STRATABOUND PATHWAYS OF PREFERRED GROUNDWATER FLOW:

AN EXAMPLE FROM THE COPPER RIDGE DOLOMITE IN EAST TENNESSEE

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Abstract

The Copper Ridge Dolomite of the Upper Cambrian Knox Group underlies a site at Oak Ridge, Tennessee under consideration by the Department of Energy (DOE) for a below ground waste disposal facility. The Copper Ridge was studied for DOE to understand the influence of lithology on deep groundwater flow. Three facies types are distinguished which comprise laterally continuous, 1-4 m thick rock units interpreted to represent upward-shallowing depositional cycles having an apparently significant effect on groundwater flow at depth.

Rock core observations indicate one of the recurring facies types is characterized by thin to medium-bedded, fine-grained dolostone with planar cryptalgal laminae and thin shaley partings. Distinctive fracturing in this facies type, that may have resulted from regional structural deformation, is considered to be responsible for weathering at depth and the development of stratabound pathways of preferred groundwater flow. In addition, geophysical data suggest that one occurrence of this weathered facies type coincides with an apparent geochemical interface at depth. Geophysical data also indicate the presence of several fluid invasion horizons, traceable outside the study area, which coincide with the unweathered occurrence of this fine-grained facies type.

The subcropping of recurrent zones of preferred groundwater flow at the weathered/unweathered interface may define linear traces of enhanced aquifer recharge paralleling geologic strike. Vertical projection of these zones from the weathered/unweathered rock interface to the ground surface may describe areas of enhanced infiltration. Tests to determine the role of stratigraphic controls on groundwater flow are key components of future investigations on West Chestnut Ridge.

Introduction

The Department of Energy (DOE) is considering locations on the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee for the development and demonstration of new technologies for below ground waste disposal facilities. To assist DOE in its decision making process to locate a suitable site, a rock coring and geophysical logging study was undertaken on West Chestnut Ridge on the ORR to develop increased understanding of saturated groundwater flow through weathered and unweathered bedrock beneath the proposed site.

Previous studies have determined that West Chestnut Ridge is potentially suitable for a below ground waste disposal site due to its comparatively thick residual soil and depth to the water table. This report describes the results of the rock coring and geophysical logging study and presents some geologic findings that provide qualitative insight into groundwater flow in the weathered and unweathered bedrock at the proposed West Chestnut Ridge site.

This paper describes the apparently controlling influence of stratigraphy on deep groundwater flow in the Copper Ridge. Specifically, it presents the detailed rock core characteristics used to define three facies types in the Copper Ridge which are interpreted to comprise laterally continuous, 1-4 m thick, upward-shallowing cycles. Fracturing and weathering of one facies type in the cycles, and a distinctive lithologic characteristic within that facies type, coincides with geophysical data which will be shown to suggest the occurrence of thin stratabound pathways for preferred groundwater flow to depth. One of these pathways will also be shown to coincide with an apparent geochemical interface at depth. Finally, the relationship between stratabound flow pathways and both aquifer recharge and infiltration will be discussed.

Physiography and Regional Geology

The Oak Ridge Reservation (ORR) in eastern Tennessee is in the Valley and Ridge Physiographic Province of the Appalachian Highlands (Figure 1). The Valley and Ridge is characterized by elongate, alternating valleys and ridges formed subsequent to the Appalachian Orogeny. Chestnut Ridge is a northeast to southwest oriented linear topographic high within the Valley and Ridge. On the ORR it consists of three discontinuous ridge lines with maximum elevations of from 280 to 320 m (920 feet to 1050 feet) and ridge crest to valley floor relief from 30 to 68 m (100 to 225 feet). The study area comprises the northernmost ridge line (Figure 2).

The ORR is underlain by Cambrian and Ordovician age clastic and carbonate rock units. A generalized stratigraphic column (Figure 3) illustrates the mappable rock units comprising and immediately surrounding Chestnut Ridge. Regional geologic structure is characterized by imbricate thrust faults, trending N 45° to 65° E, with regional dip typically about 30° southeast varying locally from 20° to more than 45°. An idealized geologic cross section across the ORR (Figure 4) shows the position of West Chestnut Ridge within the Whiteoak Mountain thrust sheet.

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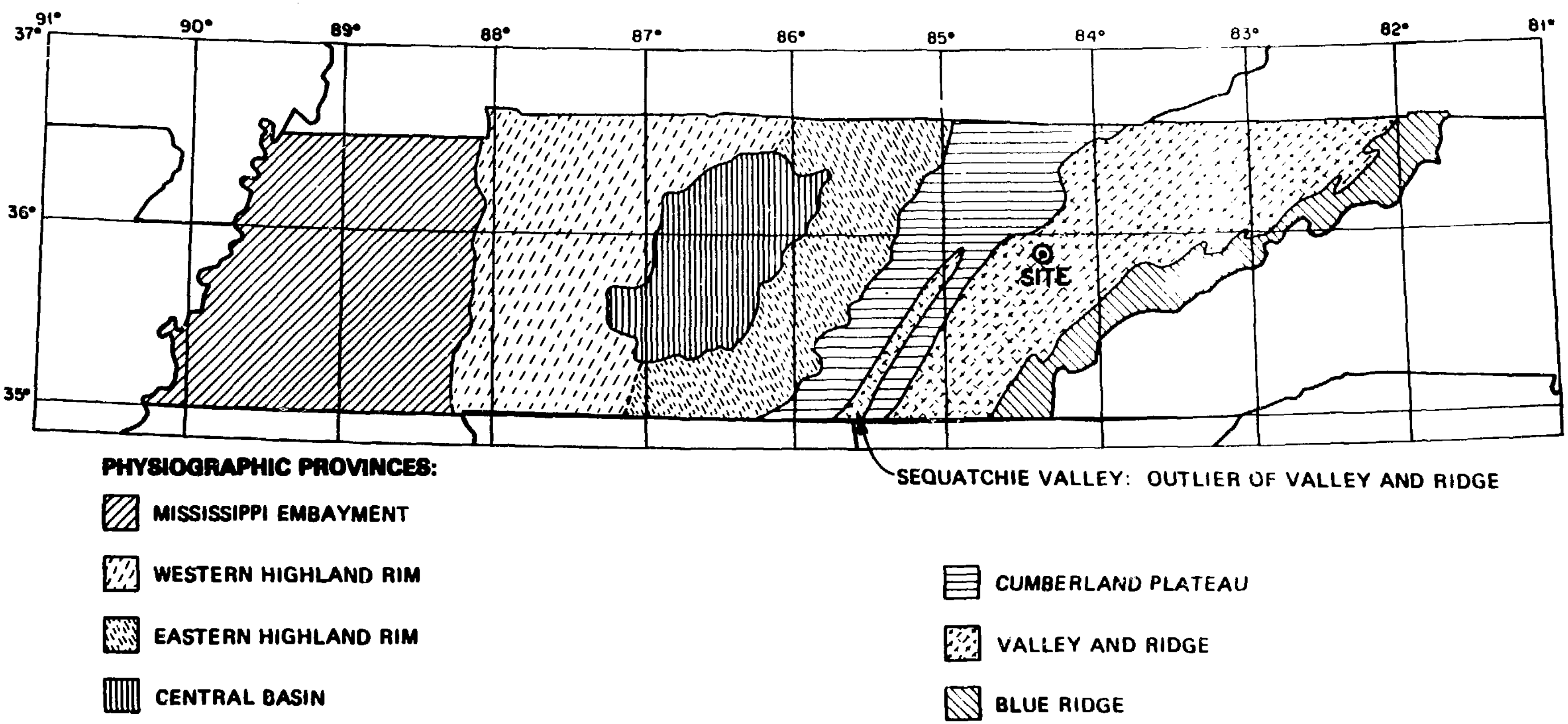

Figure 1. Physiographic map of Tennessee.

Figure 2. West Chestnut Ridge site core hole locations.

System	Group	Formation	Estimated thickness	Description
Ordovician	Chickamauga	Undivided		Thin to medium-bedded, cherty carbonate lithologies. Maroon mudstone and argillaceous limestones.
	Knox	Newala	275 m (900 ft)	Medium-bedded dolostones and limestones with variable chert content, scattered chert matrix sandstones. Abundant maroon mottling in carbonates. Thin soil development.
		"Longview"	15 m (50 ft)	Dense massive chert, bedded chert, and dolomoldic chert observed in residuum.
		Chepultepec Dolomite	215 m (700 ft)	Fine to medium-grained, light to medium gray, crystalline dolostone, medium to thick-bedded where observed, sandy in part, particularly near base. Minor maroon mottling appears near top. Thin to thick soil development.
Cambrian		Copper Ridge Dolomite	300 to 400 m (1000 to 1300 ft)	Medium to thick-bedded, fine to coarse crystalline dolostone, medium to dark gray chert varies from massive porcellanous near base to blue-gray oolitic in upper 1/3 of the unit. Thin to thick soil development.
	Conasauga	Maynardville Limestone	60 to 90 m (200 to 300 ft)	Medium-bedded, light to dark gray, fine crystalline to oolitic limestone. Moderately thick soil development.

Figure 3. Stratigraphic Column of Bedrock Formations on the West Chestnut Ridge Site.

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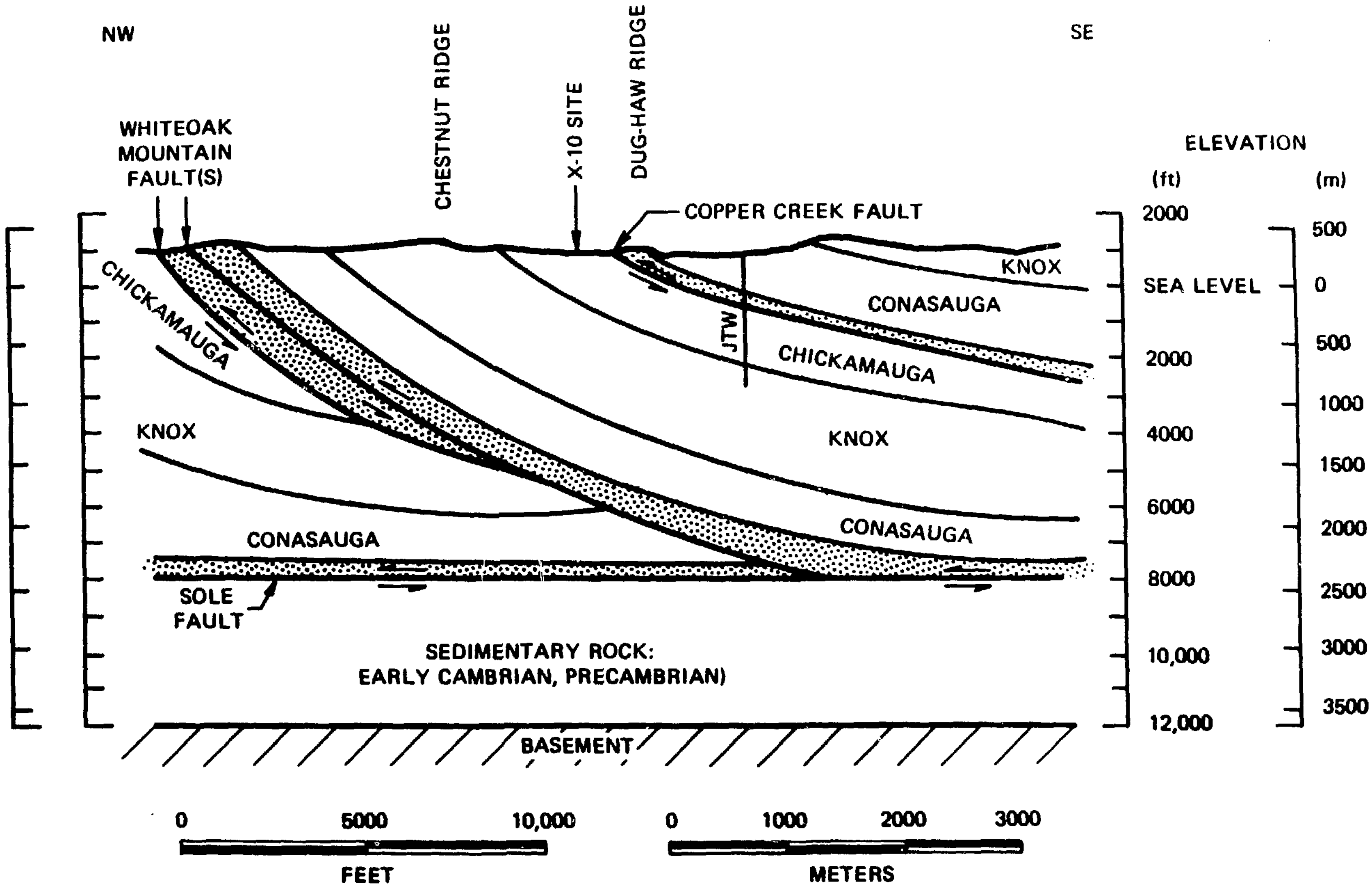

Figure 4. Geologic cross section of the Oak Ridge Reservation.

The results of drilling provided a nearly complete, spatially discontinuous stratigraphic section of the upper Cambrian Knox Group Copper Ridge Dolomite. Bedding dip ranges between 32 and 40 degrees, decreasing down the core. The Copper Ridge is a thick, megascopically monotonous accumulation of generally fine to medium-grained, buff, light gray, and dark gray dolostone. It is uniformly devoid of fauna, and primary sedimentary structures are limited to occasional faint, low-angle cross laminae. Black, blue, and gray to buff chert occurs commonly throughout the formation. Large (>1 mm) oolites occur in roughly the upper and lower thirds of the section, often in conjunction with replacement chert.

The differentiation of the Copper Ridge into locally mappable upper and lower members (see Rodgers, 1953 and Bridge, 1956) is generally supported by this study. With minor exceptions, the lower portion is generally darker gray and more massive than the upper, lighter gray and more thinly bedded portion. The reported asphalcic nature of the lower portion is not striking but can be recognized when water on core beads up around isolated asphaltic points.

Detailed core examination reveals substantial internal facies variation within the generally monotonous Copper Ridge. Three basic facies types are recognized that form repetitive, asymmetric, upward-shallowing cycles on a 1-4 m scale. Cycles are internally gradational and commonly contain only two of the three facies types. Transgression is recognized as a bedding plane of nondeposition or erosion separating aggradational cyclic deposition. Similar cyclicity has received extensive treatment in the literature (ie. Aitken, 1966, Wilson, 1967, Mossop, 1973, Read, 1973, James, 1979, Goodwin and Anderson, 1985, and Grotzinger, 1987). A more complete description of the implications of these cycles on stratigraphic correlation and groundwater flow will be presented later.

Cycles containing similar combinations of facies types recur throughout the section, each cycle possessing a nearly unique signature that distinguishes it from others. In addition, the typical occurrence of incomplete cycles complicates cycle interpretation and illustration. Therefore, an idealized cycle is presented in Figure 5 which includes paleoenvironmental interpretations for each facies type within the overall shallow marine, peritidal Copper Ridge depositional setting. In Figure 6 the bottom of the overlying cycle and the top of the underlying cycle are included to illustrate the diversity of characteristics that define each facies type. Portions of the overlying and underlying cycles are included in Figure 5 to illustrate that criteria used to define one cycle may not necessarily apply to those adjacent to it. Illustrations of representative cycles will be provided as examples.

Facies type 1 forms the cycle tops in several distinct portions of the section principally in the upper Copper Ridge. It is a medium-bedded, fine-grained to aphanitic, light gray dolostone weathering buff. Cryptalgal laminites and fenestral fabric are common. Obscure vertical burrows or dewatering features may occur. Shale occurs almost exclusively in this facies type as discrete thin beds, densely arrayed partings, or distinct thin irregular partings. Flat-pebble breccia, consisting of small angular or

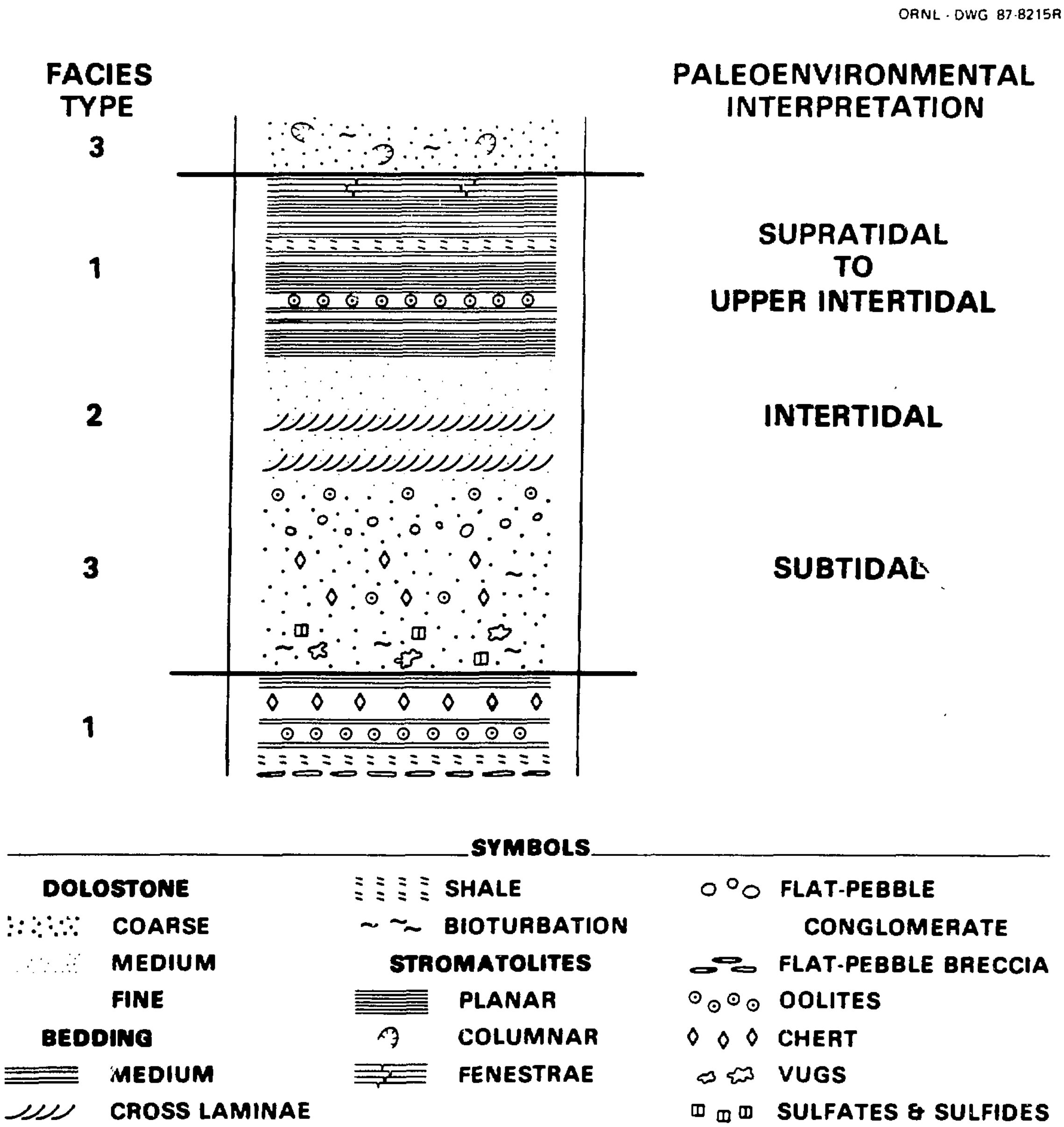

Figure 5. Idealized Copper Ridge Dolomite upward-shallowing cycle.

elliptical intraclasts, occurs when the facies is well-represented in the section. Thin oolitic zones are common, but unlike those in facies type 3, they are seldom associated with chert occurrence. Chert is most often light gray, buff when the facies type is weathered buff, or blue and occurs in thin (roughly 2 to 5 cm thick) zones. This facies type is interpreted to represent upper intertidal to supratidal deposits that may include tidal pond deposits.

Facies type 2 occupies the middle position in the idealized cycle but in different portions of the section may also form the bottom or top facies in the cycle. It is fine to coarse-grained. When coarse-grained and overlying facies type 3 deposits at cycle tops, it is dark gray; when fine-grained and underlying facies type 1 deposits at cycle bottoms, it is typically lighter gray. The facies type is quite uniform internally, current-winnowed, and possesses few internal features beyond an occasional hint of small-scale, low-angle, cross lamination. Discrete chert lenses or beds are lacking. Environmentally shallower than facies type 3, subject to the effects of wave and current action, this facies type is considered to represent upper subtidal to lower intertidal deposits.

Facies type 3 occurs most frequently in the lowermost portion of the Copper Ridge. It is generally coarser grained than facies types 1 and 2, dark gray, massive, and bioturbated or faintly laminated. In one distinctive portion of the section, the facies type is characterized by relatively thick accumulations of columnar stromatolites similar to those described in the upper Knox Mascot Dolomite (Harris, 1969). Large flat-pebble conglomerate may occur throughout the facies type. Chert is typically black and occurs as distinct 5 to 10 cm thick zones often replacing oolites or as roughly 10 cm diameter nodules. Sulfate and sulfide minerals occur infrequently in a limited portion of the section. Large (>1 cm) vugs often containing well-developed replacement dolomite rhombohedra are common. This facies type is considered to represent restricted subtidal deposits below wave base.

Stratigraphy

Units for stratigraphic position and core thickness are reported in downhole feet. This convention allows more ready comparison of stratigraphic position both between cores and between core and geophysical logs.

This study applies an episodic stratigraphic model to accomplish physical stratigraphic correlation. The interpreted shallow platform deposits of the Copper Ridge are conducive to the application of the model in that relatively small changes in the paleodepositional base level are seen commensurately as distinct vertical facies changes in the stratigraphic record. The model assumes that cycles represent gradual, upward-shallowing deposition (aggradation) during periods of slightly lowering or static base level and are separated by nondepositional or erosional discontinuities representing relatively rapid base level rise (transgression). For purposes of stratigraphic correlation, these discontinuities represent geologically instantaneous events that enable precise physical correlation to the bedding plane level. The implementation of this detailed correlation as it pertains to groundwater flow is the subject of the next section.

Stratigraphic overlap was achieved between core holes #4 & #5 for a coring interval of 162 feet and between core holes #3 and #4 over the 210 feet interval of hole #3. Since core recovery in core hole #3 was poor to nonexistent, extracted core is extremely weathered and fractured, and geophysical logging tools could not be lowered into the core hole, detailed stratigraphic correlations cannot be reliably conducted over this interval. In holes #4 and #5, acquisition and detailed observation of rock core allowed for excellent correlation to be achieved beyond that available from geophysical logs alone.

Relationship Between Groundwater Movement and Stratigraphy

Rock core observations, augmented by geophysical log analysis, indicates that groundwater movement in the Copper Ridge is directly related to the recurrence of stratigraphically correlative facies type 1 deposits. Fracturing and weathering at depth occurs soly in facies type 1 deposits. Similar fracturing and weathering in facies types 2 and 3 deposits is limited to occurrences near the weathered/unweathered interface and when bounded by weathering of facies type 1. The frequency of geophysical evidence of fluid invasion is significantly higher in facies type 1 deposits than facies types 2 and 3 combined. Fluid invasion of facies type 1 deposits is also stratigraphically continuous whereas fluid invasion of facies types 2 and 3 appears to be stratigraphically localized.

Ketelle and Huff (1984) and Pin et al. (1984) report representative hydraulic conductivity in unweathered rock on West Chestnut Ridge to be 1 x 10E-4 cm/s which is similar to the measured hydraulic conductivity in the overlying weathered rock. The unweathered rock permeability is attributed to flow in fractures and/or open bedding planes.

Long/short Normal Resistivity Logs

Long/short normal resistivity geophysical logs provide information regarding the hydraulic conductivity of rock units. Separation between the long and short normal resistivity log traces indicates fluid invasion of the logged interval (Asquith, 1982). In the Copper Ridge long/short normal resistivity trace deflections occur in areas representing both primary and secondary lithologic features.

Provided below are examples of the dominantly recurring secondary lithologic features exhibiting significant long/short normal resistivity deflections and their associated primary lithologic features. Each example is accompanied by a figure illustrating the long/short normal resistivity anomaly, its correlative gamma ray log trace, and a lithologic drawing of a representative cycle within the illustrated interval.

Figure 6 shows a major long/short normal resistivity anomaly in core hole #2 between 690 and 640 feet. The interval is dominated by cycles with thick accumulations of facies type 3 containing extensive unremineralized, cm-scale vugs overlain by thin, medium-grained facies type 2 deposits. The lack of character of the gamma ray trace illustrates the overall facies uniformity in this portion of the Copper Ridge. The long/short normal resistivity anomaly is presumed to be identifying fluid invasion within the vugs. By contrast, the two cycles above the 640 feet depth that are lithologically similar to those between 640 and 690 feet lack well-developed vugs and possess no corresponding long/short normal resistivity anomalies.

Higher in core hole #2, Figure 7 shows most of a distinctive lithologic sequence that occurs in the Copper Ridge between 340 and 280 feet. The sequence is comprised of cycles with bioturbated columnar stratomatolites (facies type 3) underlying light gray, fine-grained facies (facies type 1) with cryptalgal laminites, fenestral fabric, and shaley partings. The long/short normal resistivity deflections correspond to the shaley partings in the fine-grained facies, seen as deflections on the gamma ray trace, as well as bedding-normal fractures.

Examination of four cores, recovered from similar stratigraphic intervals as core #2 (Haase, et al., 1987), suggests this distinctive lithologic sequence may be a good stratigraphic marker. Core hole locations are from 1.6 km (1 mile) to nearly 14.4 km (9 miles) northeast of the West Chestnut Ridge study area. Unlike core #2, the fine-grained, laminated facies at the top of the interval from 2 of these 4 cores are fractured and weathered. Depth comparisons of all 5 correlative intervals indicates that, with one exception, weathering is directly related to depth. This suggests that deep weathering represents infiltration through the weathered/unweathered interface and that along strike flow may supercede or complement down dip flow.

Two abrupt long/short normal resistivity anomalies from 640 and 632 feet in hole #4 are shown in Figure 8. The anomalies occur in medium-grained, current winnowed facies type 2 deposits at cycle tops exhibiting extensive fracturing now recemented with dolomite. Pyrite is abundantly incorporated around the recrystallized dolomite. The occurrence of these long/short normal resistivity anomalies is not fully understood. A similar dolomite and pyrite recrystallized fractured zone occurs at 655 feet but has no associated long/short normal resistivity anomaly. In addition, many bedding planes possess pyrite mineralization on disarticulated surfaces. It is anticipated that they too would exhibit long/short normal resistivity deflections when none exist. At this time we can only observe that geophysical logs do not indicate ubiquitous fluid invasion in fractured and dolomite/pyrite recrystallized facies type 2 deposits.

The last long/short resistivity anomalies, Figure 9, are in hole #4 between 316 and 284 feet and include the lower portion of the stratigraphically overlapped interval with hole #5. These anomalies and their associated gamma spikes represent either 5 to 10 cm thick shale beds or 5 to 10 cm thick zones of densely arrayed thin shale partings in fine-grained facies type 1 deposits at cycle tops. In the cycle selected for illustration in Figure 9, the fine-grained facies is weathered, buff-colored, and contains iron stained coatings on shaley partings and algal laminae. Mineralogical analysis indicates the iron staining results from the weathering of pyrite, presumed to occur throughout the section.

Of the 49 discrete long/short normal resistivity anomalies or anomaly clusters identified in this study, 6 occurred in facies type 3 deposits with well-developed vugs, and 3 were in facies type 2 deposits with dolomite/pyrite healed fractures. The remaining 40 long/short resistivity

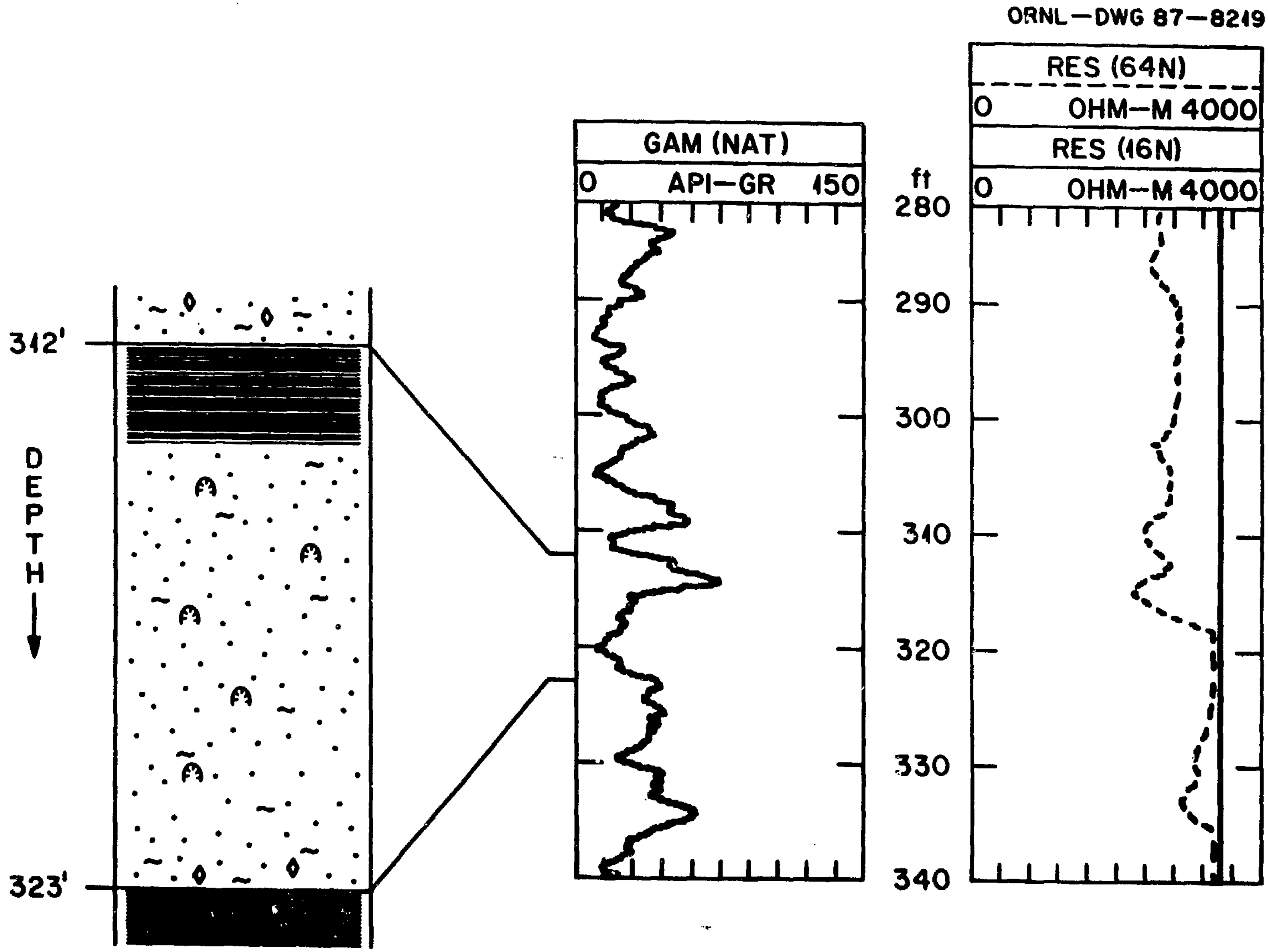

Figure 7. Long/short normal resistivity anomaly; 334-284 feet in core hole #2.

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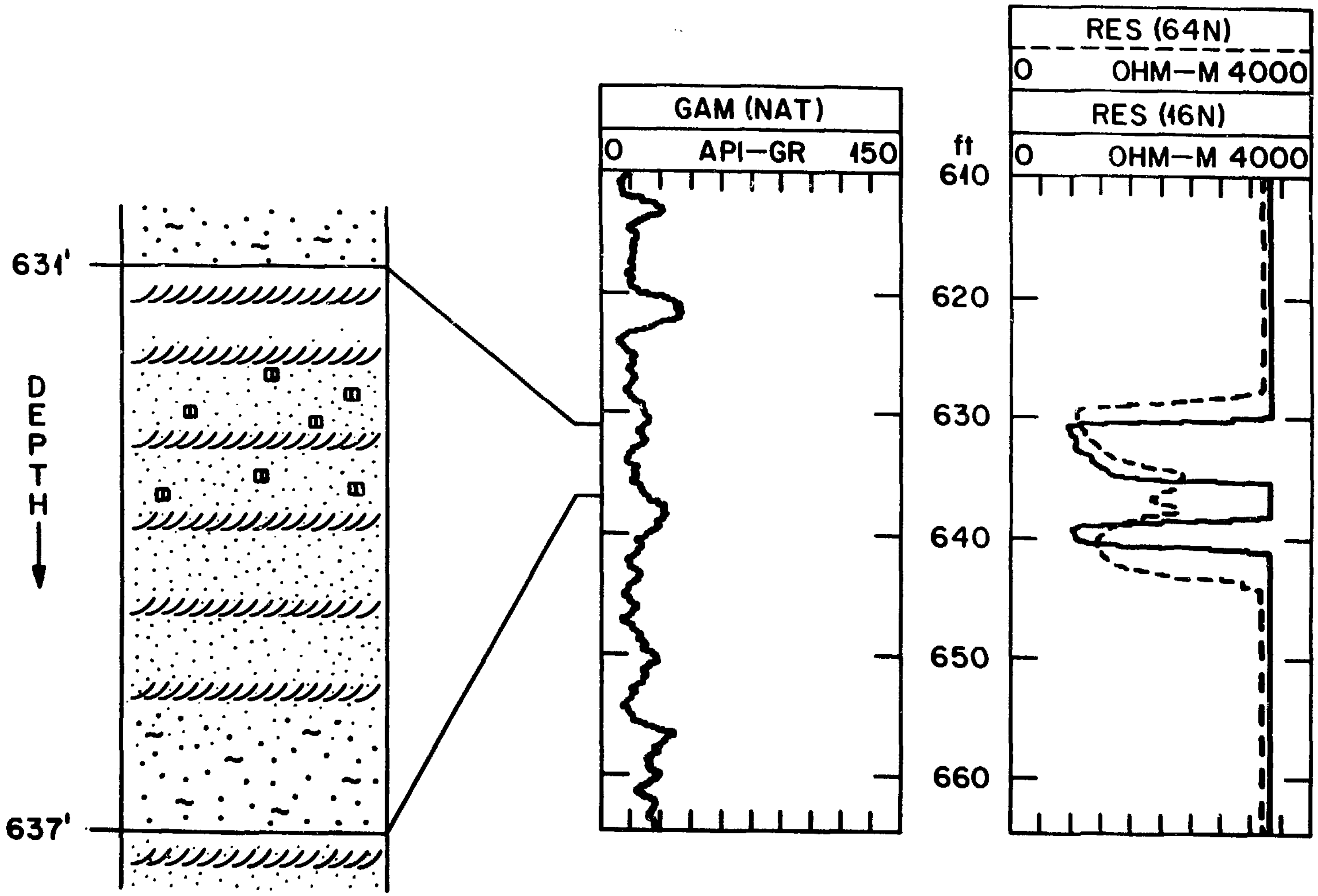

Figure 8. Long/short normal resistivity anomalies; 640 and 632 feet in core hole #4.

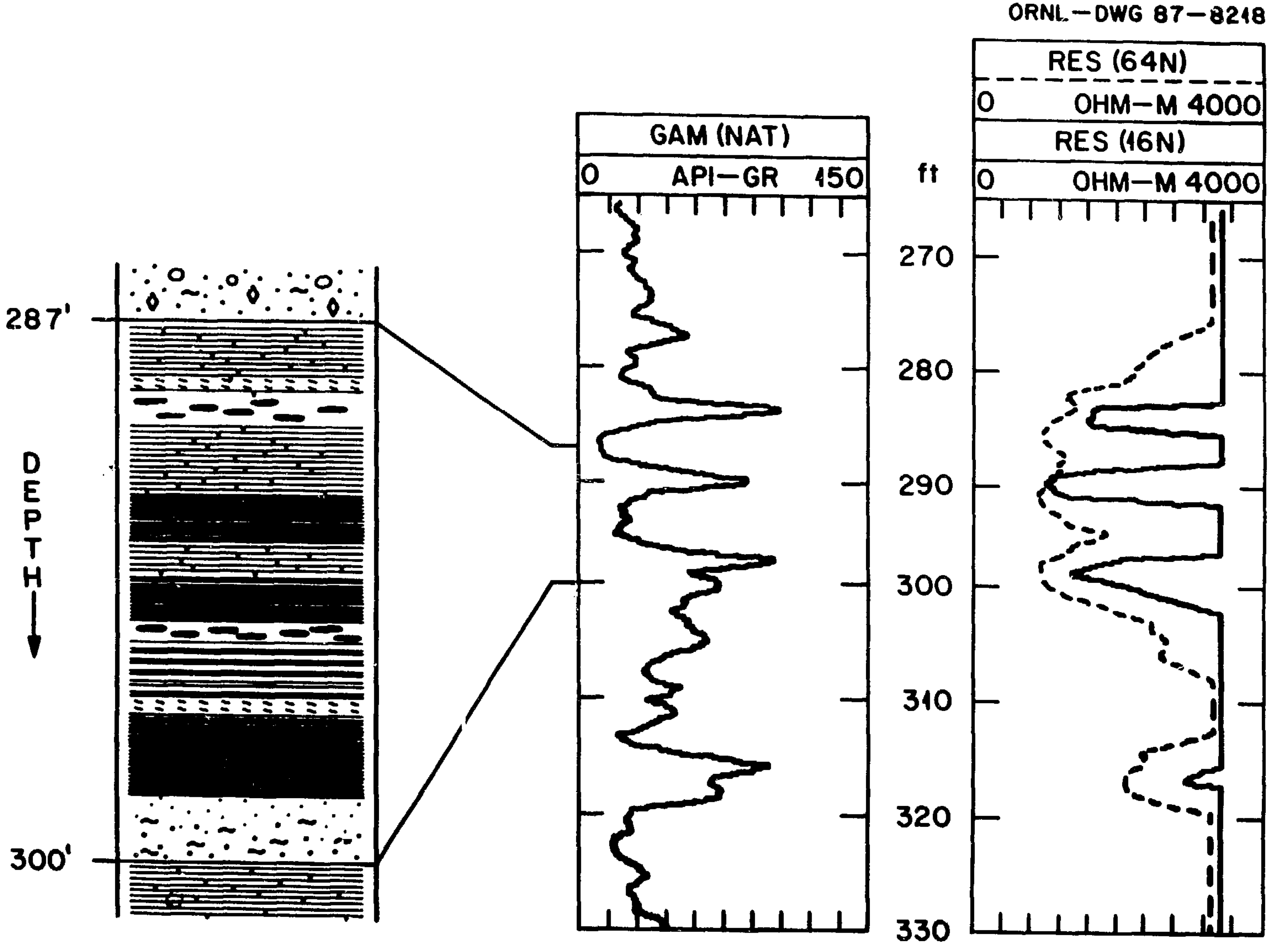

Figure 9. Long/short normal resistivity anomalies; 316-284 feet in core hole #4.

anomalies were in fine-grained facies type 1 deposits with thin shale beds or densely arrayed shale partings, bedding plane fractures along thin shale partings, bedding-normal fractures, or offset fractures.

Preliminary examination of geophysical logs accompanying the four cores located northeast of the West Chestnut Ridge study area reveals the presence of three prominent groups of long/short normal resistivity anomalies. The cores from these borings were examined to determine the stratigraphic continuity of the facies corresponding to the prominent anomalies.

The three long/short normal resistivity anomalies occur in the lower Copper Ridge at roughly 30 to 50 feet spacings. Their shallowest occurrence ranges from 310 to 550 feet in the four logs. The anomalies correspond to thin shale beds. densely arrayed shale partings, or disseminated shaley fine-grained facies type 1 deposits, similar to those illustrated in Figure 9. These facies may be the asphaltic beds described by earlier workers. The core is fractured along bedding planes separated by shale partings, and some contain unremineralized, small-scale offset fractures. None exhibit evidence of weathering. Although the detailed characteristics of the shaley, fine-grained facies vary from core to core, as do the magnitude of the corresponding long/short normal resistivity anomalies, their lateral continuity is remarkable on geophysical log and supports the indications from this study that groundwater flow is confined to narrow stratabound pathways.

Fluid Resistivity Logs

Two major fluid resistivity anomalies were recorded during geophysical logging of the core holes that correspond with the occurrence of facies type 1 deposits. The fluid resistivity, long/short normal resistivity, and natural gamma traces are illustrated in Figures 10 and 11. The apparently discontinuous fluid resistivity traces result when the plotting pen recycles to accommodate values outside the range of the initial scale settting. The fluid resistivity traces are continuous. Actual ohm-meter values are included at selected depths in the figures for reference.

The first fluid resistivity anomaly, Figure 10, begins at 490 feet and equilibrates at 522 feet in core hole #2. The log shows that fluid resistivity equilibrates immediately below the long/short normal resistivity anomaly minimum and the initiation of gamma trace maximum. The extreme negative deflection of the fluid resistivity trace suggests that the water below 522 feet depth is a brine, and an interface exists that marks the bottom of fresh water at this core hole location.

Core examination offers no compelling lithologic explanation for the fluid resistivity anomaly. Cycles for roughly 40 feet above and below the anomaly are dominated by fine-grained facies type 1 deposits and are distinguishable only in that more clearly defined thin shale partings, identifiable on the gamma log trace, exist above the anomaly. The long/short normal resistivity trace indicates that these shale partings above the anomaly provide discrete horizons of fluid invasion within generally impermeable rock. Below the anomaly, diffusely distributed shale is represented by pervasive fluid invasion throughout the interval. This lower portion is the interval where drilling fluid return was lost and which correlates with the most prominant of the three groups of long/short normal

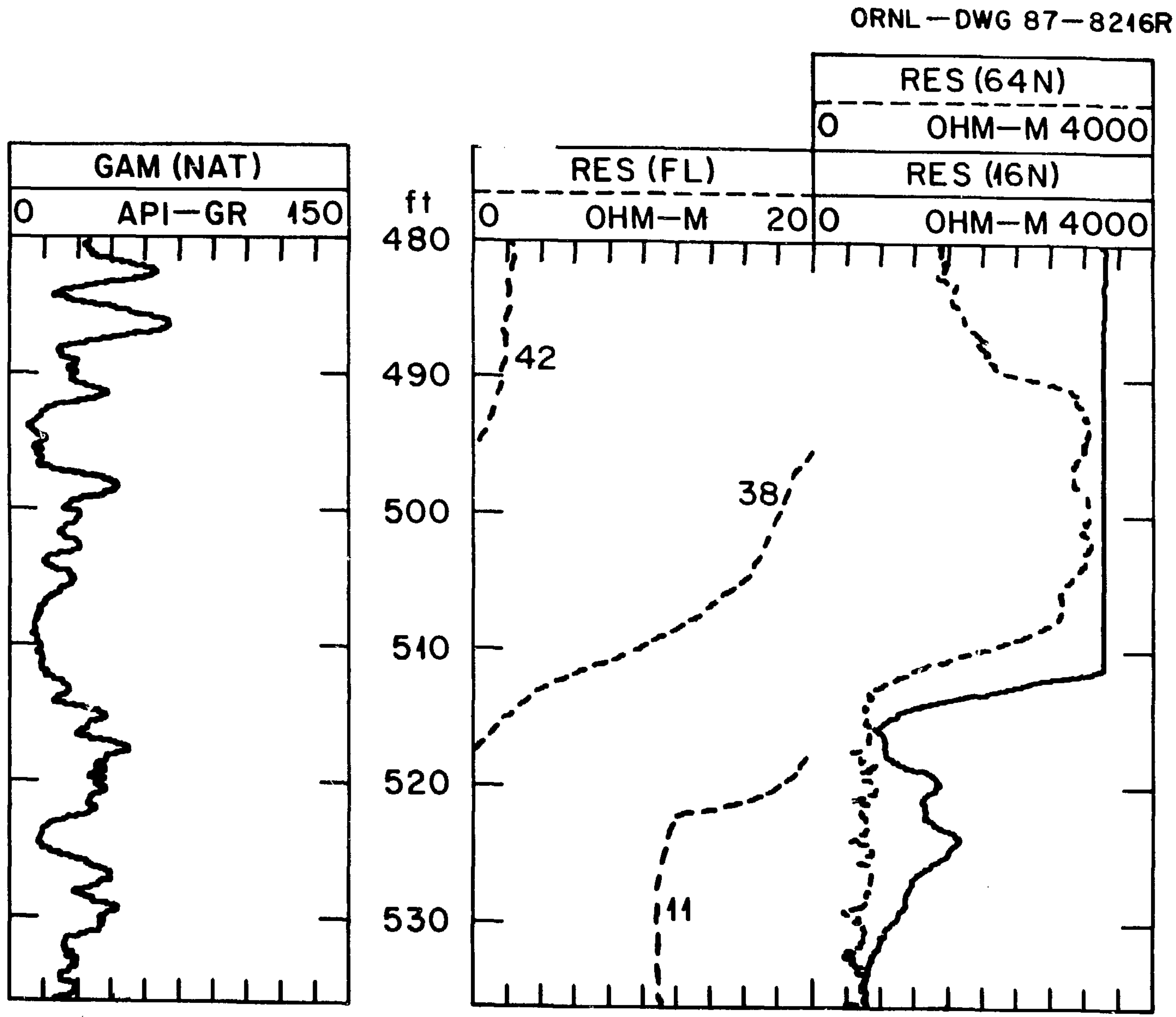

Figure 10. Fluid resistivity anomaly; core hole #2. Ohm-m values are included for reference.

resistivity anomalies from the additional core and geophysical logs discussed above.

The second major fluid resistivity anomaly reaches its maximum value at 522 feet in core hole #5 (Figure 11). The anomaly occurs immediately below a group of long/short normal resistivity anomalies and gamma spikes corresponding to heavily fractured, weathered, fine-grained facies type 1 deposits. The lower portion of this fractured interval correlates precisely with the top of core retrieval, at the weathered/unweathered rock interface, in core hole #4 described previously. It should be noted that core hole #5 used drilling fluid pumped from a nearby creek and was geophysically logged six days after drilling was completed, when the lower portion of the core hole was filled with largely drilling fluid. The fluid resistivity anomaly appears to represent a stratigraphically bound interface between drilling fluid below and groundwater above. This suggests that groundwater is moving from the weathered/unweathered rock interface at 158 feet depth in core hole #4 through cycles with well-represented, weathered, and fractured facies type 1 deposits to a depth of 522 feet in core hole #5.

Stratabound Groundwater Pathways

Figure 12 shows the gamma ray and long/short normal resistivity traces for the complete portion of the section for which stratigraphic overlap was achieved between holes #4 and #5. Correlation was achieved to the bedding plane level through observations of rock core conducted prior to geophysical log acquisi ion. For lack of a precise stratigraphic datum, the logs are hung near the middle of the overlapped section to more readily illustrate and discuss the correlative long/short normal resistivity anomalies. The lines connecting log sets represent correlative cycle boundaries (nondepositional surfaces) and are also included to discuss the long/short normal resistivity traces. Apparent section thickness differences are artifacts of slightly increased structural dip in hole #4. Notice, however, that within the overall structural complexity of the section, individual cycles thicknesses differ slightly.

The prominent long/short normal resistivity anomalies in the lower left portion of Figure 12, between 316 and 284 feet in hole #4, occur in weathered, fine-grained facies type 1 deposits. The correlative long/short normal resistivity anomalies in hole #5 correspond to facies type 1 deposits that are light gray and unweathered. These anomalies are less pronounced than those in hole #4 but suggest that down dip hydrologic communication exists between these core holes in stratigraphically correlative packages.

In the upper portion of Figure 12, the thin shale lenses and fractured facies type 1 deposits in hole #4 occur close to the weathered/unweathered interface. The long/short normal resistivity trace suggests, and core examination confirms, that facies type 2 deposits have been incorporated in the fluid invasion and weathering. At greater depth in hole #5, however, the discrete, thin strata of preferred groundwater flow are readily identified and are limited to the facies type 1 deposits. This is the same stratigraphic interval in hole #5 which contains one of the fluid resistivity anomalies discussed above and illustrated in Figure 11.

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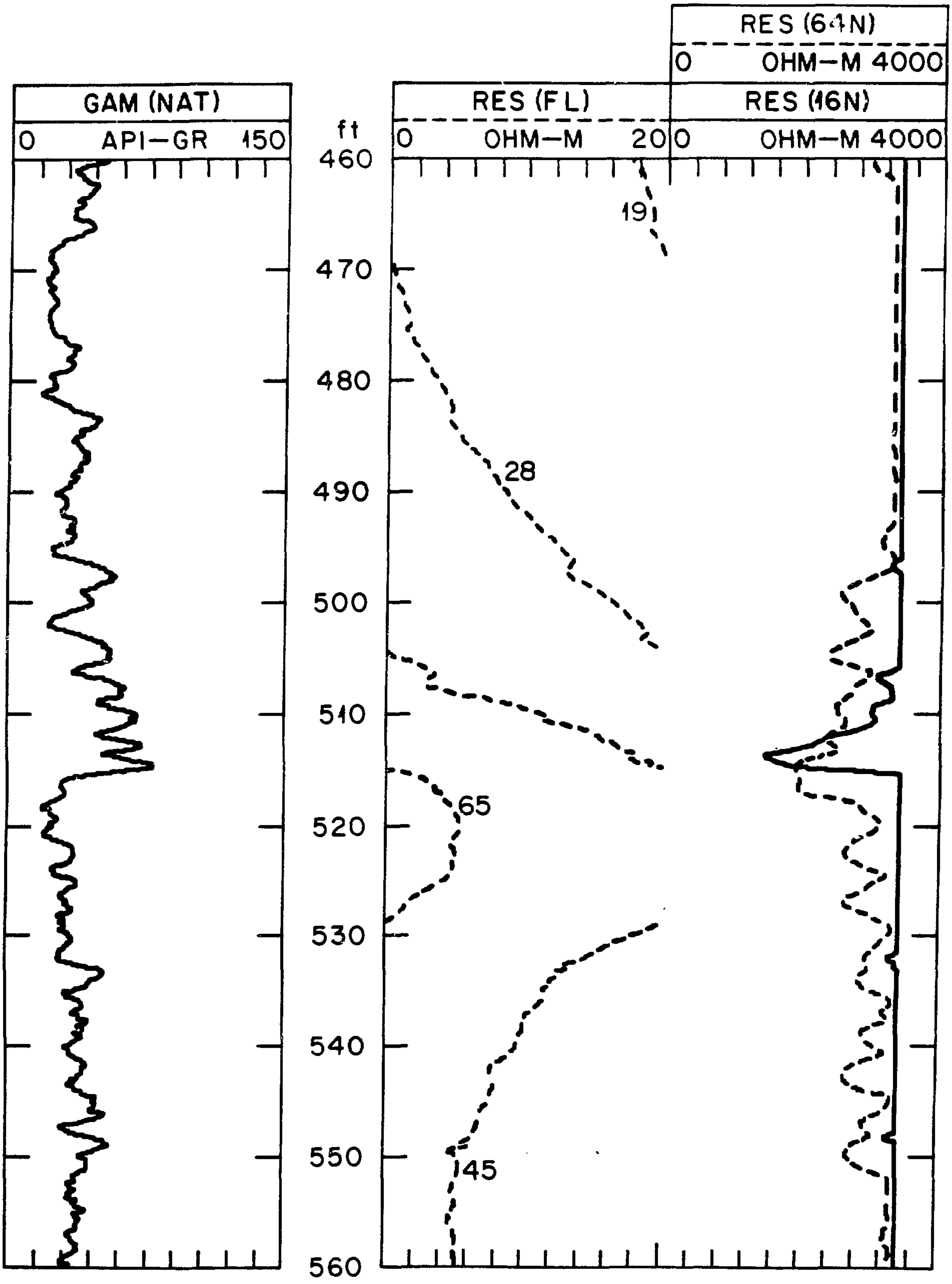

Figure 11. Fluid resistivity anomaly; core hold #5. Ohm-m values are included for reference.

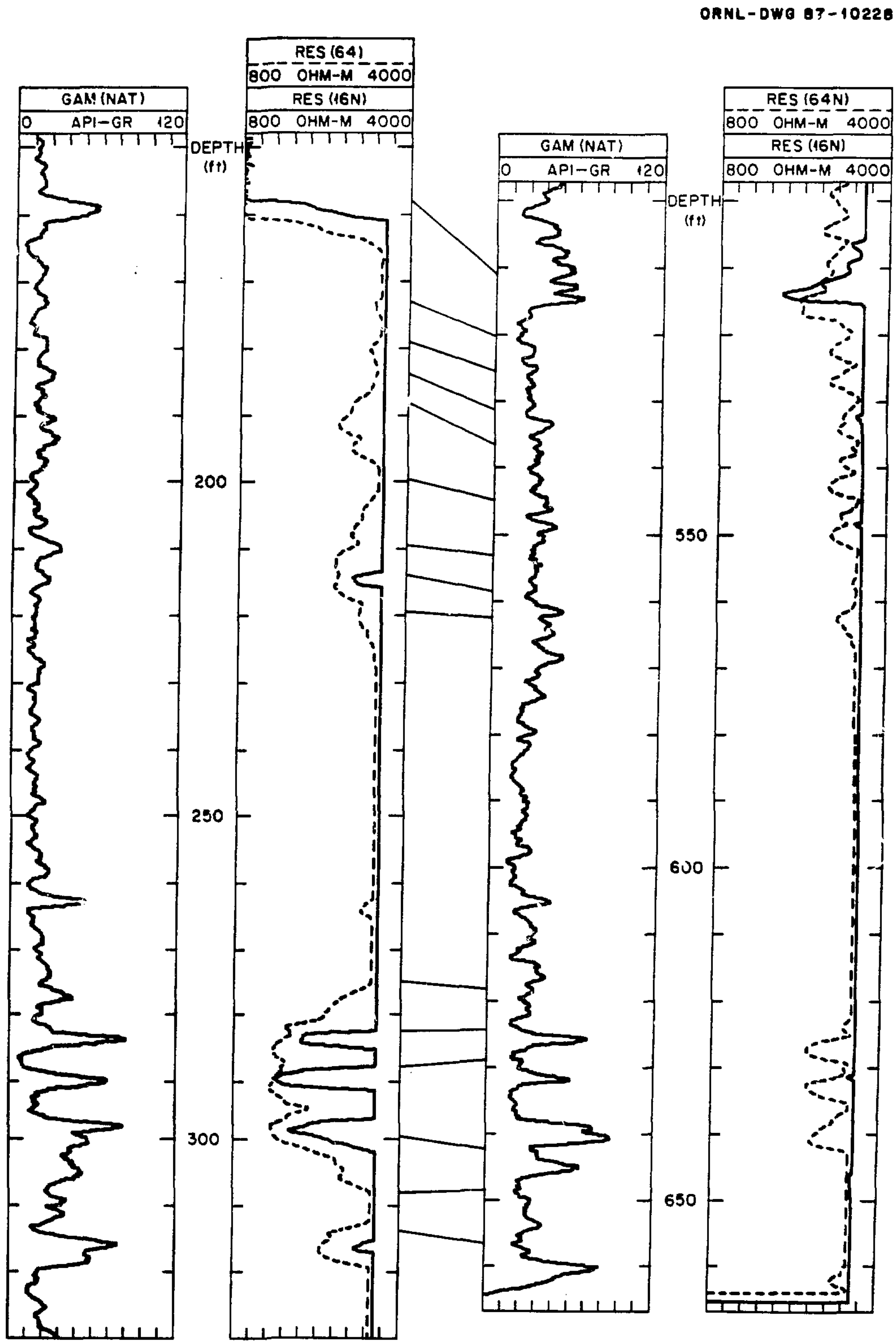

Figure 12. Correlation of long/short normal resistivity anomalies; core holes #4 and #5. Line connecting logs represent some of the cycle boundaries in this part of the section.

Clearly defined weathering characteristics in deep portions of the core are limited to narrow stratigraphic zones confined by the occurrence of well-developed, fine-grained facies type 1 deposits and are considered to be preferential groundwater pathways in the Copper Ridge. Four such pathway zones are identified in the upper Copper Ridge (Figure 13). One, at 284 feet depth in core hole 4, occurs at the bottom of the correlative interval between cores #4 and #5 illustrated in Figure 12. (Reference to Figure 9 shows one of the cycles in this groundwater pathway). Another weathered facies type 1 groundwater pathway, at 522 feet depth in core hole 5, occurs at the top of the overlapped interval illustrated in Figure 12. (Reference to Figure 11 shows the fluid resistivity trace immediately below this pathway). Two additional weathered pathways occur in portions of the section in which no stratigraphic overlap was achieved at 440 feet in core #4, and at 405 feet in core #5.

Two zones of suspected weathering potential are included in Figure 13. The first, at 284 feet depth in core #2, was mentioned briefly earlier and illustrated in Figure 7. Although unweathered, correlative weathered core from locations northeast of this study area makes it a potential weathering horizon. The second is at the top of core #2. It and its correlative interval from additional core are weathered, but their depth near the weathered/unweathered interface makes an interpretation of a deep weathering horizon unreliable. However, since they possess features nearly identical to those in the deeply weathered horizons, they too may be weathered at depth.

The three shaley fine-grained zones with prominent long/short normal resistivity anomalies from the other studies are in the lower Copper Ridge in Figure 13. Although none of the zones is weathered, their occurrence in facies type 1 deposits, their bedding plane fracturing, pervasive stratigraphic continuity, and occurrence immediately below one of the fluid resistivity anomalies from this study, make a compelling case for potential stratabound groundwater flow.

As Figure 13 suggests, the subcropping of stratabound groundwater pathways at the weathered/unweathered interface appears to describe linear traces of preferred aquifer recharge. Infiltration is envisioned to be effectively funnelled from the weathered/unweathered interface down dip through these pathways to the underlying bedrock aquifer. In similar fashion, precipitation is envisioned to be effectively funnelled vertically from the ground surface to the weathered/unweathered rock interface above the pathways to describe linear surface traces of enhanced infiltration.

Conclusions

Specific stratigraphic cycles in the Copper Ridge exhibit primary and secondary lithologic characteristics and weathering features considered to represent recent to ongoing groundwater movement at depth. Below the weathered rock zone, evidence of weathering is most clearly recognized in four discrete horizons with cycles containing well-represented facies type 1 deposits and presumably coincident with the described locally mappable upper member. These horizons are considered to reflect groundwater movement to drilled depths as great as 440 feet.

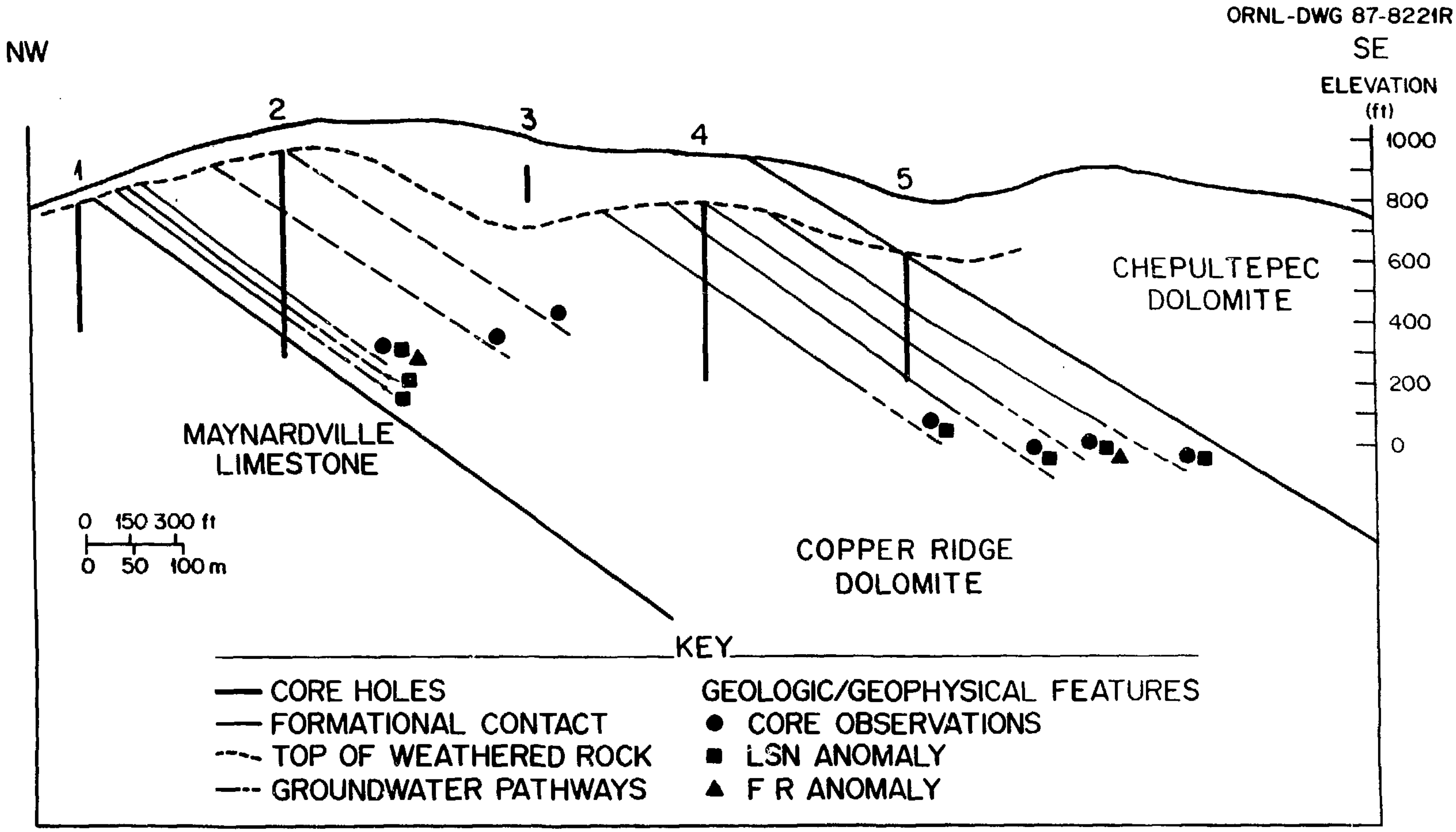

Figure 13. Proposed groundwater pathways. Refer to Figures 10, 12, and 13 for illustrations of representative geologic/geophysical features.

Based on physical correlation with weathered facies in core from other studies, unweathered facies type 1 deposits in the lower Copper Ridge are also considered to be potential avenues of preferred groundwater flow. Geophysical logs of these core holes strongly suggest that three correlative zones, occurring in unweathered facies type 1 deposits, possess pervasive evidence of stratabound fluid invasion. Geophysical evidence also suggests that the occurrence of facies type 1 deposits contributes to, or may significantly control, groundwater geochemistry at depth.

Without the benefit of downhole hydrologic testing, these findings indicate that a comparatively significant down dip stratabound groundwater gradient exists in the Copper Ridge. Discrete lithologic packages have been identified through which groundwater flow appears to be preferentially channeled at depth and which will be targeted for further downhole testing.

On the basis of this study, the following conclusions can be made:

(1) Core observations indicate the Copper Ridge is composed of 1-4 m thick, upward-shallowing cycles within an overall peritidal depositional setting.

(2) Cycles exhibit remarkable lateral continuity over at least the 14.4 km from which core is available for study.

(3) Nine zones with cycles containing well-developed, fine-grained facies type 1 deposits exhibit lithologic and geophysical evidence of preferred groundwater movement at depth.

(4) The subcropping of these zones at the weathered/unweathered interface appears to define positions for preferential, stratabound funnelling of groundwater to depth and linear traces of preferred aquifer recharge.

(5) Vertical projection from the weathered/unweathered rock interface to the surface may describe linear surface traces of enhanced infiltration.

(6) Geophysical evidence suggests groundwater geochemistry may be controlled by the occurrence of weathered facies at depth.

(7) Geophysical evidence suggests a fresh water/brine interface may exist in the lower Copper Ridge that is directly related the lithologic character of facies type 1 deposits.

References

Aitken, J.D., 1966, Middle Cambrian to Middle Ordovician cyclic sedimentation, Southern Rocky Mountains of Alberta; Can. Petrol. Geol. Bull., v. 14, p. 405-441.

Asquith, G.B., 1982, Basic Well Log Analysis for Geologists, The Am. Assoc. of Petro. Geol., Tulsa, OK.

Bridge, 1956, Stratigraphy of the Mascot-Jefferson City zinc district, Tennessee; U.S. Geol. Survey Prof. Paper 277, 76 p.

Goodwin, P.W. and E.J. Anderson, 1985, Punctuated aggradational cycles: A general hypothesis of episodic stratigraphic accumulation, J. Geol., 93,

p. 515-533.

Grotzinger, J.P., 1987, Cyclicity and paleoenvironmental dynamics, Rocknest platform, northwest Canada, Geol. Soc. Am. Bull., 97, p. 1208-1231.

Haase, C.S., G.A. Gillis, and H.L. King, Subsurface Data Base for Bear Creek Valley, Chestnut Ridge, and Parts of Bethel Valley on the U.S. Department of Energy Oak Ridge Reservation, ORNL/TM-10000, April, 1987.

Harris, L.D., 1969, Kingsport Formation and Mascot Dolomite (Lower Ordovician) of East Tennessee: in State of Tennessee Division of Geology, Report of Investigations No. 23, Papers on the Stratigraphy and Mine Geology of the Kingsport and Mascot Formations (Lower Ordovician) of East Tennessee.

James, N.P., 1979, Shallowing-Upward Sequences in Carbonates: in Walker, R.G., ed., Facies Models, Reprint Series, v. 1, Geoscience Canada, 211 pp.

Ketelle, R.H. and D.D. Huff, Site Characterization of the West Chestnut Ridge Site, ORNL/TM-9229, September, 1984.

Mossop, G.D., 1973, Lower Ordovician evaporites of the Baumann Fiord Formation, Ellesmere Island: in Rept. of Activities, Part A, Geol. Survey Canada Paper 73-1, p. 264-267.

Pin, F.G., J.P. Witherspoon, D.W. Lee, J.B. Cannon, and R.H. Ketelle, Radionuclide Migration Pathways Analysis for the Oak Ridge Central Waste Disposal Facility on the West Chestnut Ridge Site, ORNL/TM-9231, October, 1984.

Read, J.F., 1973, Carbonate cycles, Pillara Formation (Devonian) Canning Basin, Western Australia, Can. Bull. Petrol. Geol. Bull., v. 21, p. 38-51.

Rodgers, J., 1953, Geologic map of East Tennessee with explanatory text: Tenn. Div. Geology Bull. 58, Part II, 168 pp.

Wilson, J.L., 1967, Carbonate-evaporite cycles in Lower Duperow Formation of Williston Basin, Can. Petrol. Geol. Bull., v. 15, p. 230-312.

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