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Stratigraphic and Structural Data for the Conasauga Group and the Rome Formation on the Copper Creek Fault Block near Oak Ridge, Tennessee: Preliminary Results from Test Borehole ORNL-JOY No. 2

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ENVIRONMENTAL SCIENCES DIVISION

Publication No. 2392

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STRATIGRAPHIC AND STRUCTURAL DATA FOR THE CONASAUGA GROUP AND THE ROME FORMATION ON THE COPPER CREEK FAULT BLOCK NEAR OAK RIDGE, TENNESSEE: PRELIMINARY RESULTS FROM TEST BOREHOLE ORNL-JOY No. 2

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ABSTRACT

To resolve long-standing problems with the stratigraphy of the Conasauga Group and the Rome Formation on the Copper Creek fault block near Oak Ridge National Laboratory (ORNL), an 828.5-m-deep test borehole was drilled. Continuous rock core was recovered from the 17.7- to 828.5-m-deep interval; temperature, caliper, neutron, gamma-ray, and acoustic (velocity and televiewer) logs were obtained.

The Conasauga Group at the study site is 572.4 m thick and comprises six formations that are – in descending stratigraphic order – Maynardville Limestone (98.8 m), Nolichucky Shale (167.9 m), Maryville Limestone (141.1 m), Rogersville Shale (39.6 m), Rutledge Limestone (30.8 m), and Pumpkin Valley Shale (94.2 m). The formations are lithologically complex, ranging from clastics that consist of shales, mudstones, and siltstones to carbonates that consist of micrites, wackestones, packstones, and conglomerates.

The Rome Formation is 188.1 m thick and consists of variably bedded mudstones, siltstones, and sandstones. The Rome Formation thickness represents 88.1 m of relatively undeformed section and 100.0 m of highly deformed, jumbled, and partially repeated section. The bottom

of the Rome Formation is marked by a tectonic disconformity that occurs within a 46-m-thick, intensely deformed interval caused by motion along the Copper Creek fault.

Results from this study establish the stratigraphy and the lithology of the Conasauga Group and the Rome Formation near ORNL and, for the first time, allow for the unambiguous correlation of cores and geophysical logs from boreholes elsewhere in the ORNL vicinity.

1. INTRODUCTION

1.1 BACKGROUND

Geological investigations undertaken over the past 30 years at radioactive waste disposal sites located in Melton Valley have resulted in a large data base of geochemical, lithological, and structural properties for Conasauga Group strata (see Stockdale 1951; Barnett 1954; Cowser 1958; deLaguna et al. 1958; Carroll 1961; Cowser, Lomenick, and McMaster 1961; deLaguna 1961; Struxness 1962; McMaster 1963; Lomenick and Wyrick 1965; McMaster and Waller 1965; deLaguna et al. 1968; Weeren et al. 1974; Duguid 1975; Webster 197[illegible], Krummhansl 1979a and 1979b; Haase and Vaughan 1981; Sledz and Huff 1981; Vaughan et al. 1982; Haase 1982, 1983, and in press; Davis et al. 1984; and Rothschild et al. 1984). The site-specific nature of most of these investigations, however, severely limits the areal extent of the Conasauga Group data base and makes correlation of the bedrock geology between sites difficult. Furthermore, it has proved difficult to synthesize a reservation-wide geological summary of the stratigraphy and lithology of Conasauga Group strata despite the large number of data available for any one particular locality within the reservation.

The drilling project described in this report was undertaken to obtain the data necessary to determine the stratigraphy of the Conasauga Group on the Copper Creek fault block on the U. S. Department of Energy (DOE) Oak Ridge Reservation. In the Oak Ridge National Laboratory (ORNL) vicinity, Conasauga Group sediments on this fault block underlie past and current radioactive waste storage and disposal facilities located in Melton Valley. Lithologic and geophysical data from this study provide a reference stratigraphic section to aid in the unambiguous interpretation of site geology at the various Melton Valley facilities.

1.2 PURPOSE

The purpose of this report is to present stratigraphic, lithologic, structural, and geophysical data obtained from a stratigraphic test borehole drilled to a depth of 828.45 m. It is a preliminary summary of the drilling project and contains raw data, such as stratigraphic logs and lithologic descriptions, based on initial study of the drill core and the borehole geophysical logs. Data presented in this report, and those contained in a companion report (Haase 1985) summarize subsurface data on the Conasauga Group obtained during a 4-year study of drill core and geophysical logs obtained from numerous boreholes on the DOE Oak Ridge Reservation. Regional analysis of the data contained in these reports is presented elsewhere (Hasson and Haase 1985).

1.3 LOCATION

ORNL is part of the DOE Oak Ridge Reservation (Fig. 1). The location of the borehole is ~5 km southwest of the ORNL plant site (Fig. 2) and ~15 km southwest of the city of Oak Ridge. The borehole was collared on the crest of Copper Ridge at an elevation of ~315.5 m above mean sea level.

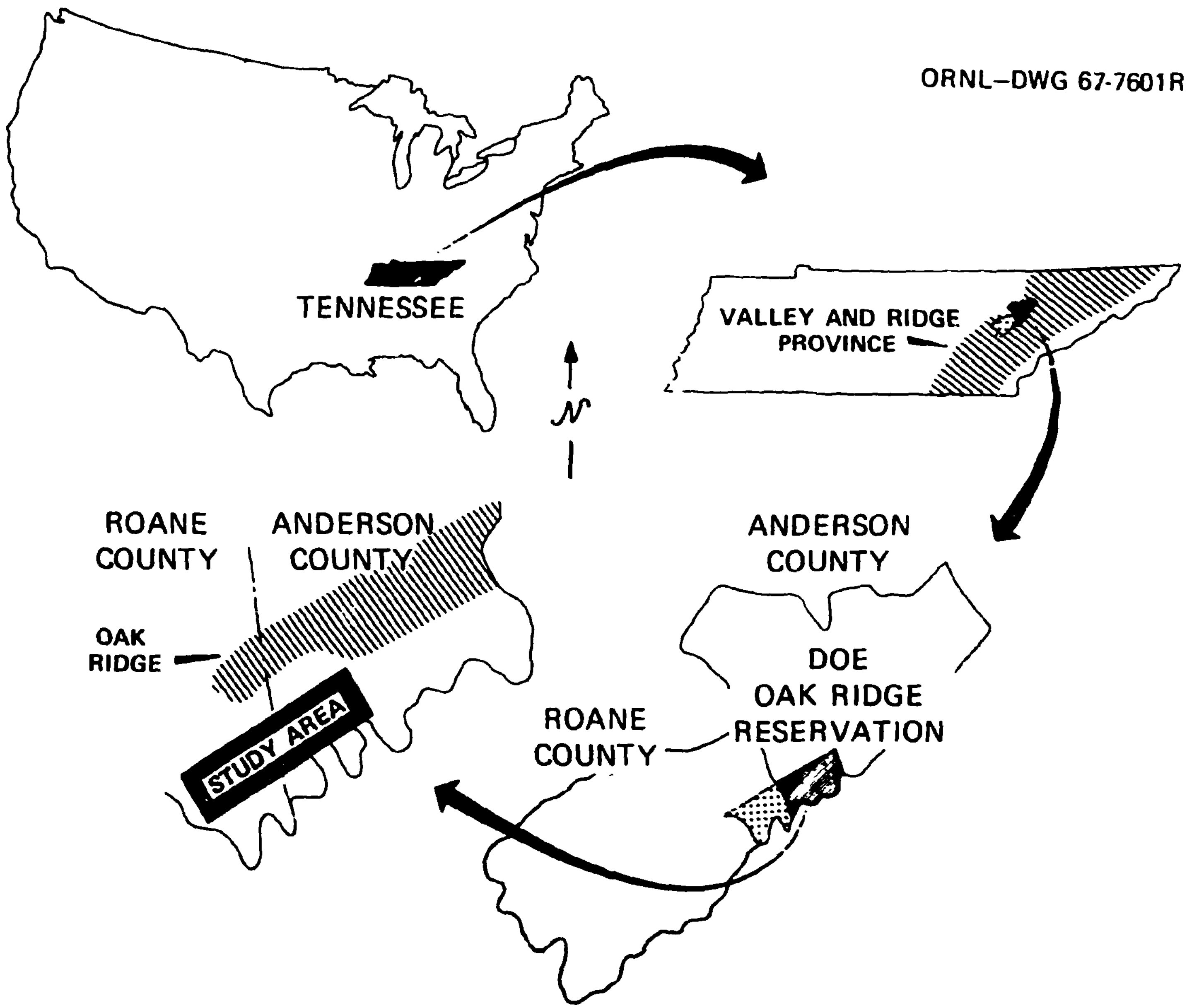

Fig. 1. Location map for DOE Oak Ridge Reservation in east Tennessee. Valley and Ridge Province and city of Oak Ridge are within hatched areas. Study area illustrated in greater detail in Fig. 2.

Physiographically, the drill site is located on the northwestern margin of the Valley and Ridge Province of the Appalachian Mountains. It is situated on the northwest leading edge of a fault block formed by the regionally persistent Copper Creek fault (Figs. 1 and 2).

2. GEOLOGICAL SETTING

2.1 STRATIGRAPHY

The bedrock stratigraphy on the DOE Oak Ridge Reservation consists of Cambrian through Ordovician age sediments. From oldest to youngest the stratigraphic units are the clastic Early Cambrian Rome Formation, the mixed clastic and carbonate Middle and Late Cambrian Conasauga Group, the carbonate Late Cambrian and Early Ordovician Knox Group, and the mixed carbonate and clastic Middle Ordovician Chickamauga Group (Stockdale 1951; McMaster 1963). The stratigraphic units crop out in a series of southwest- to northeast-trending linear belts (see Fig. 2) that are the result of fault motion along the Copper Creek and Whiteoak Mountain thrust faults. Strata within such belts are stratigraphically right-side up and have dips to the southeast.

In the study area, the Rome Formation crops out at Haw Ridge, the Cambrian Conasauga Group underlies Melton Valley, and the Knox Group crops out along Copper Ridge. The borehole was collared in the basal part of the Knox Group. Because of the southeast dip of the strata, Chickamauga Group strata of the Copper Creek fault block were not intersected by the borehole. Stratigraphically older units were encountered progressively further downhole as drilling proceeded until

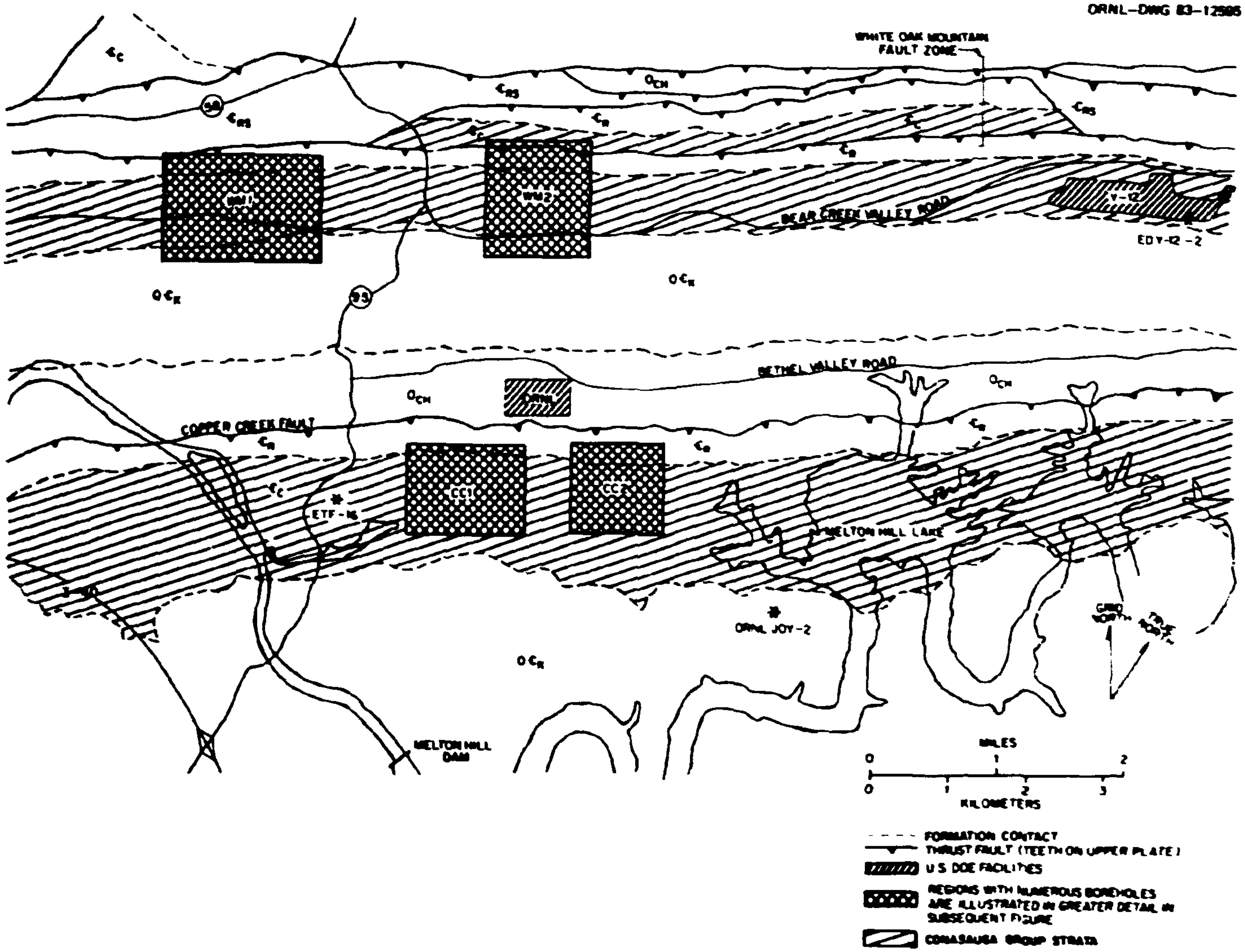

Fig. 2. Geological map of the Oak Ridge National Laboratory vicinity, illustrating the Copper Creek and Whiteoak Mountain fault blocks (after McMaster, 1963). Location of ORNL-JOY No. 2 is below and right of cross-hatch area CC2. Thrust fault traces are denoted by heavy black lines with teeth on upper plate. Outcrop belts of Conasauga Group sediments are represented by hatching. General strike of sediments is northeast with dip to the southeast, as illustrated by symbols. Geological data from cross-hatched areas discussed by Haase (1985).

the base of the Copper Creek fault block was encountered. The base of the fault block is a tectonic contact that occurs within the Copper Creek fault zone. Below this contact, Chickamauga Group sediments contained of the Whiteoak Mountain fault block were encountered.

2.2 STRUCTURE

Thrust faulting in the Valley and Ridge Province has moved upward in the stratigraphic section in a northwestward direction thereby moving older strata on top of younger strata. Such thrust faulting is part of a major decollement of the the Southern Appalachian thin-skinned orogenic thrust belt (Roeder, Gilbert, and Witherspoon 1978). In the general vicinity of the DOE Oak Ridge Reservation, such faulting has resulted in the Lower Cambrian Rome Formation being juxtaposed on top of the Middle Ordovician Chickamauga Group. Regional strike of strata in this portion of the Valley and Ridge Province is N50° to 60°E, and the dip of rocks at the surface is 45° to 55° to the southeast (Ossi 1979). At depth, the dip decreases to nearly horizontal, and the thrust faults become nearly horizontal in the subsurface to form essentially bedding-parallel faults (Roeder, Gilbert, and Witherspoon 1978). Horizontal displacement along the major fault can be as great as 50 to 100 km (Roeder and Gilbert 1978).

The regionally persistent Copper Creek fault dominates the geology of the study site. The attitude of the Copper Creek fault is generally parallel to the strike of the Conasauga Group, which is N55°E; the dip is 5° to 15° SE. Such dip values are somewhat less than are typically observed elsewhere in the Oak Ridge vicinity and may reflect complicated subsurface structure along the Copper Creek fault (Roeder, Gilbert, and Witherspoon 1978).

Late Paleozoic tectonic activity that produced the thrust faults also produced numerous deformational structures within the interiors of the fault blocks (Roeder, Yust, and Little 1978). Within the Copper Creek fault block in the study area, several generations of small amplitude folds and faults are recognized (Ossi 1979; Sledz 1980). Furthermore, the strata are pervasively jointed. As many as four distinct joint sets can be recognized in the vicinity of the study area that are related to major and minor tectonic structures developed within the Copper Creek fault block (Sledz and Huff 1981).

2.3 REGIONAL GEOLOGIC HISTORY

Early Cambrian to Middle Ordovician strata in the Valley and Ridge Province of east Tennessee record a history of sedimentation on a shallow shelf bordered by a craton to the west and a shelf-margin carbonate bank to the east (Harris and Milici 1977; Markello and Read 1981; Hasson and Haase 1982). The Rome Formation was deposited in the shallow carbonate bank of the Lower Cambrian Shady Dolomite. Clastic material for the peritidal depositional environment of the Rome formation was supplied from the craton to the west (Samman 1975). The craton-marginal peritidal environments of the Rome Formation were succeeded by a shallow marine shelf environment characterized by an intrashelf basin and shelf-marginal carbonate ramp (Markello and Read 1981; Hasson and Haase 1985). The Conasauga Group was deposited in such a setting. By the Late Cambrian, the intrashelf basin and shallow shelf environment were replaced by a peritidal carbonate bank environment initiated by the westward transgression of the self-marginal carbonate bank environment. Initiation of the carbonate-dominated depositional environment produced the Knox Group in Late Cambrian to Early Ordovician time.

3. DRILLING AND GEOPHYSICAL LOGGING OPERATIONS

3.1 CONTRACTORS

Diamond core drilling operations were conducted by the Contract Drilling Division of Joy Manufacturing Company, Inc (Joy). Personnel and equipment were assigned from Joy's Jefferson City, Tennessee, office: drilling operations at the site were supervised by P. H. Pollard.

Geophysical logs of the completed borehole were obtained by the Borehole Geophysics Group of the Water Resources Division, U. S. Geological Survey (USGS), Denver, Colorado Logging was conducted under the direction of W. S. Keys.

3.2 SUMMARY OF DRILLING OPERATIONS

Drilling of ORNL-Joy No. 2 began on August 26, 1982, and was completed at a total depth of 828.45 m (2718 ft*) on December 15, 1982. The borehole was collared in overburden developed on the Copper Ridge Dolomite of the Knox Group. Drilling began with a 15.88-cm

(0.55-ft) tricone rock bit and proceeded to a depth of 17.68 m (58 ft) where bedrock was encountered. A 10.16-cm (0.33-ft) inside diameter flush joint casing with a drillable set shoe was installed. This casing was drilled ~ 0.31 m (1.0 ft) into the top of the bedrock and was grouted in place to serve as a surface casing. Core drilling began at a depth of 17.68 m (58 ft) with NC-size tools, which gave a rock core diameter of 6.10 cm (0.2 ft) and a nominal borehole diameter of 9.40 cm (0.30 ft). Core drilling continued to the final total depth of 828.45 m (2718 ft). Core recovery, calculated over the entire cored interval, was better than 99 %. Return of drilling water was lost below a depth of ~ 18.29 m (60 ft) and was never regained throughout the entire drilling operation. The borehole was left open (uncased) for the 17.68- to 828.45-m (58- to 2718-ft) interval.

Borehole deviation attained a maximum value of 10° from vertical to the northwest during the course of the drilling (Table 1). For the interval from 17.68 to 274.32 m (58 to 900 ft), the borehole was nearly vertical, reaching a maximum deviation of 3° at a depth of269.75 m (885 ft). Borehole deviation increased from 3 to 8° from vertical within the interval 269.75 to 394.72 m (885 to 1295 ft). This interval of the borehole includes a structurally complex zone within the uppermost Maryville Limestone that is thought to be responsible for most of the increase in deviation. Below 394.72 m (1295 ft), the borehole maintained an essentially constant deviation value of 10° to the northwest (Table 1).

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* To facilitate reference to drilling records, field notes, and specific intervals of drill core as stored in the Core Storage Facility (ORNL Building 7042), specific borehole depths or intervals are also given in English System units of feet.

TABLE 1. Borehole Deviation Data for ORNL-JOY No. 2

Date	Depth [m (ft)]		Azimuth	Inclination[a]
8/30/83	26.82	(88)	N26°W	89
9/02/83	153.92	(505)	N09°W	89
9/08/83	269.75	(885)	N13°W	87
9/13/83	358.14	(1175)	N44°W	84
9/16/83	394.72	(1295)	N41°W	81
9/22/83	516.03	(1693)	N43°W	80
9/29/83	611.12	(2005)	N17°W	80
10/11/83	668.12	(2192)	N43°W	80
11/10/83	731.52	(2400)	N33°W	80

[a] Inclination angle is measured with respect to horizontal; a vertical borehole would have an inclination of 90°.

Core drilling proceeded without serious problem throughout the entire Conasauga Group interval to a depth of 616.00 m (2021 ft). This depth was reached on September 29, 1982, and up to this time, drilling progress had averaged 8.84 m (29 ft) per 8-h shift. The depth of 616.0 m (2021 ft) was the point where the Rome Formation was encountered and was marked by a significant lithologic change. A massive and hard-to-drill sandstone was encountered that slowed progress to 2.44 m (8 ft) per 8-h shift for the period October 1 – 29, 1982. At this date, a depth of 737.92 m (2421 ft) had been reached, and another lithologic change was encountered that further complicated drilling operations. The intensity and degree of deformation of the strata being drilled increased sharply. Below the 737.92 m (2421 ft) depth, because of the increased deformation, bedding was typically parallel, or at very shallow angles, to the direction of drilling. Furthermore, many 0.31- to 1.52-m-thick (1- to 5-ft) horizons encountered below 797.92 m (2421 ft) were shattered and brecciated. Such a situation, coupled with problems caused by inefficient removal of cuttings because of a lack of return circulation of the drilling fluid, slowed the rate of progress to 1.22 m (4 ft) per 8-h shift for the remaining period of drilling (November 1 – December 15, 1982).

At the completion of drilling on December 15, 1982, Joy personnel removed the drill stem but left it and the drill rig on site. This was done in the event that the equipment would be needed to assist in clearing the borehole for the geophysical logging activities.

3.3 SUMMARY OF GEOPHYSICAL LOGGING OPERATIONS

Geophysical logging of the borehole was begun by the USGS on January 13, 1983. Temperature and caliper logs were initially obtained for the 17.68- to 821.74-m (58- and 2696-ft) interval. These results suggested that ~ 6.10 m (20 ft) of the borehole was lost because of problems with removal of cuttings. The caliper logging tool caused unstable portions of the borehole to collapse, however, and resulted in the borehole's being blocked below a depth of 566.93 m (1860 ft). Personnel from Joy were called back to the site to attempt to reopen the borehole and to flush debris from it. Further attempts at logging were suspended until the borehole clearing and stabilization could be attempted.

On January 19, 1983, logging resumed. After several unsuccessful attempts by Joy to clear and stabilize the borehole, it was decided to leave, temporarily, 731.52 m (2400 ft) of drill stem in place so that logging could be attempted from inside. In this fashion, gamma-ray and neutron logs were obtained for the interval from 17.68 to 731.52 m (58 to 2400 ft). Gamma-ray spectral logs were obtained for selected shale/mudstone intervals in the lowermost Maynardville Limestone [141.73 m/(465 ft)]; the Nolichucky Shale [274.31 m/(900 ft)]; the Maryville Limestone [317.91 m/(1043 ft), 327.36 m/(1074 ft), and 403.56 m/(1324 ft)]; the Pumpkin Valley Shale [545.59 m/(1790 ft) and 586.74 m/(1925 ft)]; and the uppermost Rome Formation [624.23 m/(2048 ft)]. After these logs were obtained, drilling mud was circulated in the borehole in a final attempt to stabilize the walls before the drill stem was finally removed.

Because of scheduling problems, further logging was delayed until February 12, 1983. At this time acoustic velocity and waveform logs were successfully obtained for the interval from 17.68 to 601.98 m (58 to 1975 ft), and an acoustic televiewer log was obtained for the interval from 17.68 to 304.80 m (58 to 1000 ft). Attempts to obtain any electric logs, such as SP and resistivity logs, were unsuccessful because of interferences within the logging tools from signals of unknown origin. Logging was completed on February 14, 1983.

4. STRATIGRAPHIC DATA

4.1 INTRODUCTION

The lowermost portion of the Copper Creek fault block at the drill site consists of the Knox Group, the Conasauga Group, and the Rome Formation. The Conasauga Group is a complex mixture of carbonate and clastic lithologies. It is transitional between the Rome Formation which is essentially carbonate-free, and the Knox Group, which is dominantly clastic-free. The statigraphy and lithology of the formations within the lowermost portion of the Copper Creek fault block are summarized in Fig. 3 and in the Appendix.

4.2 THE KNOX GROUP

Within the Oak Ridge vicinity, the Knox Group is 600 to 900 m thick and consists mainly of dolostone with some interbedded limestone and lesser amounts of sandstone (Milici 1973). Five or six (Milici 1973)

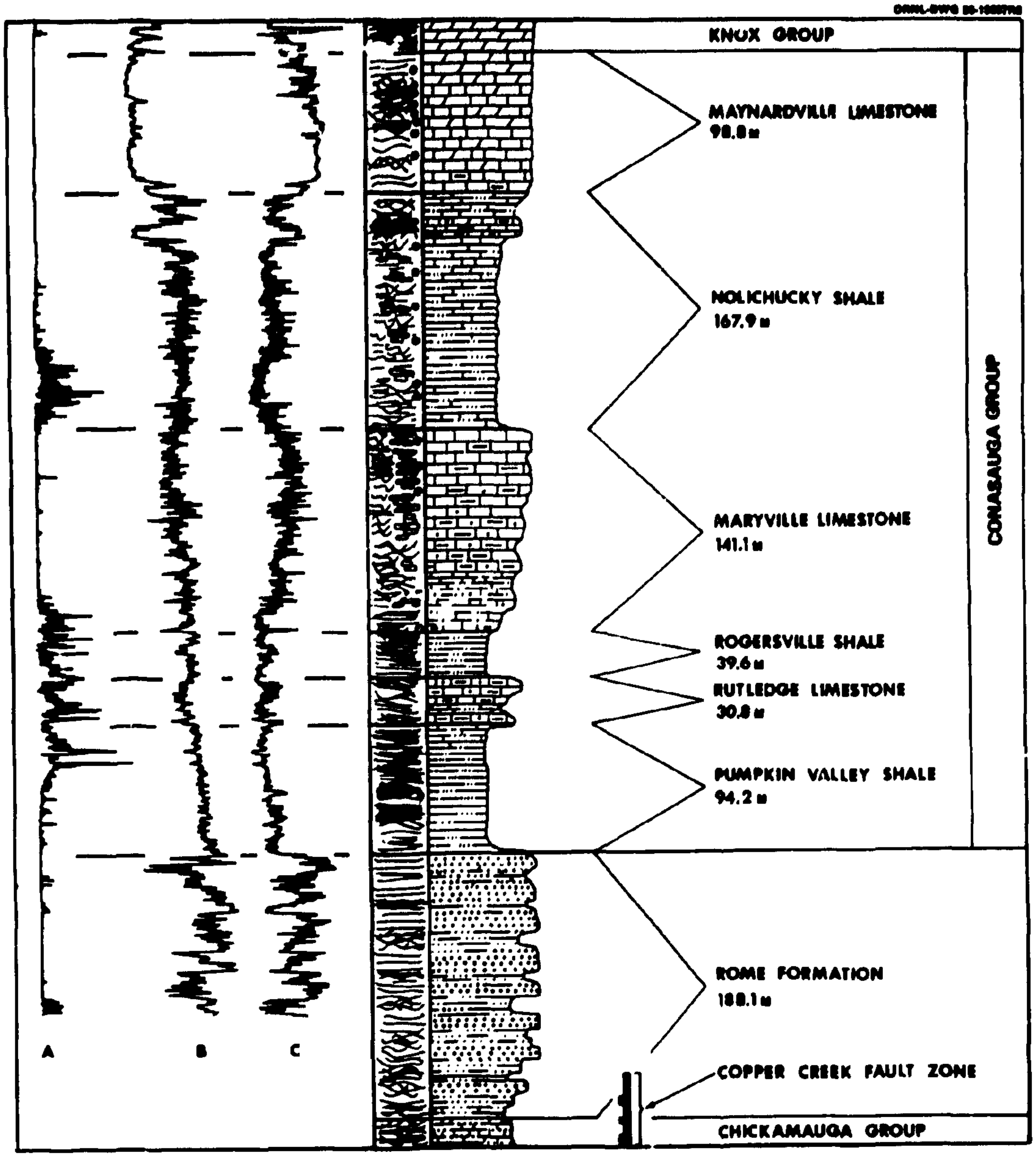

Fig. 3. Borehole geophysical logs and generalized lithologic log for ORNL-JOY No. 2. (a) Caliper log illustrating borehole diameter. Borehole diameter increases to right. Nominal diameter is 9.4 cm, and maximum deflections to the right represent diameter of 30.5 cm. (b) Gamma-ray log illustrating naturally occurring gross gamma-ray activity. Activity increases to right, and values on log range between 50 and 250 Bq. (c) Neutron-epithermal neutron log. Scale increases to the right and the count rates on the log illustrated range between 50 and 3800 Bq. The central column represents generalized lithologic log illustrating bedding character and composition of Conasauga Group and Rome Formation. Note Copper Creek fault zone and the juxtaposition of Rome Formation strata on top of Chickamauga Group.

regionally persistent formations can be delineated within the Knox Group throughout most of east Tennessee.

At the drill site, the Knox Group is composed of massive dolostone and subordinate amounts of limestone. Lithologies within the Knox Group vary from dark-gray, massive, crystalline dolostones to light-gray, chert-poor, thinly bedded to massive dolostones (McMaster 1963). Only the basal portion Copper Ridge Dolomite, which is the lowermost formation of the Knox Group on the DOE Oak Ridge Reservation, was intersected.

The Copper Ridge Dolomite — In the Knoxville vicinity, this formation is typically 240 to 300 m thick (Milici 1973). Within the USDOE Oak Ridge Reservation, Copper Ridge Dolomite thicknesses are poorly known, but available data from reconnaissance mapping on Copper Ridge near the drill site suggest that the formation is at least 150 m thick (E. C. Walls, unpublished data, 1982) Only the lowermost 43.59 m of the formation were penetrated by the borehole (Table 2).

The Copper Ridge Dolomite is composed predominantly of two lithologies interstratified to form equally abundant alternating horizons (Fig. 4 and Appendix). One lithology is a thinly bedded to laminated, evenly parallel stratified, dark gray (N6 to N4)* dolostone and micrite† forming 0.5- to 3.0-m-thick beds that grade into

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* Munsell color designations (Goddard et al. 1948).

† Carbonate rock nomenclature is based on the classification system of Dunham (1962) with one exception: fine-grained carbonates are called micrites instead of mudstones as in Dunham's nomenclature. In this report, mudstone refers to a fine-grained clastic rock.

TABLE 2. Stratigraphic Thicknesses Measured in ORNL-JOY No. 2

Stratigraphic Unit	Thickness[a] [m (ft)]		Downhole Footage (ft)
Knox Group[b]	43.59	(143)	0-143
Copper Ridge Dolomite[b]	43.59	(143)	0-143
weathered	17.68	(58)	0-58
unweathered	25.91	(85)	58-143
Conasauga Group	572.42	(1878)	143-2021
Maynardville Limestone	98.76	(324)	143-467
Chances Branch member	43.89	(144)	143-287
Low Hollow member	54.86	(180)	287-467
Nolichucky Shale	167.95	(551)	467-1018
Upper Shale member	18.90	(62)	467-529
Bradley Creek member	9.14	(30)	529-559
Lower Shale member	139.90	(459)	559-1018
Maryville Limestone	141.12	(463)	1018-1 81
upper member	74.98	(246)	1018-1264
lower member	64.92	(213)	1264-1481
Rogersville Shale	39.62	(130)	1481-1611
Craig member	2.74	(9)	1485-1494
Rutledge Limestone	30.78	(101)	1611-1712
Pumpkin Valley Shale	94.18	(309)	1712-2021
upper member	48.46	(159)	1712-1871
lower member	45.72	(150)	1871-2021
Rome Formation	188.06	(617)	2021-2638
upper part	88.09	(289)	2021-2310
lower part	99.97	(328)	2310-2638
Copper Creek Fault Zone	46.03	(151)	2561-2712
Chickamauga Group[b,c]	24.38	(80)	2638-2718
Moccasin Formation[b]	24.38	(80)	2638-2718

[a] Formation thickness is taken as equivalent to downhole thickness. This assumption is valid for most of ORNL-JOY No. 2 because borehole attitude was within 10° of perpendicular to bedding. The assumption is not valid for highly faulted intervals of Maryville Limestone and Rome Formation.

[b] partial thickness value from a formation or group that was not completely penetrated during drilling.

[c] Chickamauga Group strata occur on Whiteoak Mountain fault block.

mottled and diffusely bedded dolostone [Fig. 4(a)]. The other lithology consists of evenly to wavy lenticularly laminated, medium-gray (N7 to N6) dolostone that grades into evenly ribbon-bedded dolostone containing a minor amount of shale stringers and locally abundant 0.3- to 1.0-m-thick beds of oolitic and mottled dolostone [Fig. 4(b)]. Stylolites are common within both lithologies throughout the entire Copper Ridge Dolomite section. Oolitic lithologies occur throughout most of the section of Copper Ridge Dolomite examined but are absent from a 10-m zone immediately above the lower contact. Chert is essentially absent from the lowermost Copper Ridge Dolomite except for two 1- to 3-cm-thick beds of disseminated nodules that occur within the lowermost 10-m zone.

The lower contact of the Copper Ridge Dolomite with the underlying Maynardville Limestone (the uppermost formation in the Conasauga Group) is gradational over a 4-m-thick interval. The contact zone is marked by the appearance of mottled to irregularly bedded tan to light-brown (5YR8/1 to 5YR4/1) calcarenite. Within the contact zone, calcite content increases from essentially 0 to over 90 percent, while the dolomite content decreases rapidly, although dolomite does not disappear altogether. The lowermost Copper Ridge Dolomite does not contain large amounts of chert or the massive petroliferous dolostones commonly reported from the contact zone elsewhere (Rodgers 1953; Milici 1973). Thus, the lower contact of the Copper Ridge Dolomite is marked principally by an abrupt decrease in dolomite content and a change in stratification patterns.

The Maynardville Limestone has somewhat lower gamma-ray activity and lower neutron absorptivity than the lowermost Copper Ridge

ORNL-Photo 2711-85

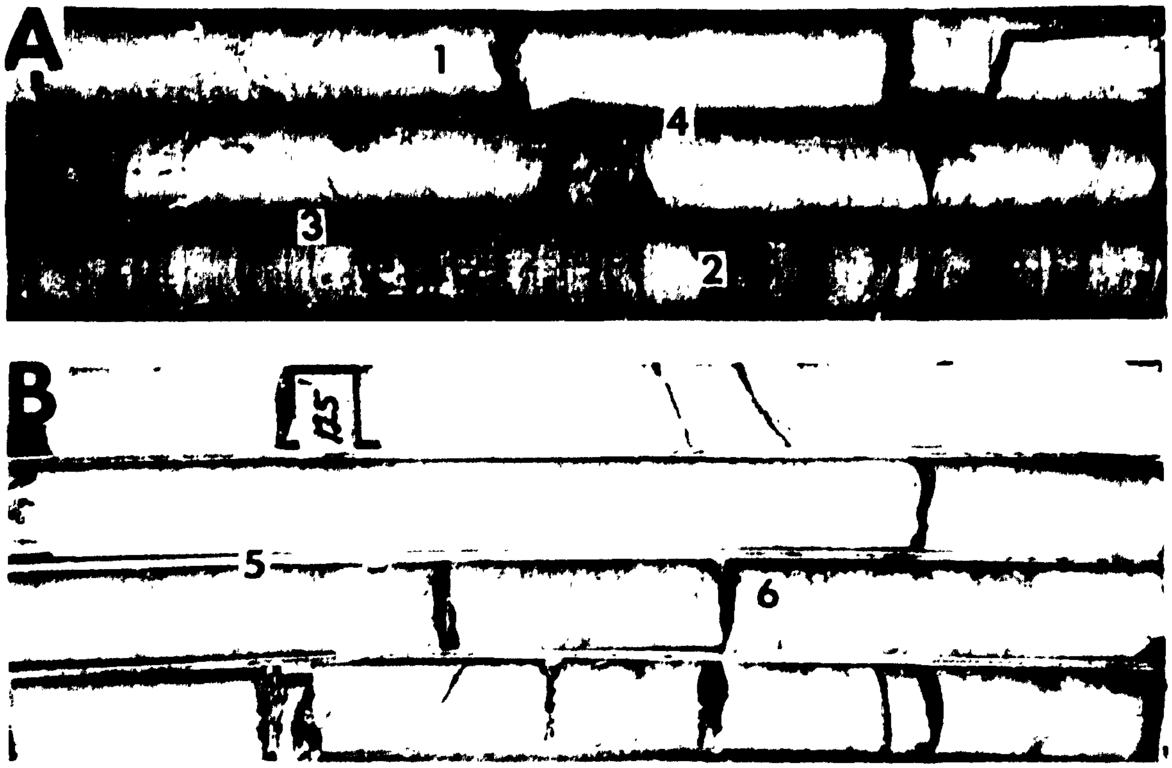

Fig. 4. Lithologies of Copper Ridge Dolomite. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 4: 90-97.5 ft) Diffusely bedded to mottled dolostone (1) and evenly parallel laminated dolomite micrite (2). Note stylolites (3) and solution cavities (4) developed along bedding planes. [b] (Box 8: 124.5-132 ft) Wavy to evenly laminated dolomite micrite (5) interbedded with mottled dolostone (6).

Dolomite (Fig. 3). The gamma-ray and neutron logs exhibit broad deflections within a 5- to 10-m-thick zone that overlaps with the contact zone defined by lithologic criteria. The baseline of both logs exhibits a readily recognizable shift that coincides with the location of the abrupt change from predominantly dolostone lithologies to predominantly limestone lithologies. This suggests that borehole geophysical techniques may provide a reliable means of locating the contact between these two carbonate-rich formations in other boreholes for which no drill core is available.

4.3 THE CONASAUGA GROUP

The Conasauga Group crops out throughout the Valley and Ridge Province in east Tennessee and southwest Virginia. Within its outcrop extent, the group undergoes complex lithofacies transitions associated with a change from clastics in the west to carbonates in the east (Rodgers 1953; Markello and Read 1981, 1982; Hasson and Haase 1985). Rodgers has divided the Conasauga Group into three phases that occur in northeast-southwest trend belts. Within the central phase, six formations that represent complex interfingering of carbonate and clastics are identified. To the west, in the northwestern phase, most of the carbonates disappear, and only two formations are recognized. To the east, in the southeastern phase, the clastics disappear and three formations can be identified.

The Conasauga Group at the drill site occurs near the western margin of the central phase (Hasson and Haase 1985), and six formations can be recognized (Fig. 3 and Appendix). The Rutledge and

Maryville limestones, however, are thinner than is typical for the central phase and they contain 30 to 60% clastics (Hasson and Haase 1985).

<u>The Maynardville Limestone</u> – The Maynardville Limestone is recognized throughout east Tennessee and occurs within all three phases of the Conasauga Group (Hasson and Haase 1985). At the drill site, the Maynardville Limestone is 98.76 m thick and is divisible into two regionally persistent members: the uppermost Chances Branch member that is 43.89 m thick and the underlying Low Hollow member that is 54.86 m thick (see Appendix). The two members have slightly different gamma-ray and neutron log signatures and can be readily identified on such logs (Fig. 3).

The Chances Branch member consists of medium- to thin-bedded, buff and light gray (5Y8/1 to N7) dolostones, ribbon-bedded dolomitic calcarenites, wackestones, and micrites, and medium-gray (N7 to 6) oolitic packstones and grainstones. The uppermost 20 m of the Chances Branch member consists of massive to laminated dolostone and intraclastic dolomitic calcirudites [Fig. 5(a)] interstratified with irregularly bedded to mottled, bioturbated calcarenites and dolomitic wackestones [Fig. 5(b)]. Lenticularly to wavy laminated beds of dolomitic micrites, 0.1 to 0.5 m thick, occur throughout the mottled wackestones. The lower 24 m of the Chances Branch member consists of alternating horizons of wavy to evenly ribbon-bedded wackestones interbedded with dolomitic oolitic packstones and grainstones [Fig. 5(c)]. Subordinate amounts of lenticularly ribbon-bedded dolomitic micrite occur in the lowermost portion of the Chances Branch member.

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Fig. 5. Lithologies of Chances Branch Member of Maynardville Limestone. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 12: 163-168 ft) Massive to diffusely laminated dolostone (1) and dolomitic intraclastic calcirudite (2). [b] (Box 18: 221-226 ft) Mottled dolomitic calcarenite wackestone. [c] (Box 19: 231-238.5 ft) Wavy ribbon-bedded dolomitic micrite (3) and wavy bedded dolomitic oolitic packstone (4).

Wavy to evenly ribbon-bedded calcarenite and micrite alternating with oolitic packstones and grainstones are the principal lithologies in the Low Hollow member (see Appendix). Throughout much of the member, carbonates have a distinctive petroliferous odor when freshly broken. Wavy ribbon-bedded and mottled dolomitic calcarenites and micrites [Fig. 6(a)] are most abundant in the upper portions of the member. Oolites become more common lower in the member, while wavy ribbon-bedded oolitic and pelloidal grainstones are more abundant in the bottom 35 m of the member [Fig. 6(b)].

The contact of the Maynardville Limestone with the Nolichucky Shale is gradational over a 4.5-m-thick interval. Within this interval, the Low Hollow member contains 0.1- to 0.3-m-thick beds of massive to thinly laminated calcareous mudstone (N4 to N2) interbedded with wackestones and micrite. The abundance of such shale-rich lithologies increases gradually downward through the interval, and at the contact, shale accounts for 40 to 60% of the Maynardville Limestone. Within the contact interval, gamma-ray and neutron logs (Fig. 3) exhibit pronounced shifts consistent with an increase in mudstone content. Gamma-ray energy spectrum measurements within a mudstone bed at 141.73 m (465 ft) downhole suggest that the majority of gamma-ray activity in the mudstone within the lowermost Maynardville is caused by naturally occurring ^{40}K.

The Nolichucky Shale — Throughout east Tennessee and southwestern Virginia, the Nolichucky Shale can be divided into Upper Shale, Bradley Creek, and Lower Shale members (Markello and Read 1981; Hasson and Haase 1985). Typically, the Bradley Creek member occurs toward

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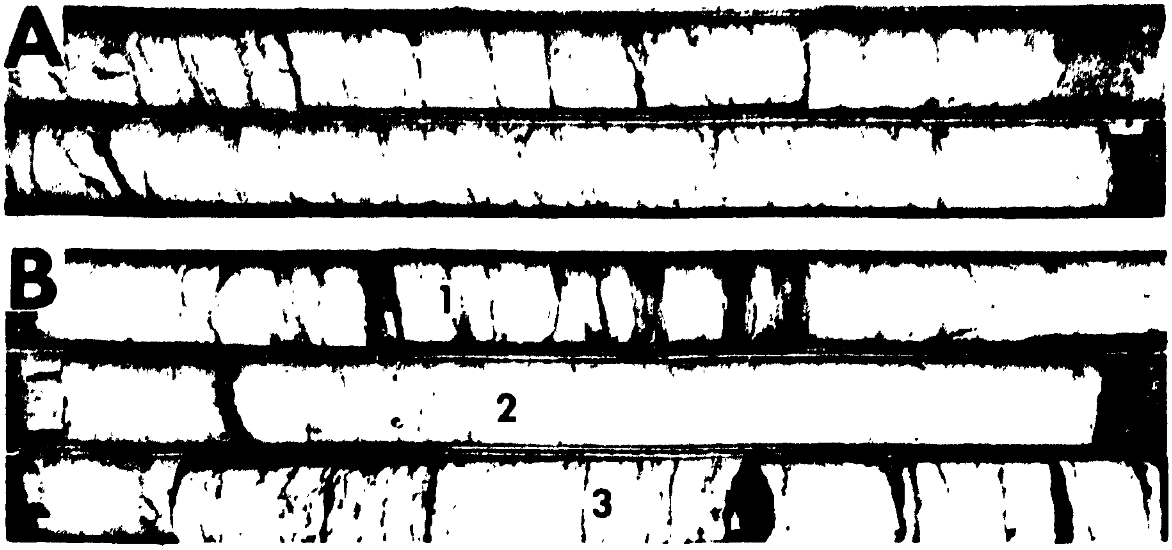

Fig. 6. Lithologies of Low Hollow Member of Maynardville Limestone. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 33: 365-370 ft) Wavy to lenticularly ribbon-bedded oolitic calcarenite and micrite. [b] (Box 39: 416-423.5 ft) Alternating horizons of ribbon-bedded dolomitic calcarenite (1), massive oolitic and pelloidal packstone and grainstone (2), and wavy to lenticularly bedded dolomitic micrite (3).

the middle of the Nolichucky Shale, and the Upper and Lower Shale members are of similar thickness. At the study locality, however, the Bradley Creek Member occurs in the uppermost interval of the Nolichucky Shale and the Upper Shale member is only 18.90 m thick. The Bradley Creek member is 9.14 m thick, the Lower Shale member is 139.9 m thick, giving a complete Nolichucky Shale thickness of 167.95 m (Fig. 3).

The Upper Shale member consists of interstratified calcareous mudstone and limestone lithologies (see Appendix). The mudstones (N4 to N2, locally 5YR2/1) are wavy to evenly stratified and thickly laminated. Interbedded throughout the mudstones of the Upper Shale member are 1- to 7-cm-thick siltstone beds with upward-fining graded bedding [Fig. 7(a)]. The limestones (N8 to N7) are wavy ribbon-bedded to laminated micrites, oolitic fossiliferous wackestones and packstones [Fig. 7(a)].

The Bradley Creek Member consists predominantly of lenticularly to irregularly stratified algal wackestones and packstones (N7 to N4) with interstratified micrites and oolitic grainstones [Fig. 7(b)]. Regionally, the Bradley Creek contains abundant bioherms composed of Renalcis algal remains (Markello and Read 1981). Structures very similar to those described by Markello and Read for stratigraphically equivalent limestones in southwestern Virginia are noted within the Bradley Creek member at the study site. Interbedded with the algal limestones are wavy to lenticular, discontinuously stratified shaly micrites, intraclastic and oolitic wackestones and calcareous mudstones [Fig. 7(c)]. Abundances of such lithologies are highly variable but generally increase to 30 to 50% toward the base of the

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Fig. 7. Lithologies of Upper Shale and Bradley Creek members of Nolichucky Shale. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 49: 509-516.5 ft) Laminated calcareous mudstone (1), wavy ribbon-bedded shaly calcarenite and dolomitic wackestone (2), and oolitic and fossiliferous packstone (3) typical of the Upper Shale member. [b] (Box 52: 537-542 ft) Massive crenulated oolitic algal packstone from top of Bradley Creek member. [c] (Box 53: 551-556 ft) Dolomitic oolitic pelloidal grainstone (4) interbedded with micrite (5) typical of lowermost Bradley Creek member. Horizontal lines are scratches caused by core catcher during drilling.

Bradley Creek member. The bottom of the Bradley Creek member is marked by 2 m of wavy to evenly bedded oolitic and pelloidal packstone with thin flaserlike stringers of dolomitic micrite [Fig. 7(c)].

The Lower Shale member consists of numerous repeated cycles of shale and limestone. The complex interbedded nature of the member is reflected in the highly modulated gamma-ray and neutron geophysical logs (Fig. 3). Limestone-rich lithologies compose 20 to 40% of the member (see Appendix) with the remainder composed of calcareous mudstones and shales. Such mudstones are typically red-brown to maroon or red-gray in color (N6 to N4 or 5YR4/1 to 5YR3/2). The mudstones are massively to thinly laminated [Fig. 8(a)] and typically are interbedded with 1- to 5-cm-thick upward-fining calcareous siltstone beds. Such lithologies have wavy to evenly parallel strata typical of microhummocky cross stratification (see Dott and Bourgeois 1982).

Mudstone-rich intervals at the top and the bottom of the Lower Shale member define mudstone baselines on neutron and geophysical logs. Such baselines are defined as the line that can be drawn through the leftward-most positions of the neutron log trace and the rightward-most positions of the gamma-ray log traces. Deflections to the right or left on the respective logs are a general indication of the occurrence of nonmudstone lithologies, such as carbonates or siltsones and sandstones, interbedded with or in place of mudstones. The mudstone baseline on the neutron log for the entire Nolichucky Shale falls at approximately the same position as the baseline for other mudstone-rich formations in lower portions of the Conasauga Group. Gamma-ray spectral analyses from red-brown and gray mudstone

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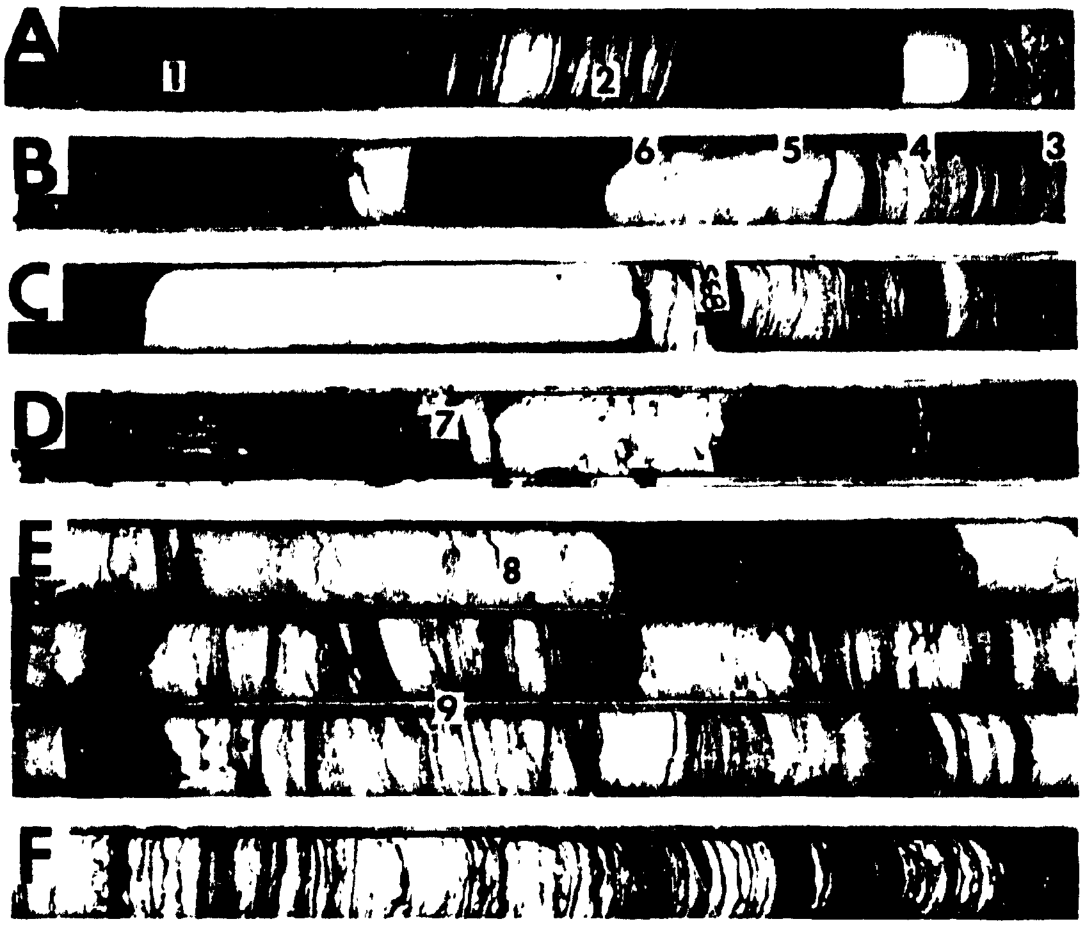

Fig. 8. Lithologies of Lower Shale member of the Nolichucky Shale. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 84: 840.5-843 ft) Massive to laminated mudstone (1) with wavy to evenly cross-stratified calcareous siltstone (2). [b] (Box 69: 696-698.5 ft) Upward-coarsening stratification cycle consisting of, from bottom to top: wavy current-ripple-bedded silty calcarenite (3), evenly bedded calcarenite (4), massively bedded dolomitic oolitic packstone (5), and intraclastic, oolitic, pelloidal packstone or grainstone (6). [c] (Box 83: 833.5-836 ft) Upward-coarsening cycle without topmost intraclast-bearing packstone or grainstone. [d] (Box 92: 912-914.5 ft) Intraclastic oolite wackestone with abundant glauconite pellets (7) interbedded wit massive mudstone. [e] (Box 73: 737-744.5 ft) Incomplete upward-coarsening cycle missing lowermost calcarenite interval (8) and series of amalgamated cycles (9). [f] (Box 56: 581-583.5 ft) Lenticular to nodular micrite and wavy bedded and burrowed calcarenite interbedded with mudstone.

lithologies within the Lower Shale member indicate that naturally occurring ^{40}K is responsible for most of the gamma-ray activity observed within the mudstones.

Carbonates in the Lower Shale member are silty calcarenites, oolitic packstones, fossiliferous pelloidal wackestones and packstones, and intraclastic packstones and conglomerates. Carbonates within the Nolichucky Shale are associated with distinctive 0.2- to 1-m upward-coarsening cycles. Such cycles [Figs. 8(b) and (c)] begin with calcareous mudstone that is covered in turn by (1) evenly parallel stratified, thinly bedded calcarenite and calcareous siltstone; (2) wavy to lenticularly bedded calcarenite and wackestone; (3) evenly to wavy bedded oolitic packstone or grainstone that typically contains abundant glauconite pellets and trilobite fragments, and (4) a cap of lithologically distinctive "flat pebble" intraclastic and oolitic grainstone or packstone [Fig. 8(b)]. In many examples, however, this conglomerate lithology is absent and the cycle is capped with the ooid-bearing material [Fig. 8(c)]. There is much variability within the upward-coarsening cycles; one or more of the lithologies may be absent from a particular occurrence or several cycles may be aggraded [Figs. 8(d) and (e)]. At the top and bottom of the Lower Shale member, 0.2- to 1.0-m beds of wavy ribbon-bedded to nodular micrite to wackestone are interbedded with mudstone [Fig. 8(f)] and appear to be replace, in part, the upward-coarsening limestone lithologies.

The distribution of the limestone-bearing units throughout the Lower Shale member is quite uniform (see Appendix) within the upper two-thirds of the member. For this interval, carbonate lithologies typically compose 30 to 60% of the formation, and this abundance of carbonates causes a pronounced deflection of the neutron log to the right of the mudstone baseline (Fig. 3). Carbonate abundance decreases in the lower one-third of the member, where the limestone cycles are thinner and occur less frequently. Such a decrease is reflected by a pronounced leftward deflection on the neutron log toward the botton of the Nolichucky Shale (Fig. 3).

The lower contact of the Nolichucky Shale is a gradational zone marked by an increasing carbonate content over the lowermost 10 m of the Nolichucky Shale. This interval contains calcarenites and fossiliferous wackestones and packstones interbedded with calcareous mudstones and shales. The mudstone content of this lowermost interval decreases gradually and at the lower contact drops to 10 to 20%. Intraformational clasts and flat pebble conglomerates, though present, are rare in this interval. The bottom of this interval is marked by an abrupt increase in the intraclast content of the limestones and the virtual disappearance of mudstones. The lower contact of the Nolichucky Shale is placed at this lithologic transition that is marked by an abrupt step in the rightward and leftward deflections observed on neutron and gamma-ray logs (Fig. 3).

The Maryville Limestone - The Maryville Limestone is not subdivided into members throughout most of east Tennessee (Rodgers 1953; Hasson and Haase 1985). Within the Oak Ridge vicinity, however, the formation contains rapid lithofacies changes (Hasson and Haase 1985), and it can be divided informally into an upper and lower member. The Maryville Limestone at the drill site is 141.12 m thick; the upper part is 74.98 m and the lower part is 64.92 m.

Although borehole inclination effects and general formation dip have been taken into account, the 141.12-m-thickness value is larger than the true stratigraphic thickness (see Table 2) because of the occurrence of several severely deformed intervals within the Maryville Limestone. Based on attempts to straighten out the deformed intervals, it is estimated that the true thickness of the Maryville Limestone is within 10 to 20% of the 141.12-m value.

The upper member of the Maryville Limestone is characterized by distinctive "flat pebble" conglomerates [intraclastic and locally oolitic packstones, Figs. 9(a) and (b)]. Such lithologies occur elsewhere in the Conasauga Group but not as abundantly as noted in the upper part of the Maryville Limestone. Interbedded with the "flat pebble" conglomerates are subordinate amounts of calcareous mudstones (N7 to N5), wavy to lenticularly stratified nodular micrite and dolomitic wackestones [Fig. 9(c)], wavy to lenticuarly bedded calcarenite, and fossiliferous pelloidal packstone [Figs. 9(b) and (c)]. Calcarenite and packstone occur in upward-fining cycles that have scoured bases and wavy to even bedding typical of microhummocky cross stratification [Fig. 9(c)].

Within the upper member, conglomerates account for over 80% at the top of the upper part and decrease in abundance toward the bottom of the upper part to 40 to 60%. Other lithologies, especially the calcarenites and mudstones, increase correspondingly from the top to the bottom of the upper part of the Maryville Limestone (see Appendix). With the exception of the Maynardville Limestone, the upper portions of the upper member of the Maryville Limestone are the most pure carbonate rock in the Conasauga Group at the study site.

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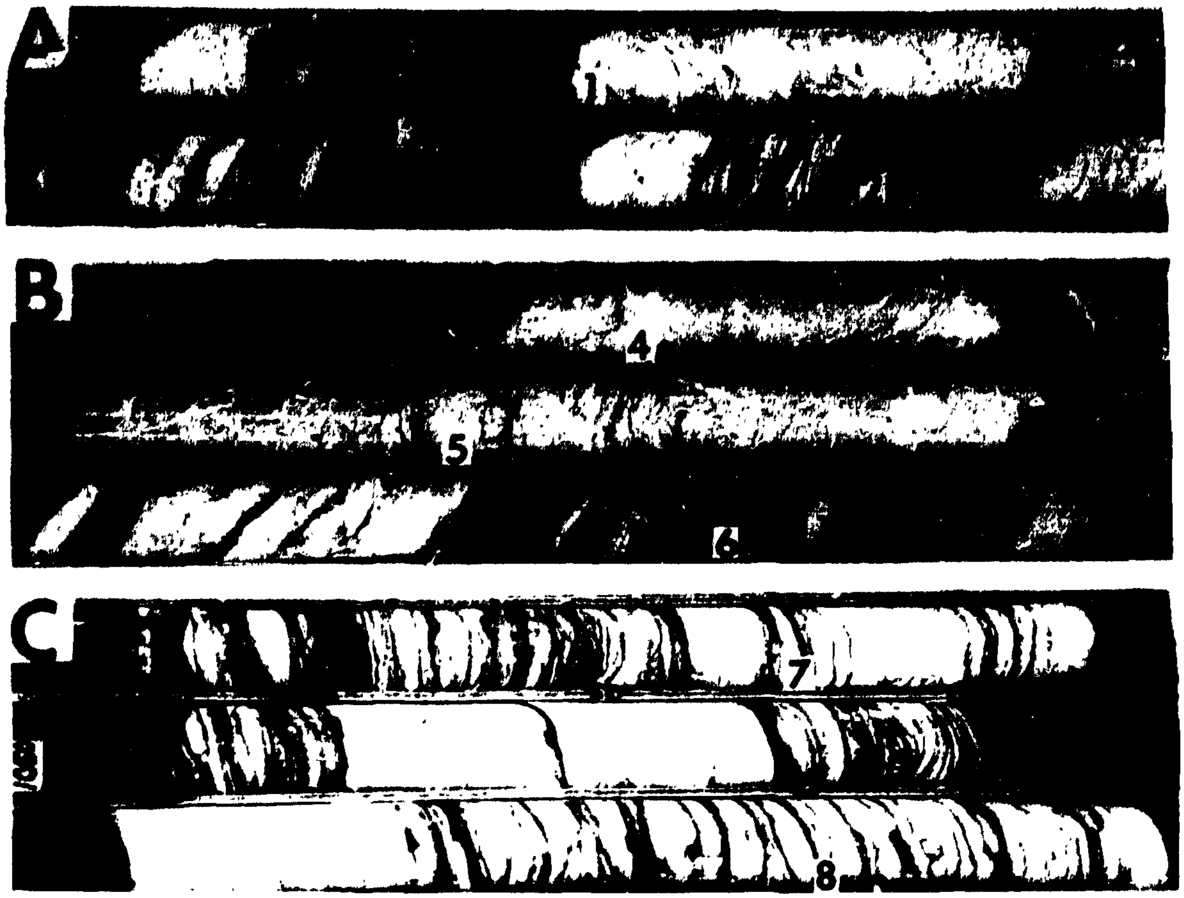

Fig. 9. Lithologies of upper member of Maryville Limestone. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 109: 1066-1071 ft) Intraclastic and oolitic grainstone "flat pebble" conglomerate (1), wavy to lenticularly ribbon-bedded calcarenite and pelloidal wackestone (2), and massive calcareous mudstone (3). [b] (Box 126: 1222-1229.5 ft) Dolomitic glaucontite-bearing oolitic grainstone (4), intraclastic grainstone (5), and mudstone with wavy bedded upward-fining calcarenite beds (6). Note calcite-filled joints and fractures. [c] (Box 107: 1047.5-1055 ft) Intraclastic oolitic packstones and amalgamated upward-coarsening cycles (7) and wavy ribbon-bedded calcarenite and micrite (8).

Such a high carbonate content results in a distinctive rightward bulge or hump on the neutron log for this stratigraphic interval. The rightward deflection of the neutron log diminishes toward the bottom of the upper member with the trace approaching a mudstone baseline similar to that characteristic of the Nolichucky Shale. This trend is in response to increasing amounts of mudstone in the lower portion of the upper member. A corresponding, but less distinctive, leftward bulge is observed on the gamma-ray log for the same interval. Superimposed on this bulge in the gamma-ray log are three left-to-right oscillations (Fig. 3). Such oscillations are typically observed on gamma-ray logs for the upper member of the Maryville Limestone within the Oak Ridge vicinity (Haase 1985) and reflect interbedded mudstone-rich intervals within the upper member. Gamma-ray spectral analysis of two mudstone-rich intervals within the upper member indicate that ^{40}K is the principal naturally occurring radionuclide within mudstones of this member.

The lower member of the Maryville Limestone is composed of 0.1- to 0.4-m-thick beds of calcareous mudstones interstratified with pelloidal or oolitic wackestones and packstones, calcarenites, and calcareous siltstones (Fig. 10 and Appendix). The mudstones are thinly bedded to thickly laminated with evenly to wavy parallel stratification that locally exhibit current-rippled structures and 1- to 3-cm-thick upward-fining siltstone-rich intervals. The limestone lithologies occur in discrete 5- to 20-cm-thick beds within upward-coarsening cycles. Such cycles are similar to those in the Nolichucky Shale except that the cycles in the Maryville Limestone are thinner. The upward-coarsening cycles begin with calcareous

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Fig. 10. Lithologies of lower member of Maryville Limestone. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 145: 1401-1408.5 ft) Oolitic, intraclastic packstones (1), glauconite-bearing oolite grainstone (2), and evenly parallel bedded calcarenite and wackestone (3). [b] (Box 142: 1370-1375 ft) Evenly parallel bedded calcareous siltstones and calcarenite and amalgamated upward-fining cylces that produce 0.1 to 0.5 m ribbon-bedded carbonate horizons (4). Note bioturbated calcareous mudstones (5).

mudstone. The mudstone is covered by thinly bedded calcareous subarkosic siltstones and calcarenites that are evenly to wavy current-rippled stratified. Such lithologies include several amalgamated upward-fining sequences 1 to 4 cm thick [Fig. 10(a)]. The upward-coarsening cycle is capped by massively to thinly bedded, evenly to wavy stratified oolitic or intraclastic packstone. The top of the cycle is marked by an abrupt change to calcareous mudstone. Glauconite pellets are common within the oolite and intraclast packstones in the uppermost portions of many upward-coarsening cycles. Hardgrounds, which are typified by planar concentrations of glauconite pellets that exhibit parallel to slightly cross cutting relationships with bedding, are commonly observed within the ooid-bearing upper portions of the upward-coarsening cycles. Such hardground structures are similar to those described by Markello and Read (1981, 1982) as occurring within carbonates of the Maryville Limestone and Nolichucky Shale in southwest Virginia.

The mudstone content of the lower member of the Maryville Limestone ranges from 50 to 80% with the remainder compring carbonate lithologies. The increased mudstone content is reflected by relatively flat neutron and gamma-ray logs that are in line with the mudstone baseline previously observed for other portions of the Conasauga Group.

Within the lower part of the Maryville Limestone, the upward-coarsening cycles exhibit a large amount of variability. One or more of the components of the cycle may be absent; a commonly observed variation is the absence of the coarse-grained ooid-bearing top of the cycle. Another commonly observed variation is the amalgamation of two or more upward-fining cycles that locally produces 0.1- to 0.5-m-thick wavy to evenly ribbon-bedded silty packstone and calcarenite horizons [Fig. 10(b)].

The lowermost 15 m of the Maryville Limestone is characterized by an increase in calcareous mudstone content from 30 to 50% of the rock to 60 to 80%. Limestone-rich intervals decrease in thickness and frequency over the same interval. Although the contact with the Rogersville Shale falls within such an interval, marked by a gradual increase in shale content, the formational contact itself is distinct because it is placed at the bottom of the lowermost ooid-bearing upward-coarsening cycle. Immediately below this limestone is a 0.7- to 1.2-m-thick bed of massive shale (N6-N4) that contains few siltstone laminae, is massive to thinly laminated, and is quite distinct from the mudstones and shales of the Maryville Limestone. This mudstone is the uppermost portion of the Rogersville Shale.

On neutron and gamma-ray logs, the lower contact of the Maryville Limestone is readily definable as occurring immediately below the lowermost of two sharp spikes that occur toward the bottom of the lower member interval (Fig. 3). These spikes are prominent features that mark abrupt departures from the baseline position of the relatively mudstone-rich lower member. Such spikes correspond to ooid-bearing limestone horizons within the basal Maryville Limestone and are recognizable throughout the Oak Ridge vicinity (Haase 1985).

Rogersville Shale — The Rogersville Shale at the drill site is 39.62-m thick. Throughout much of east Tennessee, the Craig member, a limestone-rich interval, can be delineated within the upper portion of the Rogersville Shale (Rodgers 1953; Hasson and Haase 1985). The Craig member is recognizable at the study site and is 2.74 m thick, while regionally, it ranges from 0 to 9 m thick (Hasson and Haase 1985).

Lithologically, the Rogersville Shale consists of massive to laminated noncalcareous mudstones and evenly bedded to wavy current-rippled calcarenites and subarkosic siltstones [Figs. 11(a) and (b); Appendix]. The mudstones range from red-brown (5R4/2-3/3 to 5YR4/1-2/1) to gray (N6-3) and gray-green (5G4/1-2/1). A distinctive, reddish, massive to thinly bedded, evenly parallel stratified mudstone occurs immediately below the Craig member. This lithology, which is 7.92 m thick at the study site, is persistent throughout the Oak Ridge Reservation (Haase 1985) and serves as an excellent stratigraphic marker for the upper Rogersville Shale. Below this interval, the remainder of the Rogersville Shale is composed of interbedded mudstones and subarkosic siltstones. The mudstones are massively to evenly stratified with wavy to straight lenses and disseminations of siltstone throughout. The subarkosic siltstones are 1 to 20 cm thick and exhibit wavy to evenly parallel stratification that frequently contains cross-bedding and current-rippled features [Fig. 11(b)]. Most siltstone intervals have upward-fining graded bedding with scour surfaces at their bottoms and mud-draped tops. Amalgamation of two or more siltstone intervals is common. Glauconite pellets are common in siltstones throughout the Rogersville Shale interval; locally glauconite accounts for 10 to 30% of the individual siltstone horizon. Such glauconite contents contrast with those for siltstones in the overlying Maryville Limestone where glauconite is essentially

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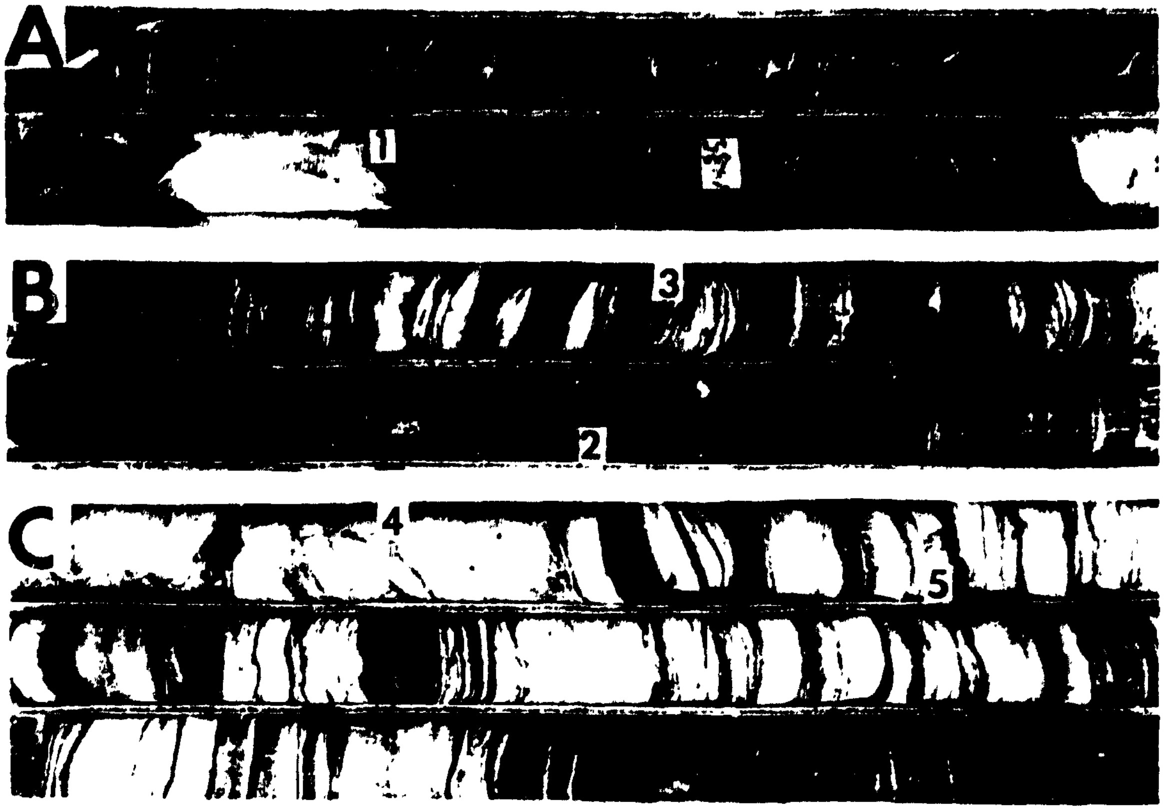

Fig. 11. Lithologies of Rogersville Shale and Craig member. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left.
[a] (Box 153: 1482-1487 ft) Massive mudstone of uppermost Rogersville Shale. High-angle fault trace is filled with calcite (1).
[b] (Box 155: 1495-1500 ft) Thinly laminated mudstone (2) and wavy, parallel-bedded subarkosic siltstone (3).
[c] (Box 154: 1486-1493.5 ft) Craig member is capped by dolomitic glauconite-bearing oolitic grainstone (4) and wavy to lenticularly bedded fossiliferous wackestone and silty calcarenite (5).

absent, except for random disseminations in siltstones of the lowermost portion of the formation and for concentations associated with truncation layers contained within oolitic packstones that cap upward-coarsening cycles.

Carbonates within the Rogersville Shale occur with abundance only within the Craig member. This member is an upward-coarsening cycle that begins with evenly and wavy bedded calcareous siltstones and grades upward to (1) wavy and lenticularly bedded calcarenites and silty wackestones; (2) pelloidal packstones and silty calarenites; and (3) capping glauconitic and dolomitic oolitic and intraclastic grainstones [Fig. 11(c)].

The lower contact of the Rogersville Shale is continuous but abrupt, occurring over an interval of 0.5 m. The contact is defined by a sharp transition from mudstone with subordinate amounts of interbedded subarkosic siltstone to thinly bedded calcarenites and silty wackestone, and micrite of the uppermost portion of the underlying Rutledge Limestone. The mudstones and siltstones of the lowermost Rogersville Shale are lithologically homogeneous but have alternating intervals of gray (N5-3) and red-gray (5R4/2-2/2 and 5YR4/1-2/1). The mudstones immediately at the contact are red-gray and contrast sharply with the light gray-gray (N8-6) limestones and siltstones of the uppermost Rutledge Limestone.

The borehole geophysical signature of the lower contact of the Rogersville Shale is represented on gamma-ray and neutron logs by moderately abrupt rightward and leftward deflections, respectively, away from the mudstone baseline position (Fig. 3). Neutron and gamma-ray logs for most of the Rogersville Shale are characterized by baselines similar to those for the overlying mudstone-rich lower member of the Maryville Limestone. The contact with the limestone-rich uppermost Rutledge Limestone produces significant deflections that permit easy recognition of the contact from throughout the Oak Ridge vicinity (Haase 1985).

The Rutledge Limestone – The Rutledge Limestone exhibits a rapid lithofacies transition in the Oak Ridge vicinity (Hasson and Haase 1985). Eastward of the Oak Ridge locality, the Rutledge Limestone is dominantly ribbon-bedded carbonate. Westward from this locality, the Rutledge Limestone rapidly becomes clastic-rich and thins to extinction (Rodgers 1953). At the study site, the formation is 30.78 m thick. A prominent clastic-rich interval in the central portion of the formation divides the Rutledge Limestone into upper and lower limestone-rich parts in addition to the central clastic-rich interval (Fig. 3 and Appendix). Such a subdivision is persistent throughout the Oak Ridge Reservation (Haase 1985) but has not been reported elsewhere in east Tennessee.

The limestones of the upper part of the Rutledge Limestone are micrites, locally fossiliferous pelloidal wackestones and packstones, and silty calcarenites. The limestones are thinly bedded with highly variable stratification patterns. The calcarenites and most of the wackestones and packstones range from wavy to lenticularly bedded. The micrites are lenticularly ribbon-bedded to nodular; such ribbon-bedded intervals do not attain a thickness greater than 0.4 m. The silty calcarenites form 1- to 15-cm-thick upward-fining intervals with wavy current-rippled and evenly cross-stratified bedding [Fig.

12(a)]. Interbedded with the coarser-grained lithologies are gray (N6-3) to gray-green (5GY4/1-2/1) calcareous and noncalcareous mudstones. These mudstones are thinly bedded to laminated with wavy to even parallel stratification.

The clastic-rich lithologies in the middle interval of the Rutledge Limestone consist of red-brown (5YR4/1-2/1), red-gray (5R4/1-2/1), and gray (N6-3) mudstones and shales with interbedded laminae and lenses of subarkosic siltstone [Fig. 12(b)]. Siltstones have upward-fining graded bedding and wavy to evenly parallel to discontinuous current-rippled stratification. Locally such intervals resemble microhummocky cross-stratification.

The lowermost part of the Rutledge Limestone consists of limestones that range from lenticularly bedded to mottled and bioturbated gray (N7-6) to gray-green (5GY4/1-2/1) wackestones and calcarenites [Fig. 12(a)]. Such limestones are interbedded with shales and mudstones similar to those of the middle part of the Rutledge Limestone. These lithologies combine to form a 6-m-thick sequence of three gray limestone horizons separated by two red-gray mudstone-rich horizons. This stratigraphic interval is referred to as the "three limestone beds" (deLaguna et al. 1968) and produces a very distinct three-pronged pattern on gamma-ray and neutron borehole logs (Fig. 3) that serves as an excellent stratigraphic marker throughout the Copper Creek fault block in the Oak Ridge vicinity (Haase 1985).

The contact with the underlying Pumpkin Valley Shale is gradational over a 10-m-thick interval. Within the contact zone, the amount of calcarenite and calcareous siltstone decreases from 40 to 70% in the lowermost Rutledge Limestone to 10 to 20% in the uppermost Pumpkin

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Fig. 12. Lithologies of Rutledge Limestone. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left.
[a] (Box 168: 1621-1628.5 ft) Wavy and lenticularly ribbon-bedded fossiliferous pelloidal packstone (1), lenticularly bedded micrite (2), and wavy to evenly bedded calcarenite and calcareous siltstone (3). mudstone containing stringers of calcareous subarkosic siltstone is interbedded (4). [b] (Box 174: 1679-1684 ft) Massive mudstone.
[c] (Box 177: 1707-1712 ft) Bioturbated silty fossiliferous wackestone (5) and calcareous mudstone (6).

Valley Shale. The contact is placed at the bottom of the lowermost limestone horizon of the "three limestone beds". This position marks the most abrupt decrease in carbonate content within the contact zone.

The Pumpkin Valley Shale – Regionally, the internal stratigraphy of the Pumpkin Valley Shale is not well known, and formal stratigraphic members have not been defined (Rodgers 1953; Harris 1964; Hasson and Haase 1985). The formation has been informally divided into an upper and lower member on the Whiteoak Mountain fault block near Oak Ridge, Tennessee (Law Engineering 1975) and such a subdivision can be applied to the formation throughout the Copper Creek fault block (Haase and Vaughan 1981; Haase 1985). Within the Oak Ridge Reservation, the upper and lower members are of approximately equal thickness (Haase 1985). At the drill site, the Pumpkin Valley Shale is 94.18 m thick with the upper and lower members being 48.46 m and 45.72 m thick, respectively.

The upper member of the Pumpkin Valley Shale consists of red-brown (10R6/2-2/2), red-gray (5R4/2-2/1), and gray (N6-3) mudstones and shales interbedded with subarkosic siltstones (Appendix). The mudstones are massively to thinly bedded and evenly to wavy parallel stratified. They range from essentially pure mudstone to silty mudstones with thin 0.1- to 2-cm-thick stringers and disseminations of subarkosic siltstone [Fig. 13(a)]. Such disseminations locally coalesce to form discontinuous lenticular siltstone beds that occur throughout silty mudstone-rich intervals. Siltstone-rich horizons exhibit complex stratification patterns that range from thinly laminated to thinly bedded 1- to 25-cm-thick intervals with wavy to

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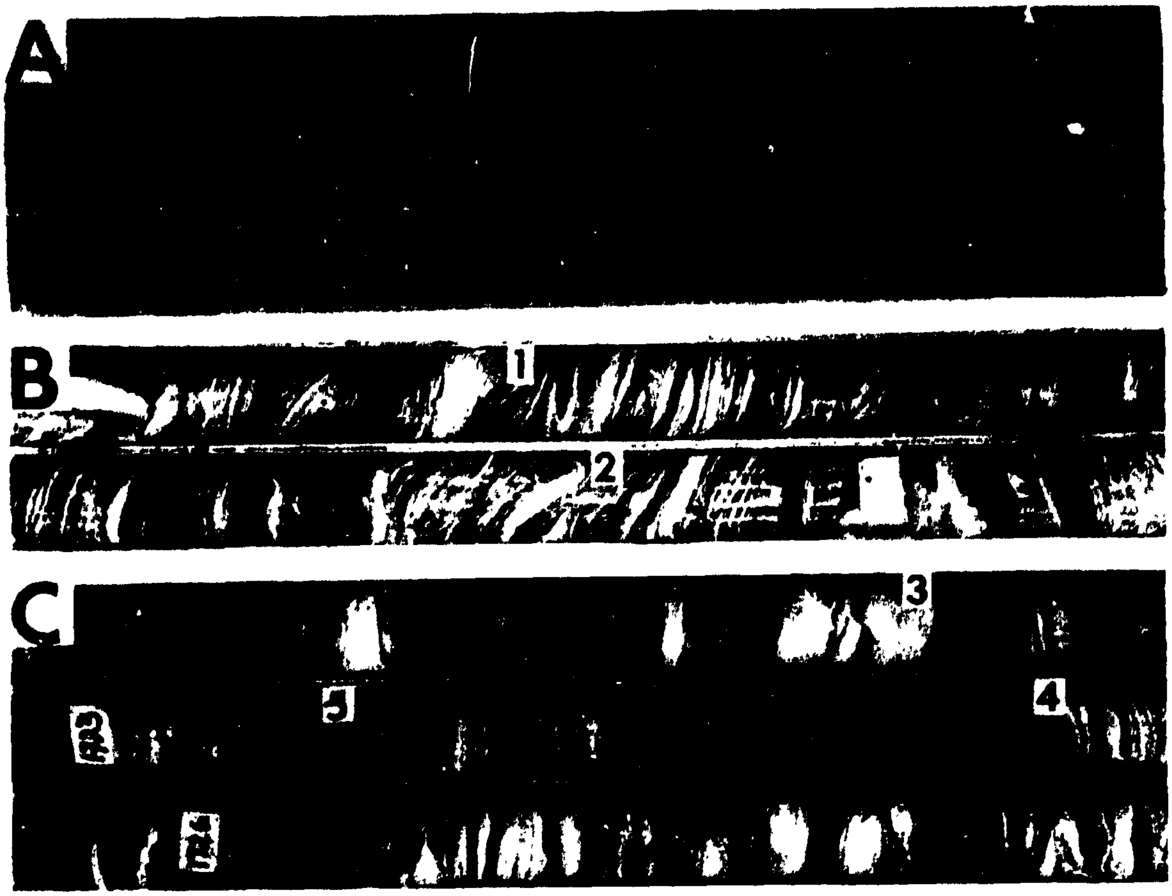

Fig. 13. Lithologies of upper member of Pumpkin Valley Shale. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 191: 1835-1842.5 ft) Evenly to wavy bedded mudstone with subarkosic siltstone stringers and lamellae. [b] (Box 182: 1750-1755 ft) Current-rippled cross-stratified siltstones (1) with local slumping (2). [c] (Box 179: 1721-1728.5 ft) Upward-fining evenly laminated siltstones (3) interbedded with wavy and current-rippled subarkosic siltstone (4) and thinly laminated mudstones (5).

evenly parallel to nonparallel stratification. Such siltstone horizons may exibit evenly cross-stratified or current-rippled internal laminations typical of microhummocky cross-stratification. Amalgamation of several such cross-stratified siltstones is typical [Fig. 13(b)]. Siltstone also ocurs as isolated upward-fining beds disseminated throughout dominantly mudstone-rich horizons [Fig. 13(c)]. Such occurrences have scour bases and internal laminations ranging from evenly to wavy parallel. Where such upward-fining beds are closely spaced, each siltstone bed is capped by a mud-drape. Glauconite pellets are ubiquitous within siltstone intervals and occur in random disseminations throughout individual beds or are concentrated into discrete laminae and bedding planes. Locally, 0.5- to 2.0-cm-thick horizons composed of 40 to 60% glauconite pellets are interbedded within siltstones and mudstones in the upper member.

The lower member of the Pumpkin Valley Shale is slightly more siltstone-rich than the upper member, as is reflected by the slight rightward shift of the neutron log trace (Fig. 3 and Appendix). The lower member is characterized by the occurrence of maroon-brown (10R4/1-2/1) and maroon-gray (5R4/1-2/1) bioturbated siltstones [Fig. 14(a)]. Bioturbated horizons, which are 0.2 to 1.5 m thick, are massive to mottled and wavy or lenticularly bedded. Stratification within the lower member is highly variable, with the massively bedded horizons being the most completely bioturbated and homogenized. Compositionally, the bioturbated intervals resemble simple physical mixtures of the siltstone and mudstone lithologies identified in the upper member. Glauoconite pellets are very abundant within

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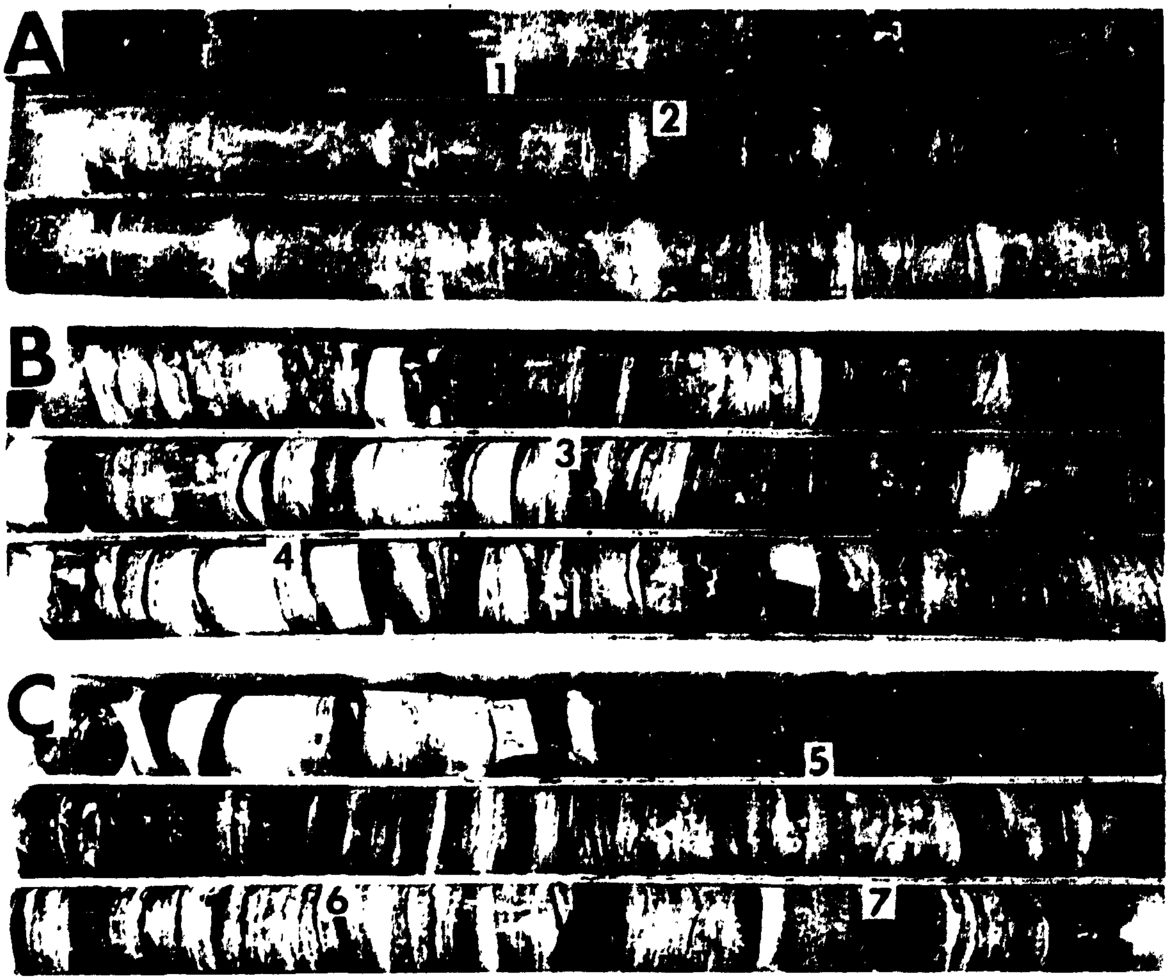

Fig. 14. Lithologies of lower member of Pumpkin Valley Shale. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 195: 1872-1879.5 ft) Massive bioturbated shaly siltstone (1) with stringers of evenly cross-stratified siltstone (2). [b] (Box 204: 1958-1965.5 ft) Interbedded wavy and lenticularly current-rippled siltstone (3) and evenly parallel stratified siltstone (4). [c] (Box 207: 2004-2011.5 ft) Interbedded mudstone (5) and wavy to evenly stratified thinly bedded siltstone (6). Note thin bioturbated horizons throughout interval (7).

bioturbated horizons and can constitute as much as 40% of selected beds. Gamma-ray spectral analysis of red-brown and gray mudstone-rich intervals of the lower member indicate that ^{40}K accounts for the majority of naturally occurring gamma-ray activity.

Interbedded with bioturbated siltstones are mudstones and siltstones very similar to those previously described for the upper member [Figs. 14(b) and (c)]. Gray (N6-3) and maroon-gray (5R4/1-2/1) silty mudstones are somewhat more common in the lower member than in the upper member, and the evenly laminated and cross-bedded siltstones locally occur in somewhat thicker (15 cm maximum) beds than in the Upper Member [Fig. 14(b)]. In general, the siltstone content of the lower member is greater than that of the upper member: ~ 40 to 70% versus 25 to 50%.

The lower contact of the Pumpkin Valley Shale with the Rome Formation is continuous but abrupt. The lowermost 7.5 m of the Pumpkin Valley Shale is a gray-brown (5YR7/1-4/1), wavy to lenticularly stratified, shaly siltstone with localized bioturbated intervals [Fig. 14(c)]. This horizon is somewhat more silt-rich than most of the lower Pumpkin Valley Shale and appears transitional in composition and color to the sediments of the underlying Rome Formation. The base of this interval marks the abrupt transition to the massively to thickly bedded gray to gray-green (N7-6 also 5G6/1-5GY6/1) quartz arenites of the uppermost Rome Formation. The lower contact of the Pumpkin Valley Shale is placed at the bottom of the shaly gray-brown siltstone. The borehole geophysical signature of the contact consists of very sharp and prominent deflections of both the neutron and gamma-ray logs away from the relatively constant mudstone baseline of the Pumpkin Valley Shale.

4.4 THE ROME FORMATION

For the Copper Creek fault block in east Tennessee, thickness values reported for the Rome Formation range between 90 and 215 m (Rodgers 1953; Samman 1975; Wojtal 1981). For the Copper Creek fault block on the Oak Ridge Reservation, Rome Formation thickness values between 90 and 125 m have been reported (Stockdale 1951; McMaster 1963; Sledz 1981). Such variability is characteristic of the Rome Formation within the Valley and Ridge Province of east Tennessee where regional thicknesses and internal stratigraphic patterns for the Rome Formation are extremely variable (Rodgers 1953; Saman 1975). Such a situation is caused by the structural setting of the formation. Several of the major thrust faults of the Valley and Ridge Province are located in the Rome Formation, and at various localities thrust faulting and associated intraformational deformation have caused intervals to be repeated or removed. The situation is complicated further by the complex lithofacies transitions that occur both laterally and vertically within the Rome Formation throughout the Valley and Ridge Province in east Tennessee.

At the study site, 188.06 m of Rome Formation was penetrated. The true thickness of Rome Formation present is considerably less than this value, principally because of the repetition of several horizons of the formation associated with complex motion along the Copper Creek fault. Preliminary analysis suggests that the 188.06 m of Rome Formation can be divided into two parts. One part of the interval is 88.09 m of essentially undisturbed strata that represents the stratigraphically uppermost interval of the Rome Formation at the study locality (2021- to 2310-ft interval; see Fig. 3 and Appendix). The other part of the Rome Formation is a 99.97-m-thick, severely deformed interval that appears to be composed of several imbricated slices of Rome Formation lithologies derived from stratigraphically higher portions of the formation (2310- to 2638-ft interval; see Fig. 3 and Appendix).

Upper Rome Formation — Regionally the Rome Formation is characterized by lithologic heterogeneity and consists of variously bedded gray, green, and maroon sandstones interbedded with gray to maroon shales and mudstones (Rodgers 1953; Milici 1973). The upper Rome Formation in the Oak Ridge vicinity is well described by this generalized description (McMaster 1963). At the study site, massive- to medium-bedded, subarkosic to quartz arenitic sandstones make up 60 to 80% of the upper Rome Formation. The remainder of the formation consists of medium-bedded sandstones and siltstones interbedded with thinly-bedded silty mudstones and shales. Stratigraphically, the upper Rome Formation contains a distinctive gray to gray-green, sandstone-rich top part and a bottom part that is lithologically much more heterogeneous than the top portion.

Sandstones are abundant within the Rome Formation. A massive, diffusely to evenly bedded, gray (N8-6) to gray-green (5GY8/1-6/1) quartz arenite occurs at the top of the Rome Formation [Fig. 15(a)]. This massive sandstone is interbedded with thinly bedded sandstone composed of 2- to 10-cm-thick, upward-fining cycles that have scour bases and are capped by mudstone drapes. Each cycle contains wavy

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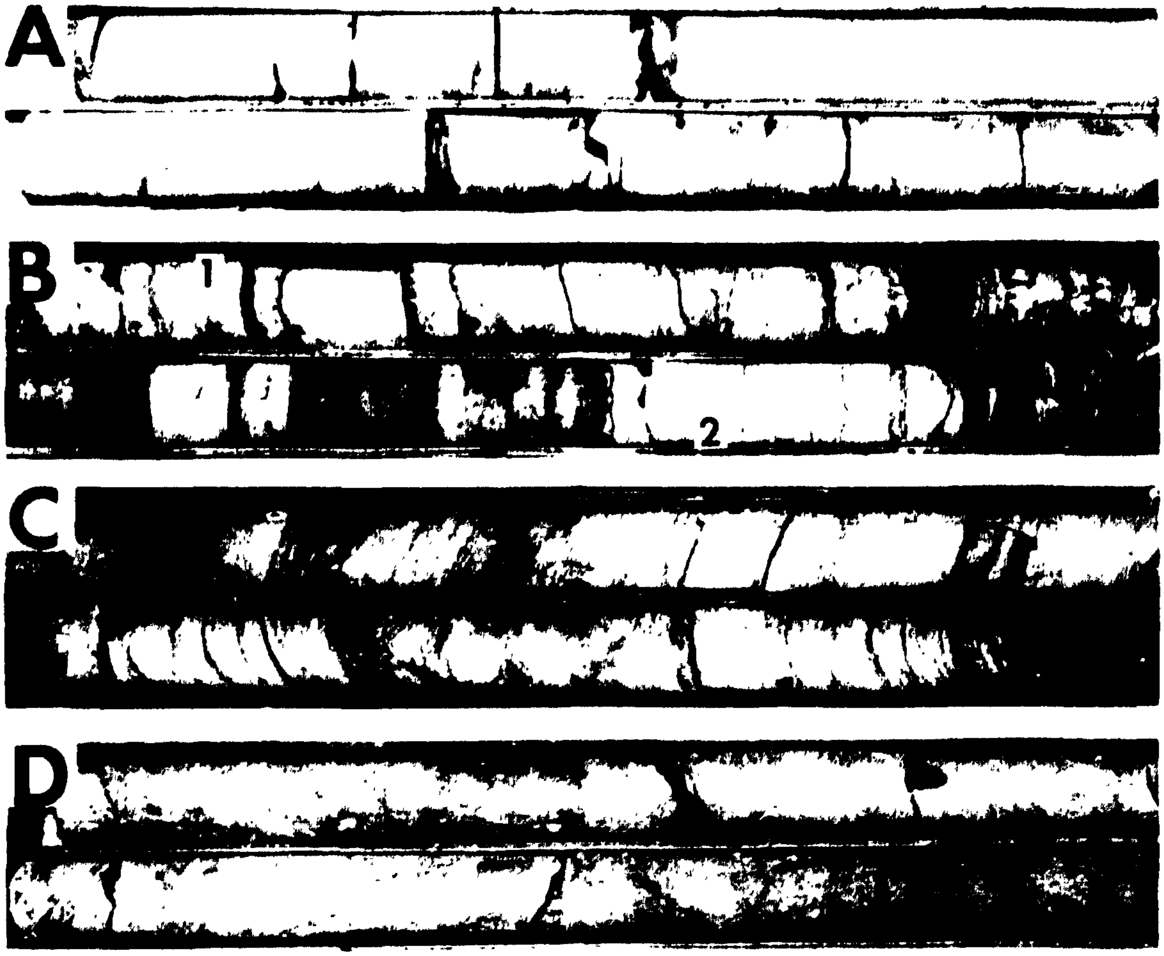

Fig. 15. Sandstone lithologies of upper part of Rome Formation. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 214: 2052-2059.5 ft) Massive, diffusely bedded to mottled sandstone. [b] (Box 211: 2021-2026 ft) Wavy bedded sandstone comprised of upward-fining beds with mudstone drapes (1). Note massive bed formed by amalgamated cycles (2). [c] (Box 243: 2309-2316.5 ft) Laminated to thinly bedded parallel cross-stratified sandstone. [d] (Box 237: 2254-2259 ft) Massive sandstone with wavy and irregularly bedded shale stringers.

laminated shale stringers, and several individual cycles are commonly amalgamated into 0.2- to 0.5-m-thick beds of massive sandstone that contain wavy discontinuous shale stringers disseminated throughout (Fig. 15(b)]. A 15-m-thick interval of such lithology occurs ~ 12 m below the top of the Rome Formation and is a locally dolomitic gray-green shaly sandstone with wavy to lenticular stratification. This example represents the only significant occurrence of carbonate-bearing lithologies within the upper Rome Formation at the study site.

Another common sandstone type is a massively to thickly bedded, maroon-brown to gray (5R6/2-4/2), subarkose with diffusely to evenly parallel stratification. This sandstone grades into a massively appearing thinly bedded sandstone [Fig. 15(c)] that forms 1 to 4 m-thick intervals throughout the lower 60% of the upper Rome Formation (see Appendix). Such lithologies alternate with massive, irregularly bedded maroon sandstones that contain 1- to 15-cm-thick, shale-rich intervals associated with lenticular to mottled bedding; bioturbation and vertical burrowing occur throughout. Disseminated throughout this lithology are intervals of flaserlike, wavy to lenticular discontinuous laminae and stringers of maroon mudstone and shaly siltstones [Fig. 15(d)].

Alternating with major sandstone intervals are horizons of thinly bedded shaly siltstone and mudstone. The shaly siltstones range from gray (N7-5) to gray-maroon (5R4/2-2/2). Stratification patterns are highly variable, ranging from evenly bedded to wavy, lenticularly, and discontinuously flaser bedded [Fig. 16(a)]. Bioturbation and mottled bedding are also commonly observed [Fig. 16(b)]. Interstratified,

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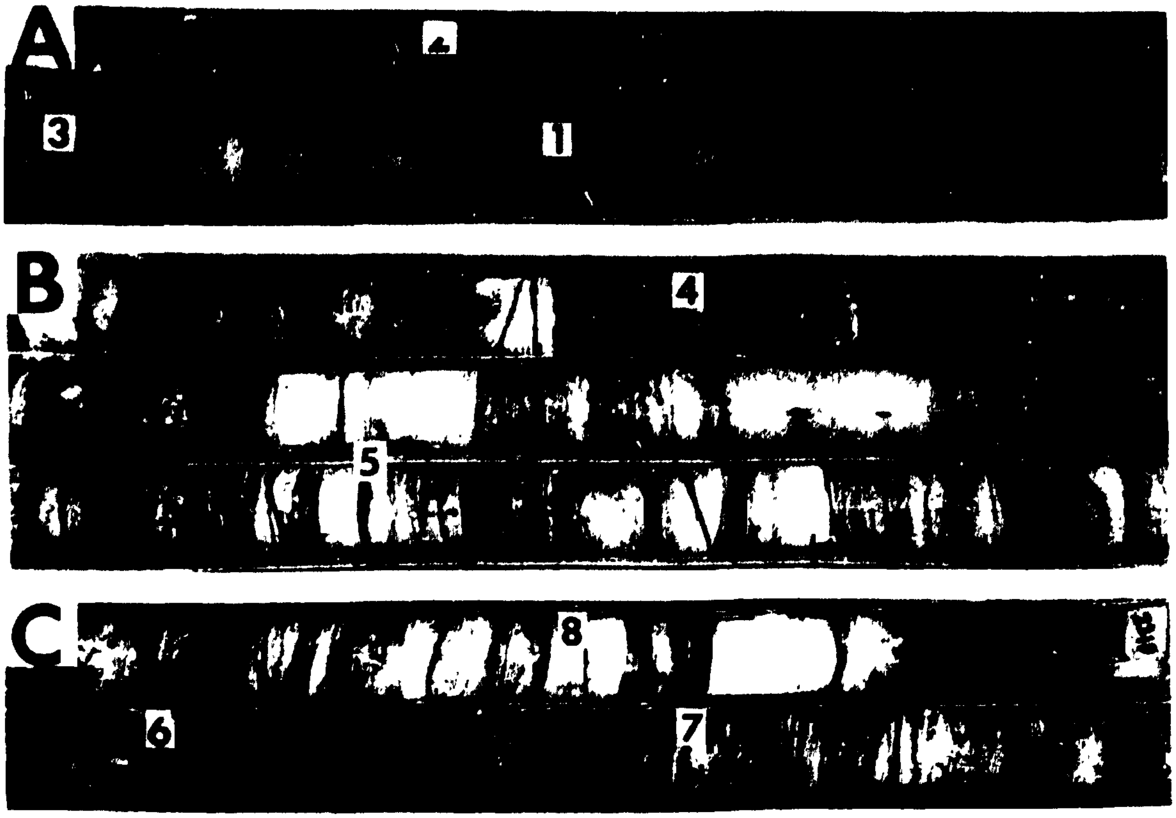

Fig. 16. Siltstone and mudstone lithologies of upper part of Rome Formation. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 241: 2290-2295 ft) Current-rippled and wavy bedded shaly siltstone (1), partially bioturbated and mottled silty mudstone (2), and evenly laminated siltstone stringers (3).
[b] (Box 233: 2216-2223.5 ft) Bioturbated silty mudstone (4) interbedded with current-rippled to parallel cross-stratified siltstone (5). [c] (Box 232: 2208-2213 ft) Massive mudstone (6) with interbedded with wavy cross-stratified siltstone stringers (7) and massive evenly to wavy bedded sandstone (8).

0.1- to 5-cm-thick siltstones with wavy to evenly laminated upward-fining cycles occur locally within mudstones. Such lithologies, however, are noted much less frequently than in the Pumpkin Valley Shale. Mudstones forming 0.1- to 1.0-m-thick beds occur with greatest abundance in the lower 50% of the upper Rome Formation. Mudstones range from maroon (10R3/3-6/3) to gray-maroon (5R4/1-2/1). They are massive to thinly laminated and commonly contain lenticular laminae, stringers, and disseminations of siltstone [Fig. 16(c)].

Lower Rome Formation - Lithologically, this interval is composed of essentially the same, or very similar, material as that which composing the upper Rome Formation (see Appendix). The principal difference between the upper and lower parts of the formation is the degree of deformation. The upper Rome Formation has localized fault zones 0.1 to 1.0 m thick and small-scale folds, but it is essentially undeformed. The lower Rome Formation, however, is characterized by severe deformation and extremely chaotic stratification patterns (Figs. 17(a) and (b)]. Preliminary analysis of the structures in this interval suggests that most, if not all, of this interval consists of slices and fragments of lithologies that compose the upper Rome Formation. Such slices have been tectonically juxtaposed and mixed to form a complexly imbricated and jumbled interval that lithologically resembles the upper Rome Formation. It has not been possible to delineate with certainty which parts of the upper Rome Formation are included within this interval or what the stratigraphic succession of the juxtaposed slices is. It is possible that significant portions of

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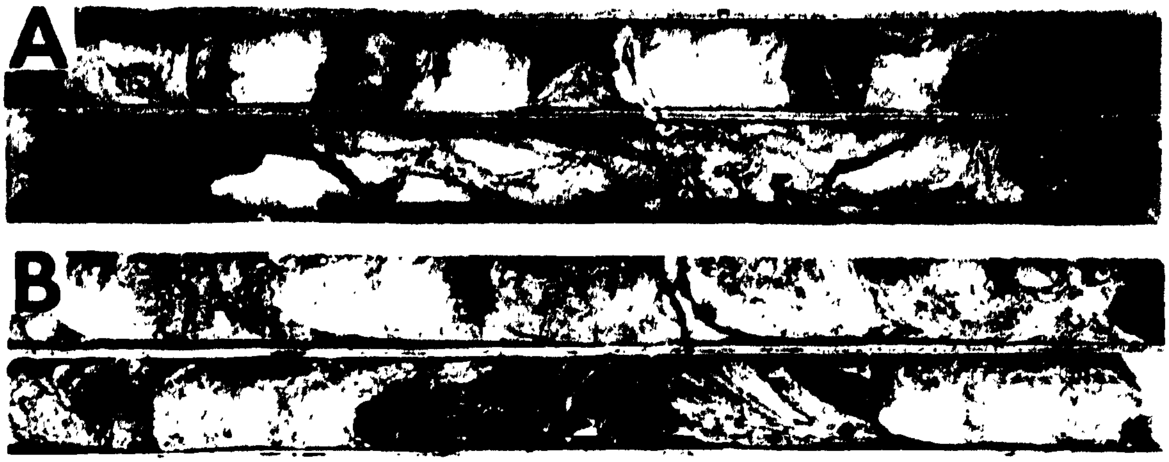

Fig. 17. Lithologies of lower part of Rome Formation. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is to the left. [a] (Box 250: 2375-2380 ft) Deformed wavy to lenticularly bedded siltstone with shale stringers. [b] (Box 271: 2550-2555 ft) Severely brecciated, wavy to lenticularly bedded, shaly siltstone.

the lower Rome Formation may not be tectonically emplaced but may simply represent intensely deformed material stratigraphically below the relatively undeformed upper Rome Formation.

The lower contact of the Rome Formation in the Oak Ridge vicinity is a discontinuous tectonic boundary that corresponds approximately with the stratigraphic position of the Copper Creek fault (Stockdale 1951; McMaster 1963). This regional structure juxtaposes the Rome Formation over the younger Chickamauga Group contained in the underlying Whiteoak Mountain fault block. Deformation associated with motion along the Copper Creek fault is concentrated within a 46-m-thick interval that includes the lowermost part of the lower Rome Formation and the uppermost portion of the Moccasin Formation of the Chickamauga Group (equivalent in part to Unit H in Stockdale 1951). Structures within this interval will be described in a subsequent section, but generally, it contains numerous faults and folds. At a borehole depth of 804 m (2638 ft), a major fault is penetrated that is characterized by a 1-m-thick zone consisting of two 0.2-m-thick mylonites [see subsequent section and Fig. 21(b)]. This fault zone also corresponds to a significant change in bedding plane attitude. Below the fault zone, dip angles are shallow, ranging between 0 and 10^{o}, which are values generally representative of regional dip: while above the zone, dip angles are steep and highly variable. The fault zone also corresponds to a significant lithology change. Below the fault zone, carbonate-bearing maroon (10R6/3-8/3) to gray-maroon (5R6/3-8/3) siltstones and gray (N8-6) limestones occur. Lithologies characteristic of the Rome Formation are absent below the fault zone. The lower contact of the Rome Formation is placed, therefore, at the bottom of this fault zone. The lower Rome Formation contact marks not only the bottom of that formation but also the bottom of the Copper Creek fault block at the study site. Strata below the contact are part of the Whiteoak Mountain fault block that immediately underlies the Copper Creek fault block.

4.5 THE CHICKAMAUGA GROUP

The Ordovician Chickamuaga Group is the youngest formation encountered in the drilling and lies stratigraphically above the Cambro-Ordovician Knox Dolomite Group. Because of the effect of motion along the Copper Creek fault, however, the Chickamauga Group lithologies encountered at the bottom of ORNL-JOY No. 2 were not those associated with the Copper Creek fault block, but were rather those belonging to the Whiteoak Mountain fault block. The Chickamauga Group is between 450 and 600 m thick in the Oak Ridge vicinity and consists of alternating limestone and siltstone/mudstone lithologies (Stockdale 1951; Rodgers 1953; McMaster 1963; Switek 1984). Only the stratigraphically uppermost formation in the group, the Moccasin Formation, was encountered in the borehole.

The Moccasin Formation — In east Tennessee, the Moccasin Formation is of variable thickness and consists of calcareous gray to gray-maroon mudstones and 3- to 10-m-thick intervals of gray limestones (Rodgers 1953; Milici 1973). On the DOE Oak Ridge Reservation, Stockdale (1951) divided the Chickamauga Group into eight lithostratigraphic units, the uppermost being Unit H, which includes the Moccasin Formation (J. Switek, personal communication, 1984). Unit H averages 90 to 95 m in thickness, and its uppermost part consists of ~ 26 m of maroon to gray calcareous siltstone with shaly partings and thin limestone lenses that are underlain by 66 m of gray limestone (Stockdale 1951).

At the drill site, only 24.38 m of the uppermost siltstone-rich portions of the Moccasin Formation were penetrated. The thick gray limestone middle unit of Unit H, as described by Stockdale (1951) was not intersected. Lithologically, the Moccasin strata at the drill site consists of interbedded calcareous siltstones and shaly limestones. The siltstones are maroon-gray (5R4/2-2/1) and medium to thinly bedded with wavy to lenticular discontinuous stratification. Flaser-bedded, maroon, mudstone-rich intervals 0.1- to 1-m thick occur throughout [Fig. 18(a)]. The thinly bedded limestones are gray (N7-4) to maroon-gray (5R4/2-2/1) micrites, wackestones, and calcarenites with wavy, irregular, and lenticular stratification [Fig. 18(b)]. Locally intraformational conglomerates occur in discontinuous horizons associated with the limestones.

5. STRUCTURAL DATA

The structural fabric of strata within the Copper Creek fault block on the DOE Oak Ridge Reservation is complex (McMaster 1963; Sledz and Huff 1981) and is the result of multiple periods of deformation associated with several pulses of the Appalachian orogeny. Examination of the drill core and geophysical logs permits characterization of several important structural elements common to

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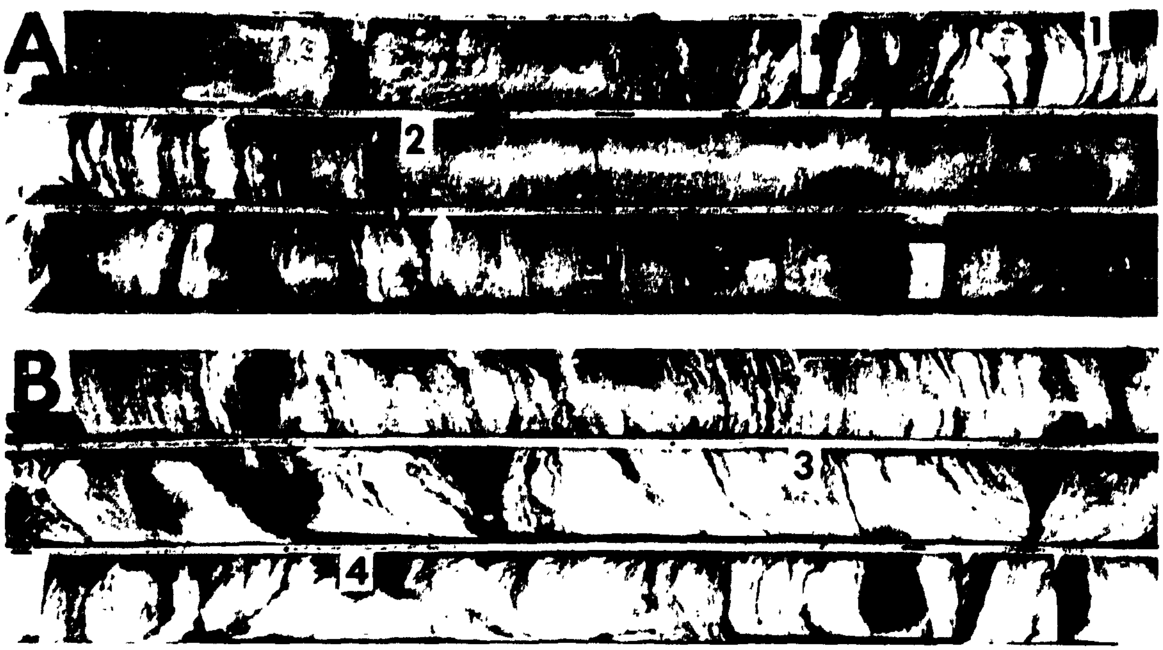

Fig. 18. Lithologies of uppermost Moccasin Formation. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left.
[a] (Box 284: 2669-26676.5 ft) Wavy to lenticularly bedded calcarenite and wackestone (1) interbedded with laminated and wavy bedded calcareous siltstone (2) with localized flaser bedding.
[B] (Box 285: 2675-2683.5 ft) Thinly bedded lenticularly to wavy ribbon-bedded calcarenite and micrite (3) with mudstone stringers. Deformed interval (4) marks fault trace.

the strata of the Conasauga Group and the Rome Formation on the Copper Creek fault block in Melton Valley. Fabric elements observed include bedding plane-parallel and high-angle faults, intraformational thrust faults, small-scale folds, multiple joint sets, and small-scale fractures. A brief discussion of such structures is included here because the structures can influence the stratigraphic data obtained from the borehole. Specifically, intra- and cross-formational faults can accomodate varying amounts of strain during deformation of the section. In so doing, the initial thickness and stratigraphic relationships of the sedimentary section have been modified to some extent.

Bedding-plane faults — Bedding plane-parallel small-scale faults are ubiquitous within the Conasauga Group and the Rome Formation. Such faults characteristically occur at contacts between lithologies that have greatly different tensile strengths (e.g. mudstone and limestone), although such faults are also observed within mudstone-rich intervals, where they apparently are not related to lithology differences [Figs. 19(a) and (b)]. The density and spacing of bedding-plane faults is highly variable throughout the stratigraphic section, but the faults are most abundant in thin- to medium-bedded intervals of limestones or siltstone, and mudstones. Bedding-plane faults are localized within a disturbed zone 2.0 to 5.0 mm thick and are characterized by the development of slickensided and striated textures on the bedding plane surface [see Fig. 19(b)]. Commonly the fault surface is associated with a very thin (0.1 to 2.0 mm thick) zone of "glassy" mylonitelike material that is x-ray amorphous and is petrographically cryptocrystalline [Fig. 19(a)].

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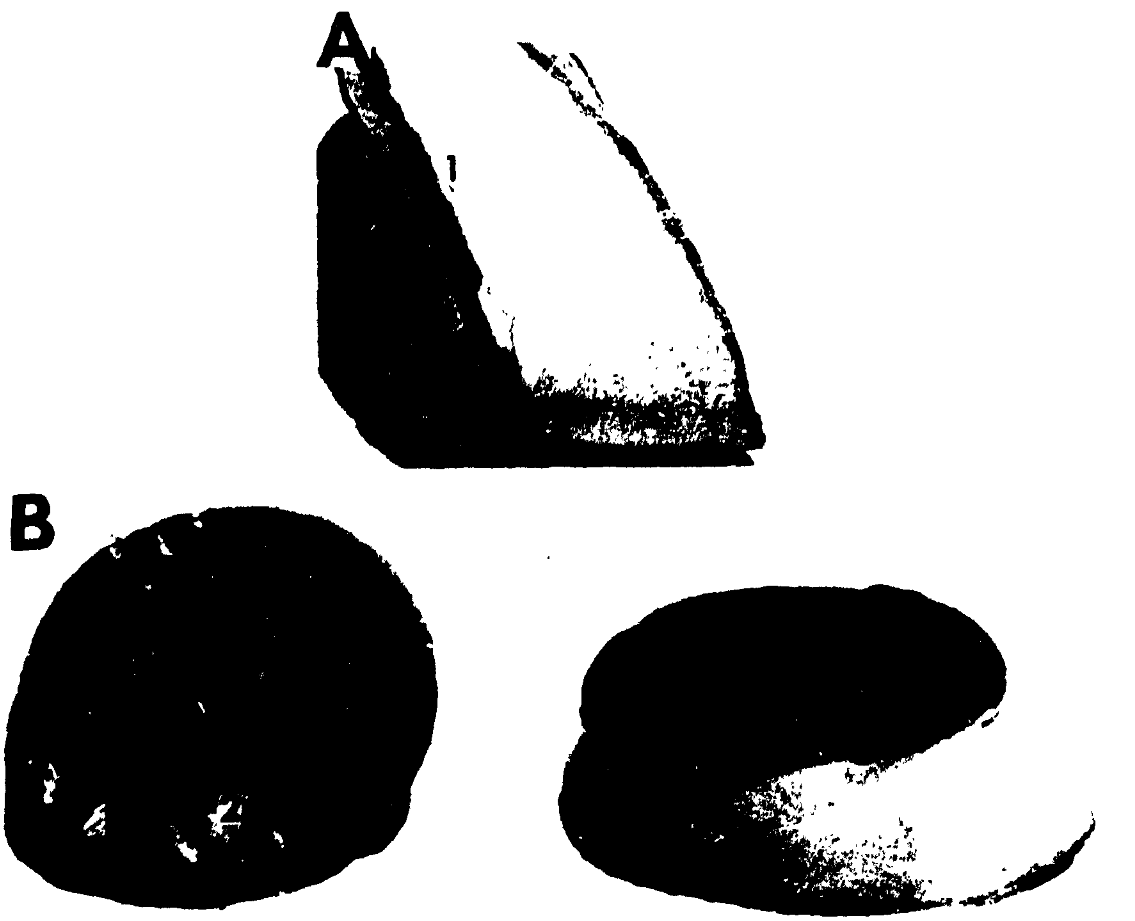

Fig. 19. Bedding plane-parallel fault within Maryville Limestone (Box 108: 1022 ft). [a] (Core is 61 mm in diam.) Side view of bedding plane-parallel fault that occurs at limestone-mudstone contact (1). Fault is approximately 1 to 2 mm thick and is composed of mylonitelike cryptocrystalline material. [b] (Core is 61 mm in diameter) Plane view of fault illustrated in [a]. Note the glassy, polished appearence of fault surface and striations (2).

Because of their abundance, bedding-plane faults represent a mechanism that could have accomodated large amounts of strain during deformation and thrust-faulting events. The amount of such strain accomodation cannot be determined, but it may have significantly changed the original thicknesses of particular individual stratigraphic units.

High Angle Faults — Faults situated at high angles to bedding are common throughout the entire section studied but appear to be most abundant in the Rogersville Shale, Rutledge Limestone, and Pumpkin Valley Shale formations of the Conasauga Group and in the lower part of the Rome Formation. Such faults are commonly observed in outcrop (Sledz 1980; Sledz and Huff 1981; Davis and Stansfield 1984) and in drill core from throughout the Oak Ridge vicinity (Haase 1985). As measured in outcrop, the faults have either a normal or a reverse sense of motion and are characterized by small amounts of displacement (several meters to several tens of meters; Walls and Haase, unpublished data). High-angle faults are characterized by 0.2- to 1.5-m-thick intensely deformed zones in which bedding and sedimentary structures are highly disturbed, brecciated, or partially to completely obliterated (Fig. 20). In addition, drag folds, developed in the otherwise unaltered strata immediately adjacent to the localized fault zone, are commonly associated with high angle faults. Within the deformed zones, the host lithology appears to be mineralogically altered to a very fine-grained, clay-rich, bleached material. Typically, fault zones have calcite-filled veins that cross-cut the interval at orientations parallel or subparallel to the

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Fig. 20. Localized structures associated with high-angle faults within Conasauga Group. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 105: 1026-1028.5 ft) Small drag fold (1) associated with fault at limestone-shale contact. Such structures are common within Maryville Limestone. [b] (Box 183: 1765-1772.5 ft) Drag fold (2) and calcite-filled fracture (3) associated with high-angle fault within Pumpkin Valley Shale. [c] (Box 160: 1543-1550.5 ft) Drag fold and brecciated siltstone associated with high angle fault in Rogersville Shale [see also Fig. 14(a)]. [d] (Box 115: 1118-1128 ft) Brecciated and folded oolitic, intraclastic packstone (4) and shale. Deformation associated with low angle thrust fault within Maryville Limestone.

fault plane. Such veins are 0.1 to 5 cm thick and locally coalesce to form 4.0- to 10.0-cm-thick calcite-rich intervals. In a few rare examples, calcite veins are absent from fault zones.

Intraformational Thrust Faults – Within the upper portion of the upper part of the Maryville Limestone and in the middle portion of the Rogersville Shale, two extensively deformed 5- to 20-m-thick intervals occur. Within such zones, bedding is chaotic and portions of the formation may actually be repeated, suggesting that the zones may represent small-scale imbricate thrust faults. The attitude of the fault plane(s) within these zones is difficult to determine, however. In the Rogersville Shale example, the fault planes appear to be at high angles to bedding, suggesting that such zones may be the result of a large-scale, persistent, high-angle fault, although the possibility of an intraformational thrust fault that has locally repeated part of the Rogersville Shale cannot be ruled out. Recently, such a situation has been documented for the Rogersville Shale elsewhere in the Oak Ridge vicinity (Rothschild et al. 1984). In the fault zone located in the Maryville Limestone, the fault plane(s) appear to be at shallow angles or subparallel to the bedding. The occurrence of similarly deformed zones within approximately the same stratigraphic interval of the upper member of the Maryville Limestone elsewhere along the Copper Creek fault block in the Oak Ridge vicinity (Haase 1985) suggests that the deformed interval within the Maryville Limestone intersected in ORNL-JOY No. 2 is an intraformational thrust fault that has a lateral extent of several kilometers.

Joint Sets and Small Scale Fractures - Strata of the Conasauga Group and the Rome Formation are characterized by the development of at least two and, locally, as many as five, pervasive joint sets (Sledz and Huff 1981). The frequency, spacing, and length of joints developed within the Conasauga Group have been demonstrated to be complex functions of bed thickness and lithology (Sledz and Huff 1981). Because of such a relationship, the degree of jointing observed for a particular stratigraphic horizon within drill core is quite variable (Fig. 21). Typically, joints observed in drill core have orientations that are either nearly perpendicular to or parallel to bedding. Within limestone and siltstone/sandstone lithologies, joints are partially to completely filled by secondary mineralization of calcite or dolomite [Figs. 21(a) to (c)]. Joints within mudstones, however, are open with little, if any, secondary mineralization [Figs. 21(d) and (e)]. Development of secondary mineralization within joints appears to be related most strongly to the host lithology in which a particular joint is developed; it does not appear to be related to depth within the borehole.

Numerous small-scale fractures, 0.1 to 1.5 m long, are observed within the limestone-rich members of the Conasauga Group and the massive sandstone horizons within the Rome Formation. The fractures are readily apparent in drill core (Fig. 22). Open fractures that lack appreciable secondary mineralization are observable on acoustic televiewer [illegible]igs. 22(d) to (f) and Fig. 23]. Fracture frequency is highly variable, although most occur within limestone or sandstone intervals [illegible] than 0.5 m in thickness. Fracture orientation is less va[illegible] with most fractures oriented within 15° of vertical

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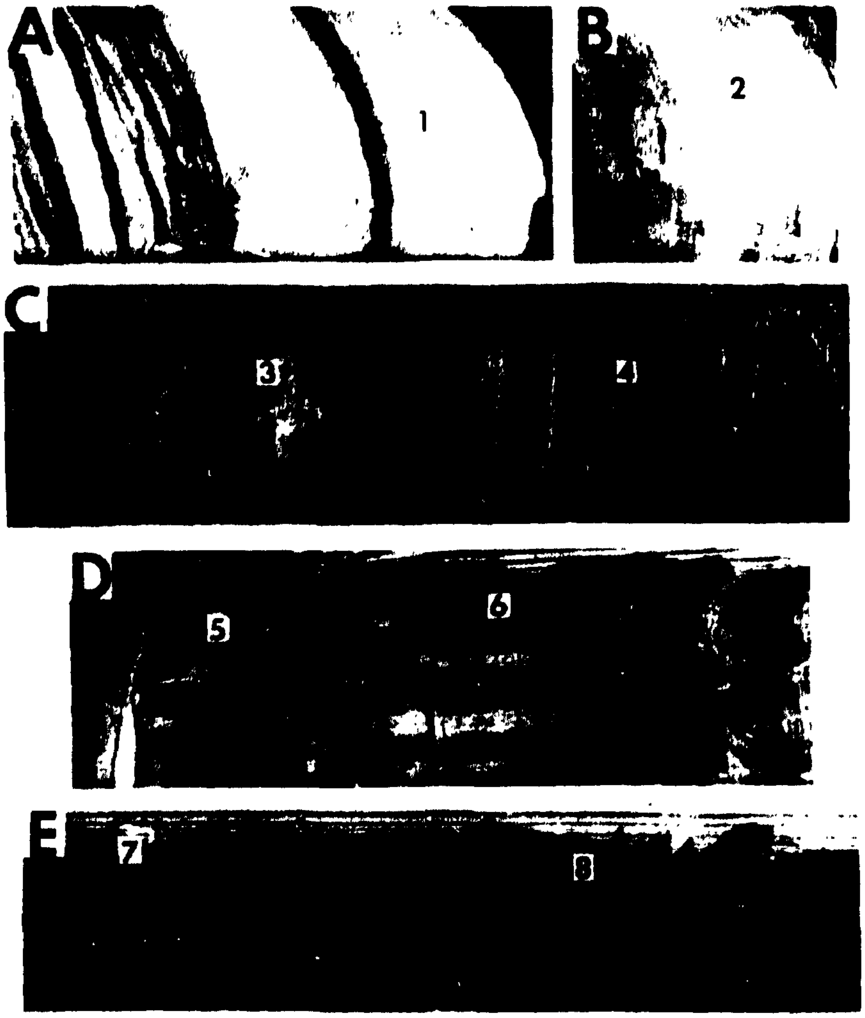

Fig. 21. Joints within Conasauga Group. Diameter of core is 61 mm. [a] (Box 106: 1040 ft) Evenly laminated silty calcarenite of Maryville Limestone with calcite-filled joints (1) oriented perpendicularly to bedding trends. Note the termination of joints at contacts with interbedded mudstone layers. [b] (Box 179: 1721 ft) Parallel-bedded siltstone of upper Pumpkin Valley Shale with calcite-filled joints (2). Note lack of continuity of joints across bedding contacts. [c] (Box 192: 1848 ft) Interlaminated siltstone and mudstone of upper Pumpkin Valley Shale illustrating two orientations of calcite-filled joints (3 and 4). [d] (Box 72: 725 ft) Mudstone of Nolichucky Shale illustrating development of two major joint sets (5 and 6) and bedding plane parting (perpendicular to the edge of core). Note that these joints are not filled with secondary mineralization. [e] (Box 267: 1985 ft) Mudstone of lower Pumpkin Valley Shale exhibiting two "shattered" intervals (7 and 8) resulting from a high density of joints and bedding plane partings. Orientations of joint sets and bedding plane parting is similar to that observed in [d].

ORNL-Photo 2729-85

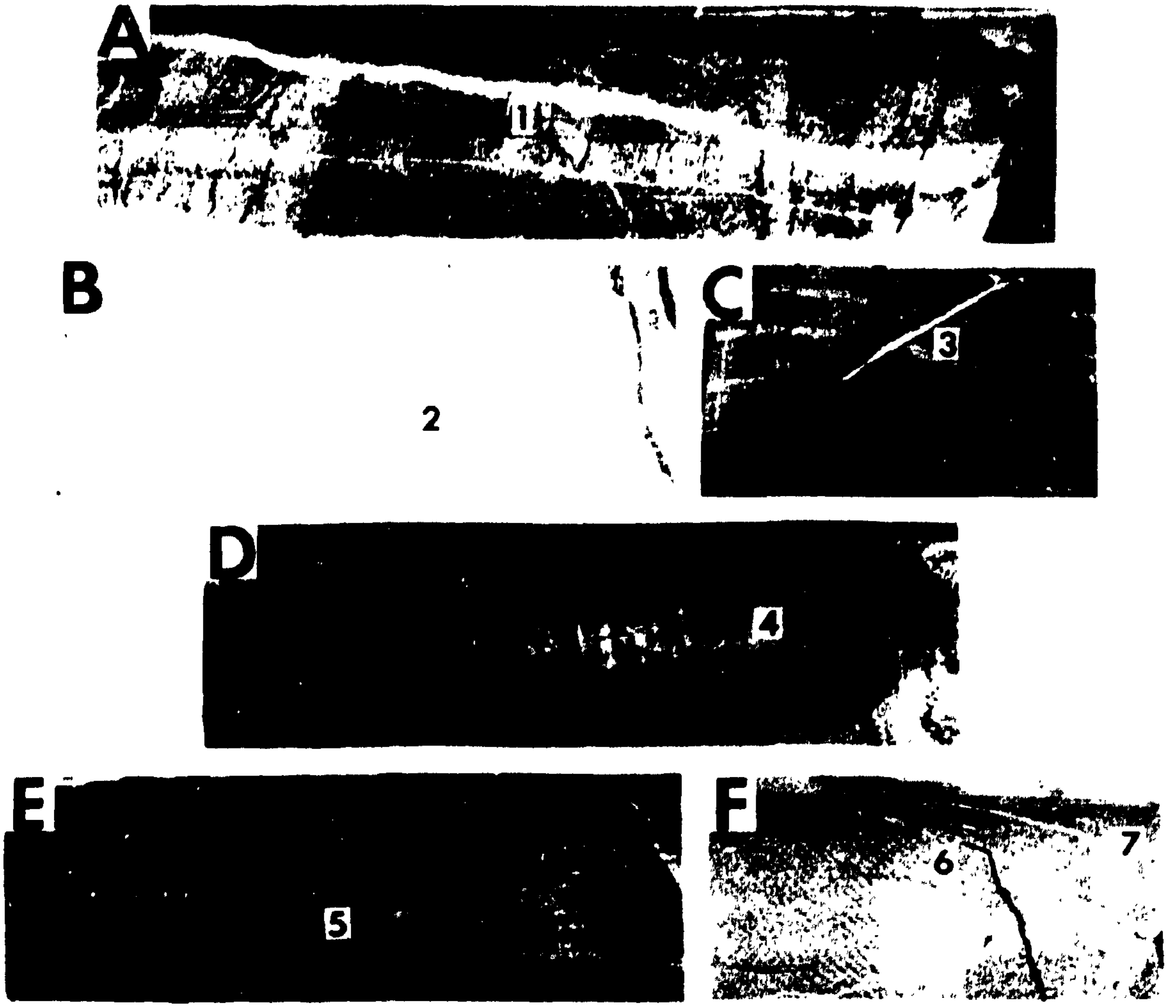

Fig. 22. Fractures with Conasauga Group and Rome Formation. Core diameter is 61 mm. [a] Box 98: 970 ft) Oolitic and intraclastic grainstone of Nolichucky Shale that exhibits two sets of calcite-filled fractures. One set parallels edge of core and cuts second set of fractures with a different orientation (1). [b] (Box 104: 1021) Calcite-filled fracture within intraclastic grainstone of Marville Limestone. Note fracture is offset at bedding contacts (2). [c] (Box 83: 832 ft) Mudstone of Nolichucky Shale with calcite-filled fracture (3) oriented parallel to principal joint set. [d] (Box 25: 288 ft) Fracture within oolitic packstone of Maynardville Limestone (4) that is open and only locally filled with secondary mineralization. [e] (Box 91: 907 ft) Open, unfilled fracture (5) within a mudstone of the Nolichucky Shale. [F] (Box 222: 2123 ft) Two generations of fractures within massive sandstone of upper Rome Formation. One fracture is only partially filled with secondary mineralization (6) and cuts across earlier quartz-filled fracture (7).

ORNL-Photo 2730-85

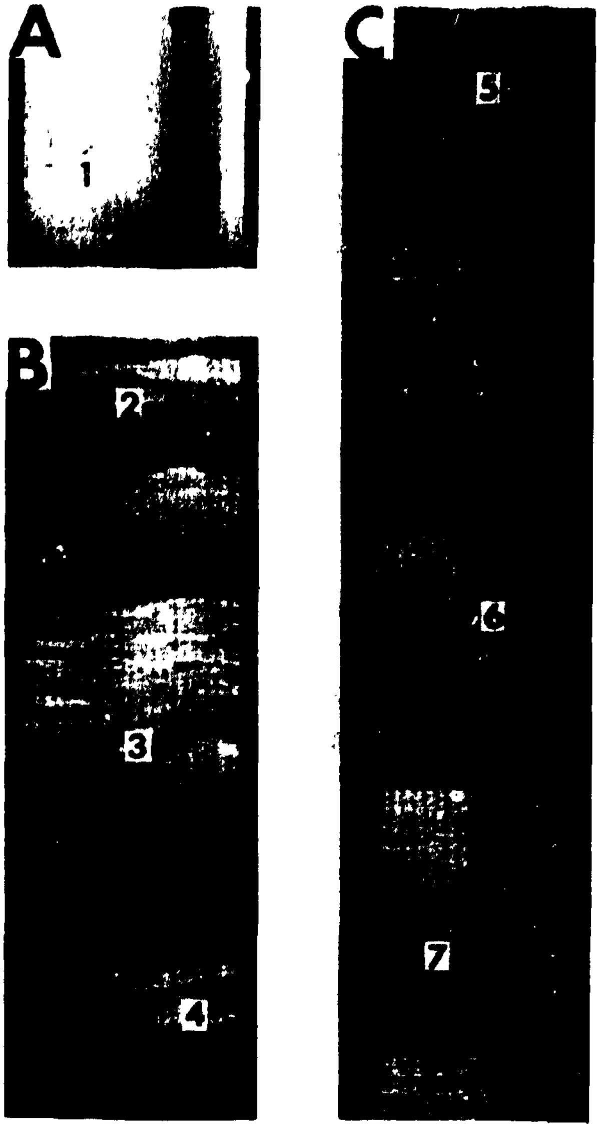

Fig. 23. Borehole wall images obtained with acoustic televiewer logger. The photographs represent complete 360° scan of borehole wall with north on left side of the photograph and south in middle. Stratigraphically up direction is toward top of figure. [a] (Borehole depth 285 to 290 ft) Prominent open fracture (1) within Maynardville Limestone. This same fracture is illustrated in Fig. 22(d). [b] (Borehole depth 768 to 778 ft) Interbedded limestone (light areas) and mudstone (dark areas) interval of Nolichucky Shale with three open fractures visible (2 – 4). [c] (Borehole depth 523 to 537 ft) Extensive vertically-oriented, open fractures (5 – 7) within limestone-rich interval of Nolichucky Shale.

or horizontal. Fractures within limestones are typically filled or partially filled with secondary mineralization, usually calcite [Figs. 22(a) and (b)]. Fractures within siltstone or sandstone intervals (Fig. 22(f)] are open or only slightly filled by secondary mineralization that can be either calcite, dolomite, or quartz. There is no readily apparent, simple relationship between borehole depth and the degree of fracture filling; open fractures were observed throughout the entire borehole.

Copper Creek Fault Zone – Deformation associated with the Copper Creek fault is concentrated within a 45-m-thick interval that is intersected close to the bottom of ORNL-JOY No. 2. In additon to this fault zone, the lower section of the Rome Formation, as described previously, is a jumbled composite of fragments and slices of various lithologies juxtaposed and separated by numerous intraformational thrust and high-angle faults that have highly variable orientations. Deformation within the fault zone occurs throughout and is concentrated within several discrete zones. Within such zones, cataclastites and mylonites are commonly observed (Fig. 24). Such material represents intensely deformed and broken-up rock material that is very heterogeneous in grain size. The fine-grained matrix of the cataclastite consists of crypto- to microcrystalline material composed of fragmented and ground-up host-rock lithology. Partially disaggregated and fragmented pieces of the host rock are randomly scattered throughout (Fig. 24). Mylonites are associated within cataclastite intervals. They are 1- to 5-mm-thick zones of cryptocrystalline material that typically has a glasslike appearance

ORNL-Photo 2731-85

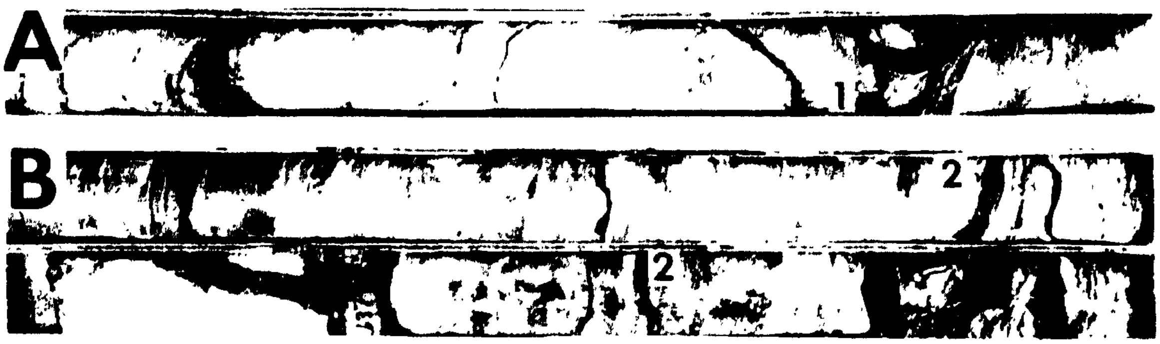

Fig. 24. Cataclastites and mylonites associated with Copper Creek fault. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. [a] (Box 278: 2614-2616.5 ft) Mylonite (1) and cataclastite formed within thickly bedded sandstone horizon of lower Rome Formation. [b] (Box 280: 2634-2639 ft) Cataclastites (2) associated with faults within calcareous mudstones and siltstones of upper Moccasin Formation.

similar to the bedding plane-parallel faults discussed previously (Figs. 19 and 24)

The breccia zones are of variable thickness (0.1 to 5 m) and range from slight brecciation and disruption of bedding patterns, to complete disruption and disaggregation of the rock that is accompanied by cataclastite and mylonite formation (Fig. 22). The principal Copper Creek fault interval is a breccia zone 6 m thick where the calcareous siltstones and micrites of the Moccasin Formation have been reduced to a soft, friable, highly altered and bleached, unconsolidated mud (Fig. 25). Stockdale (1951) reports similar 2- to 6-m-thick, highly brecciated and disaggregated zones at the bottom of the Copper Creek fault block elsewhere in the Oak Ridge vicinity.

The breccias and mylonites of the Copper Creek fault zone represent intervals where very large amounts of strain have been accommodated during thrust movement. Such intervals, together with the numerous faults throughout the lower interval of the Rome Formation, account for an undoubtedly large but still unkown amount of change in the stratigraphic thickness of the Rome Formation.

6. SUMMARY

The stratigraphy of the Conasauga Group in Melton Valley is complex. In simplified terms, the strata of the group represent three clastic-to-carbonate cycles (Fig. 3). This stratification pattern is characteristic of the central phase of the Conasauga Group throughout east Tennessee (Rodgers 1953; Hasson and Haase 1985). The Oak Ridge locality is on the western margin of this phase and is at a point

ORNL-Photo 2732-85

Fig. 25. Main trace of Copper Creek fault within upper Moccasin Formation. Core rows are 0.76 m (2.5 ft) long and stratigraphic top is left. (Boxes 286-289: 2685-2718 ft) Moccasin Formation consists of wavy to lenticularly bedded micrite and calcarenite (1) interbedded with calcareous mudstone (2). Within the 2702- to 2712-ft interval, thrust fault movement has produced high stain zone marked by development of friable and severely altered gouge (3).

where the group is undergoing very pronounced lithologic changes, marked by the disappearance of the lower and middle carbonate formations (the Rutledge and Maryville limestones, Fig. 26).

Regionally, along the Copper Creek fault block in east Tennessee, there is a southwestward trend of clastic enrichment that is accompanied by a gradual thinning of the group (Fig. 26). The complex lithologic sequences described for the study locality are the result of the paleogeographic setting that was a landward margin of an intrashelf basin (Hasson and Haase 1985).

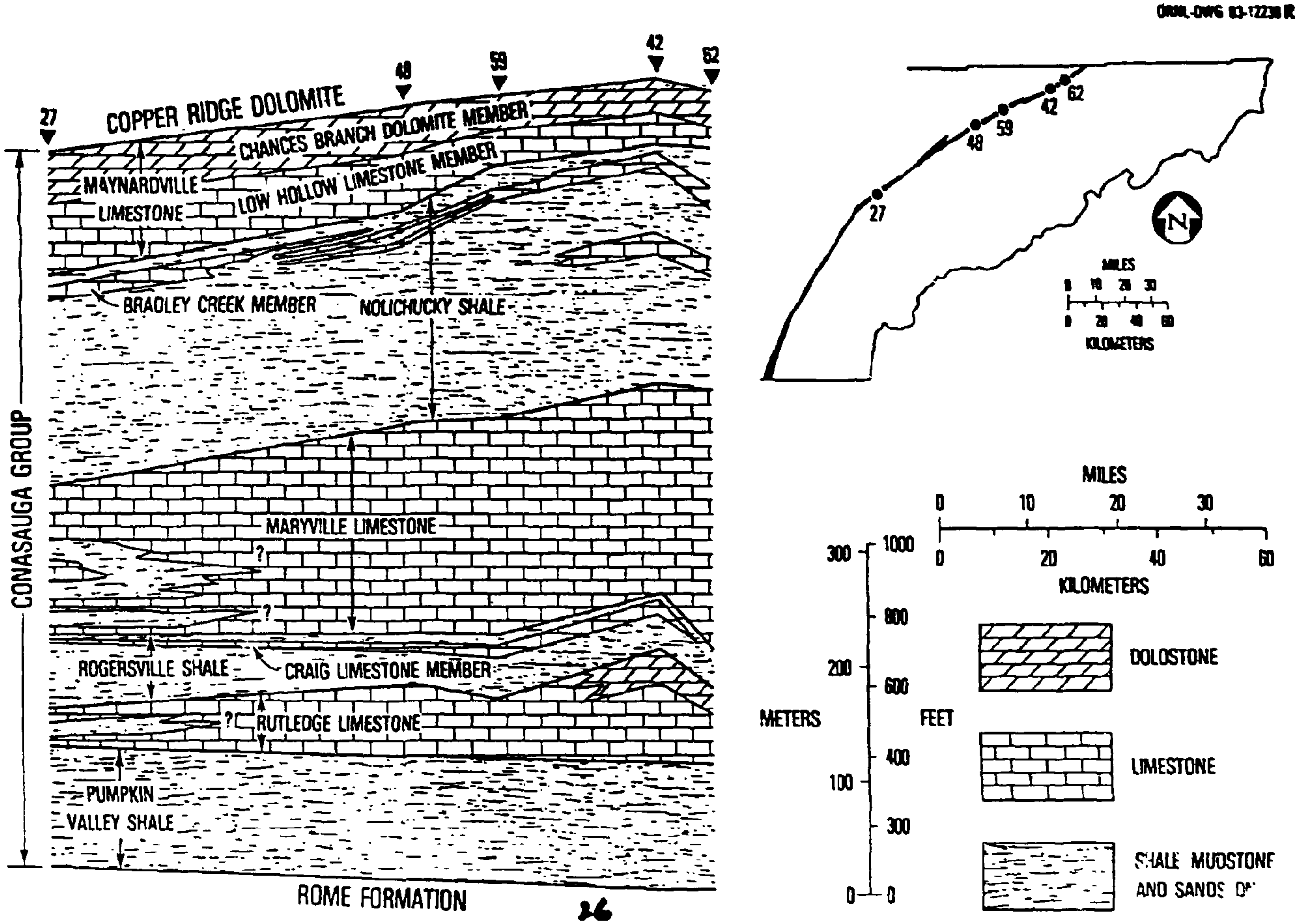

Fig. 26. Cross section along Copper fault block in east Tennessee illustrating regional thickness and stratigraphic variations in Conasauga Group. Locality No. 27 is borehole ORNL-JOY No. 2; other localities are surface exposures (see Hasson and Haase 1985: Tables 1 and 2 and Figs. 6 – 8).

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APPENDIX

DETAILED LITHOLOGIC LOG FOR BOREHOLE ORNL-JOY No. 2

ORNL-DWG 83-13888

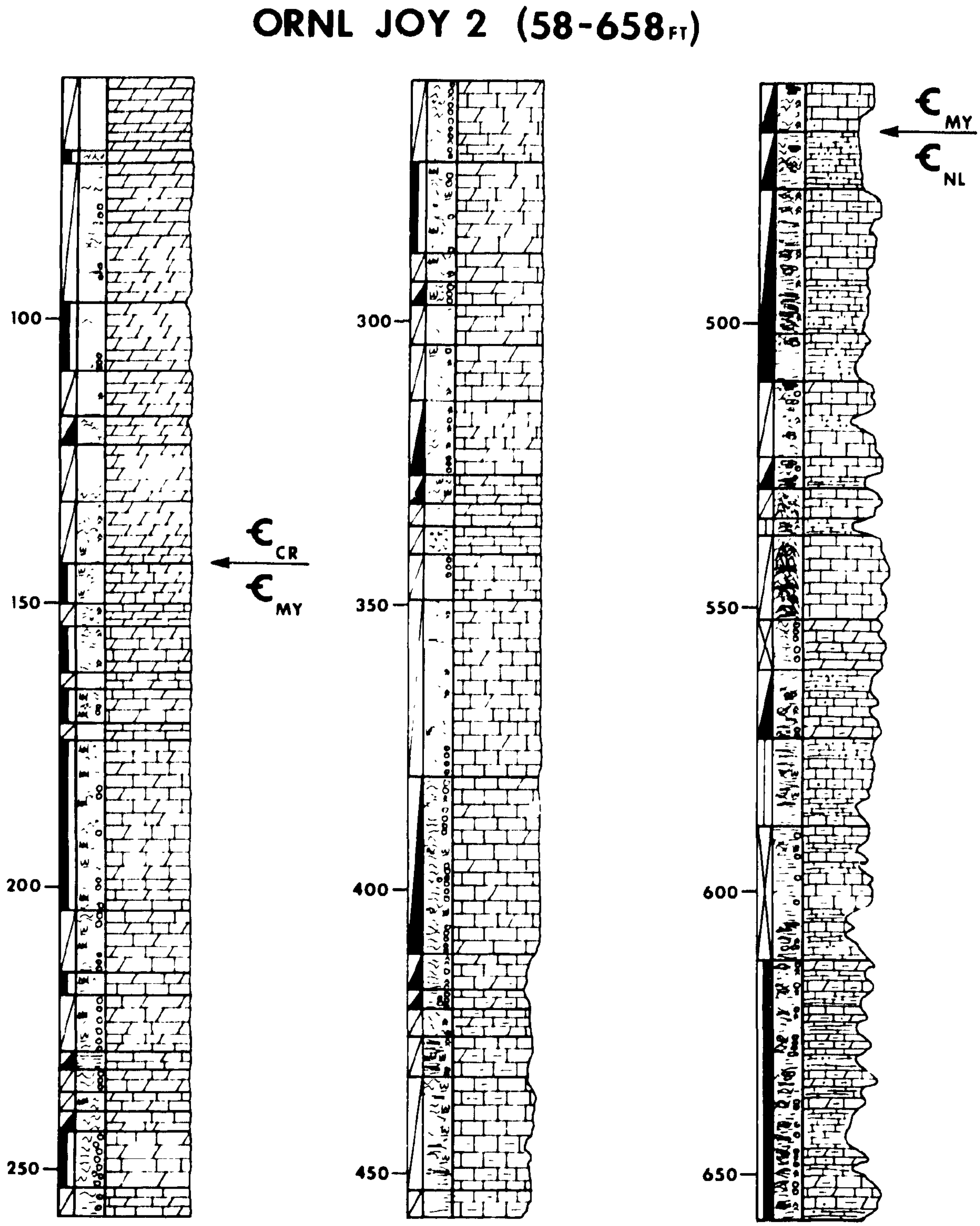
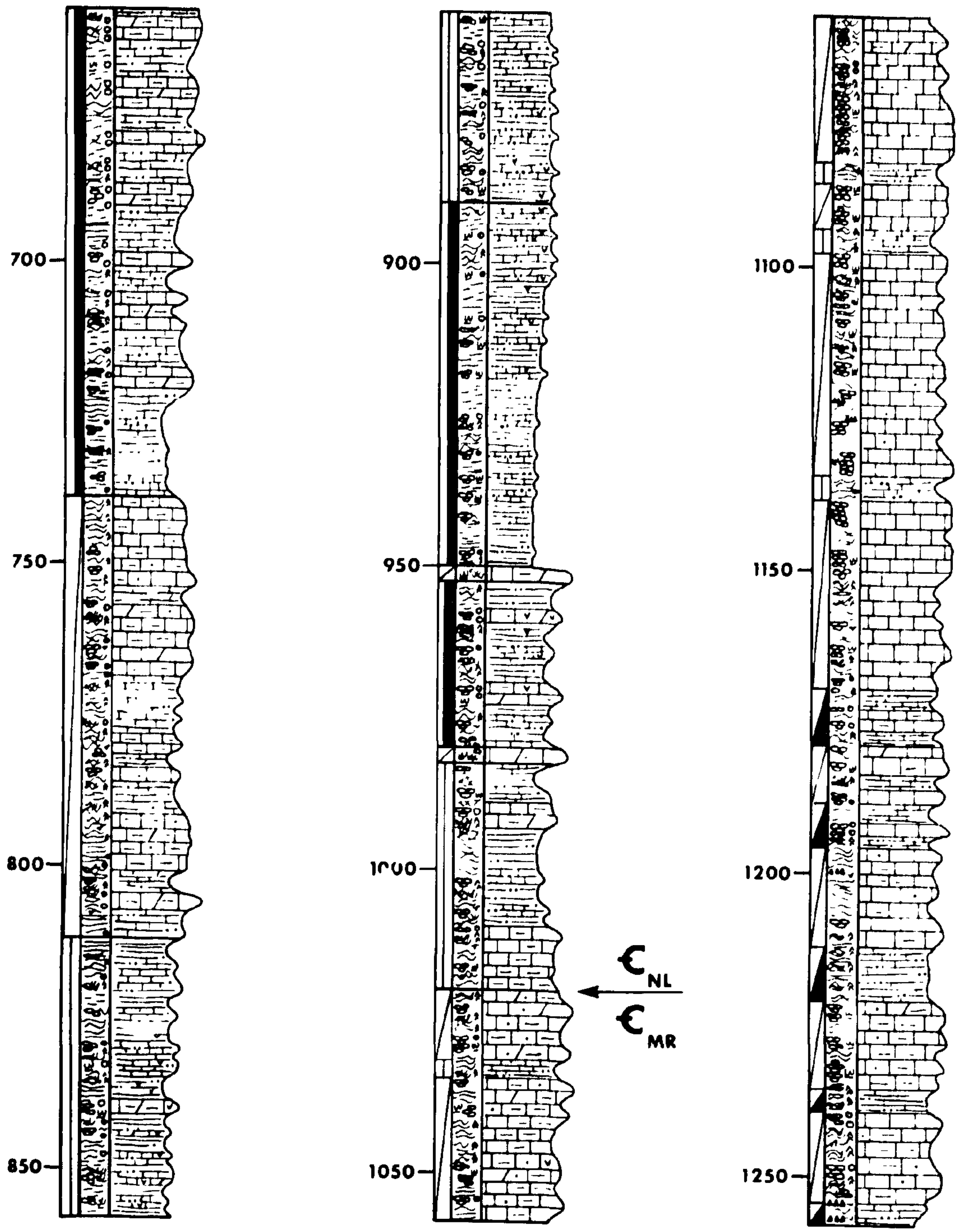


Fig. A1. Lithologic log for borehole ORNL-JOY No. 2. Figure consists of three columns illustrating, from left to right, rock color, bedding and stratification patterns, and lithology (symbols summarized in Fig. A2). Section is based on detailed core logging at 1-ft intervals.

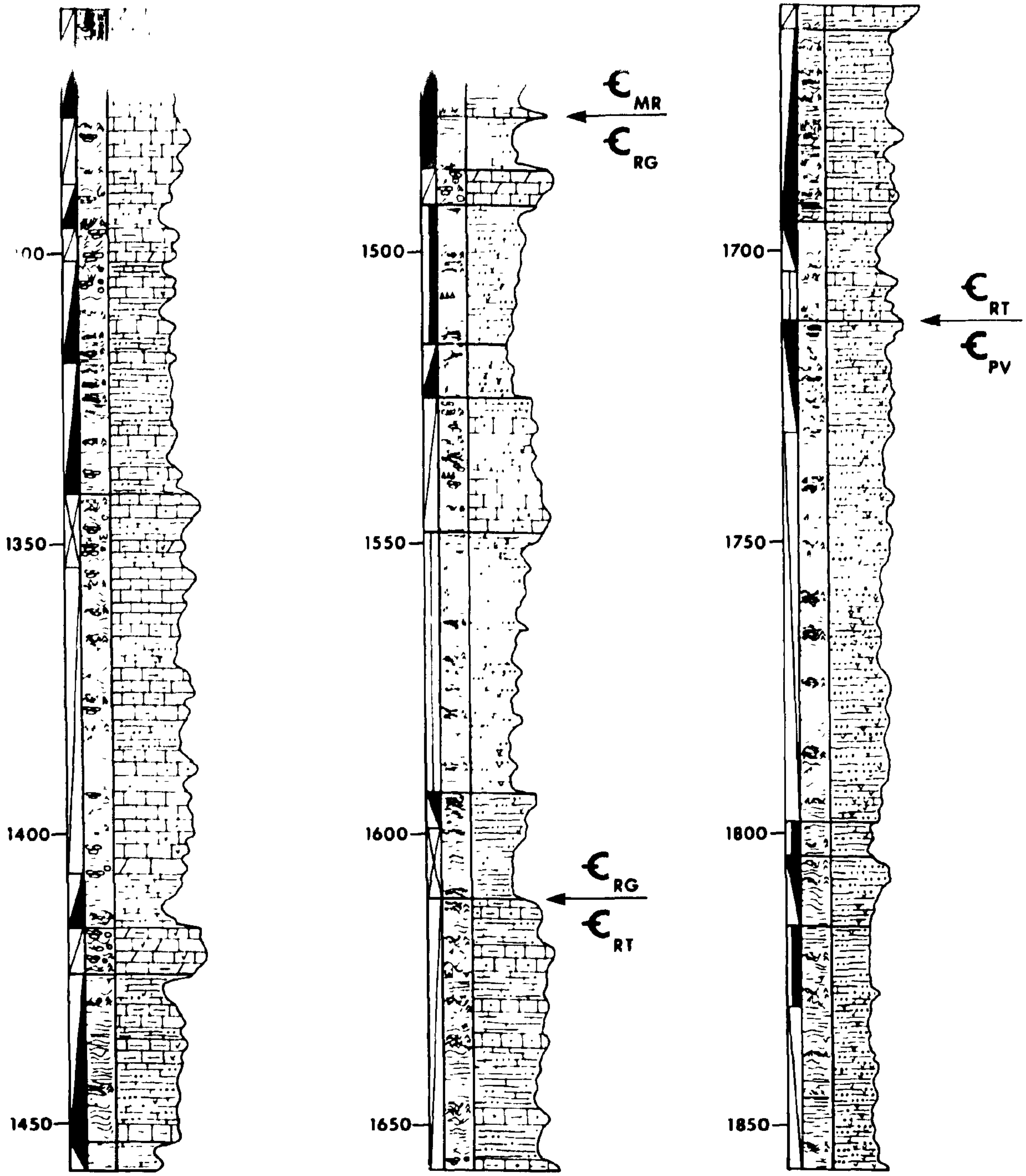
ORNL-DWG 83-13889

ORNL JOY 2 (658-1258 FT)



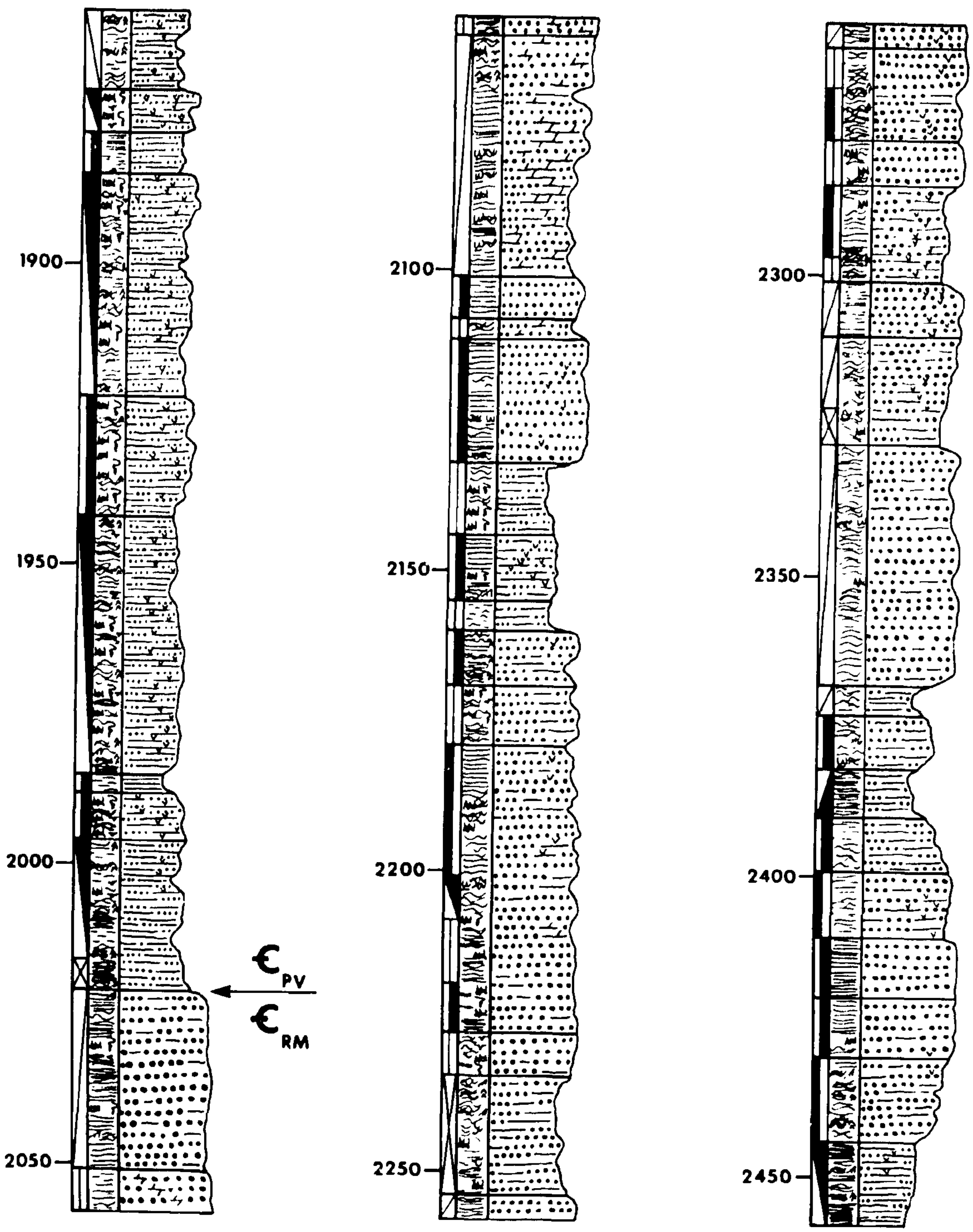
ORNL-DWG 83-13890

ORNL JOY 2 (1258-1858FT)



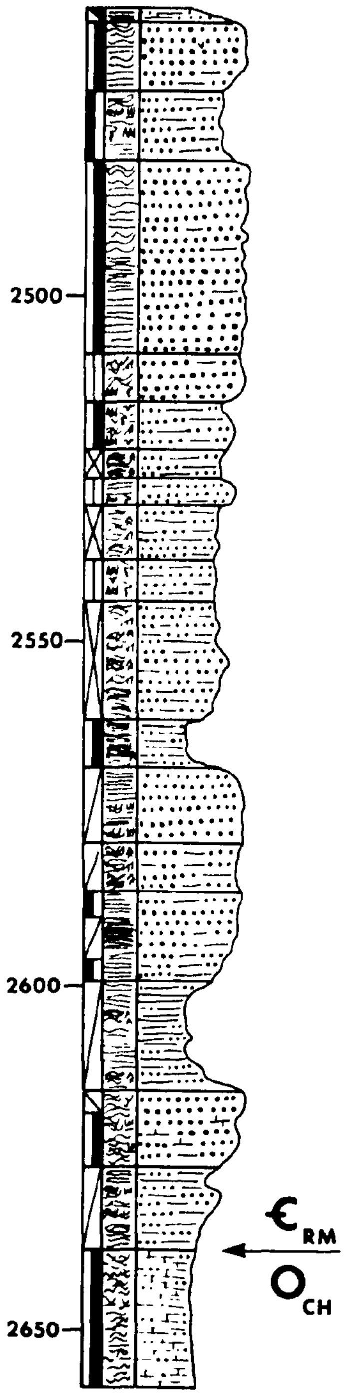
ORNL-DWG 83-13891

ORNL JOY 2 (1858-2458FT)



ORNL-DWG 83-13892

ORNL JOY 2 (2458-2718FT)



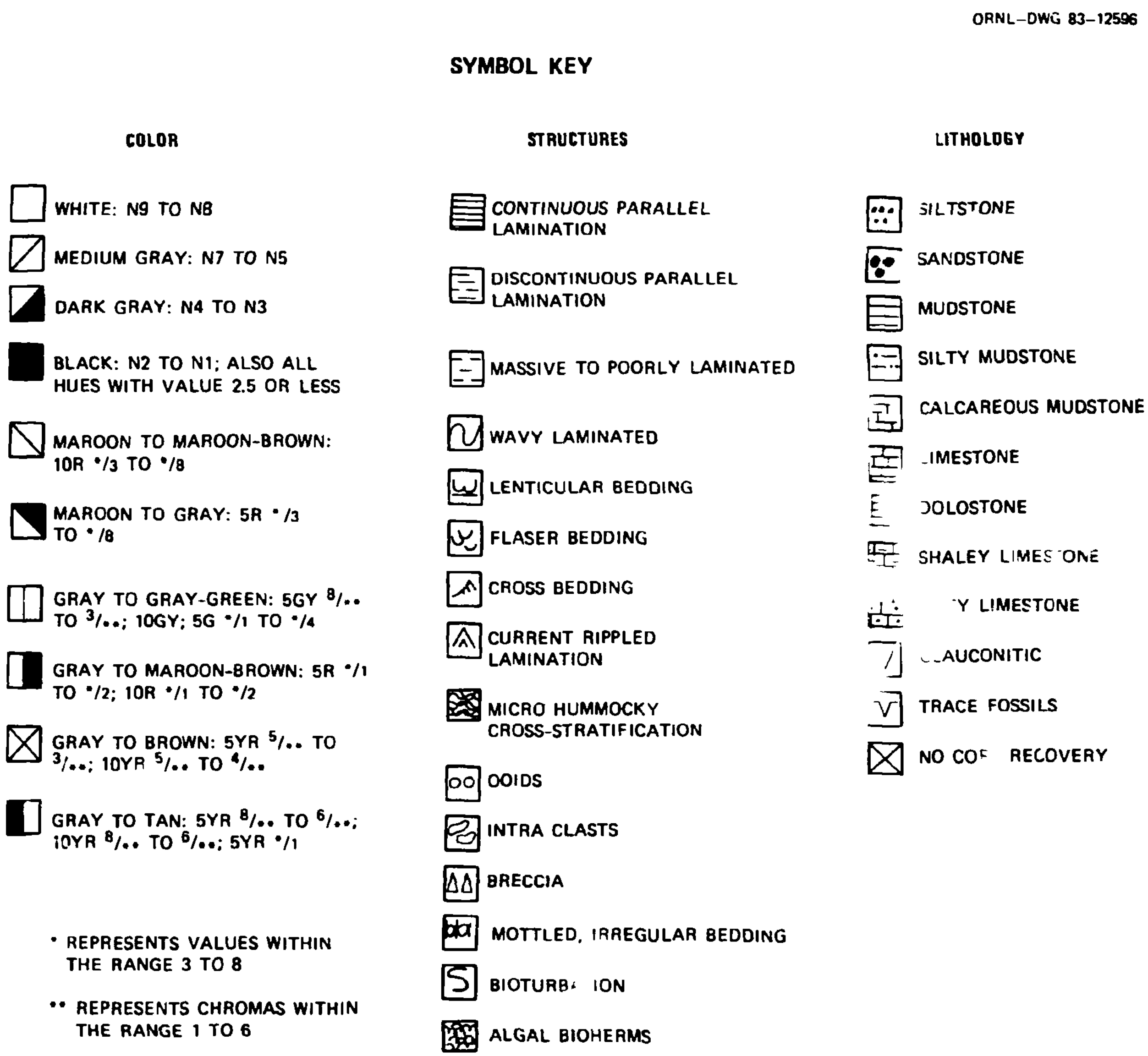


Fig. A2. Symbol key for lithologic log of ORNL JOY No. 2.

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