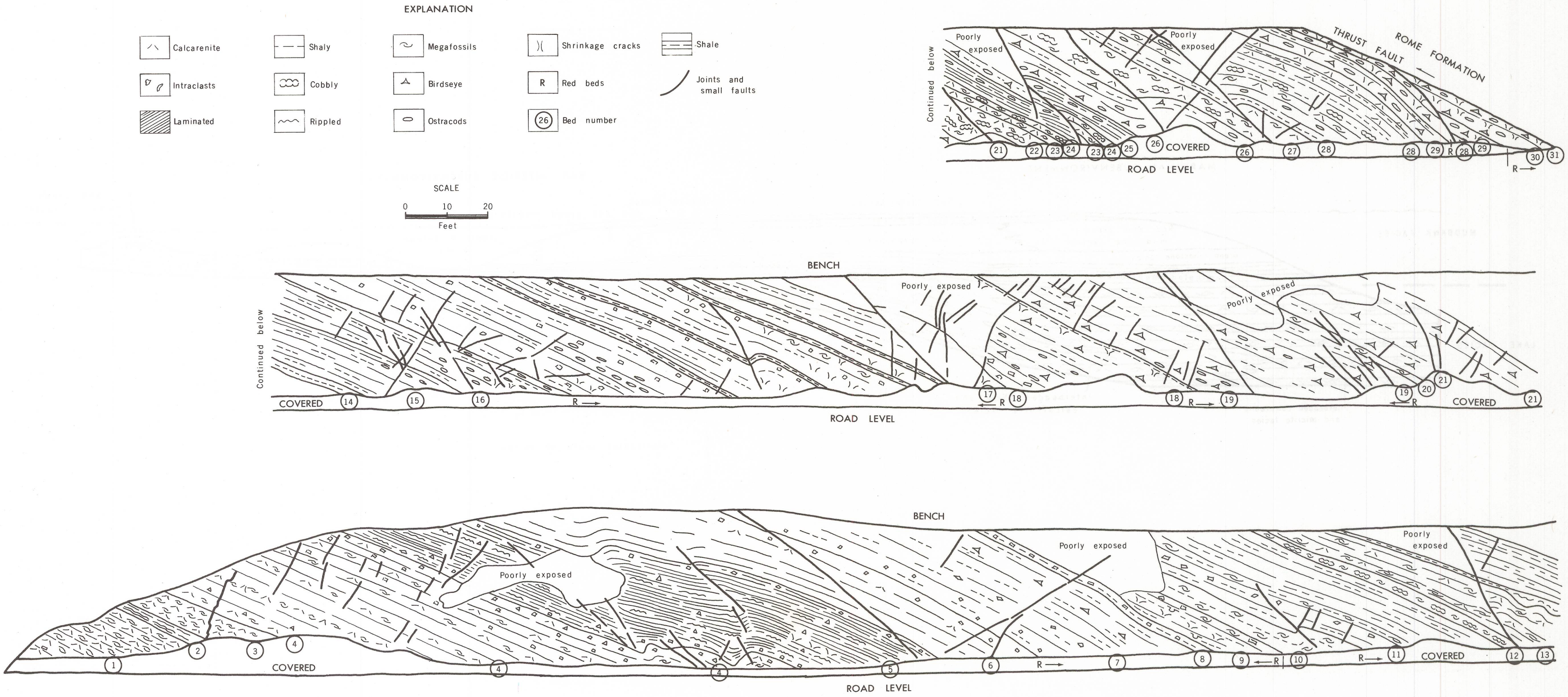

Figure 19. Moccasin mudbanks and "lakes."

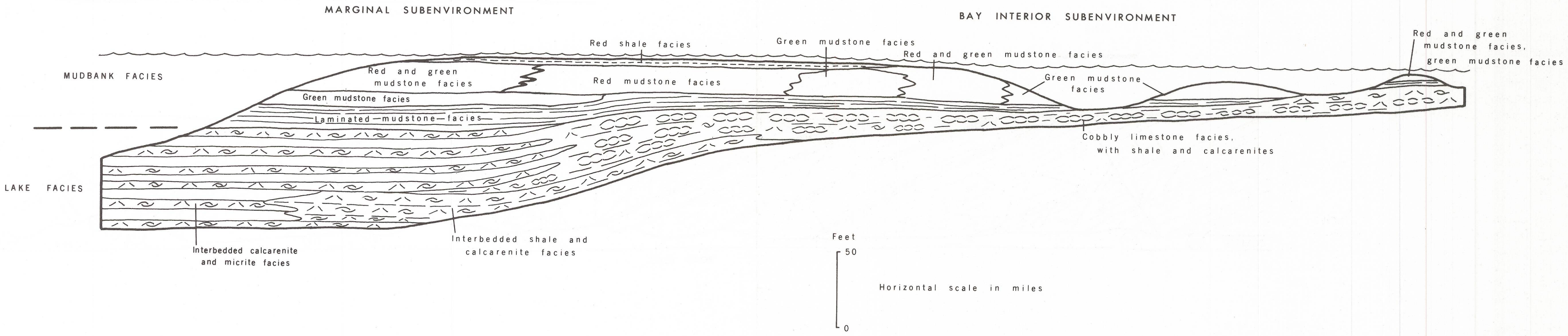

Figure 20. Generalized model of mudbanks and "lake" facies in the Moccasin.

CHICKAMAUGA BIOGENIC MOUND DEPOSITS, RACCOON VALLEY, KNOX COUNTY, TENNESSEE

BY

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This stop was selected to illustrate another aspect of the Middle Ordovician carbonate complex in the belts northwest of the Saltville fault. Whereas the road cuts display stratigraphic or vertical characteristics of the environments, this stop provides an opportunity to examine the areal dimensions, gross internal composition, and variable surface features of the rocks, and to identify some of the organisms involved in the construction of one of the repetitive depositional components in the Raccoon Valley section.

In contrast to the prominent, massive, wave-resistant, organically framed and cemented Holston reef ridge or tract which is assumed to lie to the southeast during the time interval represented by the Raccoon Valley rocks at this stop and, perhaps, provided a protective barrier for the environments in which they were formed, the biogenic structures in view here are interpreted to be bank or mound deposits or build-ups. Within the bay complex, if such an analogy may be drawn, these environments were disposed marginally to each other and to a lagoon or basin of some extent in a direction southeastward across the valley and parallel to the strike of the beds.

In outcrop, the mound or bank facies in this part of Zone III, as it is designated elsewhere in this volume, occurs in two shape classes. One is fine-grained, more massive, areally restricted, and less fossiliferous; the other is fine- to coarse-grained, stratiform, persistent along strike, and more fossiliferous. Both types are gradually or abruptly terminated upward in the section by argillaceous muds believed to have been introduced into the environment in advance of an encroaching "argillaceous influx." There is evidence of channel scouring on the bedding surfaces of some units and the lensoid massive facies alternate with muddy channel deposits. Differential weathering has separated the more argillaceous units from the purer carbonate units.

Silicification of the massive units is localized, irregular, and commonly internal. The stratiform units break down along strike and release thin, small rectilinear, flinty chert fragments into the ferruginous regolith. This process produces a great quantity of fossil debris in a narrow to broad talus apron parallel to the units, Silicification of many fossils can be traced into the regolith and is apparently a recent phenomenon in these cases, probably related to ground water movement. By this means, remains of many of the organisms involved in the construction of the mounds and banks have been preserved and can be identified. Others, however, can be observed only in the parent rock.

In comparison with the well-bedded stromatolithic platform buildups within the upper Knox and the stromatoporoid units in the lower zones in Raccoon Valley, the mounds or banks appear to have had low to high relief. Relief on the depositional surface, current truncation, inequal energy distribution during growth, and variable resistance due to diagenetic effects all might be expected to contribute to the shape of the biogenic structures. There seems to be little doubt that retention of the basic character of the structures required, initially at least, development below wave base or in an area of low to moderate current activity. Subsequent resistance was added as the banks and mounds were constructed by sediment bafflers and binders, predominantly bryozoans and algae with some pelmatozoans. Within the stop area a minor bank type composed of packed strophomenid brachiopod shells and recrystallized lime mud contrasts with the porous skeletal petrofabric of the baffle mounds and banks which come apart rapidly when exposed to weathering.

Aside from the widely distributed binder and baffler fauna with trapped debris, much of which appears to be indigenous to the community, localized clusters of sessile benthos and other epifauna can be seen at this stop. This fauna consists of rostrate and thin-valved, straight hinged small to medium sized brachiopods, small, low-spired gastropods, and trilobites. The trilobites appear to belong to two groups: local, benthic types commonly fossilized as casts and molds in chert pieces, and more vagrant, perhaps pelagic, types represented by unmineralized cephalic and pygidial remains some of which may be molts. *Amphilichas* (*Acrolichas*), *Illaenus,* and *Bumastus* are among the trilobites in this zone. Brachiopods includes species of *Mimella, Rhipidomena, Protozyga, Macrocoelia,* and *Fascifera.*

Numerically, the bryozoans were clearly the dominant organisms in the stratiform banks as both binders and bafflers, and in the more massive mound or bank as binders. Probably the whole range of trepostome habit from encrusting, bifoliate, and frondescent to ramose, hemispherical, and massive is on display here. Forms referable to *Batostoma, Hallopora,* and *Eridotrypa* are present in this zone along with monticuliporids, constellarids, and at least one phylloporinid. A species of the bifoliate cryptostome *Rhinidictya* and a ptilodictyid are important binder taxa in both the stratiform and massive banks and mounds. The sponge *microspongia* (*Hindia*) *parva* Ulrich and the sponge-like *Nidulites pyriformis* Bassler and *N. ovoides* Butts are regarded as direct or indirect contributors to the stability of the banks but their distribution is more restricted. Remobilization of silica initially trapped or used by some of these organisms during the build-up stages is believed to account for secondary silification features in some of these rocks.

A considerable amount of pelmatozoan debris is present in the stratiform banks. The camerate crinoids include a species of *Diablocrinus.* Fragments of possible palaeocrinoids, carabocrinids, and glyptocrinids are present in the debris also. The cystid *Echinosphaerites* has been found in this zone but specimens are in badly weathered condition and are difficult to recognize. Columnals in growth position in some units suggest that the surface of these banks were populated by pelmatozoans from time to time but not uniformly.

The larger cephalopod mollusks, such as the nautiloid *Gonioceras* and a few isolated orthocones occur here in the mudstones. Similarly, the larger gastropod *Maclurites* seems to be restricted to the more massive, fine-grained limestone facies in this part of the zone. *Oxydiscus* has been recorded from the bank facies and there are other small gastropods present.

A fuller discussion of the fauna and its age relationships is given elsewhere in this volume. Further study in this part of the zone is expected to add important details concerning the fauna and the environment.

Interval	Cumulative	ROAD LOG
0.1	20.3	Entrance ramp to I-75 North; proceed to end of entrance ramp and stop.
0.3	20.6	STOP 5: The Mascot Dolomite, a Lower Ordovician carbonate mudbank.

STOP 5: THE MASCOT DOLOMITE, A LOWER ORDOVICIAN CARBONATE MUDBANK*

BY

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INTRODUCTION

The upper 291 feet of the Mascot Dolomite (the youngest formation in the Knox Group) is continuously exposed along Interstate I-75 on the northwest side of Raccoon Valley. Approximately 80 percent of the Mascot is dolosiltite, and the remainder includes beds of very finely to medium crystalline dolomite, chert, sandstone, and shale. The Mascot can be subdivided into five facies on the basis of color and types and relative abundance of organic, sedimentary, and diagenetic structures (see figs. 21 and 22).

1. *Red mottled facies:* Dolosiltite, light-gray to greenish-gray within which grayish-red mottling is so pervasive that it tends to obscure most sedimentary features. Characteristically this facies contains abundant randomly oriented shrinkage cracks, numerous shale partings, and few thin beds of quartz sandstone (fig. 21).
2. *Red laminated facies:* Dolosiltite, light-gray, light-olive-gray, or greenish-gray with distinctive red laminae. In contrast to the red mottled facies, this facies contains abundant microcurrent structures, such as cross laminations, both starved and continuous ripple laminae, and minor scour-and-fill (fig. 21). Shrinkage cracks and shale partings are less abundant than in the red mottled facies, but beds of sandstone are more common.
3. *Dark-gray laminated facies:* Dolosiltite, light-olive-gray to olive-gray with distinctive dark-gray laminae. This facies contains the most sandstone beds and micro-current related structures, and the least shale partings and shrinkage cracks (fig. 21).
4. *Banded facies:* Dolosiltite, light-olive-gray to olive-gray, in 1- to 2-inch bands that may be laminated or mottled. This facies contains the most intraclasts which are derived mostly from facies 1, 2, 3, and more rarely 4.
5. *Stratiform algal stromatolite facies:* The most abundant algal stromatolites in the Raccoon Valley section have a growth form of discrete columnar elements with paper-thin vertically stacked laminae. The columns ranging from ¼ to 1 inch in diameter, are olive-gray, vuggy, finely to medium crystalline dolomite, and the areas between columns are very finely to finely crystalline, light-olive-gray dolomite. This difference in grain size and color produces a distinctly mottled rock, unlike any other lithic type in the Mascot Dolomite. The term "stratiform stromatolite" is used to designate this facies because thousands of the small columnar elements occur in laterally continuous growth layers, that closely resemble normal sedimentary layering (Harris, 1973). In the Raccoon Valley section all stratiform algal units are composed of algal columnals in growth position and algal debris in varying proportions.

CARBONATE MUDBANK ENVIRONMENT

Most primary and secondary features inventoried are common to facies 1 through 4 of the Mascot Dolomite but none of these elements are recognized in the algal facies (fig. 21). This difference in preservation appears related to marked differences in replacement texture. Facies 1 through 4 are dominantly composed of silt-size dolomite crystals that are not large enough to mask most primary structures, whereas, consistently the algal facies is composed of very fine to medium size crystals of dolomite that apparently obliterated previous sedimentary structures during the process of their development. The primary and secondary features in facies 1 through 4 emphasize that

(1) most features are present in some degree in most facies,

(2) each facies characteristically contains certain select elements in greater or lesser abundance.

(3) the distribution of some elements progressively

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*Publication authorized by the Director, U.S. Geological Survey increases or decreases from one facies to another (fig. 22).

(4) the relative abundance of shale partings, thin sandstone beds, and microcurrent structures may be used as a rough index to energy levels developed within and between facies (figs. 21 and 22).

Although differences in energy levels between facies 1 through 4 are detectable, this does not imply that large differences were involved. Rather the microscale nature of all current structures and the abundance of a single lithologic type (dolosiltite) favors an overall low energy environment. Locally, minor differences in physical and chemical factors within the environment apparently contributed to a lateral development of facies with detectable differences.

The shallow subtidal low-energy carbonate mudbank environment in Florida Bay appears to be a modern analogue of the Mascot environment. Florida Bay is subdivided by an irregularly spaced network of shallow mudbanks into a series of deeper more extensive shallow basins, commonly called "lakes" (Scholl, 1966). Relief in the bay is about 6 feet; depth of water averages less than 2 feet over the banks and as much as 10 feet in the lakes (Ginsburg, 1956). Environmental studies of Florida Bay by Ginsburg (1956) show that rather abrupt lateral changes from shallow bank to deeper lake produced variations in sediment size and constituents on a local scale greater than the regional changes across the bay. Because of better circulation, clay- and silt-size particles are commonly swept out of the lakes leaving a thin veneer of sand-size skeletal debris. In contrast, the banks, are composed dominantly of carbonate clay and silt as much as 10 feet thick, except where exposure to prevailing winds results in a local accumulation of sand-size skeletal debris. Because clay and silt far exceed the sand in Florida Bay, gradual filling of the bay would result in a carbonate facies dominated by clay and silt. However, should filling progress to the point where large tidal mudflats were developed, the relative simplicity of a subtidal facies dominated by a single lithology would be replaced by a more complex intertidal-supratidal mudflat facies. As described by Shinn, Lloyd, and Ginsburg (1969), a mudflat facies is characterized by (1) lack of uniformity in sediment types, (2) presence of recognizable construction features such as tidal channel bars, levees, and beach ridges, (3) abundance of

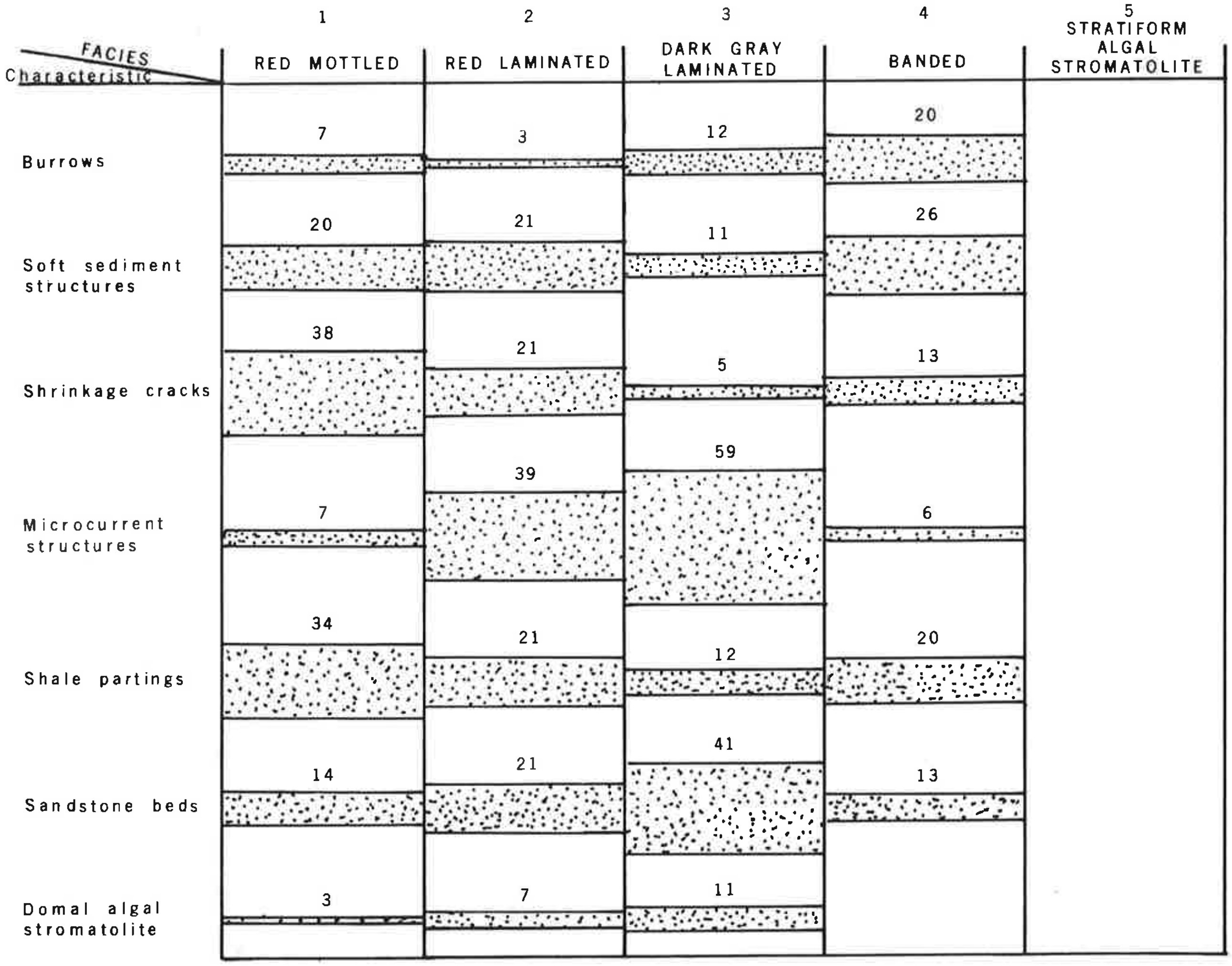

Figure 21. **Frequency distribution of primary and secondary features within the five facies of the Mascot Dolomite. Numbers above each bar is the percent of the total number of samples for each facies exhibiting a particular feature.**

Characteristic FACIES	Shale partings	Sandstone beds	Microcurrent structures	Relative energy levels
1 RED MOTTLED	High	Low	Low	Lowest
2 RED LAMINATED	Moderate	Moderate	High	Medium to highest
3 DARK GRAY LAMINATED	Low	High	High	Highest
4 BANDED	Moderate	Low	Low	Lowest to medium

Figure 22. The relative abundance of shale partings, thin sandstone beds, and microcurrent structures in facies 1 through 4, and an interpretation of the relative energy levels developed between facies within an overall low-energy environment.

desiccation features, and algal mats, and (4) distinctive erosional and abandonment of tidal channels. Facies characteristics of a tidal mudflat environment have not been recognized in the Mascot Dolomite section at Raccoon Valley. Instead, the Mascot section is more like a mudbank facies which on the basis of primary and diagenetic features can be subdivided into a bank and a lake subfacies.

The bank facies of the Mascot is typified by light-gray or greenish-gray dolomite that is intricately mottled grayish-red and contains abundant randomly oriented shrinkage cracks. The cracks are hair-thin features ranging from ¼ to 2 inches in length. Each crack is filled with hematite and is readily visible in hand specimens. Concentrations of hematite in the shrinkage cracks appears to be related to an internal chemical process that selectively extracted oxidized iron from the rock as much as ¼ inch from the crack and redeposited hematite as a crack filling. Donovan and Foster (1972) summarized the origin of small-scale shrinkage cracks which have been experimentally produced in fine-grained sediment and are thought to result from subaqueous shrinkage by a syneresis mechanism.

The vertical succession (figs. 23, 24) in the Raccoon Valley section suggests that most bank facies (facies 1) were flanked on one side by light-gray to greenish-gray red laminated dolosiltite (facies 2) and on the other side by stratiform algal stromatolites (facies 5). Distribution of insoluble residue across the change from bank facies to algal facies shows a direct relationship between the amount of clay residue and rock type (Harris, 1973). Clay content of stratiform algal stromatolites is usually less than one percent; in contrast the clay content of dolosiltite beds exceeds 5 percent. The low clay content of the algal beds implies that they grew in an environment where the current level was just large enough and consistent enough to prevent the accumulation of clay. The close relationship of bank facies and stratiform algal stromatolites appears to be similar to the zonation of animals and plants on the windward side of mud mounds such as Rodriguez Bank adjacent to Florida Bay (Turmel and Swanson, 1964).

In contrast to the shallow bank facies, where oxidation apparently contributed to the development of abundant grayish-red mottled to laminated dolosiltite, colors of rocks in the lake facies are light olive gray, olive gray, and dark gray, apparently reflecting a deeper water less oxidizing environment. The lake facies is dominated by dark laminated dolosiltite (facies 3) containing abundant current structures and by banded dolosiltite (facies 4) containing few current structures other than moderately abundant intraclast zones (fig. 22). Some intraclast beds contain a few reddish pebbles derived from the bank facies (facies 1 and 2), while others contain small pebbles similar to rock in facies 3 and 4.

As mentioned, there are a number of similarities between the Florida Bay mudbank environment and the inferred environment for the Mascot Dolomite. However, the Mascot has one feature not found in rocks of Florida Bay. This is the development of subtidal dolomite. Indeed, on a worldwide basis, numerous studies of Holocene carbonates have shown that dolomite is mainly restricted to supratidal areas, where penecontemporaneous replacement of calcium carbonate is by magnesium-rich hypersaline water (Harris, 1973). Although Holocene dolomite is mainly restricted to supratidal areas, the worldwide development of hypersaline water is not. For example, highly saline water with increased magnesium ion content does exist on the Great Bahama Bank (Cloud, 1962). Moreover, the distribution of magnesium in bottom sediments on the Bank west of Andros Island appears to be related to the configuration of a seasonally developed high salinity mass (Harris, 1973). Similarly rapid penecontemporaneous subtidal dolomitization may have been favored on ancient mudbanks, where the necessary chemical and physical factors favorable for the development of magnesium-rich hypersaline water may have existed. Extreme shallow water over the ancient bank could result in relatively high temperatures with increased evaporation rates, thus promoting the development of magnesium-rich hypersaline water necessary for dolomitization to operate. Perhaps the abundant shrinkage cracks in the bank facies of the Mascot simply reflects volume loss due to rapid penecontemporaneous dolomitization.

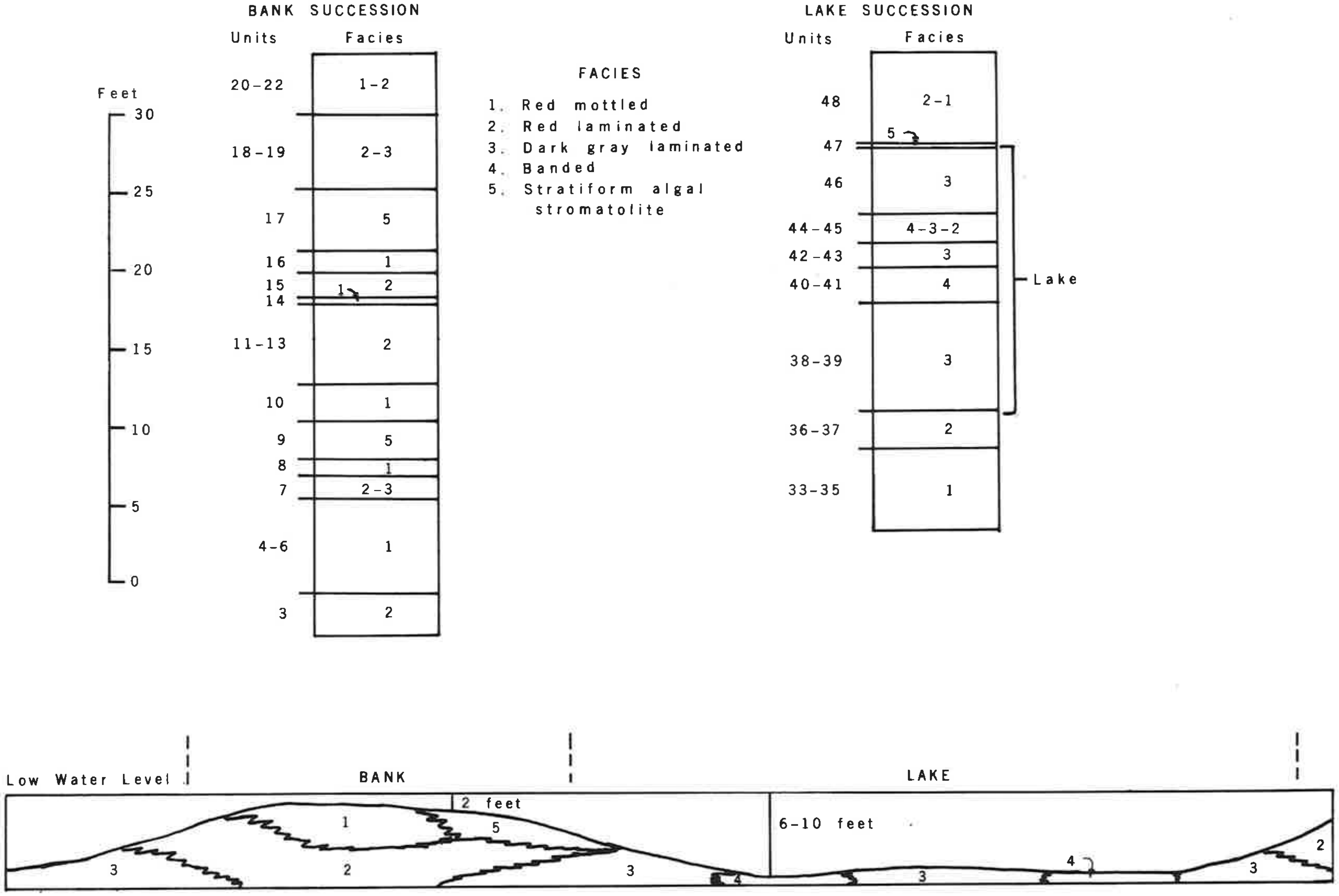

Figure 23. Columnar sections showing the close vertical relationship between facies 1-2-5 in the bank facies and facies 3-4 in the lake facies. Cross section is an interpretative mudbank sedimentation model based on the relation shown in the columnar section. Unit numbers keyed to measured section.

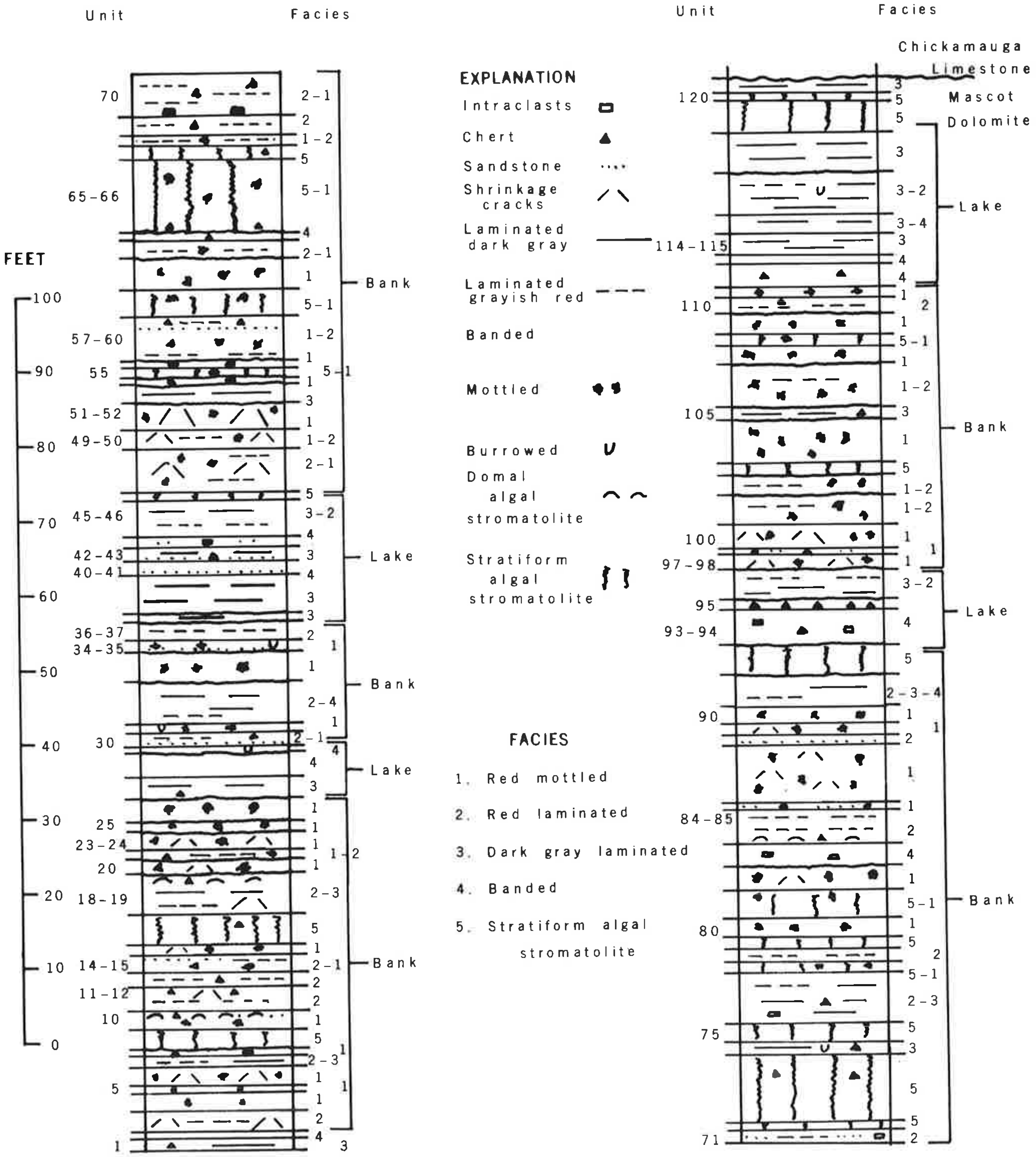

Figure 24. Columnar section of the Mascot Dolomite on I-75 in Racoon Valley. Unit 1 is the base of section.

STOP 5

MEASURED SECTION OF THE MASCOT DOLOMITE ALONG INTERSTATE I-75, IN RACCOON VALLEY

(UNIT 1 IS AT BASE OF SECTION)

UNIT	THICKNESS (feet)	DESCRIPTION
1	1.8	Dolosiltite, light-gray, laminated with chert nodules about 0.1 foot thick at base.
2	0.8	Dolomite, finely crystalline, light-olive-gray, burrowed, with 0.1 foot shale parting at top.
3	2.8	Dolosiltite, light-olive-gray with grayish-red laminae; shrinkage cracks filled with hematite; greenish-gray and grayish-red shale parting in upper half.
4	2.5	Dolosiltite, mottled light-gray and grayish-red.
5	1.0	Dolosiltite, light-olive-gray, laminated and mottled grayish-red.
6	2.6	Dolosiltite, light-olive-gray, mottled grayish-red; shrinkage cracks; burrowed.
7	1.5	Dolomite, very fine to finely crystalline, coarsens upward, light-olive-gray, laminated mottled grayish-red.
8	1.0	Dolosiltite, light-olive-gray, faint grayish-red mottling; grayish-orange to moderate brown chert nodules at top; upper surface undulatory.
9	2.4	Dolomite; finely to medium crystalline, light-olive-gray to olive-gray, mottled with chert matrix between dolomite rhombs; stratiform algal stromatolite and algal debris.
10	2.0-2.8	Dolosiltite, light-gray, mottled grayish-red; light-gray mottled grayish-red chert containing domal algal stromatolite structures and lenses of fine to medium sandstone in upper part.
11	3.0	Dolosiltite, light-olive-gray with grayish-red laminae; shrinkage cracks.
12	0.1-0.3	Chert, grayish-red and greenish-gray; grayish-red shale parting at top.
13	2.0	Dolosiltite, light-gray to yellowish-gray with grayish-red laminae spaced 0.1 to 0.5 foot apart; shrinkage cracks; a few olive-gray chert nodules at top.
14	0.5	Dolomite, finely crystalline, light-gray, mottled grayish-red; shrinkage cracks.
15	1.7	Dolosiltite, light-olive-gray laminated grayish-red; bands of very fine to medium-grained sandstone containing chert pebbles; base is undulatory.
16	1.4	Dololutite, olive-gray, mottled and laminated grayish-red; shrinkage cracks.
17	4.0	Dolomite, very fine to finely crystalline, mottled olive-gray and light-olive-gray; stratiform algal stromatolite and algal debris with irregular silica patches; olive-gray chert lenses 2.7 feet from top.
18	4.8	Dolosiltite, light-olive-gray and grayish-red, laminated; shrinkage cracks, undulatory upper surface.
19	0.5-0.8	Chert, light-gray to light-olive-gray; undulatory top; domal stromatolite.
20	2.0	Dolosiltite, light-greenish-gray mottled grayish-red; shrinkage cracks; undulatory upper surface.
21	0.1	Shale, greenish-gray to grayish-red.
22	1.1	Dolosiltite, light-gray, mottled and laminated grayish-red; olive-gray chert nodules near base.
23	0.5	Dolomite, very finely crystalline, light-greenish-gray mottled grayish-red; shrinkage cracks.
24	2.1	Dolosiltite, light-gray, mottled grayish-red, shrinkage cracks; undulatory upper surface.
25	1.3	Dolosiltite, grayish-red; rock is bleached greenish-gray parallel to vertical joints and along some bedding surfaces; undulatory upper surface with greenish-gray shale filling the lows.
26	3.0	Dolosiltite, yellowish-gray, faintly mottled grayish-red; coarsens upward to very finely crystalline dolomite; 0.05 foot shale parting at top.
27	2.9	Dolosiltite, light-olive-gray, laminated dark-gray; light-gray chert bed and very fine grained sandstone at base filling in depressions in unit 26.
28	3.1	Dolosiltite, light-gray, siliceous; with disturbed and discontinuous bedding.
29	0.8	Dolomite very finely crystalline; rounded intraclasts at base; upper bed burrowed, undulating at top with 0.05 foot of greenish-gray shale filling lows.
30	2.3	Dolomite, very finely crystalline, light-olive-gray, mottled; fine- to medium-grained sandstone at base with rounded pebbles ¼ to 1 inch long.
31	1.1	Dolomite, very fine to finely crystalline, light-olive-gray, laminated and mottled grayish-red; burrowed.
32	5.7	Dolomite, finely crystalline, light-olive-gray and grayish-red, laminated to banded; undulatory upper surface filled with 0.05 foot greenish-gray shale.
33	3.9	Dolosiltite, grayish-red, mottled light-gray; upper surface undulating filled with 0.01 to 0.1 foot greenish-gray shale.
34	0.9	Dolosiltite and very fine to medium chert matrix sandstone, light-gray to grayish-red; rounded intraclast.

UNIT	THICKNESS (feet)	DESCRIPTION
35	0.5	Dolosiltite, light-olive-gray, mottled grayish-red; floating quartz grains; burrowed.
36	1.4-1.9	Dolosiltite, olive-gray, laminated and mottled grayish-red.
37	0.7-1.0	Dolosiltite, light-gray, laminated grayish-red; a few thin sandstone bands; overlain by 0.05 foot of dark-gray shale.
38	1.4	Dolosiltite, olive-gray, laminated dark-gray; shrinkage cracks; burrowed (?); undulatory top, overlain by shale parting.
39	5.6	Dolosiltite, olive-gray, faintly laminated and banded dark-gray.
40	1.9	Dolomite, very finely crystalline, medium-dark-gray; 0.05 foot of dark-gray fine- to medium-grained sandstone at base.
41	0.3	Chert and shale, dark-gray.
42	0.7	Sandstone, dolomitic, light-olive-gray, with discontinuous dolosiltite beds.
43	0.8	Dolosiltite, light-olive-gray, laminated dark-gray; a few floating sand grains.
44	1.5	Dolosiltite, olive-gray, floating sand grains and rounded intraclasts ¼ inch long.
45	0.5	Dolomite, finely crystalline, light-olive-gray, mottled to laminated grayish-red; contains some fine to coarse intraclasts; undulatory top overlain by a greenish-gray shale parting.
46	4.2	Dolosiltite, light-olive-gray, laminated dark-gray; with thin chert zones.
47	0.7	Dolosiltite, light-olive-gray, mottled olive-gray; stratiform algal stromatolite and algal debris; dark-gray shale 0.05 foot thick at top.
48	5.8	Dolosiltite, light-olive-gray, mottled to laminated grayish-red; shrinkage cracks.
49	0.2	Sandstone, fine- to medium-grained, chert matrix, light-gray to pinkish and light-greenish-gray.
50	2.5	Dolosiltite, greenish-gray, mottled and laminated grayish-red; shrinkage cracks; greenish-gray shale parting at base.
51	0.3	Dolosiltite, greenish-gray, laminated to mottled grayish-red.
52	3.1	Dolosiltite, greenish-gray, mottled grayish-red, shrinkage cracks, irregular shale parting at top.
53	2.7	Dolosiltite, olive-gray, laminated dark-gray; irregular base.
54	0.7	Dolosiltite, light-olive-gray, mottled grayish-red at top; upper and lower contacts uneven.
55	1.5	Dolosiltite, light-olive-gray, faintly mottled greenish-gray and grayish-red; stratiform algal stromatolite with algal debris; greenish-gray shale parting at top.
56	1.1	Dolosiltite, light-olive-gray, mottled grayish-red; upper surface irregular with shale parting.
57	0.4-0.6	Dolosiltite, greenish-gray, laminated grayish-red; fills irregularities on unit 56; undulatory upper surface with lows filled by shale parting.
58	4.4	Dolosiltite, greenish-gray, mottled grayish-red, some relict lamination.
59	0.3	Dolosiltite, greenish-gray, laminated grayish-red; 0.1 foot fine- to medium-grained sandstone at base.
60	0.7	Dolosiltite, greenish-gray, laminated grayish-red; grayish-red chert nodules at top.
61	3.4	Dolosiltite, olive-gray, mottled grayish-red; greenish-gray chert nodules; stratiform algal stromatolite with algal debris.
62	4.3	Dolosiltite, greenish-gray, mottled grayish-red; upper surface uneven filled with sandstone.
63	2.6	Dolosiltite, greenish-gray, laminated to mottled grayish-red, some light-olive-gray, laminated dark-gray; 0.2 foot sandstone at base.
64	0.6-1.3	Dolomite, very finely crystalline, light-olive-gray, nodules of grayish-red chert; irregular upper surface.
65	0.9	Chert, grayish-orange to grayish-red, fragmental; in discontinuous lenses filling depression in unit 64; some dolosiltite, light-gray, laminated at top.
66	9.5	Dolosiltite, light-olive-gray, some laminated and mottled grayish-red with shrinkage cracks; stratiform algal stromatolite and algal debris.
67	2.0	Dolomite, finely crystalline, light-olive-gray; stratiform algal stromatolite and algal debris; a few medium-gray chert nodules at top.
68	1.4	Dolosiltite, light-olive-gray, laminated greenish-gray and grayish-red; floating sand grains.
69	2.7	Dolosiltite, light-olive-gray, laminated grayish-red; lenses of very pale orange chert; 0.7-foot breccia zone at base.
70	5.8	Dolosiltite, medium-light-gray; very pale orange chert fragments at base; upper part greenish-gray, mottled and laminated grayish-red.
71	0.6-1.0	Sandstone, fine- to medium-grained; contains rounded intraclasts of dolomite and chert.
72	1.0	Dolosiltite, light-olive-gray; algal debris(?).

UNIT	THICKNESS (feet)	DESCRIPTION
73	9.0	Dolosiltite, olive-gray, mottled light-olive-gray; stratiform algal stromatolite and algal debris; irregular areas filled with chert and white crystalline dolomite.
74	1.9	Dolomite, finely crystalline, light-olive-gray laminated; light-gray to yellowish-gray chert nodules in basal 0.4 foot; burrowed(?).
75	2.3	Dolomite, very finely to finely crystalline, olive-gray, stratiform algal stromatolite and algal debris; lenses of yellowish-orange chert in upper part; irregular upper surface.
76	7.0	Dolosiltite, light-olive-gray, laminated dark-gray and grayish-red; lenses of pale-orange chert; some intraclasts ¼ to 1 inch long.
77	1.4	Dolosiltite, light-olive; stratiform algal stromatolite; some grayish-red mottled dolosiltite with shrinkage cracks; chert lenses at top as much as 2.5 feet long.
78	1.9	Dolosiltite, greenish-gray, laminated grayish-red; shrinkage cracks; a few floating sand grains at base.
79	1.4	Dolomite, finely crystalline, olive-gray, mottled light-olive-gray; stratiform algal stromatolite and algal debris.
80	2.4	Dolosiltite, dark-greenish-gray, mottled grayish-red.
81	4	Dolomite, fine-grained, light-olive-gray stratiform algal stromatolite; laminated to mottled, greenish-gray to grayish-red in upper 1 foot.
82	3	Dolosiltite, greenish-gray, mottled to laminated grayish-red; shrinkage cracks; partings of shale along irregular bedding surfaces.
83	3	Dolosiltite, olive-gray, banded light-olive-gray; contains abundant intraclasts.
84	3.8	Dolosiltite, olive-gray, laminated grayish-red; pale-red to grayish-orange, 0.1 to 0.2 foot thick chert lense at base; may be domal stromatolite.
85	0.7	Dolosiltite, light-olive-gray, laminated grayish-red; abundant lenses of yellowish-orange to reddish-brown chert.
86	0.8	Dolomite, finely crystalline and dolosiltite, light-olive-gray; fine- to medium-grained sandstone in lower part containing abundant coarse to ½-inch long intraclasts.
87	7.7	Dolosiltite, greenish-gray, laminated to mottled grayish-red; shrinkage cracks.
88	1.1	Sandstone, fine- to medium-grained greenish-gray to grayish-red.
89	1.5	Dolosiltite, light-olive-gray, mottled grayish-red; abundant shrinkage cracks.
90	2.3	Dolosiltite, greenish-gray, laminated and mottled grayish-red.
91	3.9	Dolosiltite, light-olive-gray, some grayish-red laminae; irregularly bedded undulating upper surface.
92	4.0	Dolomite, finely to medium crystalline; stratiform algal stromatolite and algal debris; undulatory upper surface; becomes light-olive-gray, faintly mottled grayish-red in upper foot; discontinuous shale parting at top.
93-94	4.6	Dolosiltite, olive-gray, massive; disrupted internal bedding, yellowish-orange to reddish-orange chert cobbles.
95	0.5-3.0	Chert, yellowish- to reddish-orange or reddish-brown, and dolosiltite, olive-gray; undulatory upper surface.
96	4.0	Dolosiltite, light-olive-gray, laminated dark-gray; abundant yellowish-orange to yellowish-brown chert nodules, irregular upper surface.
97	1.4	Dolosiltite, greenish-gray, mottled grayish-red; shrinkage cracks.
98	1.0	Dolosiltite, light-olive-gray, mottled grayish-red.
99	0.5	Dolosiltite, greenish-gray, mottled grayish-red; chert nodules containing very fine-grained sandstone and oolite.
100	3.5	Dolosiltite, greenish-gray, mottled and laminated grayish-red; abundant shrinkage cracks.
101	4.0	Dolomite, very finely crystalline, greenish-gray laminated and mottled grayish-red; irregular upper surface.
102	2.8	Dolosiltite, greenish-gray, laminated and mottled grayish-red; with irregular upper surface.
103	1.6	Dolomite, very finely crystalline, light-olive-gray, mottled olive-gray; stratiform algal stromatolite and algal debris.
104	6.0	Dolosiltite, light-olive-gray; lower 3 feet faintly laminated grayish-red; undulatory upper surface.
105	1.5-2.0	Dolosiltite, light-olive-gray, faintly laminated yellowish-orange chert breccia as much as 0.8 foot thick at base; undulatory upper surface.
106	5.5	Dolosiltite, greenish-gray, mottled and laminated grayish-red; a vertical parting of shale and several horizontal stylolites filled with shale partings; joints bleached; undulating upper surface with lows filled by 0.1 to 0.2 foot of greenish-gray shale.
107	2.5	Dolosiltite, light-gray, banded to mottled grayish-red.

UNIT	THICKNESS (feet)	DESCRIPTION
108	1.6	Dolosiltite, light-olive-gray, mottled olive-gray; stratiform algal stromatolite and debris; becomes greenish-gray, laminated to mottled grayish-red in upper 0.5 foot; 0.1 foot of greenish-gray shale at top.
109	2.5	Dolosiltite, greenish-gray, mottled and laminated grayish-red; bleached high-angle joints; undulating upper surface filled by 0.1 foot of greenish-gray and grayish-red shale.
110	2.5	Dolosiltite, light-gray-olive, laminated grayish-red; discontinuous 0.1 foot thick very pale orange chert lenses at top.
111	1.5	Dolomite, finely crystalline, light-olive-gray; upper 0.05 foot is greenish gray, mottled grayish-red; with abundant vertical bleached joints; greenish-gray to grayish-red shale 0.2 to 0.3 foot thick at top.
112	3.0	Dolosiltite, light-olive-gray to olive-gray; irregular lenses of very pale orange chert.
113	1.4	Dolosiltite, light-olive-gray to olive-gray.
114	2.1	Dolosiltite, light-olive-gray, laminated olive-gray, some faintly grayish-red; 0.1 foot greenish-gray shale at top.
115	0.8-0.9	Dolosiltite, light-olive-gray, laminated; chert with domal stromatolite structures at top; upper surface uneven.
116	2.5	Dolosiltite, light-olive-gray, faintly laminated; uneven upper surface.
117	5.5-6.0	Dolosiltite, light-olive-gray; upper 3 feet laminated and faintly mottled greenish-gray and grayish-red; upper surface very uneven and lows filled with a 0.1 to 0.3 foot greenish-gray shale; burrowed.
118	5.0-5.3	Dolosiltite, light-olive-gray, faintly laminated dark-gray, grades upward to mottled, light-olive-gray.
119	4.4	Dolomite, very finely to finely crystalline, mottled light-olive-gray and olive-gray; stratiform algal stromatolite and algal debris.
120	1.2	Dolomite, finely to medium crystalline, olive-gray; stratiform algal stromatolite and algal debris.
121	1.6-2.5	Dolosiltite, light-olive-gray, laminated dark-gray.

Middle Ordovician unconformity

Chickamauga Limestone

122	1.5	Conglomerate, dolomite and chert pebbles, cobbles, and boulders in a matrix of very finely crystalline light-greenish-gray dolomite.

ROAD LOG

Interval	Cumulative	
		Continue on Interstate to next interchange.
0.4	21.0	Knox-Anderson County line; route crosses low ridge of cherty Knox residuum.
0.8	21.8	Knox-Conasauga contact; route enters Conasauga Shale Valley.
0.5	22.3	Pine Ridge; cuts are in Rome Formation.
1.2	23.5	Conasauga Shale exposed in cuts on right (north) side of Interstate.
0.8	24.3	Lone Mountain; Rockwood, Sequatchie, Reedsville, and Middle Ordovician formations are exposed in cuts through the ridge.
1.1	25.4	Exit 122; leave Interstate to Tenn. Hwy. 61 to Norris, Clinton.
0.4	25.8	Top of ramp; turn left onto Tenn. Hwy. 61 toward Clinton. Stay left, cross over Interstate.
0.2	26.0	Enter I-75 South toward Knoxville, retrace route back to Knoxville.
17.6	43.6	Right lane; junction I-75 South and I-40 West; enter I-40 West; stay in right lane to 17th Street Exit.
0.6	44.2	17th Street Exit. Leave Interstate. Turn right (south) on 17th Street toward Fort Sanders; move to left lane.
0.4	44.6	Highland Avenue, turn left (east).
0.3	44.9	15th Street, turn right (south).
0.4	45.3	Parking Garage; end road log.

FIELD TRIP NO. 3: MINERAL RESOURCES OF KNOX COUNTY, TENNESSEE

BY

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INTRODUCTION

This trip is designed to show the relationship of mineral industries to an urban area; to afford geologists an opportunity to see how some raw materials are processed prior to consumption; and to use Knox County as an example valid for many other areas. Therefore, the trip emphasizes the product of industrial minerals of widespread occurrence.

Population density and consumption of industrial minerals (especially construction materials) are closely related. Therefore, the availability of supplies of sand and gravel, aggregate stone, brick clays, and lightweight aggregate shales exerts a significant influence on urban economy. We have assumed that demand for these materials will lead to the development of adequate supplies. While this was generally true in the past this assumption has become less and less valid as our population has become 75 percent urban, as our technology has developed and required very large supplies of minerals for its growth, and our concepts of acceptable living conditions demand greater convenience, comfort, and varieties of goods.

The demand for industrial minerals has increased geometrically while potential mine and quarry sites have been preempted for other purposes. Suburban developments around central cities have especially limited the availability of mineral supplies. In some instances mineral properties cannot be developed because of zoning restrictions. In other instances increases in land costs prevent development of low unit value industrial minerals. Recently, pollution abatement regulations that apply to existing facilities are affecting operations. Unfortunately, most planning agencies and governing bodies seem to be unaware that the welfare of their communities is affected by the adequacy of industrial mineral supplies at reasonable prices.

Geologists are being called upon in problems arising from these conditions, and we shall probably be more involved in the future. It is important that we be aware of the effects of zoning codes, pollution regulations, and economics on mineral supplies. It is also important for us to be able to relate these considerations to non-geologists in such a manner that our views are understood. The processing of industrial minerals is an important aspect of their utilization, and is generally an aspect little known to geologists. Hopefully this trip will add to your understanding.

ROAD LOG

Interval	Cumulative	
0.00	0.00	Begin at entrance to parking garage behind U.T. Student Center, 15th Street (Stadium Drive), Knoxville. South on Stadium Drive turn east (left) on Lake Loudoun Drive by steam plant.
0.5	0.5	Turn east (left) on Neyland Drive. Plant of Knoxville Sand and Gravel Division across Tennessee River.
0.9	1.4	Turn north (left) on Market Street.
0.1	1.5	Turn east (right) on Hill Street. Cross Gay Street. Cross viaduct.
0.3	1.8	Turn south (right) on Riverside Drive.
0.8	2.6	Mill of Tennessee Marble Division of Georgia Marble Company on right (south); parking lot on east side of mill.

STOP 1: MILL OF TENNESSEE MARBLE DIVISION OF GEORGIA MARBLE COMPANY.

The first product of a marble operation is a large block of stone (average size 7 feet long, 4 feet high, and 6 feet wide) called a "mill block." Mill blocks are obtained in the quarry by use of a bar drill. This machine consists of a pneumatic drill mounted on a steel bar supported at either end by adjustable legs. The drill can be moved horizontally along the bar and rotated to various angles. The legs can be adjusted to control drill height above the rock. The bar drill bores a series of holes on 2½-inch centers that outline the block.

After bar drilling has outlined the block the remaining bands of stone are broken either by wedging or broaching. Wedging consists of driving tapered steel rods into the drill holes between two flat wedges, called feathers, until the block is split free. This is done by hand and with great care to distribute the stress uniformly so that the block breaks evenly. Broaching involves cutting through the bands of stone between drill holes with a vibrating saw blade mounted on the bar drill rod. Broaching is used along the block opposite the surface to be cut.

The freed block is now ready to be hoisted and loaded for delivery to the marble mill. The blocks average 33,600 pounds in weight. Derricks having fixed steel masts and booms averaging 90 feet in length hoist the block to truck, rail car, or stock pile. Power is from 440-volt, 50-horsepower electric motors.

Quarry losses are reported to range from 50 to 80 percent. Losses are caused by fissures, joints, hairline fractures, and intercalated clay seams or shale.

Nearly all mill block received at the mill is first sent to the gang saw. This machine consists of a series of steel blades mounted parallel to each other in a forward-and-backward moving frame. Blade spacing is adjusted to slab the block into the desired thickness of marble. Cutting is generally done by an abrasive sand slurry.

Slabs from the gang saws move next to a coping saw. This is a circular diamond bladed saw that can cut at various angles and directions. Here the slab is sized and shaped to its final specifications.

The sawn marble is now polished in a series of steps. The first polishing is done on a cast iron circular rotating turntable, the rubbing bed. A continuously supplied slurry of fine, uniform-size sand removes saw marks and irregularities.

If a higher polish is required it is obtained by the use of buffers covered with felt, using successively finer abrasives. A mirror-like sheen is supplied by using a buffing mixture of aluminum oxide dust and sulfur.

These milling operations are governed by user specifications; the specifications also determine color of stone, etc. Generally, therefore, the block is quarried upon receipt of an order, assigned a job number which is marked on the block, and is successively used until it finally marks the packing crate.

Today most Tennessee marble is used in interiors. Here it serves in floors, walls, and window sills. Some waste material is wire sawed and used for split face exterior construction, and some is crushed for terrazzo chips.

Interval	Cumulative	ROAD LOG
		Return to Riverside and continue east.
0.2	2.8	Mill of General Shale Products Corp. on right (south). Enter lot and park.

STOP 2: GENERAL SHALE KNOXVILLE PLANT[1]

The brick manufacturing plant you are visiting was placed in operation in 1967. It is a fully automated, continuous flow plant of revolutionary design.

The plant cost about $1,350,000 exclusive of rail siding, land, clay mining and grinding facilities, and some reused equipment. It has a capacity of 90,000 bricks/day. Unlike most kilns the green bricks are fed into the kiln turned on end, and not in stacks. As a result the firing is entirely uniform and quality control is easily maintained.

Shale is quarried from the Rome Formation (Lower Cambrian) and Pumpkin Valley Shale (Middle Cambrian) and trucked to the plant. Raw shale is ground in a 12-foot rod mill and in two pan crushers to minus 20 mesh. The grinding plant has a capacity of 650 tons/day.

The ground clay is stored in silos, and goes from storage to a surge hopper by belt conveyor. Colorants and other additives are blended in the surge hopper. Material in the surge hopper is fed to the pug-mill and extruder. The mixture now contains about 20 percent moisture. The extruder forms some 5,000 bricks/hour.

A belt from the extruder conveys the mixture to a wire guillotine which cuts a slug 28 bricks thick. Another belt takes the slug through a fixed vertical wire cutter that cuts it into bricks. A setting head picks up the bricks and transfers them to an 8 ft. x 10 ft. kiln car (672 bricks per car). The loaded car is taken to a 220-foot long drier; the drier operates on waste heat from the kiln. Twelve hours are required for drying and the bricks leave the drier at 450°F. Each 11 minutes a car leaves the drier for the kiln.

The kiln is 432 feet long, has 106 continuous burners in the ceiling and 12 side burners. The kiln is fired to a maturing temperature of 1830°F., but contains 5 temperature zones. Fuel consumption is estimated at between 4,000 to 4,200 cu. ft. of natural gas per 1000 standard bricks.

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[1] Data furnished by American Limestone Division of ASARCO.

The cars from the kiln are transferred to an unloading station where the bricks are grabbed and deposited on a belt. The belt feeds them to a packaging system that builds and straps the full package. Packages are removed and stacked by forklift.

Unique features of this operation are its continuous operation and single brick high loading for firing. The system allows a labor cost of 1.5 to 1.8 man hours per thousand bricks as compared to about 3 man hours for conventional tunnel kilns.

Interval	Cumulative	ROAD LOG
		Return to Riverside and continue east.
0.9	3.7	Bear left on Delrose Drive.
1.5	5.2	Turn east (right) on Boyds Bridge Pike The wooded hill to the southwest is the site of several old marble quarries and is called Marble Hill.
0.2	5.4	Cross Holston River on Boyds Bridge. The bridge is 1.8 miles above the confluence of the Holston and French Broad rivers ("Forks of the River"). Pass through Mule Hollow and Ramsey communities.
1.2	6.6	Turn east (left) on Strawberry Plains Pike.
1.1	7.7	Turn south (right) on John Sevier Highway. Outcrops of Mosheim Limestone.
2.3	10.0	Turn west on access road to quarry of American Limestone Division, ASARCO, just before Dr. J. H. Gammon Bridge.
0.2	10.2	STOP 3: Forks of the River quarry, American Limestone Division. Lunch Stop.

STOP 3: FORKS OF THE RIVER QUARRY, AMERICAN LIMESTONE DIVISION[1]

This quarry is a new one developed primarily to meet crushed stone requirements in metropolitan Knoxville. The chief factors in the site selection (exclusive of raw material) involved availability of the property, access to utilities, and means of delivery to markets. Geologic factors bearing importantly on cost are quality of stone, both physical and chemical, overburden depth, and dip.

Geologic investigations, including diamond drilling, showed an unusually thick (up to 150 feet) Mosheim Member of the Lenoir Limestone, a dense, sound high carbonate calcilutite which occurs at the site. An extensive area of outcrop showed the overburden to be generally shallow. Dips range from nine to fifteen degrees on the northwest limb of a large anticline. Some 75 acres of land was available for leasing.

Plans are to develop a 5- to 20-acre pit, and to eventually locate some of the crushers in the pit. Crushing will be chiefly by impact type equipment.

The proximity of the quarry to the Governor John Sevier Highway and to navigable water offer unusually good access to markets for the stone. The company plans to erect either a dock or a retractable conveyor to load barges for delivery to downstream sites.

Features of particular interest here are the use of impact crushers, transportation, and rigid adherence to environmental protection criteria for a large crushed stone operation.

Interval	Cumulative	ROAD LOG
0.2	10.4	Return to John Sevier Highway. Turn north (left) on Gov. John Sevier Highway.
0.5	10.9	Turn west (left) on Asbury Road; follow Asbury Road southwest and then northwest.
1.4	12.3	Large idle marble quarry on north side of Asbury Road. Foote Minerals Company lime kiln on south side.

FORKS OF THE RIVER MARBLE DISTRICT

The confluence of the French Broad and Holston rivers was the site of early pioneer settlements in East Tennessee. These pioneers called the area "the Forks of the River" and this designation is still used. The student of history is impressed with "Lebanon in the Forks" Church (established 1791) and with Ramsey House (Swan Pond), the home of Francis A. Ramsey (1795).

The earliest recorded dimension marble quarry here in the Forks of the River is the westernmost opening, some 600 feet northeast of Lebanon Church. There the Federal Government opened a quarry to supply marble for a customs house and post office in Knoxville in 1872. The building stands on the southeast corner of Clinch Avenue and Market Street and is locally called the "old post office." G. W. Ross, paymaster for the building, and William Patrick of St. Louis, later purchased the quarry and mill from the Government and established the Knoxville Marble Company. This company operated the quarry for about 15 years as a source of gray and light-pink stone. Final levels were 25 feet below river level. The marble was floated down the river on flat boats to Knoxville, then the rail head. Stone from this district was used in the New York State Capitol. The quarry is now owned by the Appalachian Marble Company.

Altogether 7 dimension stone quarries can now be identified in this district, some of which represent consolidations of small earlier openings. As of November 1972, none of the marble quarries in the district was

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[1] Data furnished by General Shale Products Corporation.

operating for dimension stone. However, Foote Minerals Company has an operating quarry that supplies rock to a lime kiln in this district. This site has been a source of lime since the early 1900's. Another lime kiln, now in ruins, is at the eastern end of the district.

The district is on the northwest limb of a regional anticline with small amplitude folds imposed on the major structure, and containing minor faults. Prevailing dip is northwest, but reversals are common, and in places the dip is gentle (Cattermole, 1955).

The nature and geologic origins of the marble are discussed by Gordon (1924) and by Walker in stop descriptions for field trip 2 in this guidebook.

Interval	Cumulative	ROAD LOG
0.5	12.8	Appalachian Marble Co. quarry on north side of road. Source of limestone as well as marble. Heart of marble district. Follow Asbury Road west and then north. 18th century church (Lebanon) on bend in road.
1.3	14.1	Bear left onto Thorngrove Pike.
0.2	14.3	West (left) on Strawberry Plains Pike. Cross Boyds Bridge.
1.3	15.6	Turn north (right) on Holston Hills Road; follow Holston Hills Road north and northeast.
1.3	16.9	Turn north (left) on Chilhowee Drive.
1.0	17.9	Intersection with U.S. Highway 11-E. Turn east (right) on 11-E.
6.6	24.5	Junction of U.S. Highway 11-E and U.S. 25W-70. Bear northeast (left) on U.S. 11-E.
7.6	32.1	Access road to Young mine on south (right). Head frame visible.
3.2	35.3	New Market city limits. Turn south (right) on Lost Creek Road.
1.2	36.5	Turn east (left) at New Market mine, ASARCO.

STOP 4: NEW MARKET MINE, ASARCO

MINE GEOLOGY OF THE NEW MARKET ZINC COMPANY MINE AT NEW MARKET[1]

BY

DONALD J. HATHAWAY[2]

INTRODUCTION

The New Market mine is centrally located in the Mascot-Jefferson City zinc district (fig. 1) in Jefferson County, Tennessee. Structurally, the mine is situated on the eastern flank of the gently plunging New Market syncline (Oder, 1958, p. 10, fig. 4). This syncline includes both the hanging-wall and footwall blocks of the Rocky Valley thrust fault. Oder and Ricketts (1961, p. 7) have shown that the stratigraphic displacement of this fault amounts to 4,700 feet or more, placing the Lower Cambrian to Lower Ordovician rocks of the large Rocky Valley anticline on Middle Ordovician beds (fig. 2). The axis of the syncline strikes N. 24° E. and plunges southwestward approximately 3°. In the footwall block the rocks on the easterly and westerly limbs dip from 7° to 9° (fig. 2). Around the nose and near the base of the syncline the dip of the beds is about 7°. Northeastward, along the axis, the dip increases to about 14°.

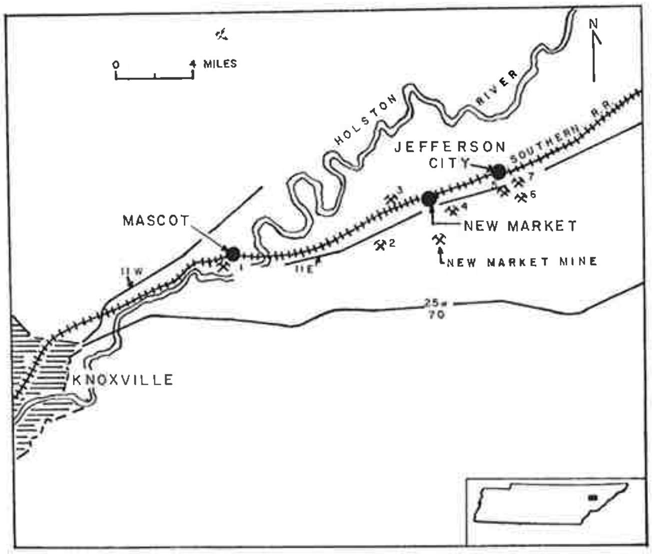

Figure 1. Index map of the Mascot-Jefferson City zinc district, Tennessee, showing the New Market mine. Numbered mine locations are: 1, Mascot No. 2; 2, Young; 3, North Friends Station; 4, Grasselli; 5, Davis-Bible; 6, Jefferson City; and 7, Coy.

MINING AND PRODUCTION

By June 1963, the main shaft was developed to a depth of 1,801 feet and the first ore from mine operations was hoisted a year later. Today, two 11-ton bottom-dump skips, in balance, hoist the ore to the surface. In addition, the shaft is equipped with an 8- by 11½-foot man cage, which runs in

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[1] Reprinted in part from Tennessee Division of Geology Rept. Invs. No. 23, p. 53-63.

[2] Formerly New Market Zinc Company, New Market, Tennessee; now with North American Exploration Company, Charlottesville, Virginia.

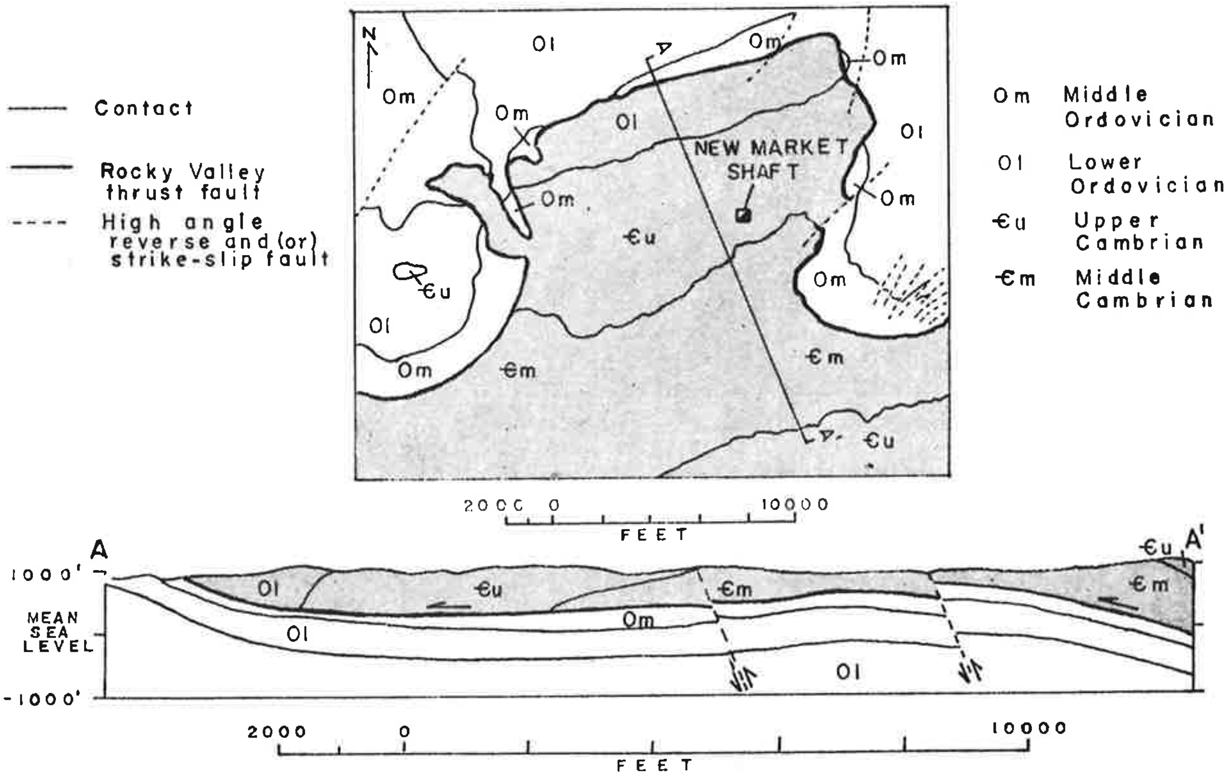


Figure 2. Geologic map and structure section, A-A', across New Market ore body. Stippled area is the upper block of the Rocky Valley thrust fault. Geology adapted from Bridge (1956); structure by Bumgarner and others (1964).

balance with a counter-weight. In favorable ore horizons 14- by 17-foot development drifts are driven to intersect known ore reserves determined earlier by either surface diamond drilling or underground long-hole drilling. Depending upon the complexity of ore-body configuration, the development drifts approach the ore body in two major ways:

(1) Advancing along the footwall and up the regional dip on about 10-percent grades, opening rooms and leaving pillars to establish future mining front. Once this is accomplished, the lower part of the ore body is mined out, and the ore overhead is removed by shrinkage-type stoping.

(2) In larger stopes, the development drifts are driven on the footwall or at some convenient ore-bearing horizon. Once a mining level is established, the ore is removed by room-and-pillar mining. The development drift is then driven upward on a spiral to another level and the same mining technique is repeated. This practice continues to near the top of the ore body. When about 20 feet of ore remains in the back of the stope, the ore is shrunk and trammed to raises pre-driven from lower levels. In the retreat phase, the sill pillars between the levels and ore in the floor on the initial level are removed by the underhand-benching method.

Loading and haulage is accomplished with rubber-tired diesel-powered front-end loaders, truck, and transloaders. Stoping and drifting is done by drill jumbos and jacklegs that use compressed air furnished by the surface compressors. Ventilation normally is downcast at the main shaft and upcast in three additional ventilation shafts.

The mine produces about 2,500 tons of ore per day. The tenor averages 2.9 percent zinc. Beneficiation of the ore by flotation results in a concentrate of approximately 63 percent zinc. Concentrates are transported by truck to a nearby rail-loading station and from there to the smelters.

STRATIGRAPHY

The important zinc-bearing host rock at the New Market mine, as well as other zinc mines in the Mascot-Jefferson City area, is the Kingsport Formation and part of the Mascot Dolomite. General and detailed descriptions of the stratigraphic sequence above and below the ore zone have been published by several authors (Crawford, 1945; Oder and Miller, 1945; Rodgers and Kent, 1948; Bridge, 1956; and Harris, 1969).

At the New Market Zinc Company mine a combination of the Grasselli bed-numbering system (Oder and Miller, 1945) and the Crawford (1945) gross-stratigraphic unit system is used (fig. 3) to aid in exploration and mine development (fig. 4). In ascending order these beds and units are: the U bed, which includes strata from the -88 to the -76 marker beds; the T bed, which includes those from the -76 to the -62; the S bed, which includes rocks from the -62 to the -19; and the R bed, which consists of the zone from the -19 to the 28. The letter system is not used above the R bed, and key markers are designated only by number.

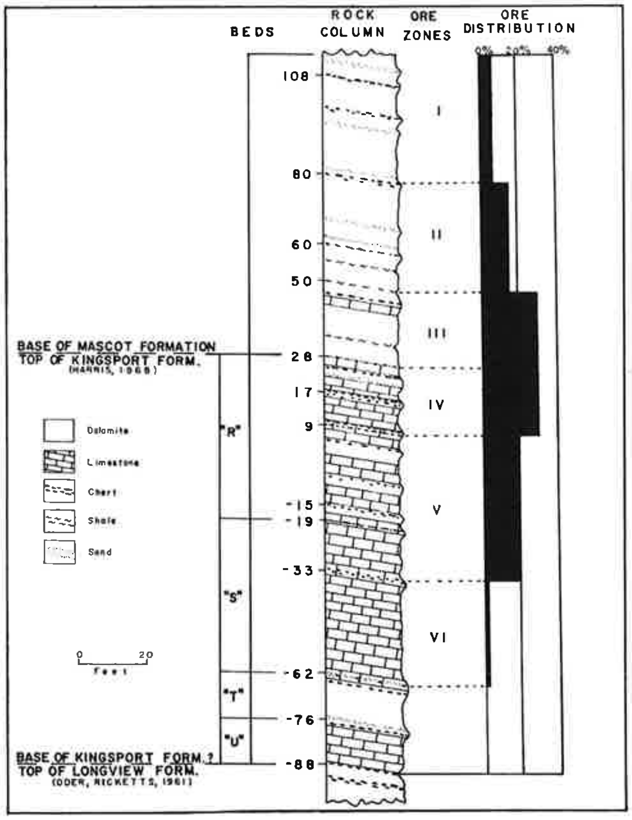


Figure 3. Unaltered columnar section showing key beds, regional dip, ore zones, and ore distribution in and around the New Market mine.

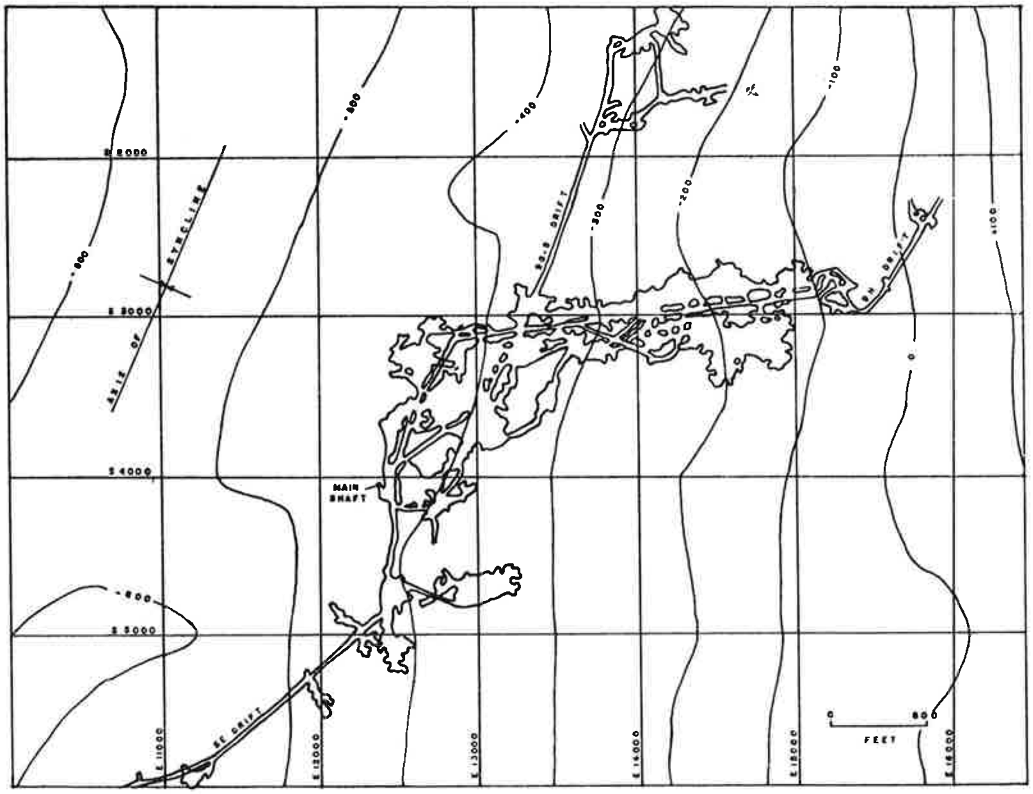


Figure 4. Structure contour map on the 28 bed in the New Market mine area, showing outline of present mine workings. Datum is mean sea level; contour interval is 100 feet.

Certain marker beds are easily recognized and are used continuously in underground development. The -33 cherts, white to gray-white in color, generally are scattered vertically through a 2-foot zone. The -19 cherts are blue-gray and form a 2- to 3-inch band of dense nodular chert. The 9 to 10 bed consists of 2- to 3-inch beds of blue-gray nodular chert separated by about 6 inches of brown, slightly banded, finely crystalline dolomite, which when unaltered is a brown stylolitic limestone. The 17 bed is similar to the 9 to 10 bed but can be distinguished easily because it is a strikingly banded crystalline dolomite in which the chert nodules are more randomly situated. The 28 bed, a ½-inch green to black shale with a few scattered quartz-sand grains, underlies a 6-foot bed of dark-gray, carbonate-spotted dolomite. The 50 bed is a ½-inch green shale underlying 5 feet of chocolate brown, carbonate-spotted, dense dolomite. Finally, the 60 bed is a 2- to 3-inch zone of dark-brown nodular chert.

ORE ZONES

Sphalerite occurs in breccia bodies 50 to 300 feet wide, more than 100 feet high, and as much as 1,000 feet long (figs. 4 and 5). The breccia bodies have irregular shapes, some of which have been distorted further by post-ore faulting. These faults can be either high-angle, reverse, normal, and/or strike-slip. Edges of these bodies are marked by an abrupt change from breccia to limestone. R-bed breccia bodies are somewhat domal-shaped and have been tilted by later structural movements. The S-bed ore breccia bodies, which are long and narrow, strike northwest-southeast. The shape of S-bed ore bodies is similar to that of the U-bed ore bodies described by Kendall (1960, p. 991-993).

Recent surface diamond drilling at New Market suggests that ore-breccia areas are enveloped with traces of ferric iron oxide (Fe_2O_3). Where discernible this red coloring is used by the miners as an aid for guiding stope advance.

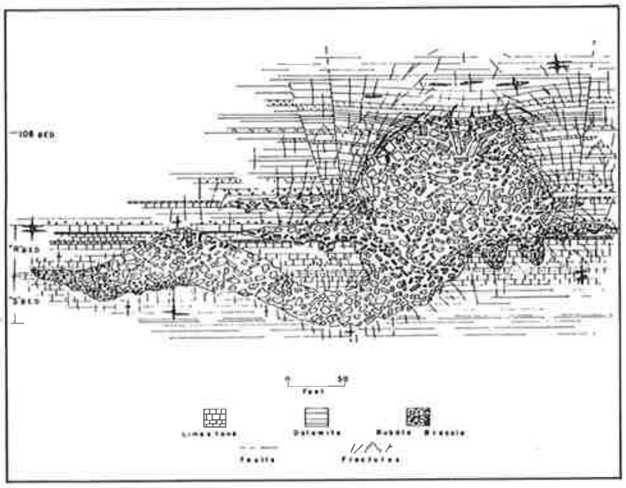


Figure 5. Generalized section through an ore-bearing breccia body in the New Market mine.

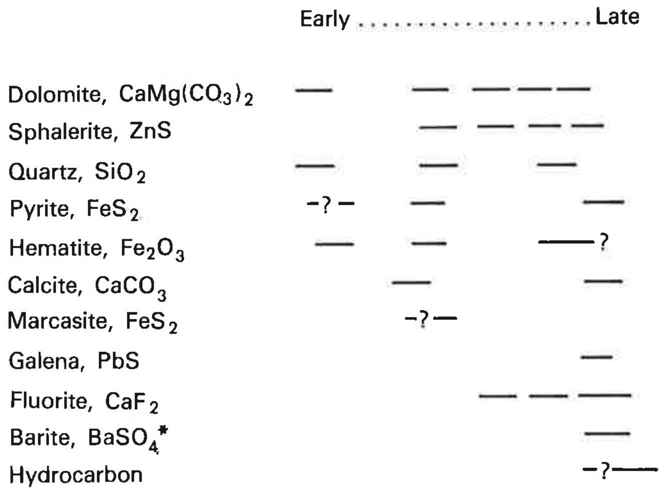
The innermost part of a breccia body is composed of sharp, rectangular blocks of crystalline dolomite. Limestone blocks however, are common near the periphery and below the 28 bed. The blocks in a collapse zone range from near microscopic size to tens of feet in largest dimension. Near the edges of a breccia body, white dolomite gangue and fine breccia-filled fractures dip away from the collapse areas.

Sphalerite occurs in two main ways: filling on and between breccia blocks in the traps that formed as a result of dissolution of the Kingsport Formation; or as replacement ore near the breccia-limestone contact and locally extending into the limestone. In one case, replacement-type sphalerite was found for some distance near the axis of a gentle anticlinal warp. The loci of highest zinc concentration are generally near the limestone-breccia interfaces.

MINERALOGY

Sphalerite is the only ore mineral at the New Market mine; it occurs in commercial quantities from the -62 bed to above the 108 bed (fig. 3). The ore column can be subdivided into six zones having the frequency of ore distribution as shown in figure 3. In general, the tenor is highest in the stratigraphically lower zones.

A detailed study of the mineralization has not been made; however a generalized paragenetic sequence, based on meager data, is shown below:



Return to 11-E and return to Knoxville via U.S. Highway 11-E, I-40.

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* Mineral was found by S.D. Van, employee of New Market Zinc Company, and identified by the author.

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