Y-12

OAK RIDGE Y-12 PLANT

LOCKHEED MARTIN

STRATIGRAPHIC VARIATIONS AND
SECONDARY POROSITY WITHIN THE
MAYNARDVILLE LIMESTONE IN BEAR CREEK
VALLEY, Y-12 PLANT, OAK RIDGE, TENNESSEE

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Prepared for the
Environmental Management Department
Health, Safety, Environment, and Accountability
Organization
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 38731

managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
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STRATIGRAPHIC VARIATIONS AND SECONDARY POROSITY WITHIN THE
MAYNARDVILLE LIMESTONE IN BEAR CREEK VALLEY,
Y-12 PLANT, OAK RIDGE, TENNESSEE

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EXECUTIVE SUMMARY

To evaluate groundwater and surface water contamination and migration near the Oak Ridge Y-12 plant, a Comprehensive Groundwater Monitoring Plan was developed. As part of this plan, the Maynardville Exit Pathways Project was implemented to locate potential groundwater pathways exiting Bear Creek Valley (BCV), and investigate the factors affecting the occurrence and distribution of water-bearing intervals. To formulate a conceptual model of the strata-bound permeability within the Maynardville Limestone, core, geophysical and well logs were analyzed to identify stratigraphic and lithologic variations that could control secondary porosity development.

Although porosities decrease with depth in the Maynardville Limestone, there are important lithologic controls on solution porosity, including carbonate grain-size, dissolution of evaporite and iron minerals and dedolomitization. Within the Maynardville Limestone, finer-grained carbonate lithologies are more prone to dissolution. Facies dominated by algal limestone and dolostone lithologies show secondary dissolution along fine-grained carbonate mudstone which were originally trapped between algal structures, resulting in fenestral porosity between the coarser-grained carbonates. Dissolution of gypsum nodules within stromatolitic dolostones results in vuggy porosity within the lower Copper Ridge Dolomite and upper Maynardville Limestone. Oxidation of pyrite and dedolomitization (calcite after dolomite) produce moldic porosity in the thrombolitic and stromatolitic facies of the Maynardville Limestone.

The lowermost Maynardville Limestone consists dominantly of thrombolitic (non-laminated, clotty algal) limestone. Dissolution along carbonate mud interbeds and along the interface of shale stringers within these algal limestones produces small vugs and elongate solution zones. Localized oxidation and dissolution of pyrite is also an important factor in secondary porosity of the lower Maynardville Limestone. The mean matrix porosities in the lower Maynardville is 0.5 percent. The lowermost Maynardville thins rapidly near the Burial Grounds Waste Management area, which could alter the direction and velocity of strike-parallel groundwater flow.

The middle part of the Maynardville consists of coarse-grained oolitic, peloidal, and oncolitic limestone. Localized solution porosity that has developed in these limestones is commonly associated with thin interbeds of algal limestone. However, large cavities are present in the middle part of the Maynardville, generally at shallow depths. Some of the cavities appear to be associated with lithologic boundaries between zones, in which downward groundwater migration may be retarded across lithologic contacts and the dominant flow (and dissolution) being along the contact interface and parallel to the geologic strike. Other cavities within the middle part of the Maynardville Limestone cross zone boundaries horizontally, suggesting strike-parallel groundwater flow. Mean matrix porosities range between 0.8 and 0.5 percent.

The upper part of the Maynardville Limestone and lowermost part of the Copper Ridge Dolomite consist of the same lithologies: stromatolitic (algal) dolostone and dolomitic limestone. Abundant solution porosity and groundwater movement occurs within these units,

thus they represent the most permeable units within BCV with the average matrix porosity being depth dependent but ranging between 3.6 and 1.0 percent. The dominant factor controlling secondary porosity in this zone appears to be dissolution of gypsum nodules and dedolomitization. The thickness and facies of these units does not vary significantly throughout BCV, thus strike-parallel as well as and down-dip groundwater flow is likely. The depth at which there is a decrease in solution-enlarged zones is currently unknown, but appears to exceed 1200 ft.

1.0 INTRODUCTION

1.1 BACKGROUND

The Department of Energy's (DOE) Oak Ridge Y-12 Plant and Burial Grounds Waste Management Area contain several hazardous and nonhazardous waste sites and underground storage tank sites that have the potential to contaminate the local surface streams and groundwater. To evaluate groundwater and surface water contamination and migration from these sites, a Comprehensive Groundwater Monitoring Plan (Comprehensive Plan) was developed (Geraghty and Miller Inc. 1990). The plan was mandated in a Memorandum of Understanding signed in 1983 by personnel from the DOE, U.S. Environmental Protection Agency (EPA), and Tennessee Department of Health and Environment (TDHE). The plan was completed in 1990 (Geraghty and Miller Inc. 1990) and, as part of this plan, the Maynardville Limestone exit pathways project was implemented during 1991-1992 (Shevenell and others 1993).

As part of the Maynardville exit pathways monitoring program, monitoring well clusters were installed perpendicular to the strike of the Maynardville Limestone, that underlies the southern part of the Y-12 Plant and Bear Creek Valley (BCV). The Maynardville Project is designed to locate potential exit pathways of groundwater, study geochemical characteristics and factors affecting the occurrence and distribution of water-bearing intervals, and provide hydrogeologic information to be used to reduce the potential impacts of contaminants entering the Maynardville Limestone (Geraghty and Miller Inc. 1990; Shevenell and others 1993).

A summary of the construction, hydrologic, and geologic data obtained from the Maynardville Project is provided by Shevenell and others (1993). As a result of this work, several geologic factors were noted that could influence the development of water-bearing intervals in the Maynardville Limestone. A recommendation was brought forward to investigate the stratigraphic variations throughout BCV that may influence strata-bound porosity (Shevenell and others 1993).

This report identifies the stratigraphic variations and their possible effects on groundwater movement within the Maynardville Limestone of BCV. The Maynardville Limestone is considered part of the Knox aquifer in which flow is dominated by solution conduits (Solomon and others 1992). Therefore, it is important to define the stratigraphic and lithologic controls on secondary porosity (porosity formed in a sedimentary rock subsequent to final deposition through the process of chemical dissolution) throughout the Maynardville Limestone to better understand groundwater flow through this karst system. A model for strata-bound porosity (porosity confined to a particular stratigraphic unit) can be developed knowing the principles of carbonate deposition and diagenesis within the Maynardville Limestone. The data provided herein is used to predict the depth and thicknesses of strata most likely to exhibit solution porosity in which contaminant transport could occur.

This report builds on the hydrogeologic data from Shevenell and others (1993), as well as data collected from existing wells and newer Dense Nonaqueous Phase Liquids (DNAPL) wells throughout BCV (Fig. 1.1). Table 1.1 lists the wells, their location, elevation, and type of data used for stratigraphic reconstructions. Gamma-ray and lithologic descriptions, alteration and water zones, and isopach maps for the Maynardville Limestone are provided in Appendix A, B, and C, respectively.

1.2 GENERAL GEOLOGY AND HYDROGEOLOGY OF BEAR CREEK VALLEY

Chestnut Ridge and BCV are located on the upper plate of the Whiteoak Mountain thrust fault within the Valley and Ridge Province of the southern Appalachian fold and thrust belt. The bedrock of BCV and adjacent ridges consists of Cambrian and Ordovician carbonate and clastic sedimentary rocks (King and Hasse 1987; Hatcher and others 1992). The majority of the waste management areas within BCV are located in the Nolichucky Shale and the Maynardville Limestone (Fig. 1.2). Bedrock strike in the area varies locally from N47°E to N67°E and dips average 45° to the southeast (King and Hasse 1987). The Nolichucky Shale lies beneath BCV (Fig. 1.2) and is gradationally overlain by the Maynardville Limestone. The Maynardville Limestone forms the southern floor of BCV and is gradationally overlain

by the ridge forming Copper Ridge Dolomite (Fig. 1.2).

Table 1.1: Well number, location, surface elevation, and data used for the stratigraphic study of the Maynardville Limestone.

WELL	LOCATION+ NORTH EAST		SURFACE ELEVATION (FT)	DATA TYPE
GW-130	28661	65090	932	core, gamma-ray
GW-131	27989	65059	1008	core, gamma-ray
GW-135	28731	53053	1175	core, gamma-ray
GW-137	28712	32796	833	core, gamma-ray
GW-138	27959	30825	839	core, gamma-ray
GW-703	28806	44931	952	cutting, well log, gamma-ray, report**
GW-704	28845	44935	942	cutting, well log, gamma-ray, report**
GW-705	28945	44916	924	cutting, well log, gamma-ray, report**
GW-711	27873	36535	902	cutting, well log, gamma-ray, report**
GW-712	28233	36507	874	cutting, well log, gamma-ray, report**
GW-722	28532	64926	956	core, gamma-ray
GW-723	29006	49089	1019	cutting, well log, gamma-ray, report**
GW-724	29198	48995	977	cutting, well log, gamma-ray, report**
GW-725	29405	48989	958	cutting, well log, gamma-ray, report**
GW-727	28725	42590	897	cutting, well log, gamma-ray, report**
GW-729	28750*	43600*	1000*	core, well log, gamma-ray, report**
GW-730	28920	44595	921	cutting, well log, gamma-ray, report**
GW-790	28170*	43000*	908*	core, gamma-ray

+ Y-12 coordinates

* Approximate location and elevation

** from Shevenell and others (1993)

Fig. 1.1: Location map and wells noted in this report for the Bear Creek Valley area.

0 2000
SCALE (ft)

0 1000
SCALE (ft)

Fig. 1.2: Generalized geologic map of the Bear Creek Valley area. (A) eastern half of the study area, and (B) western half of the study area.

The Nolichucky Shale ranges in stratigraphic thickness from 508 to 604 ft in BCV (Hatcher and others 1992). The formation consists of purple-brown to green-gray, massive to very thinly-bedded shale interstratified with light-gray, thin-to medium-bedded limestone and rare calcareous siltstone. The limestone commonly are conglomeratic and oolitic (Weber 1988; Foreman and others 1991). The Nolichucky Shale was deposited in a relatively deep-water, intrashelf basin with storm-generated, down-slope transport of sediment from fringing carbonate platform environments (Foreman and others 1991).

The overlying Maynardville Limestone ranges in stratigraphic thickness from 383 to 450 ft in BCV (Hatcher and others 1992; Shevenell and others 1993). Although data are sparse, the Maynardville appears to thin to the southeast within the Copper Creek thrust sheet to approximately 261 ft (Hatcher and others 1992). The Maynardville Limestone consists predominately of light-gray to tan, massive to thinly-bedded thrombolitic, oolitic, and peloidal limestone with an increase in algal laminated and stromatolitic dolostone upward in the formation. The Maynardville Limestone was deposited in shallow marine subtidal, intertidal, and minor supratidal environments that prograded northwest over the Nolichucky basal deposits (Weber 1988).

The Copper Ridge Dolomite overlies the Maynardville Limestone, forming the northwest part of Chestnut Ridge within the study area. The Copper Ridge Dolomite ranges in thickness from 244 to 335 ft (Hatcher and others 1992) and consists of tan-to-medium gray, massive-to-thinly bedded, locally chert-rich dolostone containing abundant stylolites (King and Hasse 1987; Hatcher and others 1992). The Copper Ridge Dolomite was deposited in shallow subtidal to supratidal environments within a carbonate platform (Weber 1988).

Several fracture sets have been identified in the BCV area, with a prominent fracture set oriented parallel to and along bedding planes (Sledz and Huff 1981; Ketelle and Huff 1984; Rothschild and others 1984; Hatcher and others 1992). A second prominent set of fractures is also parallel to strike but perpendicular to bedding (Geraghty and Miller Inc. 1989; Hatcher and others, 1992). A third set of fractures is oriented perpendicular to strike

(Hatcher and others 1992). The frequency of fracturing decreases with depth within the bedrock (Solomon and others 1992); however, the decrease may be lithologically and spatially dependent.

Although the Nolichucky Shale has a very low primary permeability, fractures and bedding planes in the formation are believed to provide groundwater and contaminant flow paths into the Maynardville Limestone (Solomon and others 1992). Localized dissolution along fractures and bedding planes has enhanced porosity in the Maynardville Limestone and Copper Ridge Dolomite. Solution cavities in the Maynardville Limestone, particularly those that underlie creeks within BCV, appear to receive groundwater from shallow-and intermediate-depth water transported through the Nolichucky Shale (King and Hasse 1988; Shevenell and others 1993).

Within BCV is a groundwater and surface water divide that is located near the northwest end of the Y-12 Plant (Geraghty and Miller Inc. 1987). Northeast of the divide, groundwater flows toward Upper East Fork Poplar Creek and southwest of the divide, the groundwater flow is toward Bear Creek (Fig. 1.1; Geraghty and Miller Inc. 1990). The surface water in BCV and groundwater in the Maynardville Limestone are highly interconnected, with springs discharging from the Maynardville Limestone into Bear Creek (Geraghty and Miller Inc. 1985). Also, a large number of solution cavities are present in the Maynardville Limestone underlying Bear Creek (Shevenell and others 1993). Hydraulic head data indicate convergent flow into the Maynardville Limestone, suggesting that the Maynardville Limestone acts as a hydraulic drain for BCV (Dreier and others 1993).

2.0 STRATIGRAPHY OF THE MAYNARDVILLE LIMESTONE

Although the Maynardville Limestone throughout East Tennessee differs lithologically (Haase and others 1985; Hatcher and others 1992), only those lithologies present in the Maynardville Limestone within BCV will be discussed in this report. Geologic descriptions for the Maynardville Limestone are based on core and cutting observations, natural gamma-ray logs,

previous studies (Weber 1988; Shevenell and others 1993) and drilling logs provided by Science Applications International Corporation personnel. Unless otherwise noted, all locations are presented in Y-12 coordinates and core thicknesses, and position of stratigraphic units are reported as downhole depths in feet.

In BCV, the Maynardville Limestone consists of two members (Chances Branch and Low Hollow members). Gamma-ray analysis by Shevenell and others (1993) further subdivided the uppermost Nolichucky, Maynardville Limestone, and Maynardville-Copper Ridge Dolomite transition into seven zones. Zone 7 is transitional between Zone 6 and the lower Copper Ridge Dolomite and difficult to recognize both lithologically and geophysically; therefore, this report groups Zone 7 into the upper part of Zone 6. A typical gamma-ray and lithologic log is shown in Figure 2.1.

2.1 ZONE 1 (UPPERMOST NOLICHUCKY SHALE)

The contact between the Nolichucky Shale and Maynardville Limestone is geophysically placed immediately above the highest right deflection on the gamma-ray log and at the bottom of the comparatively constant carbonate baseline (Hatcher and others, 1992). Lithologically, this contact can be either abrupt or gradational. Where the contact is gradational, the contact is placed where the limestone to shale ratio becomes > 50 percent within the ribbon-bedded lime mudstone below the lowermost massive limestone. This contact location is consistent with the criteria used by Bridge (1956) and Helton (1967). Locally, the Nolichucky-Maynardville contact is also abrupt within BCV (Lee and Ketelle 1989; this report).

The thickness of Zone 1 varies throughout BCV and may be a result of localized erosion within the upper Nolichucky Shale (Lee and Ketelle 1989). Interbedded limestone, carbonate mudstone, and shale give Zone 1 a light-gray and dark-green banded (ribbon-bedded) appearance. The shales and limestones are thin-to-thickly laminated with a gradual increase in limestone content and bed thickness upwards. Limestones are light-gray, peloidal, and oolitic packstone and wackestone, and are commonly graded with sharp-to-loaded basal

Fig. 2.1: Typical lithologic and natural gamma-ray log for the Bear Creek Valley area. Logs are from GW-135. Key to lithologic symbols appear at the beginning of Appendix A.

contacts. Limestone beds have wavy bedding and cross-laminations with burrowed and bioclastic beds present. Shales are dark-green, slightly micaceous, wavy to evenly stratified, thinly-bedded to laminated. Matrix supported, limestone pebble conglomerate (flat-pebble conglomerate) are also present.

The gamma-ray signatures for Zone 1 have sharp deflections to the right that correlate to interbedded shale and carbonate mudstone. Sharp deflections to the left correlate to interbeds of oolitic, peloidal, and bioclastic packstone and grainstone, and flat-pebble conglomerate. Generally, the gamma-ray signature shows a sharp decrease in frequency and amplitude at the contact between the Nolichucky and Maynardville (Fig. 2.1).

The interbedded shale, carbonate mudstone, and limestone of the upper Nolichucky are interpreted to have been deposited in a subtidal environment below normal, fair weather, wave-base (Fig. 2.2) (Weber 1988; Foreman and others 1991).

2.2 MAYNARDVILLE LIMESTONE

Correlations along geologic strike throughout BCV for the natural gamma-ray logs and lithologic logs (Figs 2.3 through 2.11) were constructed using the lowermost, laterally continuous shale bed of Zone 5 as the horizontal datum. Four overlapping gamma-ray and four overlapping stratigraphic correlation diagrams are provided in Figures 2.4 through 2.11 to provide detail correlation along strike throughout BCV. Although well control perpendicular to strike is limited, representative cross sections for Zones 2 to 6 are provided in the discussion below. Lithologic descriptions and gamma-ray logs for each well are provided in Appendix A. For each well in Appendix A there are two sections: an overview gamma-ray and general stratigraphic section followed by detailed gamma-ray and lithologic sections.

INTERTIDAL		SHALLOW SUBTIDAL			DEEP SUBTIDAL	
ZONES →	6	5	4	3	2	1

Fig. 2.2: Schematic profile of depositional environments and lithologies of the Maynardville Limestone and upper part of the Nolichucky Shale.

Fig. 2.3: Natural gamma-ray correlation across BCV. Horizontal datum placed below lowest, laterally continuous shale in Zone 5.

Fig. 2.4: Natural gamma-ray correlation between Wells GW-130, GW-131, and GW-135. Horizontal datum placed at lowest, laterally continuous shale in Zone 5.

Fig. 2.5: Natural gamma-ray correlation between Wells GW-135, GW-723, GW-703, and GW-705. Horizontal datum placed at lowest, laterally continuous shale in Zone 5.

Fig. 2.6: Natural gamma-ray correlation between Wells GW-705, GW-703, GW-730, GW-729, GW-790, and GW-727. Horizontal datum placed at lowest, laterally continuous shale in Zone 5.

Fig. 2.7: Natural gamma-ray correlation between Wells GW-727, GW-712, and GW-138.
Horizontal datum placed at lowest, laterally continuous shale in Zone 5.

Fig. 2.8: Stratigraphic correlation between Wells GW-131, GW-130, and GW-135.
Horizontal datum placed at lowest, laterally continuous shale in Zone 5. Key to lithologic symbols appear at the beginning of Appendix A.

Fig. 2.9: Stratigraphic correlation between Wells GW-135, GW-723, GW-703, and GW-705. Horizontal datum placed at lowest, laterally continuous shale in Zone 5. Key to lithologic symbols appear at the beginning of Appendix A.

Fig. 2.10: Stratigraphic correlation between wells GW-703, GW-705, GW-730, GW-729, and GW-727. Horizontal datum placed at lowest, laterally continuous shale in Zone 5. Key to lithologic symbols appear at the beginning of Appendix A.

Fig. 2.11: Stratigraphic correlation between wells GW-727, GW-712, GW-137, and GW-138. Horizontal datum placed at lowest, laterally continuous shale in Zone 5. Key to lithologic symbols appear at the beginning of Appendix A.

2.2.1 Zone 2 (Lower Low Hollow Member)

Zone 2 ranges in downhole thickness from 0 to 236 ft (0 to 173 ft stratigraphic thickness; Shevenell and others 1993) and thickens, to the west and east, in the vicinity of Gum Branch Road (GW-138) and at Scarboro Road (GW-130, GW-131, and GW-722). Near the Burial Grounds Waste Management area (Fig. 1.2), the downhole thickness of Zone 2 varies considerably over a horizontal distance of approximately 500 ft; thinning to between 0 and 20 ft (GW-705, GW-727, and GW-790) and thickening to approximately 235 ft in Well GW-730 (Figs 2.3 and 2.10). Where Zone 2 thins or is absent, a corresponding thicker section of the upper Nolichucky is present (Shevenell and others 1993).

Zone 2 is dominantly composed of thrombolitic (nonlaminated algal) limestone and dolomitic limestone (Fig. 2.1) which has a diagnostic mottled and clotted appearance of light and dark gray with abundant thin, wispy shale and carbonate mudstone stringers and partings. Very fine-to-fine crystalline limestone is light gray and dolomitic mudstone is dark gray. Beds are massive-to-thickly bedded boundstone, packstone, and grainstone. Interbeds of bioclastic, peloidal, oolitic, stromatolitic, and oncolitic limestone are common. Zone 2 is commonly stylolitic and burrowed, and small open and calcite-filled vugs and fractures are also common. Locally, pyrite is associated with shale stringers or dispersed throughout the thrombolitic limestone.

Lithologic variations normal to geologic strike are represented in Figure 2.12 from Wells GW-137 and GW-138. Zone 2 thins from approximately 147 to 96 ft to the northeast. Well GW-138, the southern-most well, consists mostly of thrombolitic limestone with several shale and oolitic and stromatolitic limestone beds. Northeastward, in GW-137, Zone 2 contains interbeds of thrombolitic and crystalgalaminated limestone and dolomitic limestone, and minor shale (Fig. 2.12).

The gamma-ray signature for Zone 2 has less extreme amplitude shifts than the underlying Zone 1 (upper Nolichucky Shale) and the overall baseline signature is shifted slightly to the

Fig. 2.12: Geologic cross-section perpendicular to the geologic strike between Wells GW-137 and GW-138. Key to lithologic symbols appear at the beginning of Appendix A.

right in comparison to the other zones within the Maynardville Limestone. The slightly higher baseline and low amplitude in the gamma-ray signature for Zone 2 is attributed to the dispersed nature of intra-algal shale and carbonate mudstone within the thrombolitic limestones and dolomitic limestones. In the Burial Grounds Waste Management Area, the gamma-ray logs for several wells (e.g., GW-727 and GW-790) do not show the diagnostic Zone 2 baseline shift above the Nolichucky Shale, suggesting Zone 2 is absent in these particular locations.

Thrombolites represent biohermal, nonlaminated, cryptalgal stromatolites of Lower Paleozoic age and indicate shallow, subtidal paleoenvironments (Fig. 2.2) (Aitken 1967; Demicco 1985). Throughout most of BCV, thick thrombolitic bioherms prograded northward into the Nolichucky basin. In the Burial Grounds area, however, gamma-ray correlations show that the upper Nolichucky Shale is slightly thicker below where the thrombolitic limestones thin (i.e., GW-705 and GW-727), and that the upper Nolichucky is thinner below thicker thrombolitic sections (GW-730). The thrombolitic bioherms may have been traversed by subtidal channels (Fig. 2.13) in which siliciclastic sedimentation inhibited algal growth. Continued deposition of ribbon bedded shale and limestone in these paleotopographic low areas, as well as differential compaction of the Nolichucky Shale below the thicker sections of Maynardville Limestone, may account for the variable thicknesses of the upper part of the Nolichucky Shale and lower part of the Maynardville Limestone.

Thickness changes have been reported in the basal part of the Maynardville Limestone elsewhere in East Tennessee (Oder and Bumgarner 1961). Oder and Bumgarner (1961) report that the stromatolitic basal Maynardville Limestone, exposed approximately 20 miles east of Knoxville, varies in stratigraphic thickness from 166 to 80 ft within 4 miles. This change in thickness, however, is attributed to thinning in the upper part of the basal Maynardville Limestone which is overlain by a thicker section of oolitic limestone (Oder and Bumgarner 1961).

Fig. 2.13: Depositional settings of the Maynardville Limestone and upper part of the Nolichucky Shale. Number refer to zones in the Maynardville Limestone and upper Nolichucky Shale; 4/3 = subzone 4/3. For discriptions of lithologic symbols, see Figure 2.2.

2.2.2 Zone 3 (Upper Low Hollow Member)

The average downhole thickness of Zone 3 is 74 ft (54 ft stratigraphic thickness; Shevenell and others 1993). As with Zone 2, the thickness of Zone 3 is relatively the same west and east of the Burial Grounds (Fig. 2.3). Zone 3 is absent in the region of the Burial Grounds, except in Well GW-730 (Figs. 2.4, 2.5, and 2.6). Where Zone 3 is absent, a hybrid of Zones 4 and 3 (Subzone 4/3) is present and discussed under the Zone 4 section below.

The base of Zone 3 is gradational with Zone 2 and interbeds of thrombolitic and oolitic limestones, matrix-supported carbonate conglomerate, carbonate mudstone, and stringers of calcareous shale are common (Fig. 2.1). Thick beds of carbonate conglomerate (commonly of dolostone clasts) occur within either a shale or coarsely crystalline limestone matrix. Interbeds of peloidal and oncolitic packstone and grainstone are common. Oolitic beds are light-to-medium gray; thrombolitic beds are mottled medium-to-dark gray, and fine-to-medium grained. The upper parts of Zone 3 consist of oncolitic and oolitic limestone, thick interbeds of digitate stromatolitic limestone, and dark gray, slightly dolomitic mudstone. Black shale interbeds and stringers are more common within the peloidal and oolitic limestone beds. Stylolites with black, clay residue and disseminated pyrite are common.

Lithologic variation normal to the geologic strike for Zone 3 are represented in Wells GW-130 and GW-131 (Fig. 2.14). The southern well (GW-131) consists of interbedded thrombolitic and oolitic limestone and shale stringers. To the north, in GW-130, Zone 3 consists largely of oolitic limestone with thin interbeds of shale and oncolitic limestone (Fig. 2.14).

The gamma-ray signature of this zone has a greater frequency and higher amplitude than the overlying and underlying zones of the Maynardville Limestone (Fig. 2.1), and is related to the interbedded nature of the shale and limestone. Low gamma-ray peaks are commonly associated with oolitic limestone beds, whereas high gamma-ray signatures represent either shale, matrix-supported conglomerate, or shale partings within the thrombolitic limestone

Fig. 2.14: Geologic cross-section perpendicular to the geologic strike between Wells GW-130 and GW-131. Key to lithologic symbols appear at the beginning of Appendix A.

interbeds. With respect to Zone 2, the gamma-ray baseline is shifted slightly to the left.

These interbedded thrombolitic and oolitic limestones suggest deposition within a shallow, subtidal environment (Fig. 2.2) (Wilson 1975; Demicco 1985). The matrix-supported dolostone conglomerates represent storm deposits in which intertidal mudstone and dolostone were transported into the subtidal environment.

2.2.3 Zone 4 (Lower Chances Branch Member)

Zone 4 has a downhole thickness of approximately 106 ft with an average stratigraphic thickness of 78 ft (Shevenell and others 1993). Generally, Zone 4 thickens to the east and west in the study area, and thins and grades into Subzone 4/3 in the area of the Burial Grounds (Fig. 2.3). The lithologies of Zone 4 are gradational and similar to Zone 3, with an increase in peloidal limestone and dolomitic limestone in Zone 4 (Appendix A). In several wells, stromatolitic and thrombolitic limestones are present (Appendix A). The thicker portions of Zone 4 generally contain peloidal and dolomitic limestone, whereas the thinner portions contain more interbeds of oolitic limestone.

Zone 4 consists of light-to-dark gray, medium-to-coarsely crystalline limestone and minor dolostone. Interbeds of oolitic, digitate stromatolitic, and algal-laminated limestones occur near the base. Interbeds of oncolitic dolomitic limestone and limestone occur in the upper part of this zone. Stromatolitic and bioclastic limestone beds, as well as gypsum-filled vugs, are common. Calcite-filled, birds-eye structures and stylolites are also present. A distinctive very light gray limestone marker unit occurs near the top of this zone, in which white calcite-filled vugs and open vugs are present. Algal lamination and a petroliferous odor (on a freshly broken surface) are also common.

Wells GW-704 and GW-705 provide data on the facies changes normal to geologic strike (Fig. 2.15). In the southern well, GW-704, oolitic limestones dominate and grade northward (GW-705) into thinner oolitic limestone with interbeds of thrombolitic limestone.

Fig. 2.15: Geologic cross-section perpendicular to the geologic strike between Wells GW-703, GW-704, and GW-705. Key to lithologic symbols appear at the beginning of Appendix A.

The predominance of coarsely crystalline carbonate and lack of shale in this zone accounts for the relatively flat baseline gamma-ray signature. Compared to Zones 3 and 5, the baseline for Zone 4 is shifted to the left and has low amplitude deflections (Fig. 2.1).

The abundance of stromatolitic, oncolitic, and oolitic limestones in Zone 4 are suggestive of very shallow subtidal to lower intertidal environments (Aitkin 1967; Demicco 1985). The presence of dolomitic limestone and birds-eye structures also indicates possible intertidal environments. Zone 4 may represent a shallow oolitic shoal and associated stromatolitic patch reefs on the carbonate ramp (Fig. 2.2).

2.2.3.1 Subzone 4/3

Within the Burial Grounds area for Wells GW-727, GW-729, and GW-790, the gamma-ray signature below Zone 5 generally does not compare with either Zones 4 or 3, but rather appears to be a combination of both and is therefore referred to as Subzone 4/3. In general, the relatively flat baseline of Subzone 4/3 suggests that it is more closely related to Zone 4 than Zone 3.

Lithologically, Subzone 4/3 consist mostly of thrombolitic and stromatolitic limestone with interbeds of oolitic limestone (Fig. 2.10) which directly overlie Zone 1 (GW-727 and GW-790) or a thin Zone 2 (GW-729). The abundance of thrombolitic and stromatolitic limestone suggests that Subzone 4/3 developed in shallow subtidal to lower intertidal environments (Fig. 2.13).

2.2.4 Zone 5 (Middle Chances Branch Member)

Zone 5 is distinctive in core and cuttings by the presence of several thin interbeds of dark green shale and carbonate mudstone within dominantly oolitic limestone (Fig. 2.1). High amplitude gamma-ray peaks are distinctive of this zone and relate directly to thin, interbedded shale and carbonate mudstone (Fig. 2.1). Gamma-ray deflections to the left correlate to

thickly bedded oolitic limestone beds. Zone 5 has an average downhole thickness of 54 ft and a stratigraphic thickness of 39 ft (Shevenell and others 1993). The thickness of this zone does not vary substantially throughout the study area (Fig. 2.3).

Most of Zone 5 consists of wavy-to-even, thickly bedded, light gray oolitic, peloidal, and oncolitic packstone and grainstone. Very thin interbeds and stringers of dark green-to-gray calcareous shale and carbonate mudstone are distinctive of this zone. Thin intraformational conglomerate beds are associated with the shale and carbonate mudstone beds.

Strike-normal facies variations in Zone 5 are represented in Wells GW-723 and GW-724 (Fig. 2.16) and Wells GW-703 and GW-704 (Fig. 2.14). In the southern wells, facies tend to be more homogeneous with mostly oolitic limestone in Well GW-723 and dolomitic limestone in GW-703. Interbedded sparry and oolitic limestone are present in the northern wells (e.g., GW-704). However, the distinctive shale and carbonate mudstone interbeds within Zone 5 are laterally persistent throughout BCV.

The abundance of intraformational breccia, dolomitic and mudstone rip-up clasts and bioclastic beds indicate that Zone 5 was deposited above storm-wave base and may represent deposition in subtidal oolitic sand and mud flats. The predominance of oolitic packstone and grainstone suggests much of Zone 5 was deposited as oolitic shoals in a subtidal environment (Fig. 2.2). The presence of interbedded mudstone and shale throughout Zone 5 indicate the development of laterally extensive subtidal mud flats.

2.2.5 Zone 6 (Upper Chances Branch Member)

The average downhole thickness for Zone 6 is 100 ft with a calculated stratigraphic thickness of 73 ft (Shevenell and others 1993). Zone 6 consists dominantly of mottled, tan-to-dark gray dolostone and slightly calcareous dolostone (Fig. 2.1). Generally, this zone is medium-to-coarsely crystalline with a saccharoidal texture, massive-to-well laminated, and stromatolitic. Algal-laminated rip-up clasts, bioturbation, and birds-eye structures are

Fig. 2.16: Geologic cross-section perpendicular to the geologic strike between Wells GW-723, GW-724, and GW-725. Key to lithologic symbols appear at the beginning of Appendix A.

common. Stylolites, open and filled (calcite and gypsum) vugs, and veins are common. The abundance of vugs is characteristic of this zone.

Only minor facies variation are present along strike, and facies are generally homogeneous perpendicular to geologic strike as well. Lithologic data from wells that intersect Zone 6 in the southern part of the study area indicate an upward gradation from dolomitic limestone into dolostone; whereas northern wells generally grade upward from limestone to dolostone (Fig. 2.15).

Zone 6 has the lowest amplitude gamma-ray signature with its baseline shifted to the left more than all other zones of the Maynardville Limestone (Fig. 2.1). The lower contact of this zone is placed above the uppermost shale spike in Zone 5, and the upper contact is placed where the gamma-ray deflections increase in frequency and amplitude within the basal Copper Ridge Dolomite.

The abundance of dolostone, dolomitic limestone, stromatolites, and birds-eye structures all indicate that Zone 6 formed in an upper intertidal depositional environment (Fig. 2.2) (Aitken 1967; Wilson 1975). Vugs within this zone are similar in size and shape to evaporite (anhydrite and gypsum) nodules which are present in the Maynardville Limestone at depth (Saunders and Toran, 1994). The presence of evaporite nodules may indicate possible supratidal depositional environments within Zone 6.

2.3 LOWER COPPER RIDGE DOLOMITE

The Maynardville-Copper Ridge contact is gradational with mottled, irregularly bedded, tan-to-light brown dolomitic limestone within the uppermost Maynardville Limestone, grading upward into cherty dolostone of the Copper Ridge Dolomite. Stromatolitic dolostone and vugs are abundant in the lower Copper Ridge Dolomite. The gamma-ray logs show broad deflections within the transition zone, which contrasts with the low gamma-ray activity of the upper Maynardville. The abundance of dolomite, stromatolites, and vugs similar to those in

Zone 6 all suggest that the lower Copper Ridge Dolomite in BCV was deposited in upper intertidal to supratidal environments.

3.0 CONTROLS ON SECONDARY POROSITY

Following the definitions of Choquerre and Pray (1970), primary porosity is considered to be that porosity present in the rock after final deposition and secondary porosity is any postdepositional porosity created within the rock. Petrographic analysis indicates occlusion of all primary porosity has occurred through cementation and that most, if not all, the porosity present in the Maynardville Limestone at this time is secondary or postdepositional in origin.

3.1 METHODS

To determine the factors that control the development of secondary porosity and permeability, several different types of data were analyzed: (1) inspection of available core, (2) evaluation of drilling logs, (3) analysis of geophysical log anomalies, and (4) petrographic analysis. A summary of these data is provided in Appendix B in which solution and alteration zones, water-producing zones, and geophysical anomalies are plotted with respect to down-hole depths below ground surface (bgs) in the Maynardville zones. The criteria used to identify zones of secondary porosity are discussed below.

3.1.1 Criteria for Identifying Porous and Permeable Units

3.1.1.1 Inspection of Core

Visual inspection of core with either a hand lens or binocular microscope was conducted on cores from Wells GW-130, GW-131, GW-134, GW-135, GW-137, GW-138, GW-722, GW-729, and GW-790. In addition to lithologic descriptions (Appendix A), the presence of vugs, cavities, solution enlarged fractures, nonaltered open fractures, faults, and breccia zones were noted and summarized in Appendix B.

3.1.1.2 Drilling Log Reports

For those wells not cored and for which only cuttings were obtained, drilling reports were important in defining the vuggy or solutionally altered intervals as well as water-producing zones. Voids and cavities encountered during drilling were noted by obvious drops of the drill string, whereas "ratty" or soft drilling are suggestive of vuggy strata and solution intervals. An increase in water production during drilling indicated the intersection of a water-producing zone.

3.1.1.3 Geophysical Anomalies

Temperature anomalies: Temperature logs record the temperature profile of standing water within the well, and deflections in the temperature log indicate waters of contrasting temperatures entering the borehole. Temperature logs were the first logs to be run down the borehole, being run slowly from top to bottom in order to minimize disruption and mixing of water within the borehole. Analyses of the temperature logs indicates an average gradient of 1°F/100 ft, which is consistent with temperature gradients measured elsewhere (Dreier and Toran, 1989) in the Oak Ridge area. Temperature deflections suggest water entering the borehole from different depths either along bedding planes, fractures, or faults.

Caliper anomalies: Disruption of bedding along faults, the presence of fractures, and cavities are identified on the caliper logs by an increase in borehole diameter.

Gamma-gamma density log anomalies: Density logs provide information on the rock density, porosity, and composition of formation fluids. This log is sensitive to secondary porosity and, in this report, decreases in density (leftward deflections) were interpreted as possible intervals of increased porosity.

Compensated neutron log (CNL) anomalies: The CNL indicates the amount of hydrogen present in the logged interval, primarily in the form of water when hydrocarbons are not present. Thus, a saturated rock with a high porosity will have a negative deflection on the CNL. The neutron log is calibrated (or compensated) for apparent limestone porosity,

therefore if the rock is indeed limestone, its porosity has a value near that shown on the log.

Sonic log anomalies: Sonic logs provide information on lithology and intergranular porosity. Anomalies on the sonic logs, not associated with shale units, suggest porous zones within the logged interval. Additionally, cycle skipping (sharp deflections) on the sonic log are indicative of fractures.

Long/short resistivity anomalies: Resistivity depends on salinity and continuity of formation waters, thus, provides information on porosity and permeability. Resistivity will be lower in water-filled vuggy units and higher in impermeable rock. Thus, a leftward deflection on the resistivity logs is interpreted as fluid invasion at the logged interval. Saline brine waters have been noted at depths > 500 ft throughout the Oak Ridge Reservation (Solomon and others, 1992), thus fluid resistivity generally decreases with depth in deeper wells.

Spontaneous potential (SP) anomalies: The SP logs can be used for determination of bed thickness, lithology, pore fluid salinity, and permeability. In this study, SP logs were used in conjunction with other geophysical logs to help delineate permeable strata within the Maynardville Limestone. Haase and King (1986) and Dreier and Toran (1989) have related SP deflections to fluid transport along fractures. Shales also cause negative SP deflections, therefore those negative SP anomalies not associated with shale are interpreted as possible areas of permeable strata or fluid-filled fractures. In this report, those SP anomalies shown in Appendix B relate to negative potentials which are not associated with shale.

3.1.1.4 Petrographic Analysis

Preliminary petrographic analysis of 28 thin sections from Wells GW-135, GW-137, and GW-138 were used to interpret the diagenetic history of the Maynardville Limestone. One-half of each thin section was stained for calcium carbonate and analyzed under a petrographic microscope. A complete synthesis of the diagenetic history and porosity development of the Maynardville Limestone will be provided in a follow-up report (Goldstrand and others, in prep.).

3.2 MAYNARDVILLE ZONES AND POROSITY DEVELOPMENT

Drilling data suggests that the majority of active karst features in BCV probably occur between 800 to 900 ft elevation, with tributary conduits at 900 to 1000 ft elevation (Shevenell and others 1993). In general, most of the active karst features intersected by wells in BCV occur above 720 ft elevation, although down-dip contaminant migration is occurring at elevations as low as 686 ft in GW-704 (Shevenell and others 1993). However, because of the regional dip of strata in this area, all zones of the Maynardville Limestone intersect elevations above which active karst features are recognized.

Core inspection and petrographic analysis provided the most important clues into the controls on secondary porosity in the Maynardville Limestone. The primary control on the development of solution porosity is dissolution of evaporite minerals, dedolomitization, carbonate grain size, and oxidation of iron sulfide minerals. Dissolution of gypsum nodules is responsible for the development of vuggy porosity within the Maynardville Limestone and Copper Ridge Dolomite. Dedolomitization (replacement of dolomite by calcite) is probably related to the dissolution of gypsum within the Maynardville Limestone and Copper Ridge Dolomite (Saunders and Toran, 1994), and is an important factor in the secondary porosity in the dolomitic parts of these formations. Carbonate mud appears to favor dissolution in several of the Maynardville zones. Similar results have been obtained in other studies (Rauch and White 1970; Dreiss 1984) and are considered related to the fact that smaller carbonate grain sizes provide a larger surface area for active dissolution by groundwater undersaturated with CaCO_3 . Locally, oxidation and dissolution of pyrite is also responsible for the development of secondary porosity.

Petrographic analysis and volumetric porosity data provided an estimate of the microporosity for the Maynardville zones with respect to depth (Fig. 3.1; Table 3.1). These limited data suggest that Zone 6 and the Copper Ridge Dolomite have the highest porosity, followed by Zone 5. Zones 4, 3, and 2 have approximately equal porosities (Fig. 3.1; Table 3.1).

Fig. 3.1: Estimated mean volumetric porosity from selected sample depths and zones in Wells GW-135 and GW-138.

Table 3.1: Estimated porosity (done petrographically and volumetrically) from selected sample depths and zones in Wells GW-135, GW-137, and GW-138. Petrographic porosities calculated from 300 points counted on a 20 x 15 mm grid.

WELL	DEPTH (BGS)	ZONE	POROSITY (%) petrographic	VOLUMETRIC porosity mean	POROSITY (%) standard deviation	WELL	DEPTH (BGS)	ZONE	POROSITY (%) petrographic	VOLUMETRIC porosity mean	POROSITY (%) standard deviation
GW-135	-634.5	Ccr		1.0	0.0	GW-138	-415	Ccr		1.3	1.1
	-638	Ccr		0.8	0.0		-425	Ccr		1.3	0.2
	-665	Ccr		1.3	0.4		-432.5	Ccr	15	6.2	1.6
	-697.5	6		0.3	0.1		-450	6		1.7	0.6
	-714	6		1.7	0.0		-462	6		4.7	0.9
	-731.5	6	1.6	1.4	0.7		-475	6		3.5	3.0
	-745	6	1.3	2.3	0.3		-483	6	4.3	4.3	1.2
	-755	6		0.4	0.2		-488	6		6.5	0.5
	-769	6	10.3	1.7	0.7		-505	6		7.2	2.5
	-775	6		0.3	0.1		-522	6		4.9	2.2
	-785	6		0.7	0.5		-526	6		0.6	0.4
	-795	6		0.6	0.2		-539	6	0	0.5	0.0
	-798	6		1.2	0.4		-560	5	0	0.4	0.0
	-808	5	0.3	0.7	0.1		-567	5	0.3	0.5	0.0
	-817.5	5	0	0.4	0.1		-575	5		0.3	0.1
	-825	5		0.4	0.1		-593	5		0.5	0.0
	-837.5	5	0	2.3	1.0		-605	4		0.2	0.0
	-845	5		0.6	0.1		-617.5	4		0.5	0.2
	-855	4		0.4	0.1		-626	4	0	0.6	0.1
	-863	4		0.3	0.1		-639	4		0.3	0.0
	-882.5	4	0	0.2	0.0		-658	4	0	0.6	0.3
	-895	4		0.4	0.1		-678	4	0	0.9	0.0
	-913	4		0.5	0.0		-685	4		0.5	0.1
	-921	4		0.5	0.1		-708.5	4	0	0.5	0.0
	-930	4		0.3	0.1		-722	3		0.2	0.0
	-940	4		0.4	0.2		-735	3	0	0.4	0.2
	-953	4	0	0.8	0.4		-755	3		0.3	0.1
	-963	4		0.3	0.1		-785	3	0	0.2	0.0
	-991.5	3		0.5	0.1		-792.5	3		0.8	0.4
	-1006	3	0	0.4	0.2		-805	2		0.3	0.0
	-1033	3		0.3	0.1		-835	2		0.3	0.1
	-1044	3	0	0.2	0.0		-849	2		1.0	0.6
	-1063	2		0.4	0.1		-860	2	3	0.5	0.0
	-1073	2		0.2	0.0		-885.5	2		0.3	0.0
	-1092	2		0.4	0.1		-895	2		0.5	0.2
	-1112	2		0.4	0.2		-903	2		0.3	0.1
	-1127.5	2		0.2	0.0		-915	2		0.4	0.1
	-1133	2	0	0.2	0.0		-935	2		0.4	0.1
	-1146	2		0.2	0.0		-945	2	1.3	1.2	0.5
	-1170	2		0.4	0.0		-954.5	2		2.3	1.4
	-1183	2		0.4	0.2		-960	2		1.1	0.5
	-1192	2		0.2	0.0		-967	2		0.6	0.2
	-1198	2	0.3	0.3	0.2		-981	2		0.4	0.0
	-1215	2		0.7	0.1	GW-137	-131.5	3	0		
	-1232	2		0.6	0.4		-218.5	2	3		

3.2.1 Lower Copper Ridge and Maynardville Zone 6

Vuggy and fenestral porosity are abundant in the lower Copper Ridge Dolomite and Zone 6 of the Maynardville Limestone down to a depth of 800 ft bgs (Appendix B). Lithologically, these units are similar, consisting mostly of stromatolitic dolostone and calcareous dolostone. The predominate cause for the secondary porosity in these units is the dissolution of gypsum nodules (leaving abundant vugs up to several cm long) and produce average vuggy porosities of up to 18 percent (Goldstrand and others, in prep.). Also of importance to the development of secondary porosity is dedolomitization. Selective dissolution of dolomite crystals (moldic porosity) has created abundant interconnected micropores (generally less than 0.5 mm in diameter) and produce an average matrix porosity of 2.1 percent (Table 3.1; Goldstrand and others, in prep.). The processes of gypsum dissolution and dedolomitization are related (Back and others 1983; Saunders and Toran, 1994; Bischoff and others, 1994) and are the major cause of porosity in these units (Goldstrand and Shevenell, 1994). Fenestral porosity has also developed due to dissolution of carbonate mud within the dolomite. The stromatolitic dolomites are coarse grained with intercalated carbonate mud which originally were trapped between the algal structures and filaments responsible for forming the stromatolites. Dissolution of the intervening carbonate mud produces small (several mm diameter), elongate vugs.

Geophysical anomalies, solution, and vuggy zones with water-producing intervals are abundant in the lower Copper Ridge Dolomite and upper part of the Maynardville Limestone (Appendix B). Caliper and density logs correlate with zones of increased porosity as a result of solution cavities and vugs. In combination with CNL, SP, and resistivity, these geophysical anomalies suggest possible water migration within these solution zones. However, it must be noted that not all geophysical anomalies correspond to known water-bearing intervals.

3.2.2 Zone 5

Secondary porosity in Zone 5 averages 0.8 percent and is slightly more pronounced than in Zones 4, 3, and 2 (Fig. 3.1). This zone consists generally of coarsely crystalline oolitic packstone and grainstone with interbeds of shale. Moldic porosity is present and developed by the dissolution of dolomite crystals that commonly form the core of ooids. Small open vugs do occur within Zone 5 along carbonate mudstone interbeds and thin fractures.

Caliper, SP, and CNL $\pm$ density and resistivity anomalies appear to be the more useful indicators of fluid within Zone 5. In general, water-producing intervals in this zone are associated with fractures and small cavities occurring at shallower depths.

3.2.3 Zone 4

Zone 4 has an average matrix porosity of 0.5 percent. Many of the lithologies present in Zones 6 are present in Zone 4 and dedolomitization is responsible for much of the porosity development in this zone. Also, vuggy porosity occurs mostly in stromatolitic limestones and is related to dissolution of carbonate mudstone interbeds.

In general, density, temperature, SP, and CNL anomalies are common in Zone 4, suggesting water transport through solution intervals. Often times, in intervals where water was noted during drilling, a single geophysical anomaly denotes the water producing interval, whereas other water-producing intervals showed no anomalies. For example, in GW-724, drilling logs note four water-producing intervals in Zone 4 between 139 and 180 ft bgs. Two had no geophysical anomalies associated with the water zones, one had a CNL anomaly (indicating saturated solution porosity) and one had a resistivity anomaly, also indicating water invasion within a solution interval.

3.2.4 Zone 3

Zone 3 has a mean porosity of 0.6 percent. Fenestral solution porosity is associated with stromatolitic and thrombolitic interbeds in which the intervening carbonate mud has dissolved. Also, water invasion along fractures appears to be important in this zone.

3.2.5 Zone 2

Another part of the Maynardville Limestone with a large number of solution cavities and vugs is Zone 2 in which vugs as deep as 1200 ft bgs have been noted (Appendix B; Shevenell and others 1993). However the average matrix porosity of this zone is 0.5 percent. Much of Zone 2 consists of thrombolitic limestone with dissolution concentrated in the intercalated carbonate mud (creating vugs) or along the wispy carbonate mud stringer (creating thin, elongate solution zones). Elongate solution zones also occur along the interface between shale stringers and carbonate lithologies, and are probably related to dissolution as groundwater moves along the shale-carbonate interface. Oxidation and dissolution of pyrite was observed in Zone 2, producing moldic porosity (<0.5 mm in diameter).

Although data are limited as to the extent of dissolution along the contact of the Nolichucky Shale and Maynardville Limestone, it is likely that enhanced dissolution does occur along this contact at shallow depths (<100 ft bgs). One of the shallow (83 ft), exit pathways wells (GW-735) near Scarboro intersected a two foot-cavity at this contact (Shevenell and others 1992).

Caliper, density, and SP geophysical anomalies appear to give the best results for interpreting water-producing intervals within Zone 2 (Appendix B). Several geophysical anomalies are common to this zone, suggesting permeable rock with water migration, and include: caliper-density $\pm$ resistivity and temperature, and caliper-CNL $\pm$ resistivity and temperature. In several wells (e.g., GW-130 and GW-724) water invasion along fractures and solutionally enlarged fractures are known from the drilling logs to account for these geophysical

anomalies.

3.2.6 Fractures, Faults, and Stylolites

Dissolution along fractures and faults is an important factor in groundwater movement in the Maynardville Limestone. A detailed fracture study is beyond the scope of this report and is covered in other reports (i.e., Sledz and Huff 1981; Ketelle and Huff 1984; Rothschild and others 1984; Hatcher and others 1992). Numerous fractures are present in all Maynardville zones and interpreted from the geophysical logs by increases in the caliper logs, sharp changes in borehole water temperature and resistivity, and sonic log cycle skips. In general, fractures aligned parallel to strike and parallel to bedding planes appear to be more important in transmitting groundwater, although fractures aligned perpendicular to bedding planes are also important (Hatcher and others 1992). Solution-enlarged fractures are generally thin (< 2 mm) and elongate. Vugs and small cavities are present where solution fractures intersect carbonate mudstone lithologies, indicating that the fractures provide a pathway for CaCO_3 undersaturated waters.

Faults also provide a zone of preferred groundwater flow paths and therefore can enhance dissolution of carbonate lithologies within BCV. For example, Well GW-790 intersected three, small-displacement, thrust faults at depths between 180 and 212 ft bgs (Fig. 3.2). These thrust faults duplicate 10-to-19 foot sections of the lower part of Zone 5. Cavities are abundant in this faulted section and a large cavity at 198 to 211 ft bgs appears to have developed above the lower thrust.

Cavities in GW-790 are connected with cavities intersected in Well GW-728, approximately 95 ft to the north. Grout was introduced into two thick solution intervals (106 to 137 ft and 163 to 171 ft bgs) in GW-728 in an attempt to fill the cavity systems during drilling operations. Grout was observed during the coring of GW-790 in the cavities at approximately 120 to 140 ft and 198 to 211 ft bgs. Possible transport routes of the grout from GW-728 to GW-790 are shown in Figure 3.3, suggesting that horizontal flow across

Fig. 3.2: Small displacement thrust faults intersected in Well GW-790. Lithologic units that are tectonically repeated are; A- intraformational breccia, A'- oolitic limestone, A''- limestone, B- oolitic limestone, C- shale, and D-stromatolitic limestone. The upper fault appears to have moved along the upper surface of unit A. The upper plate of the middle thrust has repeated section of units A-D. Units A' and A'' are that have now been juxtaposed along the thrust faults. The upper plate of the lower missing, and may have been removed during faulting or are a result of lateral facies changes thrust contains units C and D with units A-B tectonically removed. The lower thrust plane was not observed and probably occurs within the cavity present between 201 and 212.5 ft.

Fig. 3.3: Possible grout pathways from cavities in Wells GW-728 to cavities in GW-790.

zones is important in this area but a component of down-dip flow may also be active.

Stylolites are abundant throughout the Maynardville Limestone as a result of pressure solution in which insoluble materials, commonly clay, is concentrated along an irregular and interpenetrating surface. Core and petrographic analysis indicate that stylolites are not a preferred zone of groundwater migration and secondary porosity is rare along stylolite surfaces. However, minor pyrite has been observed along some stylolitic surfaces, which could lead to oxidation and formation of vugs. Although oxidized pyrite is present in Zone 2, it is dispersed throughout the thrombolitic limestones and is not associated with the stylolites. Oxidized pyrite has not yet been observed within stylolites.

In some well-and-cuttings logs, the wispy carbonate mudstone and shale stringers within the thrombolitic units have been referred to as stylolitic. However, diagenetic alteration differs significantly between thrombolitic facies and stylolites and therefore should not be confused. Stylolites commonly occur as single, black, interpenetrating surfaces of clay; whereas carbonate mudstone and shale within thrombolitic limestone occur as multiple, wispy, or anastomosing stringers.

4.0 CONCLUSIONS

In developing a model for strata-bound porosity within the Maynardville Limestone of BCV, the depositional and diagenetic history has been synthesized in this report. The major stratigraphic, lithologic, and diagenetic factors that affect solution porosity and permeability and, ultimately groundwater transport, within BCV are listed below.

- (1) The Maynardville Limestone overlies the Nolichucky Shale and formed in an upward shallowing subtidal to intertidal carbonate platform environment during the Cambrian. The Maynardville has been divided into six informal zones (numbered from bottom to top, 2 through 7) based on gamma-ray logs by Shevenell and others (1992). In the upper part of the Maynardville Limestone, Zones 6 and 7 are lithologically and diagenetically the same

and, therefore, have been combined into Zone 6 for the purpose of this report. The Maynardville Limestone grades upward into the Copper Ridge Dolomite, of which only the lowermost part of this formation was studied for this report.

(2) Controls on secondary porosity (in order of importance) are dissolution of gypsum, dedolomitization, carbonate grain-size, and oxidation of pyrite. Dissolution of gypsum nodules have created abundant vuggy porosity (with vugs up to several centimeters in diameter) within the lower Copper Ridge Dolomite and Zone 6. An effect of the dissolution of gypsum is dedolomitization (Back and others 1983; Saunders and Toran, 1994; Bischoff and others, 1994) in which dolomite is dissolved. Dedolomitization has created moldic porosity (<0.5 mm diameter) and is abundant in the lower Copper Ridge Dolomite and Zone 6 and is present to a lesser extent throughout the other Maynardville zones. Fine grain carbonate, such as lime muds, are the more likely to be affected by secondary solution due to the increased surface area of the mud particles. Thrombolitic and stromatolitic limestone and dolostone lithologies of Zones 2 and 6 are most likely to be affected by dissolution because carbonate mud originally trapped between algal structures are preferentially dissolved, leaving vugs and voids between coarser crystalline limestone and dolostone. Oxidation of dispersed pyrite crystals is locally important in producing moldic porosity within Zone 2.

(3) Zone 2 of the Maynardville Limestone overlies the Nolichucky Shale and consists dominantly of thrombolitic limestone. Of all the Maynardville zones, Zone 2 has the most rapid changes in thickness, pinching out in the region of the Burial Grounds Waste Management area. Solution zones and vugs are common in Zone 2 and related to dissolution occurring along interbeds of carbonate mudstone or along the interface of shale strings, dedolomitization, and localized oxidation of pyrite. Strata-bound permeability in Zone 2 would be most likely in the thicker and relatively homogeneous sections of thrombolitic limestone which are present to the east and west of the Burial Grounds, and may provide groundwater pathways along geologic strike. Zone 2 thins in the area of the Burial Grounds and thrombolitic strata-bound water zones would be less important than other permeable strata in the Maynardville. However, in this area, Well GW-730 intersects a thick section of

thrombolitic limestone of Zone 2, and could develop solution conduits for groundwater flow to the south beneath Chestnut Ridge. The average matrix porosity in Zone 2 is 0.5 percent, with porosity generally decreasing with depth.

(4) Facies and thickness changes in Zone 3 are also relatively rapid, thinning in the area of the Burial Grounds. Solution intervals are generally associated with the interbedded thrombolitic limestones. These interbedded thrombolites developed locally between more laterally extensive subtidal oncolitic and oolitic shoals and, therefore, strata-bound permeability will be less extensive than in the more homogeneous thrombolitic facies of Zone 2.

(5) The thickness of Zone 4 does not change as much as Zones 2 and 3, but also thins slightly near the Burial Grounds. This zone consists mostly of coarsely crystalline peloidal and oolitic limestone, thus secondary solution porosity is moderate. When solution porosity occurs, it is related to dissolution of intervening carbonate mudstone interbedded within stromatolitic and thrombolitic limestones. These more porous units represent localized algal mounds within extensive (and less porous) peloidal and oolitic shoals and strata-bound permeability will be spatially restricted.

(6) Zone 5 consists of laterally extensive oolitic limestone and interbedded shale and carbonate mudstone. Most of the large water-producing or cavernous intervals in Zone 5 are associated with fractures or dissolution along faults. Microporosity averages 0.8 percent in this zone, having developed by dissolution of dolomite crystals that core many ooids.

(7) Zone 6 of the Maynardville Limestone and the lower Copper Ridge Dolomite consist of similar lithologies; stromatolitic dolostone and dolomitic limestone. Vugs and cavities (formed by dissolution of evaporite nodules) are abundant in these units, and thus have a higher porosity than other Maynardville zones. Matrix porosities average 3.6 percent between 400 and 550 ft bgs, decreasing to an average of 1.0 percent between 600 and 800 ft bgs. These permeable units occur throughout BCV at the base of Chestnut Ridge and much

of the bedrock groundwater is probably transported through these zones.

(8) Fractures and faults are important pathways for groundwater flow. Of the three fracture orientations prominent in this area, bedding-parallel and strike-parallel fracture orientations are more permeable than fractures orientated perpendicular to strike (Hatcher and others 1992). Dissolution along fault planes in the Burial Grounds area may provide conduits for groundwater flow to deeper levels. A cavities intersected during the drilling of GW-790 is present along a thrust fault and connected to cavities intersected in GW-728.

(9) In general, there is a trend for secondary porosity to decrease with depth. However, porosity with respect to depth is highly variable and moldic, vuggy, and fracture porosities are present to depths of at least 1200 ft bgs. Along Bear Creek and at the base of Chestnut Ridge, large solution cavities are common to depths of 100 ft bgs, but do occur to depths of 200 ft bgs.

In summary, the most probable groundwater and contaminant pathways within the Maynardville Limestone of BCV are any of the zones within 200 ft of the ground surface near Bear Creek and the base of Chestnut Ridge, based on the large number of cavities intersected by wells drilled throughout the valley. The next most important pathway for groundwater flow is Zone 6, with its abundance of vugs and relatively high matrix porosities. Although porosities decrease with depth, Zone 6 still contains vugs and has matrix porosities approaching 1 percent to depths of 800 ft bgs. Zone 5 is the next most important transmissive unit within the Maynardville Limestone. Lithologies in Zones 4 and 3 with high probability of being permeable are spatially restricted and unlikely to transmit large volumes of groundwater. Although Zone 2 has higher porosities at shallower depths, it still has the ability to transmit groundwater to depths of 1200 ft bgs. Because of the variable thickness of Zone 2 within BCV, the direction and velocity of groundwater in the area of the Burial Ground may be altered and strike-parallel flow is unlikely in this area.

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APPENDIX A

Gamma-ray and lithologic descriptions of wells in Bear Creek Valley used in this report. Refer to Table 1.1 for specific data used to construct lithologic logs for each well.

Description abbreviations:

(c) =	coarse crystal or grain size
congl =	conglomerate
dk =	dark
(f) =	fine crystal or grain size
ft =	feet
lt =	light
(m) =	medium crystal or grain size
med =	medium
v =	very
(vf) =	very fine crystal or grain size

KEY

	ALLUVIUM:
	CALCAREOUS DOLOMITE:
	CALCAREOUS SHALE:
	CAVITY:
	DOLOSTONE:
	DOLOMITIC LIMESTONE:
	DOLOMITIC MUDSTONE:
	FAULT:
	INTRAFORMATIONAL BRECCIA:
	LIMESTONE:
	LIMESTONE AND SHALE INTERBEDS:
	LIMESTONE WITH MICRITE INTERBEDS:
	LIMESTONE WITH SHALE INTERBEDS:
	LIMESTONE WITH SHALE STRINGERS:
	OOLITIC LIMESTONE:
	SHALE:
	SHALE AND LIMESTONE INTERBEDS:
	SHALE WITH LIMESTONE INTERBEDS:
	STROMATOLITIC:
	THROMBOLITIC LIMESTONE:

GAMMA RAY

DEPTH
(FT)

GW-130

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

0

NO CORE DATA

-50

OOLITIC LIMESTONE: oosparite,
shell fragments

LIMESTONE: Lt gray
sparite, stylolitic

OOLITIC LIMESTONE: Lt gray,
oncolitic, stylolitic

LIMESTONE: Lt gray sparite with
interbeds of wispy slightly
dolomitic micrite (dk gray),
stylolitic, oncolites present,
oolitic near top of unit

-100

GAMMA RAY

DEPTH
(FT)

GW-130

0 30 60 90 120 150 180 210 240

-100

LITHOLOGY

DESCRIPTIONS

LIMESTONE: Lt gray sparite with interbeds of wispy slightly dolomitic micrite (dk gray), stylolitic and oncolitic

OOLITIC LIMESTONE: Lt gray, stylolitic, limestone interbeds

LIMESTONE WITH SHALE STRINGERS: Lt gray (f) sparite with wispy slightly dolomitic micrite

OOLITIC LIMESTONE: Oosparite with some pisolitic sparite beds, stylolitic; Cavity at 143 Ft; solution zone at 154 Ft

-150

LIMESTONE WITH SHALE STRINGERS: Lt gray sparite with wispy shale at top and dolomitic micrite at base

OOLITIC LIMESTONE: Oosparite with abundant pisolites, oncolites, and shale stringers, stylolitic

-200

GAMMA RAY

DEPTH
(FT)

GW-130

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-200

-250

-300

THROMBOLITIC LIMESTONE: Lt gray,
(vf) sparite, wispy shale
stringers common

LIMESTONE WITH SHALE STRINGERS:
Thrombolitic, (vf) sparite

THROMBOLITIC LIMESTONE: Lt gray,
(vf) sparite, wispy shale
stringers common

SOLUTION FRACTURE AT 261 FT

IRON STAINING AT 277 FT

GAMMA RAY

DEPTH
(FT)

GW-130

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-300

-350

-400

THROMBOLITIC LIMESTONE: Lt gray
(vf) sparite with wispy shale
stringers

SHALE: green, few limestone
interbeds; maybe faulted along
this shale zone

THROMBOLITIC LIMESTONE: Mottled
lt and dk gray (vf) sparite and
shale stringers

THROMBOLITIC LIMESTONE: Mottled
lt and dk gray (vf) sparite and
dolomitic micrite, interbeds of
oolites and oncolites, interbeds
of dk green shale with matrix-
supported limestone clasts

GAMMA RAY

DEPTH
(FT)

GW-130

0 30 60 90 120 150 180 210 240

-400

-450

-500

LITHOLOGY

DESCRIPTIONS

	THROMBOLITIC LIMESTONE: Mottled lt and dk gray (vf) sparite and dolomitic micrite and dk discontinuous shale stringers
	LIMESTONE AND SHALE INTERBEDS: Well bedded lt gray micrite and green shale
	LIMESTONE: (F) sparite with thin shale interbeds
	LIMESTONE AND SHALE INTERBEDS: Well bedded (F) sparite and shale, limestone beds commonly convoluted and laminated, some limestone rip-up beds
	SHALE: Dk green, grades upward into interbedded shale and limestone and limestone congl. beds
	SHALE: Dk green, black, and purple, interbeds of sparite, oosparite, and limestone congl.
	SHALE: Purple with thin limestone and limestone congl. interbeds, fossil fragments supported in shale matrix

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-400

-450

-500

	DOLOSTONE: Tan to lt gray, well laminated, algal, nodular and chicken-wire textures with minor back shale interbeds, few stylolites and rip-up beds, few open vugs
	DOLOSTONE: Tan to dk gray, several silicified stromatolite heads, few thin shale interbeds, open vugs assoc. with stromatolites
	DOLOSTONE: Dk to lt gray, well laminated, rip-up bed at base with chalcedony-filled vugs, few open vugs and stylolites, several shale interbeds
	DOLOSTONE: Lt to med. gray, wavy (algal) laminations, few small open vugs, at base stromatolite overlain by algal rip-up bed
	DOLOSTONE: Dk gray, well laminated, stylolitic, few open vugs with calcite rims, interbeds of thin shale and dolomitic mudstone, oolitic dolostone at base
	STROMATOLITIC: Dolostone, lt to dk gray, cryptalgalaminated, open vugs assoc. with stromatolites. some gypsum- and pyrite-filled vugs, stylolitic

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-500

DOLOSTONE: Med. gray, well laminated with several dk green shale interbeds, some cross-laminations and bioturbation, several large open vugs with calcite rims

DOLOSTONE: Lt gray to tan, wavy (algal) laminations, small open to gypsum-filled vugs

DOLOSTONE: v Lt gray to tan, massive to faintly laminated, (vf) crystalline, few thin shale interbeds, gypsum common along stylolites and in fractures, some large gypsum-filled vugs

-550

BRECCIA/CLAY AND GYPSUM

DOLOSTONE: Mottled lt gray, pink, and dk gray (algal), abundant stylolites and gypsum-filled vugs

-600

GAMMA RAY

DEPTH

GW-131

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-600

-650

-700

	DOLOSTONE: v. lt gray-pink and dk gray, well laminated dolomite and calcareous dolomite (algal), several algal rip-up beds, few stylolites, small open vugs with gypsum and pyrite crystals at base
	CALCAREOUS DOLOSTONE: Lt gray, algal and stromatolitic laminations infilled with dk gray dolomite
	DOLOMITIC LIMESTONE: Lt gray, laminated, abundant stylolites
	CALCAREOUS DOLOSTONE: Lt gray, algal and stromatolitic laminations infilled with dk gray dolomite
	DOLOSTONE: Lt gray to lt pink, cryptalgalaminated (?)
	DOLOMITIC LIMESTONE: Lt gray to lt pink sparite and micrite, white spotty sparry calcite throughout, cryptalgalaminated (?)
	LIMESTONE: Mottle gray and lt pink, sparite, white sparry bird's-eye structures, stylolitic, algal

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-700

-750

-800

LIMESTONE: with interbeds of dolomitic limestone, lt gray, (f) sparite, stylolitic, few large open vugs with calcite rims

LIMESTONE: pelsparite, med. gray, stylolitic, abundant small open vugs at top

CALCAREOUS SHALE: Dk green to gray shale and micrite with several thick interbeds of pelsparite and oncolites, calcite-filled veins present

LIMESTONE: Med. gray pelsparite with fossil fragments, stylolitic

CALCAREOUS SHALE: Dk green to gray shale and lt gray micrite with interbeds of pelsparite and possible oosparite, thin intraclastic rip-up beds

LIMESTONE: Med. gray pelsparite with fossil fragments, stylolitic, few small open vugs

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

-800

-850

-900

LITHOLOGY

DESCRIPTIONS

LIMESTONE: Med. gray sparite, interbeds of small oncolites, abundant calcite-filled and few open vugs, few algal build-ups within oncolitic zones, more algal structures and rare shell fragments near top

LIMESTONE: Lt gray sparite with interbeds of v lt gray micrite, several thick beds of small oncolites in sparry cement, possible stromatolitic laminations, dolomitic micrite near top

OOLITIC LIMESTONE: Lt gray, few lt gray micrite interbeds and stylolitic black shale

LIMESTONE: Med. gray pelsparite

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

-900

LITHOLOGY

DESCRIPTIONS

LIMESTONE: Lt gray pelsparite and small oncolitic sparite with abundant interbeds of dk gray dolomitic limestone, micrite interbeds at top

LIMESTONE: Med gray pelsparite with abundant interbeds of small oncolites, oolites, micrite, and stromatolites

THROMBOLITIC LIMESTONE: Thin bedded with med gray micrite stringers

OOLITIC LIMESTONE: oosparite and oncolitic sparite, stylolitic, thin black shale stringers, few open vugs

-950

THROMBOLITIC LIMESTONE: Thin bedded with med gray micrite stringers

OOLITIC LIMESTONE: oosparite and oncolitic (well rounded) in sparry matrix, thin black shale stringers, few interbeds of algal laminations, pyritic

THROMBOLITIC LIMESTONE: Lt gray with abundant micrite and few discontinuous shale stringers, pyritic

OOLITIC LIMESTONE: oosparite and oncolitic (well rounded) in sparry matrix, thin black shale stringers

-1000

GAMMA RAY

DEPTH
(FT)

GW-131

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-1000

-1050

-1100

	OOLITIC LIMESTONE: oosparite
	THROMBOLITIC LIMESTONE: Mottled lt gray with abundant dk green to black shale stringers, few pisolitic and possible stromatolitic interbeds, rare solution fractures
	THROMBOLITIC LIMESTONE: Lt gray (f) sparite with abundant thin black shale stringers, several thin interbeds of pelsparite and biosparite, 2 convoluted shale beds topped by micrite and rip-ups
	LIMESTONE WITH SHALE STRINGERS: Pisolitic sparite and black shale, thrombolitic interbeds
	THROMBOLITIC LIMESTONE: Lt gray (f) sparite with abundant thin black to dk green shale stringers, several thin interbeds of pelsparite and biosparite

GAMMA RAY

DEPTH

GW-135

(FT)

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-600

-650

-700

	DOLOSTONE: Dark to lt gray, well laminated, (f) crystalline, thinly laminated shale present, small gypsum-filled vugs throughout
	DOLOSTONE: Lt gray, massive, stylolitic, (f) crystalline
	DOLOSTONE: Dk gray to lt pink, well laminated, algal, gypsum-filled vugs common
	DOLOSTONE: Lt to med. gray with thick inter-laminated shale, intraclastic
	DOLOSTONE: Lt gray, well laminated with few black shale at base, gypsum-filled vugs, several oolitic beds near top
	STROMATOLITIC: Lt gray dolostone, (c) crystalline, calcite-filled vugs, laminated
	DOLOMITIC LIMESTONE: Lt gray limestone, dk gray dolostone laminations
	DOLOSTONE: Mottled lt and dk gray, algal, stylolitic, calcite veins
	DOLOSTONE: Lt gray, laminated, algal, rip-ups of algal laminae, bird's-eye structures
	DOLOMITIC LIMESTONE: Lt gray limestone, dk gray dolostone blebs, stylolitic

GAMMA RAY

DEPTH

GW-135

(FT)

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-700

-750

-800

	DOLOMITIC LIMESTONE: Mottled lt gray and dk gray, stylolitic
	DOLOSTONE: Mottled lt and dk gray, massive, stylolitic
	DOLOSTONE: Lt to dk gray, Finely laminated, algal, calcite-filled vugs and veins
	DOLOSTONE: Dk to med. gray, mottled, small open vugs throughout
	DOLOMITIC LIMESTONE: Mottled dk and lt gray, algal
	STROMATOLITIC: Dolostone, med. to dk gray, (c) crystalline, small open vugs
	STROMATOLITIC: Limestone, mottled lt and dk gray, dolomitic spots, pelaspargite between algal laminae, large open vugs common at base
	OOOLITIC LIMESTONE: Lt gray, oncolitic, stylolitic, small open vugs abundant

GAMMA RAY

DEPTH
(FT)

GW-135

0 20 40 60 80 100 120 140 160

-800

LITHOLOGY

DESCRIPTIONS

OOLITIC LIMESTONE: Lt gray, oncolites common, stylolitic, dk gray wispy micritic lamination throughout, dolomitic micrite at top

OOLITIC LIMESTONE: Lt gray, few oncolites, stylolitic, many small open vugs

OOLITIC LIMESTONE: Lt gray, abundant oncolites and stylolites, thin interbeds of dk green shale

-850

OOLITIC LIMESTONE: Med. gray, small oncolites, stylolitic, several interbeds of green shale

OOLITIC LIMESTONE: Lt to med. gray, interbed of green calcareous shale

LIMESTONE: Med. gray, oncolitic, oolitic, peloidal, fossil fragments common, thin calcareous shale stringers present, stylolitic

LIMESTONE: Lt to dk gray, pelsparite, stylolitic

-900

GAMMA RAY

DEPTH
(FT)

GW-135

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-900

LIMESTONE: Lt gray, pelsparite,
oncolitic, algal structuresOOLITIC LIMESTONE: Lt gray with
interbedded pelsparite and
stromatolites, styloliticTHROMBOLITIC LIMESTONE: mottled
lt gray with shale stringers,
pelsparite and oolitic interbeds,
styloliticOOLITIC LIMESTONE: Dk gray,
stylolitic, large open vugsTHROMBOLITIC LIMESTONE: Dk gray,
mottled, abundant oolitic
interbeds and stylolites

OOLITIC LIMESTONE: Stylolitic

-950

LIMESTONE: Med. gray, pelsparite,
open vugs, stylolitic

DOLOMITIC LIMESTONE: Dk gray

THROMBOLITIC LIMESTONE: Mottled
dk and med gray, abundant micrite
and dolomitic limestone stringers,
stylolitic, oolitic at base,
petroliferousOOLITIC LIMESTONE: with few
dolomitic limestone stringers
throughoutTHROMBOLITIC LIMESTONE: Mottled
lt and dk gray, slightly dolomitic

-1000

GAMMA RAY

DEPTH
(FT)

GW-135

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-1000

	<p>OOLITIC LIMESTONE: Lt gray, oosparite with dk gray micritic stringers, few stylolites</p>
	<p>THROMBOLITIC LIMESTONE: Mottled lt and dk gray, oncolitic at top</p>
	<p>OOLITIC LIMESTONE: massive</p>
	<p>THROMBOLITIC LIMESTONE: Lt gray, oolitic and oncolitic interbeds, wispy dolomitic micrite interbeds</p>
	<p>OOLITIC LIMESTONE: Lt gray, also oncolities and fossil fragments common</p>
	<p>LIMESTONE: Mottled lt gray limestone and dk gray micrite</p>
	<p>THROMBOLITIC LIMESTONE: Lt gray, micritic stringers increase upward, gradational with overlying unit</p>

-1050

-1100

GAMMA RAY

DEPTH
(FT)

GW-135

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-1100

THROMBOLITIC LIMESTONE: Lt gray,
micrite stringers, massive

OOLITIC LIMESTONE: Interbedded
within thrombolitic limestone

THROMBOLITIC LIMESTONE: Lt gray,
massive, with dk green micrite
stringers common, rare beds of
oncolites and fossil fragments
rare pink calcite-filled vugs

-1150

THROMBOLITIC LIMESTONE: Mottled
lt and dk gray, micritic stringers,
pink calcite filled-vugs present

-1200

THROMBOLITIC LIMESTONE: Mottled
lt and dk gray, micrite and rare
shale stringers

GAMMA RAY

DEPTH
(FT)

GW-135

0 20 40 60 80 100 120 140 160

LITHOLOGY

DESCRIPTIONS

-1200

-1250

-1300

	THROMBOLITIC LIMESTONE: Mottled lt and dk gray, micrite stringers, oolitic at base
	LIMESTONE AND SHALE INTERBEDS: Limestone- wavy and nodular with loading at base of beds; shale- dk green, laminated and low angle cross-laminations; matrix supported limestone congl. beds present
	THROMBOLITIC LIMESTONE: Lt gray with abundant dk green and wispy shale stringers
	SHALE AND LIMESTONE INTERBEDS: Shale- dk green, laminated; limestone- undulatory thin (1 cm) beds, oolitic and limestone congl. beds, fossil fragments, some bioturbation

GAMMA RAY

DEPTH
(FT)

GW-137

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

GAMMA RAY

DEPTH
(FT)

GW-137

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

0

-50

-100

NO CORE

THROMBOLITIC LIMESTONE: Med gray with abundant wispy dk micrite stringers, oncolitic at top

LIMESTONE: Med gray sparite, oncolitic, wispy shale interbeds, one oosparite bed at top, solution zone at 55 ft, bedding vertical (folded)

LIMESTONE AND SHALE INTERBEDS: Limestone- lt gray; shale- dk gray, folded and brecciated

LIMESTONE: lt gray with wispy interbeds of dk gray micrite, folded and iron stained

LIMESTONE: Lt gray, algal with interbeds of black shale, thrombolitic interbeds

GAMMA RAY

DEPTH
(FT)

GW-137

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-100

LIMESTONE: Lt gray, algal with interbeds of dolomitic micrite (dk gray), limestone and algal rip-ups, thrombolitic interbeds

THROMBOLITIC LIMESTONE: Mottled lt and dk gray, few solution zones

LIMESTONE: Lt gray, algal with interbeds of dolomitic micrite (dk gray), limestone and algal rip-ups, thrombolitic interbeds

THROMBOLITIC LIMESTONE: Mottled lt and dk gray, few solution zones

LIMESTONE: Lt gray, massive, possible algal, stylolitic, few oncolitic beds

-150

THROMBOLITIC LIMESTONE: Mottled lt and dk gray, stromatolitic beds overlie thrombolites, several thin dk green shale interbeds and stringers, few stylolites

THROMBOLITIC LIMESTONE: Mottled lt limestone and dk gray dolomitic limestone, several dk green shale interbeds, solution cavities and open vugs

LIMESTONE: v lt gray, massive, possible algal, very abundant solution cavities and vugs, stylolitic

-200

GAMMA RAY

DEPTH
(FT)

GW-137

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-200

SHALE: green with thin limestone rip-ups at top

LIMESTONE: Lt gray (vf) sparite, thrombolitic on base, overlain by laminated algal mats and stromatolites, abundant solution cavities and vugs, stylolitic

LIMESTONE: Lt gray, massive sparite with interbeds of dolomitic micrite, algal, stylolitic, biosparite and wispy dolomitic micrite and abundant solution cavities near top

SHALE: purple, grades upward into interbedded shale and thin bedded limestone

LIMESTONE WITH SHALE INTERBEDS: Shale- dk green; limestone- Lt gray, well bedded (vf) sparite, one thick oospar interbed

-250

SHALE WITH LIMESTONE INTERBEDS: Shale- dk green; limestone- thin to thick beds of laminated sparite, biosparite, oncolitic and thin beds of limestone rip-ups, one stromatolite bed overlain by thrombolitic limestone

LIMESTONE WITH SHALE INTERBEDS: Lt gray, wavy to nodular bedding, beds of oosparite and oncolites

SHALE: Dk green

LIMESTONE WITH SHALE INTERBEDS: Limestone- Lt gray, wavy and nodular beds with thin shale interbeds

OOLITIC LIMESTONE: Lt gray oosparite at base grade upwards into overlying unit

SHALE AND LIMESTONE INTERBEDS: Well bedded, thin interbeds of green shale and Lt gray (F) sparite, wavy and nodular limestone beds

-300

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-400

-450

-500

	DOLOSTONE: lt to med gray, laminated, few black shale interbeds, few large gypsum-filled vugs
	STROMATOLITIC: Calcareous dolostone, lt to med gray, abundant open vugs
	DOLOSTONE: tan, slightly calcareous, well laminated, rare rip-up beds
	STROMATOLITIC: Dolostone, dk gray, open vugs, calcite-filled birds-eyes
	CALCAREOUS DOLOMITE: Tan, massive with fine laminations at top
	STROMATOLITIC: Dolostone, lt gray, (c) crystalline, calcite birds-eye structures, laminated, v abundant open and connected vugs

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-500

-550

-600

STROMATOLITIC: Dolostone, lt gray,
open vugs DOLOSTONE: med to dk gray, finely
laminated, oncolitic LIMESTONE: dk gray sparite, mottled,
stylolitic, calcite-filled birds-
eye structures, petroliferous STROMATOLITIC: interbedded with
dk gray dolomitic limestone OOLITIC LIMESTONE: oosparite with
oncolites and biosparite, stylolitic STROMATOLITIC: lt gray, oosparite
infilling

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-600

-650

-700

LIMESTONE: lt gray, interbedded oncolites, biosparite, and stromatolitic limestone with birds-eye structures, rare gypsum-filled vugs

STROMATOLITIC: lt gray limestone, stylolitic

DOLOMITIC LIMESTONE: dk gray, interbeds of oncolites and stromatolitic sparite

STROMATOLITIC: lt to dk gray, birds-eye structures near top, dolomitic near base, stylolitic

OOOLITIC LIMESTONE: lt gray oosparite, abundant interbeds of finger-shaped stromatolites throughout

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-700

-750

-800

OOLITIC LIMESTONE: oosparite with
interbeds of stromatolites

LIMESTONE WITH MICRITE INTERBEDS:
interbeds of oncolitic sparite
and dolomitic micrite, few
stylolites, rare shale stringers

LIMESTONE WITH SHALE STRINGERS:
mostly oncolitic, some oosparite
and stromatolitic beds

LIMESTONE: limestone congl. within
a shale or sparry matrix, oolitic,
several thrombolitic interbeds

THROMBOLITIC LIMESTONE: lt gray,
with interbeds of dk gray dolomitic
micrite near top and black shale
stringers near the bottom, few
interbeds of limestone congl.
supported in a shale matrix

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-800

-850

-900

THROMBOLITIC LIMESTONE: clotty texture, rare oospirite and small oncolites, rare interbeds of dolomitic limestone, upwards more wispy dolomitic and shale stringers, bioturbated

THROMBOLITIC LIMESTONE: lt gray with wispy shale stringers, several pink calcite or black shale and limestone brecciated veins

THROMBOLITIC LIMESTONE: with several beds of dk gray dolomitic limestone, bioturbated

GAMMA RAY

DEPTH

GW138

(FT)

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-900

THROMBOLITIC LIMESTONE: with abundant wispy shale stringers, some bioturbation, rare interbeds of oosparite

STROMATOLITIC: sparite, lt gray to tan, interbeds of thrombolites upwards, stylolitic, open vugs

OOLITIC LIMESTONE: oosparite with abundant biosparite, several solution zones

SHALE: dk green, grades upward into well interbedded lt gray (vf) sparite and shale

THROMBOLITIC LIMESTONE: few interbeds oncolitic sparite, some bioturbation, one calcareous shale bed with limestone congl. base overlain by thrombolites

THROMBOLITIC LIMESTONE: abundant bioturbated dk green shale at base, grades upward into interbeds of thrombolites and limestone congl. with clasts of pelsparite and small oncolites

THROMBOLITIC LIMESTONE: lt gray sparite with wispy shale and abundant micrite

OOLITIC LIMESTONE: with interbeds of lt gray bio-pelsparite and dk gray micrite, load structures, bioturbated, wispy shale stringers

LIMESTONE WITH SHALE INTERBEDS: wavy beds lt gray (f) sparite, shale- dk green, well laminated, loading and pseudonodules of limestone, 60-70% limestone, 30-40% shale

-950

-1000

GAMMA RAY

DEPTH
(FT)

GW138

0 30 60 90 120 150 180 210 240

LITHOLOGY

DESCRIPTIONS

-1000

-1050

-1100

	<p>LIMESTONE AND SHALE INTERBEDS: wavy beds of lt gray (f) sparite and dk green shale, well laminated, loading and pseudonodules, 50-60% limestone, 40-50% shale</p>
	<p>SHALE: dk green to dk brown, several interbeds of limestone congl. and thin bedded limestone, limestone clasts supported in shale matrix throughout</p>
	<p>SHALE AND LIMESTONE INTERBEDS: shale- dk green; limestone- gray, pelsparite, sharp bases, graded, cross-laminated</p>

GAMMA RAY

DEPTH
(FT)

GW703

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM:

DOLOSTONE: Lt gray, banded, possibly stromatolitic, (f) crystalline

DOLOSTONE: Med gray, (m-c) crystalline, minor staining and vugs. Water producing interval at 47.5 ft

-50

DOLOSTONE: Med gray, (m) crystalline, minor staining, mottled at base

-100

DOLOSTONE: Med to dk gray, (m-c) crystalline, minor interbeds of micrite in basal 8 ft, small vugs at top

GAMMA RAY

DEPTH
(FT)

GW703

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

DOLOSTONE: Med to dk gray, (m-c)
crystalline, iron stained and vuggy

DOLOMITIC LIMESTONE: Med to dk gray, (f-m)
crystalline, minor silica veinlets and
stylolites

OOITIC LIMESTONE: Med gray

DOLOMITIC LIMESTONE: Med to dk gray,
(m) crystalline, oolites common, thin
interbeds of dk gray shale and micrite

DOLOMITIC LIMESTONE: Med gray, (m)
crystalline, scattered oolities,
thin interbeds of dk gray shale, minor
staining and silica replacement, water
producing interval between 160-163 ft

LIMESTONE: Dk gray, (m) crystalline,
minor oolities and stylolites

GAMMA RAY

DEPTH
(FT)

GW704

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM:

DOLOSTONE: Olive gray, (f-m)
crystalline, rare oolites,
abundant small vugs DOLOMITIC LIMESTONE: Olive gray,
(c) crystalline, high porosity,
abundant small vugs LIMESTONE: dk gray, (m) crystalline,
minor calcite replacement LIMESTONE: dk gray, (m) crystalline,
minor amounts of calcite veining,
stylolites, and interbeds of micrite
and dk gray shale

OOLITIC LIMESTONE:

-50

-100

GAMMA RAY

DEPTH
(FT)

GW704

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

	OOLITIC LIMESTONE: dk gray, (m) crystalline, thin shale interbeds, small vugs and iron staining
	LIMESTONE: dk gray, (m) crystalline, slightly oolitic, thin interbeds of dk gray shale and lt gray micrite
	LIMESTONE: olive gray, (f-m) crystalline, mottled, stylolitic and slightly oolitic
	OOLITIC LIMESTONE: Olive to dk gray, (m) crystalline, minor stylolites

GAMMA RAY

DEPTH

GW704

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-200

OOLITIC LIMESTONE: Olive gray, (m)
crystalline, stylolitic

OOLITIC LIMESTONE: olive to lt gray,
(m) crystalline, minor calcite
replacement

OOLITIC LIMESTONE: dk gray with
interbeds of lt olive gray limesto
and micritic dolostone

-250

LIMESTONE: olive gray, (m)
crystalline, minor oolites

-300

GAMMA RAY

DEPTH
(FT)

GW705

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM: soil and weathered bedrock

-50

DOLOMITIC LIMESTONE: lt to dk gray, (c) vuggy dolostone, (m) sparite, and micrite, thin oolitic zones

LIMESTONE: dk gray, (m) sparite, thin interbeds of oolites, some fossil fragments and bioturbation present, some vugs present

OOLITIC LIMESTONE: dk gray, (m-c) oosparite, water production at 79 feet

LIMESTONE: dk gray, (m) sparite, mottled, dolomitized where bioturbated, vuggy, stylolitic

-100

THROMBOLITIC LIMESTONE: (?), dk gray, (m) dolomitic sparite with wispy bedding

GAMMA RAY

DEPTH

GW705

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

THROMBOLITIC LIMESTONE: (F), dk gray,
(m) dolomitic sparite with wispy bedding

LIMESTONE: dk gray, (m) sparite, massive,
stylolitic, cavities and water
production at 120 ft

OOLITIC LIMESTONE: dk to med gray,
(m) oosparite, cavities and water
present

THROMBOLITIC LIMESTONE: (F), lt gray-
tan, (c) dolomitic, mottled

DOLOMITIC LIMESTONE: med to dk gray,
(m-c) dolomitic sparite

OOLITIC LIMESTONE: dk gray, (m)
oosparite, water production at
144 to 146 ft

OOLITIC LIMESTONE: med gray, (F)
oosparite, stylolitic

THROMBOLITIC LIMESTONE:
dk gray, dense, wispy shale
partings

THROMBOLITIC LIMESTONE: mottled
dk and lt gray micrite, dolomitic at
base, water, vugs, and solutioned
fractures between 180 and 183 ft

OOLITIC LIMESTONE: med gray, (m)
oosparite, stylolitic

LIMESTONE: med gray, (F) sparite

GAMMA RAY

DEPTH

GW705

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-200

-250

-300

LIMESTONE: med gray, (f) sparite
THROMBOLITIC LIMESTONE: (?), mottled lt and dk gray sparite, stylolitic
LIMESTONE WITH SHALE INTERBEDS:
LIMESTONE: dk gray, (f) sparite, stylolitic
THROMBOLITIC LIMESTONE: (?), mottled dk and med gray, (m) sparite, oolitic
LIMESTONE WITH SHALE INTERBEDS: med to dk gray, (m) sparite; dk green shale
LIMESTONE AND SHALE INTERBEDS: med gray, (f-m) sparite; dk green shale, stylolitic limestone
LIMESTONE: med gray, (m) sparite
SHALE WITH LIMESTONE INTERBEDS: gray-green shale; lt to med gray micrite

GAMMA RAY

DEPTH
(FT)

GW-711

0 10 20 30 40 50 60 70 80

-400

-450

-500

-550

-600

-650

LITHOLOGY

DESCRIPTIONS

	DOLOMITIC LIMESTONE :
	CALCAREOUS DOLOSTONE :
	DOLOSTONE :
	CALCAREOUS DOLOSTONE :
	DOLOSTONE :
	DOLOMITIC LIMESTONE :
	OOLITIC LIMESTONE :
	LIMESTONE :

GAMMA RAY

DEPTH
(FT)

GW-711

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-400

DOLOMITIC LIMESTONE: mixed dolostone and sparite, lt olive gray, minor oosparite and green-gray shale

CALCAREOUS DOLOSTONE: lt gray to olive gray, (m), mottled, massive, water throughout

DOLOSTONE: dk green-gray, (m), mottled, laminated, minor greenish chert

DOLOSTONE: mixed 50% lt olive gray (f) laminated dolostone and 50% olive gray (m) stylolitic calcareous dolostone

CALCAREOUS DOLOSTONE: olive gray, (f-m), massive, slightly stylolitic

-450

DOLOSTONE: green-black, (m-c), mottled, vuggy, minor sulfides and calcareous dolostone

-500

GAMMA RAY

DEPTH

GW-711

(FT)

0 10 20 30 40 50 60 70 80

-500

LITHOLOGY

DESCRIPTIONS

-550

-600

DOLOSTONE: green-black, (c),
vuggy

DOLOMITIC LIMESTONE: mixed
dolostone and sparite, green-gray,
dolostone is vuggy, sparite is
massive and (m)

OOLITIC LIMESTONE: with abundant
sparite interbeds, dk green-gray,
(f), mottled (bioturbated), stylolitic

OOLITIC LIMESTONE: lt to dk green-gray
oosparite and sparite and minor green-
black silty shale and thinly laminated
shale, stylolitic

GAMMA RAY

DEPTH
(FT)

GW-711

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-600

-650

-700

LIMESTONE: lt gray sparite (75%)
and oosparite (25%), minor shale

LIMESTONE: poor cutting return,
green-black, (F) sparite and
oosparite

GAMMA RAY

DEPTH
(FT)

GW-712

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0		ALLUVIUM: weathered bedrock below 12 ft; dk gray dolostone, massive to laminated with silty shale and olive black chert. Cavities at 13-14, 15.5-16.6, 20-22, and 22.5-24.5 ft
		DOLOSTONE: green-gray, (f), massive to slightly laminated, 5-10% green-black siltstone
-50		DOLOSTONE: olive-gray, (f), massive to slightly laminated, intervals of chert and green-black siltstone and silty shale, mud-filled cavities at 47-48 and 62-63 ft, water producing interval between 56-62 ft
		CALCAREOUS DOLOSTONE: olive gray, (f-m), saccharoidal, massive, slightly laminated, mottled and slightly stylolitic, oosparite at top of this unit, water at 66-71 ft
		DOLOSTONE: green-gray, (m), stylolitic, minor massive sparite and oosparite
-100		DOLOSTONE: olive gray to olive black, (c), mottled, abundant small vugs

GAMMA RAY

DEPTH
(FT)

GW-712

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

DOLOSTONE: olive black to olive gray (c) vuggy dolostone and lt green-gray to yellow-brown (m) laminated and saccharoidal dolostone, vuggy and water zones throughout

DOLOSTONE: olive gray, (c), massive, vuggy

DOLOSTONE: olive gray, (c), vuggy, minor olive black, (m) stylolitic dolstone, dolomite-cemented fractures, water at 155-161 ft

DOLOSTONE: olive gray to olive black, (c) saccharoidal, vuggy, dolomite-cemented fractures, water at 166-176 and 180-181 ft

OOOLITIC LIMESTONE: dk green-gray, oosparite and (m-c) sparite, stylolitic

GAMMA RAY

DEPTH
(FT)

GW-712

0 10 20 30 40 50 60 70 80

-200

-250

-300

LITHOLOGY

DESCRIPTIONS

OOLITIC LIMESTONE: green-black, (m),
oosparite and olive gray sparite,
dolomitic and stylolitic

OOLITIC LIMESTONE: olive gray to
olive black, (F), stylolitic,
oosparite, minor olive gray micrite

OOLITIC LIMESTONE: olive gray to
olive black oosparite and sparite

OOLITIC LIMESTONE: olive gray to
olive black sparite and oosparite and
micrite, (f-m), mottled, stylolitic

LIMESTONE: olive black with minor
olive gray, (m), mottled (bioturbated),
stylolitic, pelsparite and minor oosparite

GAMMA RAY

DEPTH

GW-712

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-300

-350

-400

LIMESTONE: olive black to olive gray, (m), mottled (bioturbated), stylolitic, pelsparite and minor oosparite

LIMESTONE: olive black to green-black, (m-c), massive sparite, subordinate oolites and pelsparite

OOBITIC LIMESTONE: green-black, (m), mottled (dolomitic) and (f) sparite, stylolitic, water at 341-351 ft

OOBITIC LIMESTONE: olive gray, (m), mottled (bioturbated) oosparite and oosparudite and green-black (m) sparite, mottled (dolomitic and bioturbated), stylolitic

LIMESTONE: med gray to olive gray, (f) sparite, mottled (bioturbated), minor micrite and oolites, minor vugs

GAMMA RAY

DEPTH

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-400

LIMESTONE: med gray to olive gray, (F) sparite, mottle (bioturbated), subordinate micrite and oolites, minor vugs, water between 403-408 ft

THROMBOLITIC LIMESTONE: (?) med gray to dk gray, (F), sparite with "wispy bedding", stylolitic, water at 430-431 and 438 ft

-450

-500

GAMMA RAY

DEPTH

GW722

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-50

-100

-150

ALLUVIUM: and weathered bedrock

DOLOMITIC LIMESTONE: fine to coarse grained, crystalline, mottled, dk gray and brown, faint wavy bedding, stylolitic, scattered open vugs, solution void at 73 ft, solution fracture at 76-76.5 and 78 ft, minor gypsum in fractures

LIMESTONE: packstone, crystalline, bioclastic, mottled, medium to dark gray, irregular bedding, stylolitic, (vuggy), solution fract. at 84, 84.5, 86 ft (red mud infilling), void at 86.5 and 87.5 ft mud filled.

OOLITIC LIMESTONE: wackestone, packstone, crystalline, few dolomitic interbeds, dark gray, scattered vugs concentrated along micrites, solution void at 90.5, 91, 93.5, 94.5, 96 (clay filled), 96.5 (clay filled), and 97 (clay filled)

LIMESTONE WITH MICRITE INTERBEDS: light to dark gray, thinly bedded, few thick oolitic beds and thin calcareous shale interbeds, void at 99 to 99.5, 103.5, 105.5 ft, solution fractures 104, 104.5, 105, 111, 112, 113, 114 ft, most clay filled,

OOLITIC LIMESTONE: wackestone, one 1 ft thick bed of sparite, biosparite, and dolomitic, dk gray, thin solution fract. and vugs along bedding plane assoc. with micritic intervals, solution zones at 117, 117.5 ft, solution fract. at 120 ft, void at 121.5-124.5 ft

LIMESTONE: coarse grained, wackestone, peloids, few micrite and biosparite interbeds, dk gray, solution fract. at 126, 129 ft

OOLITIC LIMESTONE: with pelisparite and several interbeds of dk green shale and lt gray micrite, micritic rip-ups common over- and-underlying shale, brecciated shale at 150 ft (3" thick) medium bedding.

GAMMA RAY

DEPTH

GW722

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-150

-200

-250

	SHALE: dark gray, laminated.
	OOLITIC LIMESTONE: coarse grained, wackestone, packstone, rare interbeds of peloids and micrite medium gray, stylolitic, 2 thin solution fract. at 160 ft
	STROMATOLITIC: Limestone, oolites, light to medium gray, massive bedding, mottled, digitate stromatolites, v. thin solution fract. at 172.5, 174.5 ft
	LIMESTONE: peloids, light gray, some biosparite
	THROMBOLITIC LIMESTONE: medium grained, crystalline, wispy micrite stringers, digitate stromatolite present at base mottled, medium to dark gray.
	STROMATOLITIC: Limestone, abundant oosparite interbeds at top, massive beds with some digitate stromatolites sparite mottled, medium to dark gray, slightly dolomitic, solution fracture and vugs at 205.5 ft
	STROMATOLITIC: same as above except light gray, wispy black shale present
	STROMATOLITIC: same as above with peloids, micrite, algal oncolites, laminated, massive bedding.
	OOLITIC LIMESTONE: packstone, sparite medium gray, with digitate stromatolites
	STROMATOLITIC: Limestone, peloids, sparite mottled, medium to dark gray, laminated.
	STROMATOLITIC: Limestone, interbeds of peloids, micrite and thick oosparite mottled, medium to dark gray, stylolitic, wispy micrite stringers

GAMMA RAY

DEPTH

GW722

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-350

THROMBOLITIC LIMESTONE: wispy interbeds of peloids, sparite and micrite, mottled, light to medium gray, massive bedding.

OOLITIC LIMESTONE: very coarse grained, wackestone, packstone, sparite, medium gray, algal oncolites, stylolitic, rare lt gray micrite interbeds, solution fractures at 358, 361, 363, 381, 384, and 386 ft solution of calcite vein at 374.5 ft and of micrite at 386 ft (tan clay in solution zone)

-400

STROMATOLITIC: Limestone, oolites, sparite, mottled, medium to dark gray.

THROMBOLITIC LIMESTONE: abundant v. thin dk green-gray, wispy micrite and shale, several gradational stromatolitic laminated units, oolites, interbeds of dolomicrite mottled, medium to dark gray, clotty texture, oxidized solution fractures at 390, 404, 425, 442, 448 and 450 ft

-450

GAMMA RAY

DEPTH

GW722

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-550

THROMBOLITIC LIMESTONE: sparite mottled, light to medium gray, clotty texture, abundant v. thin, wispy green-gray micrite stringers and thin dk green shale interbeds, burrowed, stylolitic, several gypsum filled vugs at 574 ft along dolomicrite beds

OOOLITIC LIMESTONE: packstone, medium gray, algal oncolites, interbeds of dk gray micrite and calcareous shale, stylolitic.

SHALE: dark green, slightly calcareous, grades upward into interbeds of (vf) sparite and shale, convolute bedding, some limestone rip-up clasts

-600

THROMBOLITIC LIMESTONE: sparite mottled, medium to dark gray, abundant green micrite stringers and interbeds, algal oncolites at base

LIMESTONE WITH SHALE INTERBEDS: fine grained, limestone (gray), shale (black to dk green), 60% limestone, 40% shale, load cast, thinly to thickly bedded, graded bedding, nodular bedding.

OOOLITIC LIMESTONE: packstone, sparite medium gray, algal oncolites.

LIMESTONE AND SHALE INTERBEDS: shale (dk green), limestone (lt to med gray) load cast, laminated to thickly bedded, thick shale with limestone intraclasts at base

-650

GAMMA RAY

DEPTH
(FT)

GW723

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

GAMMA RAY

DEPTH
(FT)

GW723

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0		ALLUVIUM: soil and residuum
		DOLOSTONE: olive gray, (F), massive and olive black saccharoidal, laminated, algal laminated and oolitic chert
-50		DOLOSTONE: dk green-gray, (F), massive, minor green-black silty shale, sparse laminations, possible solution zones at 42-44 and 49-50 ft
		CALCAREOUS DOLOSTONE: olive gray-black, (F-m), saccharoidal, laminated, mottled, solution zones at 60 and 63 ft
		CALCAREOUS DOLOSTONE: dk green-gray (F), laminated, stylolitic; thinly laminated olive black shale and silty shale present, solution zones at 69-70 and 71-72 ft, water at 70 ft
		DOLOSTONE: mottled lt gray to dk green-black, stylolitic, (F-m), saccharoidal, minor oolitic chert, solution zones 79-80 and 89-90 ft, water at 79-82 ft
		CALCAREOUS DOLOSTONE: dk green-gray, laminated, (F), water at 94.5-95 ft
-100		DOLOSTONE: lt gray

GAMMA RAY

DEPTH
(FT)

GW723

0 10 20 30 40 50 60 70 80

-100

LITHOLOGY

DESCRIPTIONS

-150

-200

CALCAREOUS DOLOSTONE: mottled, lt olive gray to green-black, (f), massive to slightly laminated calcareous dolostone and micrite, minor thinly laminated green shale, solution zone and water at 121.5 ft	
CALCAREOUS DOLOSTONE: mottled, lt olive gray to green-black, laminated, vuggy, saccharoidal, (f-c) crystalline	
DOLOSTONE: olive gray, (m-f) crystalline, mottled, stylolitic, vuggy, minor green to black silty shale and shale, water at 141-144 and 149 ft	
DOLOSTONE: mottled, olive gray, saccharoidal, vuggy and abundant solution zones	
DOLOSTONE: olive gray, (m) crystalline, saccharoidal, mottled, stylolitic, vuggy, minor green-black silty shale	
DOLOSTONE: olive gray, vugs filled with calcite	
DOLOSTONE: mottled olive gray and black, (m) crystalline, saccharoidal, minor green-black shale, vuggy, solution zone at 199-200 ft	

GAMMA RAY

DEPTH
(FT)

GW723

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-200

-250

-300

DOLOSTONE: olive gray to olive black, (m) crystalline, saccharoidal, mottled

DOLOSTONE: mottled olive gray to olive black, stylolitic, minor laminated green-black shale

LIMESTONE: green-black, micrite and sparite, (f) crystalline, sparsely stylolitic and dolomitic, bioturbated, thinly laminated dk green shale at base, solution zone and water at 241-243 ft

OOLITIC LIMESTONE: green-black oosparite, sparite, and micrite, minor laminated green-black shale

OOLITIC LIMESTONE: green-black oosparite and (m) sparite, minor dk green shale, solution zone at 280-281 ft

OOLITIC LIMESTONE: green-black oosparite, (m) sparite, and micrite, minor shale

LIMESTONE: green-black, (f-m) crystalline, massive sparite, rare oolites, water and vugs at 299-301 ft

GAMMA RAY

DEPTH

GW723

(FT)

0 10 20 30 40 50 60 70 80

-300

LITHOLOGY

DESCRIPTIONS

OOLITIC LIMESTONE: med to dk gray, oosparite and (F) sparite, minor dk gray micrite and green-black shale

LIMESTONE: lt gray, (m) crystalline sparite, massive, stylolitic

OOLITIC LIMESTONE: lt to dk gray, (m-f) crystalline sparite, and oosparite, solution zone at 322-323, 327-328, 332-333 ft, water at 322 ft

LIMESTONE: gray, (m-f) crystalline, sparite, mottled (bioturbated), stylolitic

(No rock return below 341 ft)

-350

-400

GAMMA RAY

DEPTH
(FT)

GW724

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

GAMMA RAY

DEPTH
(FT)

GW-724

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM: soil, fill, weathered bedrock of stylolitic and mottled (bioturbated) micrite, cavity and water at 38.5 to 40.0 ft

-50

OOLITIC LIMESTONE: green-black, (f-m) crystalline oosparite and minor green-gray micrite, stylolitic

OOLITIC LIMESTONE: oosparite with minor dk green, thinly laminated calcareous shale, mud-filled cavity at 54-55 ft

-100

LIMESTONE: green-black, (m) crystalline sparite and micrite, minor oosparite

OOLITIC LIMESTONE: green-black oosparite, stylolitic micrite, and minor dk green-black, laminated silty shale, intraclastic fragments, small vugs at 59-63 ft

LIMESTONE WITH SHALE INTERBEDS:

OOLITIC LIMESTONE: green-black oosparite, sparite, and micrite, stylolitic, rare intraclasts

LIMESTONE: lt gray, (f) crystalline sparite, stylolitic, vuggy

OOLITIC LIMESTONE: lt gray to olive gray oosparite and (m) sparite

DOLOMITIC LIMESTONE: dk green gray slightly dolomitic sparite to pelsparite, saccharoidal, sparsely stylolitic

GAMMA RAY

DEPTH
(FT)

GW724

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

DOLOMITIC LIMESTONE: dk green-gray, (m) crystalline, saccharoidal, scattered small vugs, stylolites, pelloid and oolitic beds

CALCAREOUS DOLOSTONE: yellow-gray

OOLITIC LIMESTONE: green-black, dolomitic, pelsparite and oosparite

DOLOMITIC LIMESTONE: lt gray to olive gray, pelsparite and minor oosparite and shale stylolitic, (F) crystalline, calcite-filled veins, vugs and water at 139 and 148-149 ft

-150

LIMESTONE: med gray to olive green, sparite and pelsparite, (m) crystalline, stylolitic, sparsely oolitic and dolomitic, water and solution zones at 155 and 157 ft

OOLITIC LIMESTONE: green-black, (m) crystalline, oosparite and intraclastic sparite, solution zones at 165 and 170 ft

LIMESTONE: lt gray to olive black, sparite, (F-m) crystalline, stylolitic, massive, solution zones at 170-172, 177-178, and 179-181 ft, water at 179-181 ft

-200

OOLITIC LIMESTONE: mottled green-gray to green black oosparite and intraclastic

GAMMA RAY

DEPTH
(FT)

GW724

0 10 20 30 40 50 60 70 80

-200

LITHOLOGY

DESCRIPTIONS

OOBITIC LIMESTONE: green-gray to green-black oosparite, scattered calcite-filled veins and stylolites

LIMESTONE: green-gray to dk green (f) crystalline sparite and subordinate micrite and oolites

OOBITIC LIMESTONE: dk green, increase in micrite and stylolites with depth, water at 242 ft

-250

LIMESTONE: dk green to lt olive-gray micrite, stylolitic, minor (m) crystalline sparite

LIMESTONE: mixed micrite and sparite, med gray to lt olive-gray, stylolitic, fracture and water at 274.5 ft

-300

LIMESTONE: med gray to olive-gray micrite, stylolitic, fracture or solution zone and water at 299 ft

GAMMA RAY

DEPTH
(FT)

GW725

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM: soil and weathered
bedrock, void at 17-17.3 ft

OOLITIC LIMESTONE: med gray,
mottled (bioturbated ?) oospirite
and pisolites, intraclasts of micrite

LIMESTONE: lt olive gray to lt gray,
micrite, convolute laminations,
stylolitic, minor intraclasts

-50

THROMBOLITIC LIMESTONE: (?) mottled
lt to med gray micrite and sparite,
(heavily stylolitic), minor pelsparite,
and micritic intraclastic beds, solution
and water zone between 78.5-81.5 ft

LIMESTONE: med gray to olive-gray micrite,
minor dolomitic and carbonaceous intraclasts,
stylolitic, scattered sulfides along
stylolites

-100

THROMBOLITIC LIMESTONE: (?) mottled
med gray to green-black sparite and
micrite, stylolitic, intraclastic,
solution zone at 97, 5-98.5 ft

GAMMA RAY

DEPTH
(FT)

GW725

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

THROMBOLITIC LIMESTONE: (?), mottled olive gray, micrite and sparite dolomitic, heavily stylolitic, selenite gypsum present, solution zone and water at 106-108 ft
THROMBOLITIC LIMESTONE: (?) mottled lt and med gray micrite, sparite, and dolomite, stylolitic, saccharoidal, solution and water zones at 124.5, 136 and 140 ft

GAMMA RAY

DEPTH
(FT)

GW727

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM:

DOLOSTONE: dk to med gray,
massive, some oolites present DOLOSTONE: some limestone, med to
dk gray to brown-gray, massive,
stylolitic, voids at 36-39 and 40-41
ft, water at 35 ft. OOLITIC LIMESTONE: dk gray,
oolitic packstone, micrite and
sparite LIMESTONE: gray-black to dk gray,
sparite and micrite, some
oolitic packstone OOLITIC LIMESTONE: with interbeds
of micrite, med to dk gray, packstone,
sparite, some shale interbeds LIMESTONE: lt gray sparite,
mottled, stylolitic

-50

-100

GAMMA RAY

DEPTH
(FT)

GW727

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

LIMESTONE: dk gray sparite

OOLITIC LIMESTONE: med gray,
oolitic packstone and sparite,
stylolitic, peloidal at base
fracture with water at 105 ft

LIMESTONE: brown-gray sparite,
some oolites, rare stylolites

OOLITIC LIMESTONE: med to dk gray,
oolitic packstone increase downward,
sparite present, water at 162 ft

LIMESTONE: med to dk gray,
oolitic, micritic, and sparitic,
stylolitic

GAMMA RAY

DEPTH
(FT)

GW727

0 10 20 30 40 50 60 70 80

-200

-250

-300

LITHOLOGY

DESCRIPTIONS

OOLITIC LIMESTONE: med to dk gray,
packstone and smaller amounts of
sparite, water at 204.5 ft

THROMBOLITIC LIMESTONE:
dk to med gray, mottled, minor
stylolites, oolitic packstone
and sparite present

LIMESTONE AND SHALE INTERBEDS:
med to dk gray sparite and
green shale

SHALE WITH LIMESTONE INTERBEDS:
dk green shale

GAMMA RAY

DEPTH
(FT)

GW729

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-200

-250

-300

DOLOSTONE: olive black to green-gray,
(F), massive to slightly laminated

DOLOSTONE: olive gray to dk green,
(F-m), saccharoidal, scattered small
vugs

DOLOSTONE: med to dk gray, massive,
small open vugs throughout

GAMMA RAY

DEPTH

GW729

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-300-

DOLOSTONE: dk to med gray, mottled, possibly bioturbated, small open and calcite-filled vugs throughout

LIMESTONE: dk to med gray, micritic, some dolostone and calcareous siltstone, massive, possibly bioturbated, minor small vugs throughout, stylolites at base

-350-

OOLITIC LIMESTONE: dk to med gray, packstone, massive, stylolitic, interbeds of wavy bedded micrite, 10% shale

OOLITIC LIMESTONE: med gray, packstone with peloidal packstone, massive, stylolitic, wavy micrite and dk gray shale interbeds

FAULT: brecciated oolitic limestone, dolostone, and shale, recrystallized groundmass

DOLOSTONE: dk gray, massive, mottled, intraclasts of micrite

OOLITIC LIMESTONE: med gray, packstone, some peloidal packstone, interbeds of shale and intraclasts of mudstone, stylolitic, breccia zone at 386-387 ft

-400-

GAMMA RAY

DEPTH
(FT)

GW729

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-400

OOLITIC LIMESTONE: med gray

DOLOMITIC MUDSTONE: lt gray,
massive, bioturbated, interbeds
of shale, micrite, and intraclasts
of shale, stylolitic

OOLITIC LIMESTONE: med gray

LIMESTONE: lt gray, peloidal, massive,
stylolitic, micritic OOLITIC LIMESTONE: lt to med gray,
packstone with abundant peloidal wackestone.
massive to flaser bedding, stylolitic

THROMBOLITIC LIMESTONE: (?)

med gray, peloidal
packstone and wackestone, mottled,
massive, stylolitic, interbeds of
oolitic and intraclastic limestone

THROMBOLITIC LIMESTONE: (?)

med gray, peloidal and
oolitic limestone, massive to ribbon
beds, some calcareous siltstone lenses,
stylolitic

-500

GAMMA RAY

DEPTH
(FT)

GW729

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-500

-550

-600

THROMBOLITIC LIMESTONE: (?) med to
lt gray peloidal and oolitic packstone,
massive to ribbon bedded, thin
shale drapes at the top of unit,
stylolitic

THROMBOLITIC LIMESTONE: (?) med
gray, peloidal packstone, thin wispy
shale partings, stylolitic

LIMESTONE AND SHALE INTERBEDS: med gray
peloidal packstone and dk green shale

GAMMA RAY

DEPTH

GW729

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-600

-650

-700

LIMESTONE AND SHALE INTERBEDS:

SHALE WITH LIMESTONE INTERBEDS:
green-black shale, lt to med gray
peloidal packstone and micrite, wavy
and convolute bedding, 80% shale

LIMESTONE AND SHALE INTERBEDS:
med gray peloidal packstone and
calcareous siltstone, green-black
shale, massive to lenticular beds

SHALE WITH LIMESTONE INTERBEDS:
med gray calcareous siltstone and
peloidal packstone, green-black shale,
minor oolitic and intraclastic beds

LIMESTONE WITH SHALE INTERBEDS:
lt to med gray micrite, calcareous
siltstone, and peloidal packstone,
green-black shale, thin lenticular and
slightly convoluted beds

GAMMA RAY

DEPTH
(FT)

GW730

LITHOLOGY DESCRIPTIONS

0	ALLUVIUM:
-50	OLIGITIC LIMESTONE:
-100	LIMESTONE:
-150	OLIGITIC LIMESTONE:
-200	LIMESTONE:
-250	THROMBOLITIC LIMESTONE:
-300	THROMBOLITIC LIMESTONE:
-350	THROMBOLITIC LIMESTONE:
-400	OLIGITIC LIMESTONE:
-450	LIMESTONE AND SHALE INTERBEDS:
-500	SHALE WITH LIMESTONE INTERBEDS:
	SHALE:
	SHALE AND LIMESTONE INTERBEDS:
	SHALE WITH LIMESTONE INTERBEDS:

GAMMA RAY

DEPTH

GW-730

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM: soil

-50

OOLITIC LIMESTONE: lt to dk gray,
micritic, void at 42 ft

LIMESTONE: lt gray, stylolitic

OOLITIC LIMESTONE: lt to dk gray,
packstone and wackestone, stylolitic,
peloidal and micritic intervalsLIMESTONE: med gray, laminated,
some dolomiteOOLITIC LIMESTONE: med gray,
oolitic packstone to wackestone,
possible dolomitizationLIMESTONE: dk gray, massive,
micrite present, abundant solution
zones, voids at 73-75 and 79-81 ft

-100

OOLITIC LIMESTONE: dk gray,
packstone, abundant solution zones

GAMMA RAY

DEPTH
(FT)

GW-730

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

OOLITIC LIMESTONE: dk gray,
massive packstone, water at 108 ft

LIMESTONE: med gray to green-gray,
massive

OOLITIC LIMESTONE: dk to lt gray,
packstone, stylolitic

LIMESTONE: yellow-brown to brown-
gray, massive

OOLITIC LIMESTONE: lt brown-gray
to dk gray, massive packstone,
water zone at 156 ft

-150

LIMESTONE: lt gray, stylolitic,
water at 188 ft

-200

GAMMA RAY

DEPTH

GW-730

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-200

-250

-300

THROMBOLITIC LIMESTONE: lt gray

THROMBOLITIC LIMESTONE: lt gray
to gray-brown, dolomitic, micritic,
minor shale, minor stylolites, vuggy,
calcite-filled vugs from 226 to 231 ft,
water at 250 ftTHROMBOLITIC LIMESTONE: med
gray to lt brown-gray, micritic,
minor shale, water at 264 ftTHROMBOLITIC LIMESTONE: mottled
med gray and dk gray (dolomitic),
shale and micrite present

GAMMA RAY

DEPTH
(FT)

GW730

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-300

-350

-400

THROMBOLITIC LIMESTONE: lt
to med gray, micritic, shale
interbeds, rare stylolites

THROMBOLITIC LIMESTONE: mottled
med gray and brown, micritic

THROMBOLITIC LIMESTONE: med gray,
wispy shale and micrite partings

THROMBOLITIC LIMESTONE: med gray
to brown-gray, wispy shale partings

GAMMA RAY

DEPTH

GW730

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-400

-450

-500

THROMBOLITIC LIMESTONE: med
gray to green-gray, micritic

OOBITIC LIMESTONE: med gray to
brown-gray, oomicrite

LIMESTONE AND SHALE INTERBEDS: dk
to med gray micrite and green-black
shale

SHALE WITH LIMESTONE INTERBEDS: dk
green-black shale; med gray micrite,
bioturbated

SHALE: dk green to black, thin
to v. thick interbeds of oolitic
packstone, peloidal packstone, micrite,
and thrombolitic limestone

SHALE AND LIMESTONE INTERBEDS: dk
green shale; med gray micrite, peloidal,
skeletal packstone, thin oolitic beds,
intraclastic limestone beds, fault and/or
water zones at 469-473 and 474 ft

SHALE WITH LIMESTONE INTERBEDS: green-
black shale (70%); med gray pelmicrite,
fossiliferous and oolitic packstone,
intraclastic limestone beds

DESCRIPTIONS	LITHOLOGY
ALLUVIUM:	Pattern of irregular polygons and circles
STROMATOLITIC: Dolomite	Pattern of wavy horizontal lines
DOLOSTONE:	Pattern of horizontal lines with small circles
CAVITY:	Blank white box
OLLITIC LIMESTONE:	Pattern of horizontal lines with small circles
INFORMATIONAL BRECCIA:	Pattern of irregular polygons and circles
OLLITIC LIMESTONE:	Pattern of horizontal lines with small circles
STROMATOLITIC:	Pattern of wavy horizontal lines
CAVITY:	Blank white box
OLLITIC LIMESTONE:	Pattern of horizontal lines with small circles
STROMATOLITIC:	Pattern of wavy horizontal lines
LIMESTONE:	Pattern of horizontal lines with small circles
STROMATOLITIC:	Pattern of wavy horizontal lines
LIMESTONE AND SHALE INTERBEDS:	Pattern of alternating horizontal lines and wavy lines

GAMMA RAY

DEPTH

GW790

(FT)

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

0

ALLUVIUM:

-50

STROMATOLITIC: Dolostone: med. gray (F), mottled, few open vugs and calcite filled vugs and veins

DOLOSTONE: dk gray, brecciated, thin solution along fractures

STROMATOLITIC: Dolostone: dk gray, slightly laminated, brecciated, white dolomitic-filled vugs throughout

STROMATOLITIC: Dolostone: med to dk gray, abundant white dolomite-filled vugs and "birds-eye structures, faintly laminated, small open vugs throughout, solution zone at 69 ft

DOLOSTONE: dk gray, massive, (F), small open vugs

DOLOSTONE: dk gray, laminated at top, bioturbated and mottled, abundant white blebs lower in unit, white veinlets throughout

-100

GAMMA RAY

DEPTH
(FT)

GW790

0 10 20 30 40 50 60 70 80

LITHOLOGY

DESCRIPTIONS

-100

-150

-200

DOLOSTONE: med-dk gray, mottled, white and lt gray blebs and veinlets throughout, abundant small open vugs	
DOLOSTONE: dk gray, saccharoidal, massive to laminated, white veinlets throughout, vuggy fracture at 114 ft	
CAVITY: connected to cavity in GW-728, 95 ft to north	
LIMESTONE: interbedded limestone and micrite and some black shale	
OOLITIC LIMESTONE: lt to med gray, some interbeds of micrite, pelospirite, black shale stringers and oncolites, slightly brecciated at 144 to 146 ft	
INTRAFORMATIONAL BRECCIA: dolomitic, med to dk gray, angular to subangular clasts of black shale and med gray micrite, some white dolomite cementation, abundant pyrite, matrix of peloidal packstone, thickly bedded with thin interbeds of pelospirite, micrite, and shale, stylolitic	
OOLITIC LIMESTONE: med gray oospirite, stylolitic, pyritic, some large vertical burrows, possible breccia slump	
LIMESTONE: very lt gray, biosparite at top with thin interbeds of black shale, white calcite cement throughout, stylolitic	
OOLITIC LIMESTONE: very lt gray, very thin black shale interbeds, stylolitic	
SHALE: black, with interbeds of micrite and oo-biosparite, bioturbated	
STROMATOLITIC: at top, mottled lt and med gray, thrust faults repeat sections 182-195 and 195.5-201 ft, cavity at 199.3-199.8 ft

APPENDIX B

Alteration, water zones, and geophysical anomalies for Bear Creek Valley wells used in this report.

Abbreviations:

cal =	caliper log
cnl =	compensated neutron-density log
d =	formation density log
T =	temperature log
res =	long/short resistivity log
sp =	spontaneous potential log
sonic =	sonic log

GW-130

GW-138

GW-725

APPENDIX C

Isopach maps for the Maynardville zones in Bear Creek Valley. Heavy dashed lines denote surface geologic contacts for the Nolichucky Shale (Cn), Maynardville Limestone (Cmn), and Copper Ridge Dolomite (Ccr). Light dashed lined denote isopach lines (stratigraphic thickness in feet). Numbers in parentheses below well numbers denote stratigraphic thickness at that location. UEFPC = Upper East Fork Poplar Creek.

Reference locations of isopach maps. Location 1 (New Hope Pond area), location 2 (Y-12 east), location 3 (Y-12 west), location 4 (Oil-landfarm area), location 5 (Burial Grounds area), location 6 (west of the Burial Grounds), and location 7 (Bear Creek west).

Isopach map for Zone 2 in the New Hope Pond area (contour interval 50 ft).

Isopach map of Zone 3 in the New Hope Pond area (contour interval 20 ft).

Isopach map for Zone 4 in the New Hope Pond area (contour interval 20 ft).

Isopach map for Zone 5 in the New Hope Pond area (contour interval 10 ft).

Isopach map for Zone 6 in the New Hope Pond area (contour interval 20 ft).

Isopach map for Zone 2 in eastern part of the Y-12 Plant area (contour interval 50 ft).

Isopach map of Zone 3 in the eastern part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 4 in the eastern part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 5 in the eastern part of the Y-12 Plant area (contour interval 10 ft).

Isopach map for Zone 6 in the eastern part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 2 in the western part of the Y-12 Plant area (contour interval 50 ft).

Isopach map of Zone 3 in the western part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 4 in the western part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 5 in the western part of the Y-12 Plant area (contour interval 10 ft).

Isopach map for Zone 6 in the western part of the Y-12 Plant area (contour interval 20 ft).

Isopach map for Zone 2 in the area of the Oil-landfarm (contour interval 50 ft).

Isopach map of Zone 3 in the area of the Oil-landfarm (contour interval 20 ft).

Isopach map for Zone 4 in the area of the Oil-landfarm (contour interval 20 ft).

Isopach map for Zone 5 in the area of the Oil-landfarm (contour interval 10 ft).

Isopach map for Zone 6 in the area of the Oil-landfarm (contour interval 20 ft).

Isopach map for Zone 2 in the area of the Burial Grounds (contour interval 50 ft).

Isopach map of Zone 3 in the area of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 4 in the area of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 5 in the area of the Burial Grounds (contour interval 10 ft).

Isopach map for Zone 6 in the area of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 2 west of the Burial Grounds (contour interval 50 ft).

Isopach map of Zone 3 west of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 4 west of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 5 west of the Burial Grounds (contour interval 10 ft).

Isopach map for Zone 6 west of the Burial Grounds (contour interval 20 ft).

Isopach map for Zone 2 in the west Bear Creek area (contour interval 50 ft).

Isopach map for Zone 3 in the west Bear Creek area (contour interval 20 ft).

Isopach map for Zone 4 in the west Bear Creek area (contour interval 20 ft).

Isopach map for Zone 5 in the west Bear Creek area (contour interval 10 ft).

Isopach map for Zone 6 in the west Bear Creek area (contour interval 20 ft).

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