Engineering Geology at Nine Mile Point, New York

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INTRODUCTION

The south shore of Lake Ontario for some time has been considered well suited for many industries, among them nuclear power plants. Several plants are currently in operation along the lake shore, and plans for others are being seriously pursued.

As a result of the critical nature of the engineering structures which comprise a nuclear power plant, details of the geology, seismicity, and geohydrology of the plant site are defined to an extent generally not achieved in most geotechnical investigations. In addition, there is a lengthy and intensive peer review involved in the licensing process. This review focuses attention upon site details that might be classified ordinarily as unimportant, covered in recommendations as "our experience" or "our judgement", or in some instances, perhaps forgotten. Although we may not be pleased to "overexplain" many details of our analyses, it is difficult to agree that the discipline is not good for the soul and, in addition, that information ordinarily not available to the geotechnical profession is documented for future use.

The information presented in this report is an attempt to present the consultant's understanding, although somewhat broadly and generally, of the engineering geology at the Nine Mile Point site, developed through approximately 15 years of study. It is emphasized that much of the detailed and fundamental analyses that are performed ultimately in the process of providing design parameters for the facilities are based upon the parameters presented herein. Obviously, however, the details of all the design analyses are beyond the scope of this discussion. Instead, it is important to emphasize that no matter how sophisticated the analyses, ultimately they are dependent upon precise and detailed geologic data concerning the stratigraphy, structural geology, geohydrology, seismicity, and rock stresses. This presentation focuses upon the importance and relationship of the bedrock stratigraphy to the engineering decisions involved in the design and construction of the nuclear facilities at Nine Mile Point, New York.

LOCATION AND REGIONAL SETTING

Nine Mile Point is a promontory located on the southeastern shore of Lake Ontario in the town of Scriba, Oswego County, New York. It is situated approximately 7 mi northeast of the city of Oswego, and is the present site of two operating nuclear generating facilities owned by the Niagara-Mohawk Power Corporation and the Power Authority of the State of New York (Fig. 1).

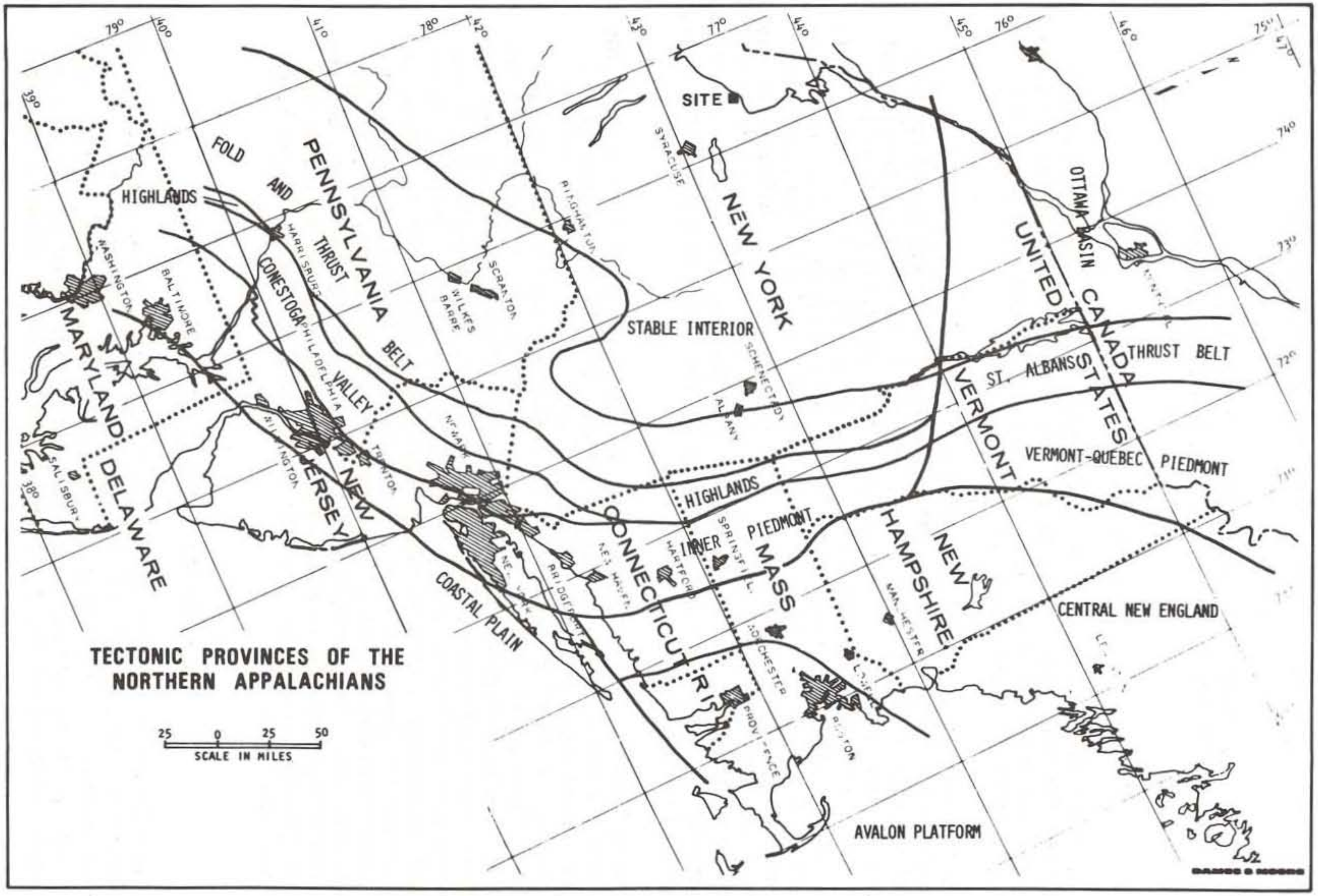

Figure 1. Tectonic provinces of northern Appalachians.

Nine Mile Point is situated within the Erie-Ontario Lowland of the Central Interior Lowland Physiographic Province. The terrain of this province characteristically is flat and gently rolling, controlled by the bedrock surface. The land surface rises gradually to the south and southeast away from Lake Ontario, where, 40 mi distant, the Portage Escarpment is the southern boundary between this province and the Appalachian Uplands. Toward the east, the Erie-Ontario Lowland is bounded by the Tug Hill Upland and the Adirondack Highlands.

Nine Mile Point is located within the Appalachian Plateau Tectonic Province as recognized by the Nuclear Regulatory Commission (Dames & Moore, 1976). This province corresponds to the Stable Interior Tectonic Province defined by Hadley and Devine (1974). The promontory is situated in the northeastern end of the Appalachian Basin, and is bounded on the west, north, and southeast by the Finlay Arch, Canadian Shield and Adirondack Massif, and the Appalachian Fold Belt, respectively.

The region surrounding Nine Mile Point within the Appalachian Basin is composed of sedimentary rocks of Paleozoic age which form a southward-thickening wedge away from the Canadian Shield and the Adirondack Massif (Broughton and others, 1966). The Paleozoic strata have an average regional gradient of 50 ft/mi (9 m/km) to the south-southwest. This gentle gradient corresponds to the southward increase in the depth to basement rocks as shown on the Tectonic Map of the Eastern United States (1962). The approximate depth to basement at Nine Mile Point is 1750 ft (535 m). The tectonic character of the Nine Mile Point region is compatible with the seismic quiescence of this area of New York State.

REGIONAL SEISMICITY OF THE NINE MILE POINT AREA

Nine Mile Point is situated in a region of only minor earthquake activity. The historical record of earthquakes in central New York, through the past 200 years, indicates that only a moderate number of small earthquakes have been recorded in this area, although larger shocks have occurred in the State to the west and northeast. Only minor structural damage has been reported from some of these earthquakes; hence, the absence of any reported earthquakes of Intensity VIII of greater (Modified Mercalli Scale) is indicative of the relative quiescence of the locale.

Locally, no known earthquake activity has originated in the immediate vicinity of Nine Mile Point in historic time. Only minor earthquakes of Intensity III or less (Modified Mercalli) have been reported within 35 to 40 mi (56 to 64 km) of this area (Fig. 2). Beyond this distance, the largest earthquake, reported within 200 mi (322 km), was of Intensity VIII in 1944 near Massena, New York, 130 mi (209 km) to the northeast. Another significant earthquake was recorded in 1929 near Attica, New York, 110 mi (177 km) to the southwest, with a reported Intensity of VII-VIII (probably VII, rather than VIII). There is evidence suggesting that these two earthquakes are each associated with geologic structures. The Cornwall-Massena earthquake seems to have been related to the northwest-trending Gloucester Fault near Massena, New York and Cornwall, Ontario (Dames & Moore, 1974b). The Attica event is associated clearly with the well-known Clarendon-Linden Fault in western New York State (Dames & Moore, 1971; 1974a).

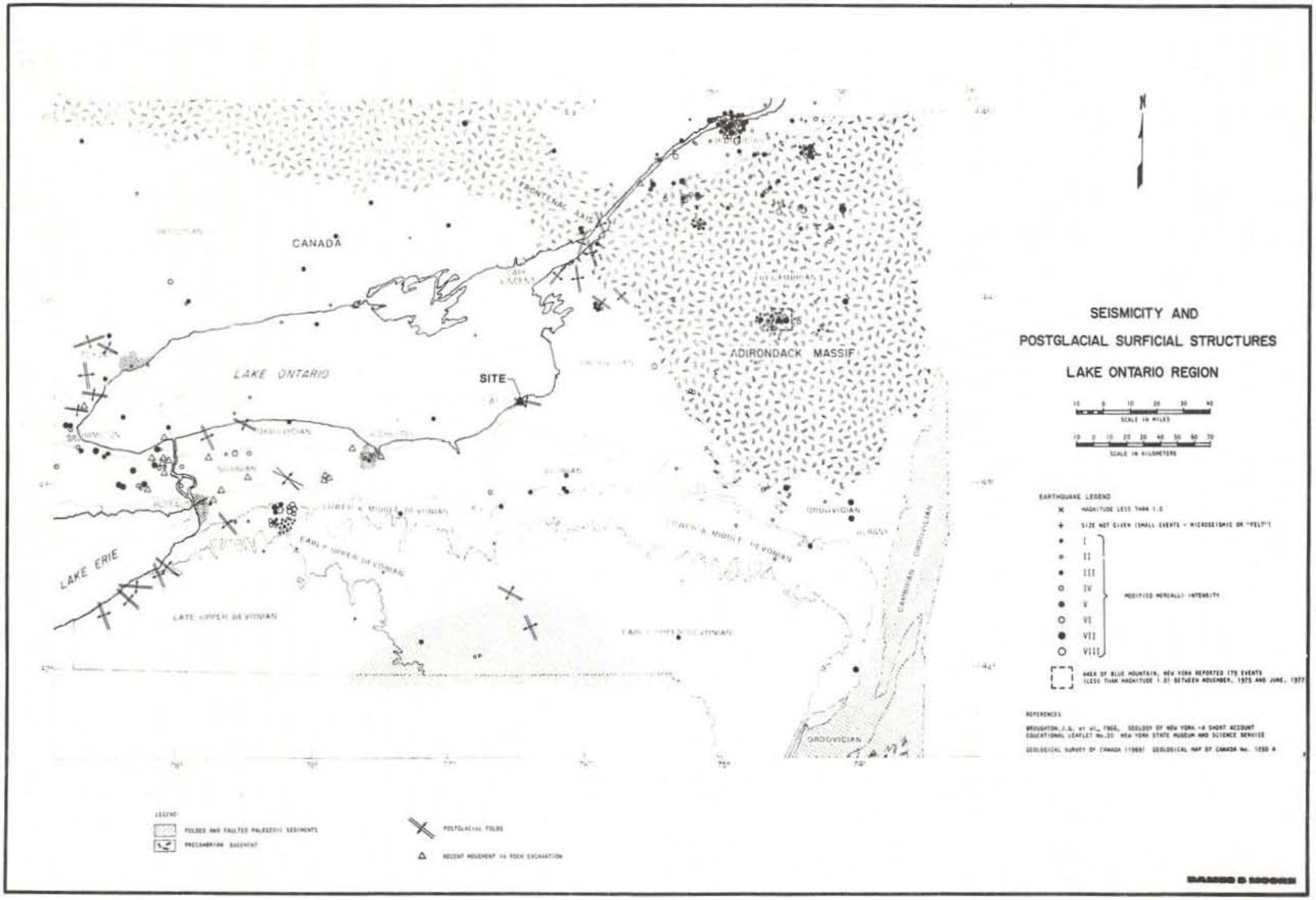

Figure 2. Seismicity and Postglacial surficial structures Lake Ontario region.

Focal plane solutions have been determined recently for earthquakes of small to moderate intensities in western and northern New York State (Fletcher and Sykes, 1977; Yang and Aggarwal, 1977). These solutions indicate high-angle reverse fault movements as associated consistently with the seismic event. The regional stress orientation calculated from these solutions shows a horizontal maximum compressive stress oriented east-northeast. Horizontal stress magnitudes have been measured in the region ranging between 1000 and 2000 lbs/sq in (Rochester Gas & Electric, 1974a, 1974b).

The seismic designs chosen for the two existing nuclear units (and one presently under construction at Nine Mile Point), ranges from 11 to 15 percent gravity (0.11 g to 0.15 g). The early (Unit 1 at Nine Mile Point) recommendation was 0.11 g; the later recommendation of 0.10 g by the consultants for the James A. Fitzpatrick Nuclear Power Plant (PASNY) was raised to 0.15 g by the Nuclear Regulatory Commission (NRC).

STRATIGRAPHY

Bedrock

Drilling at Nine Mile Point provided information concerning the stratigraphy of nearly 375 ft (114 m) of section. Figure 3 represents the stratigraphic section of the study area. Figure 4 is a lithologic log of a drillhole from the site area that is typical of the stratigraphic resolution obtained from the drilling program.

The rocks of the study area consist of sandstone, graywacke, siltstone, and shale which were deposited during Late Ordovician time under transient marine conditions. The entire sequence of rocks is highly variable in short thickness intervals because of complex interbedding of different lithologies; however, there is a general upward gradation toward more sandstone and graywacke and less siltstone and shale.

The rocks which have been expolored at Nine Mile Point belong to three formations. At the surface the rocks are part of the Oswego Sandstone which is characteristically a massive, medium- to coarse-grained feldspathic quartz sandstone, generally well cemented and resistant to erosion. The lowest 10 ft (3.1 m) of this formation represents a transition zone, of thin to medium interbeds of sandstone, graywacke, and siltstone, to the underlying rocks of the upper Lorraine Group.

The rocks encountered in the upper Lorraine Group consist of two formations: the Pulaski Formation and the underlying Whetstone Gulf Formation. The contact between the Oswego and the Pulaski characteristically has been difficult to establish accurately. The first occurrence of fossils traditionally marks the top of Pulaski Formation whereas the Oswego is essentially unfossiliferous. At Nine Mile Point the thickness of the Oswego Sandstone ranges from 60 ft (18 m), decreasing to nearly zero at the southern Lake Ontario shoreline. The Pulaski, below the Oswego, is approximately 100 ft (31 m) thick. The Pulaski has been subdivided into three units by Dames & Moore (Niagara-Mohawk, 1978) which are not

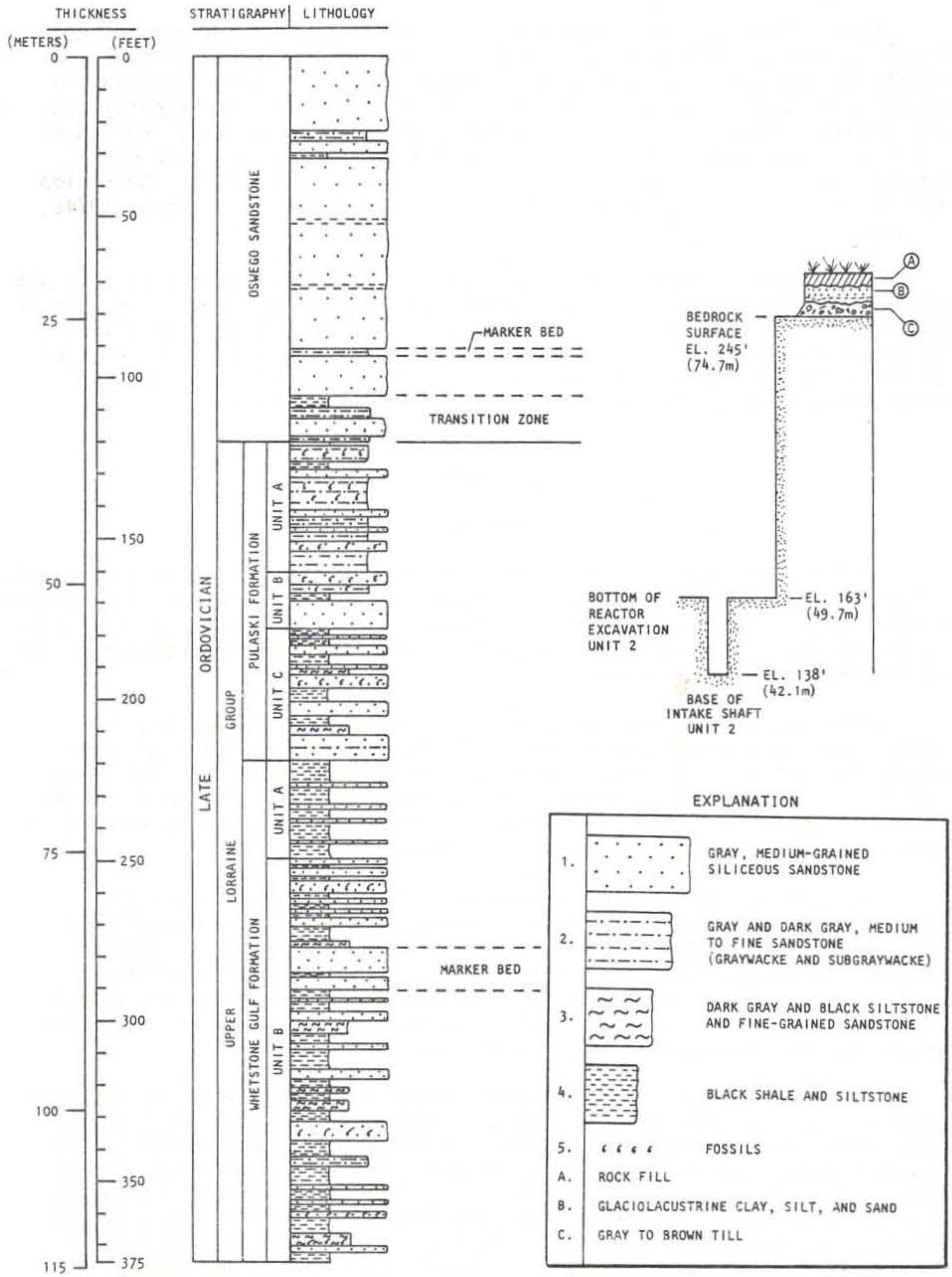

Figure 3. Relationship of stratigraphy at Nine Mile Point to engineering structures.

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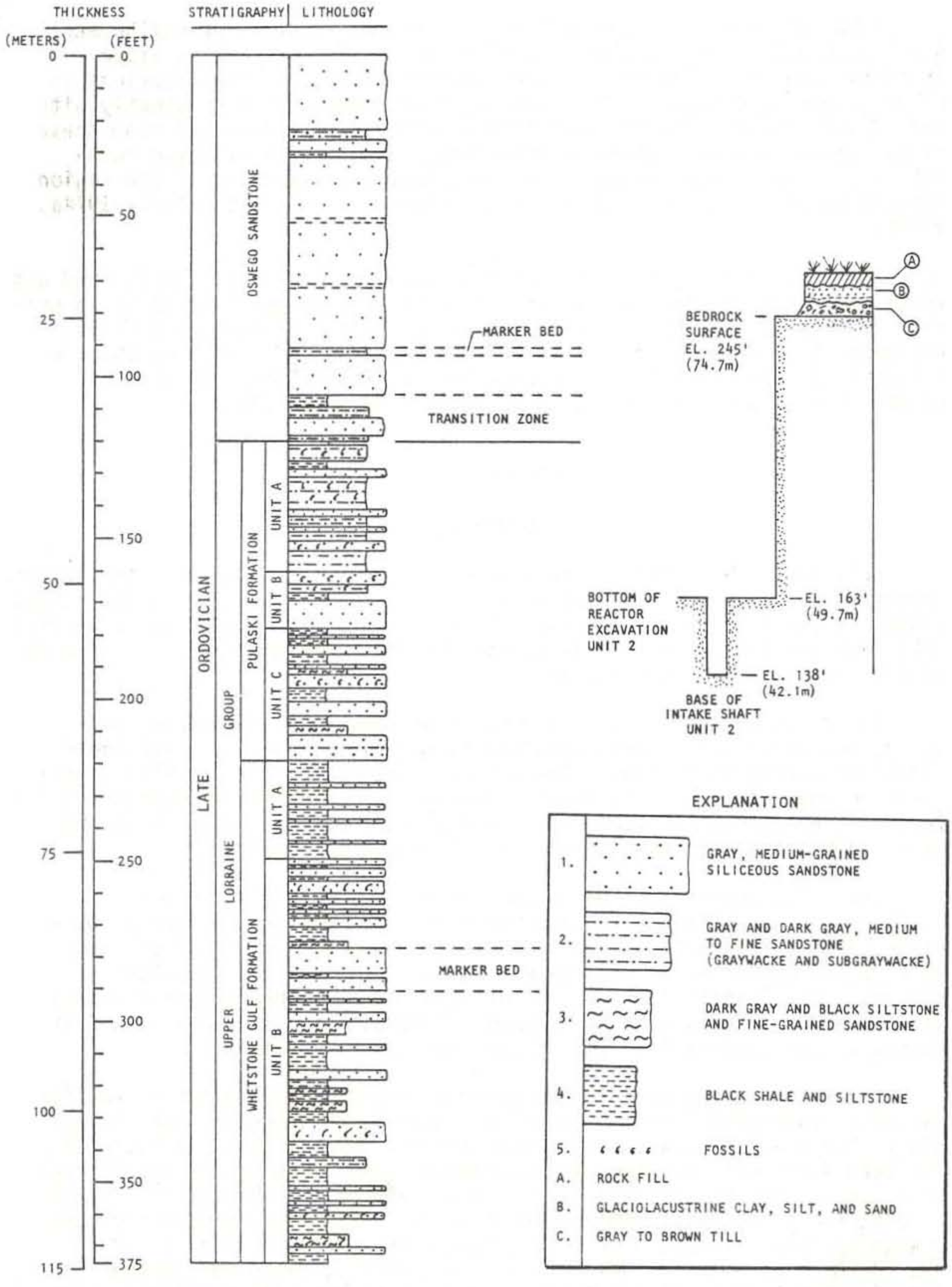

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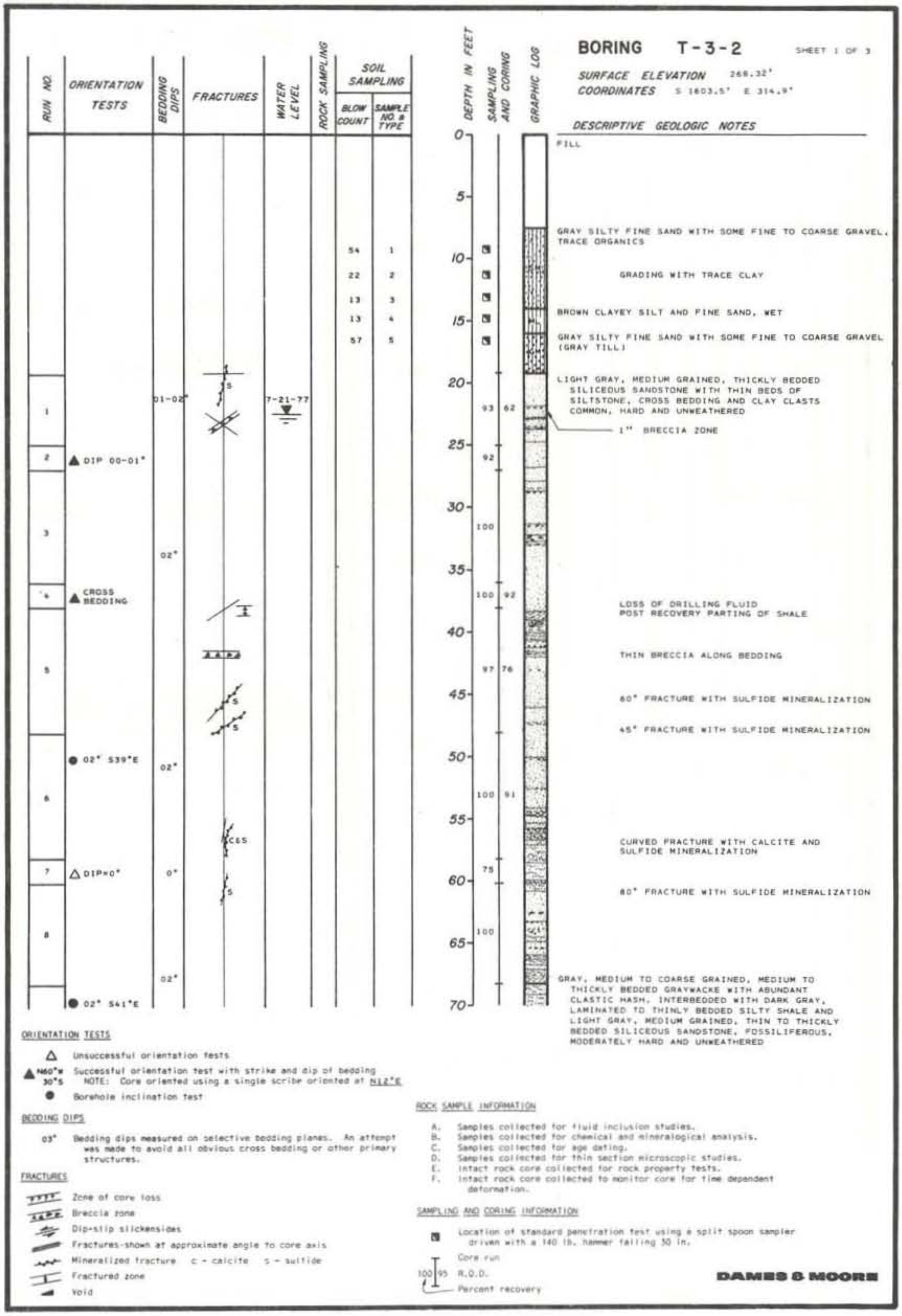

Figure 4. Boring T-3-2 at site.

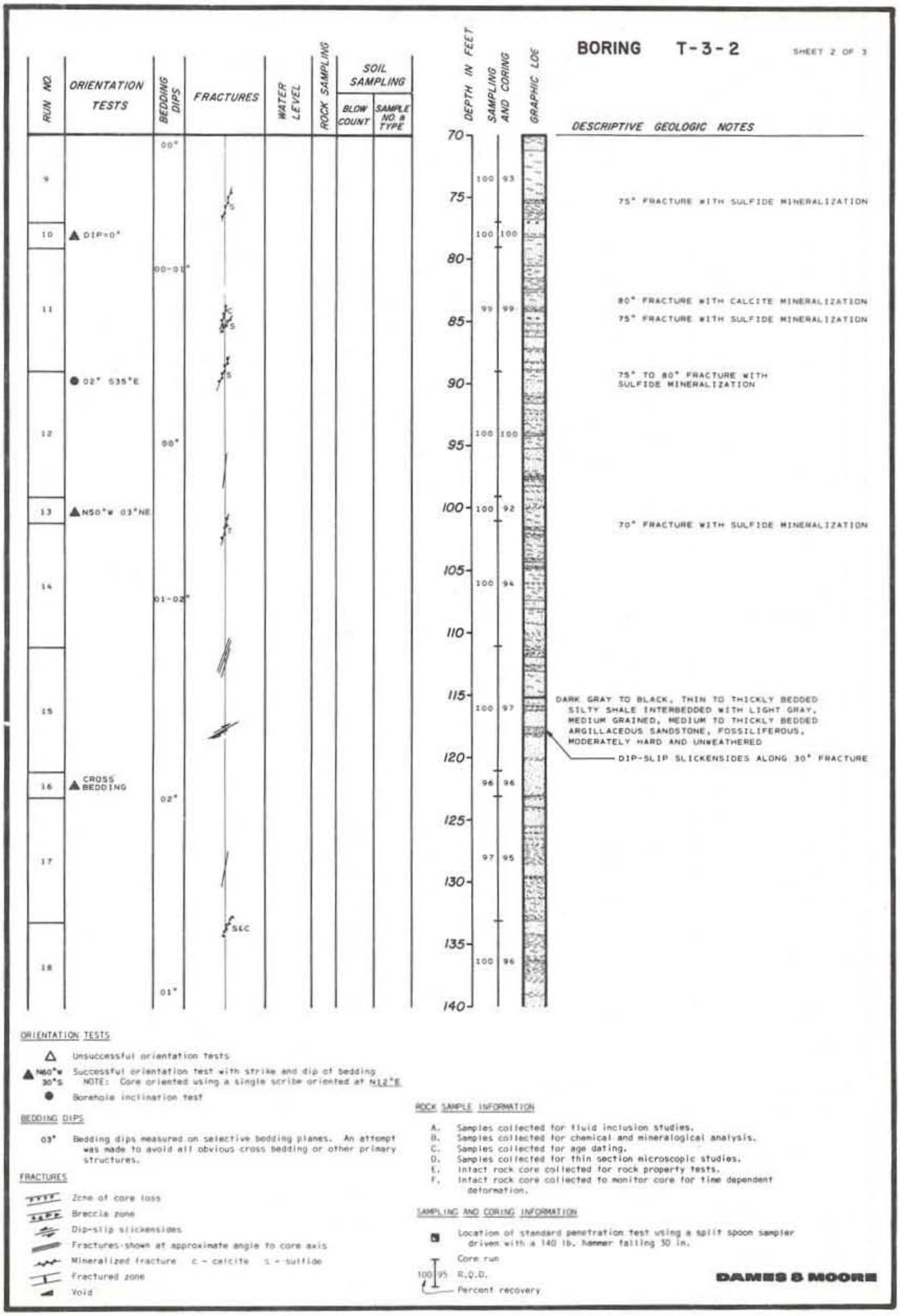

Figure 4. Continued.

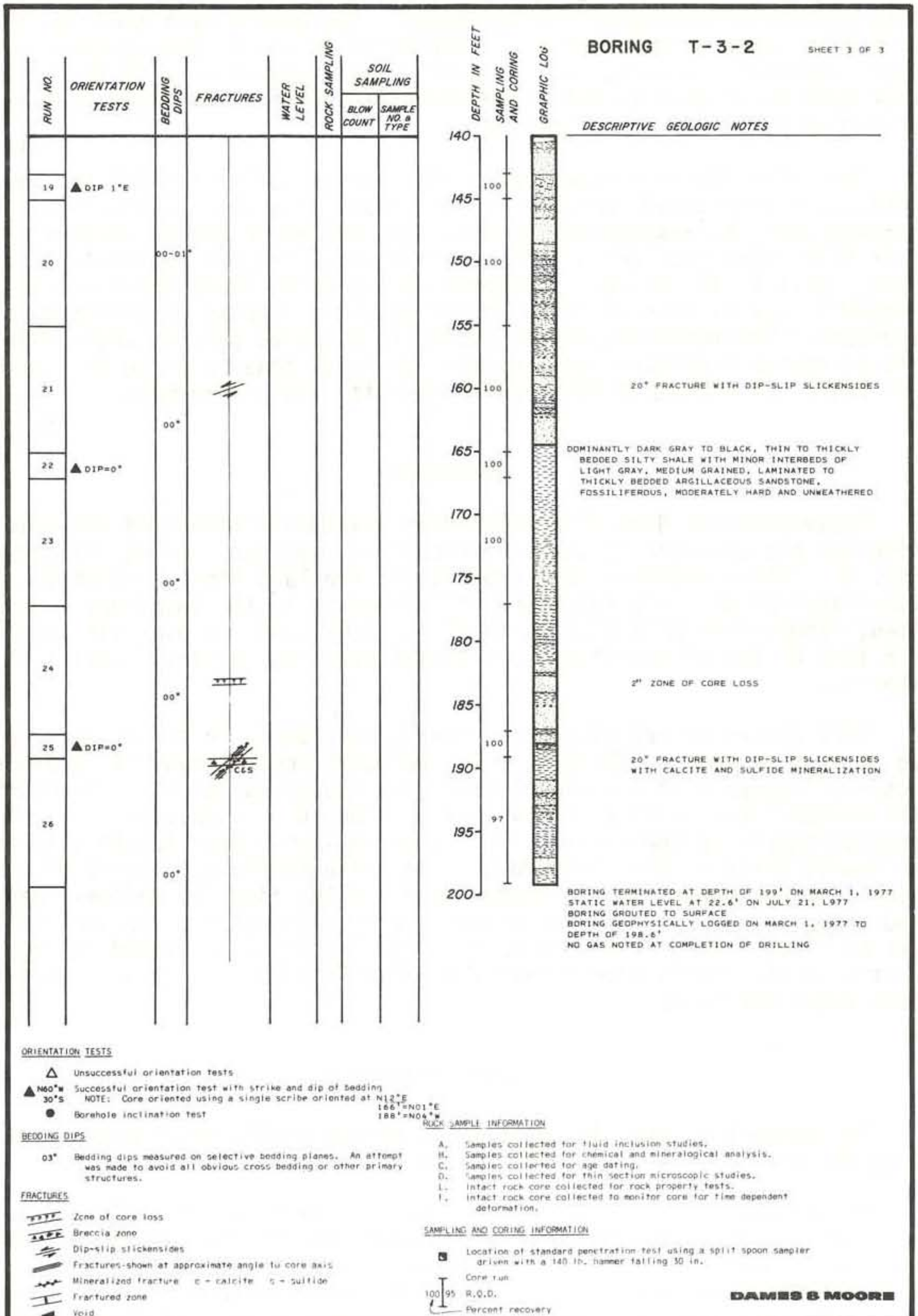

Figure 4. Continued.

recognized on a regional basis. The upper unit (Unit A) is a 40-ft (12 m) thick section of graywacke and sandstone. The middle unit (Unit B) is a 20 ft (6 m) thick section of thick sandstone beds with thin graywacke and shale interbeds. Unit C, at the base of the Pulaski is a 40-ft (12 m) thick section of thin to thick sandstone beds with interbedded shale comprising up to 50 percent of the unit.

The Whetstone Gulf Formation is encountered below the Pulaski, and is marked by a pronounced increase in the amount of shale. The base of this formation was not reached during drilling, but the explored section (150 ft or 46 m) also has been subdivided into two units not regionally recognized. Unit A, at the top, is approximately 30 ft (9 m) thick and is predominantly shale, that is 75 to 80 percent, with medium to thin beds of sandstone. The remaining 120 ft (37 m) is 50 to 60 percent shale with thin to medium sandstone beds, except for local zones 5 to 10 ft (1.5 to 3 m) thick, of medium to thick sandstone with shale interbeds.

Overburden

Excavations at Nine Mile Point have revealed a veneer of variable thickness and composition of glaciolacustrine sediments on top of bedrock (Fig. 5). These sediments are products of the last known glaciation, the Wisconsinan stage. The thickness of sediments, in the locations investigated, ranges from 5 ft (1.5 m) to 20 ft (6 m), and is overlain in places by a foot or two of recent peat, alluvial deposits, or artificial fill material.

Till occurs on top of bedrock nearly everywhere in the study area, and is gray to brown. The gray till typically occurs below the brown and contains fragments of the underlying, gray Oswego Sandstone. The brown till contains many exotic clasts derived from the crystalline rocks of the Canadian Shield to the north. Lacustrine sediments overlie the till in the lowest parts of Nine Mile Point. In these sediments, laminated clay and silt grade upward to crossbedded and rippled fine- to medium-grained sand and massive silt. These sediments are capped at the top locally by peat or fluvial sand of Recent origin. Artificial fill placed in conjunction with construction activity at Nine Mile Point occurs in numerous areas about the site.

GENERAL STRUCTURE

The bedrock at the site is dipping gently southward at a gradient of 40 to 50 ft/mi (7.6 to 9.0 m/km) to the south-southwest.

The bedrock is characterized by two systematic vertical fracture sets (or joints) which have been recognized among other sets throughout central and western New York State. One set strikes N45°W (average) and the other strikes N75°E (average). These joints are best developed in the sandstone, and are discontinuous in that many do not crosscut bedding planes which mark a major change of lithology.

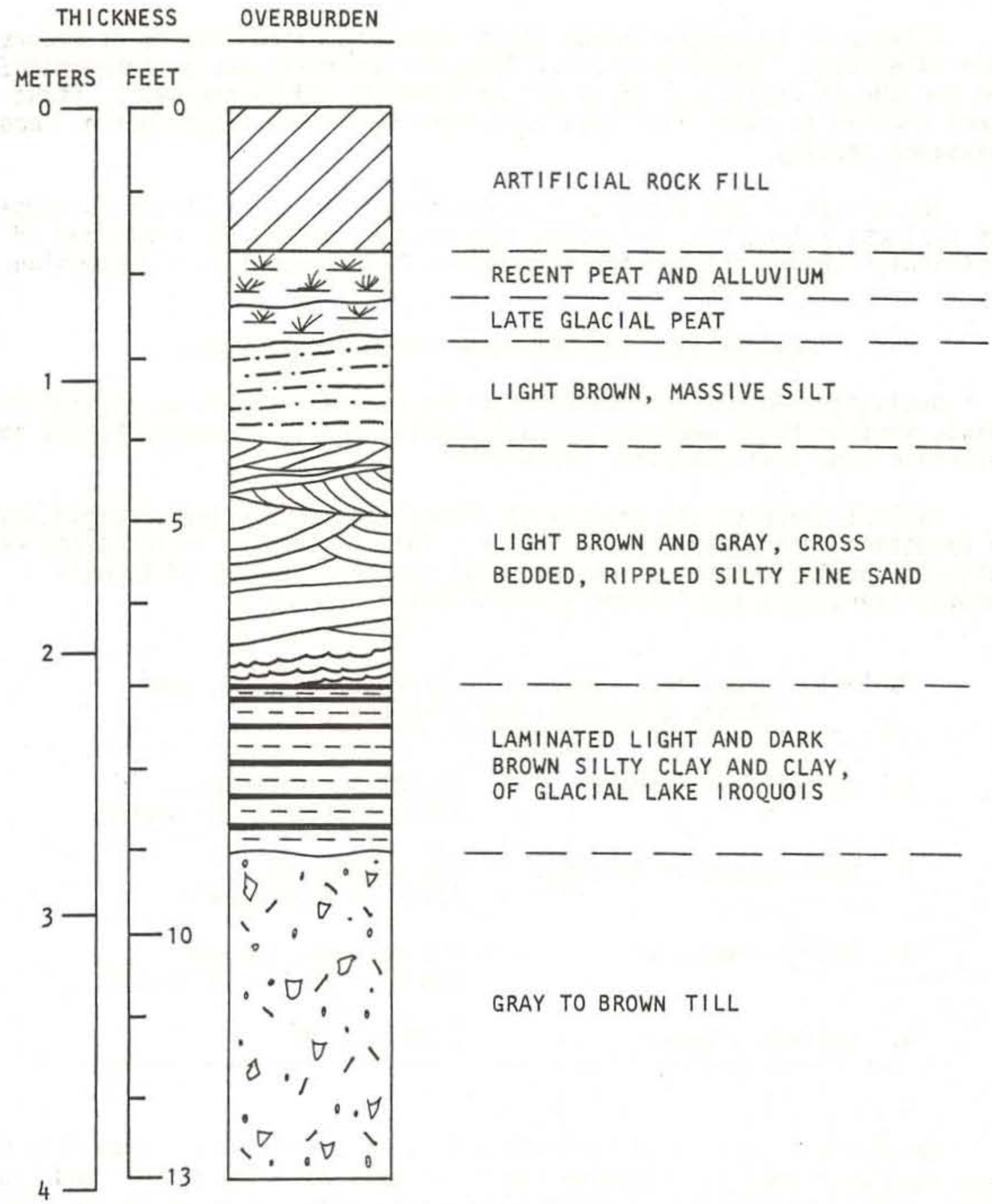

Figure 5. Idealized stratigraphic column of overburden at Nine Mile Point.

Three small high-angle fault structures occur at Nine Mile Point. The faults strike N70°W. Two of them dip 60-70° northward, whereas the third dips southward at 60-65°. The faults are similar in geometry to other structures reported in western New York State, and are not associated with any major tectonic structures in the region. Buckling of the rock in the form of "pop-up" structures has occurred on the two north-dipping faults (Niagara Mohawk, 1978).

A group of low-angle thrust faults and associated drag folds occurs at Nine Mile Point. These structural features generally are oriented N10°E, and the thrust faults dip 15 to 20° to the east and to the west. Structures similar to these also have been observed in the region during reconnaissance mapping.

The origin of the structural development of these features is complex, and reflects a long and varied geologic history of the northeast end of the Appalachian Basin, and therefore is beyond the scope of this discussion.

ENGINEERING PROPERTIES OF GEOLOGIC MATERIALS

During the foundation studies for the nuclear facilities at Nine Mile Point, various tests were run on rock samples and in the bedrock mass to determine some basic physical properties.

Table 1 presents the results of unconfined compressive strength tests on sandstone, graywacke, and siltstone. This table also includes the results of density determinations on these samples. Values of Young's Modulus (vertical) and Poisson's Ratio also are shown.

Table 1. Unconfined compressive strength tests on sandstone, graywacke, and siltstone.

1.	Compressive Strength:	15,200 to 28,700 psi (10.5 + 019.8 x 10^6 Nt/m^2)
2.	Unit Weight or Density:	157 to 167 pcf (2.52 to 2.68 g/cm^3)
3.	Young's Modulus:	4.4 to 9.0 x 10^6 psi (30.4 to 62.1 x 10^9 Nt/m^2)
4.	Poisson's Ratio:	0.08 to 0.24

Geophysical surveys of the site area were carried out. Crosshole surveys were performed to determine the shear wave velocity of soil and bedrock. Uphole surveys and a refraction survey were run to determine the compressional wave velocity of the soil and bedrock. Further testing of drill-core samples was performed with a shockscope to determine the variation of compressional wave velocity with depth.

The shear wave velocity of the overburden averaged 1100 ft/sec (335 m/sec), and of the bedrock averaged 7700 ft/sec (2350 m/sec). The compressional wave velocity of the overburden was approximately 2250 ft/sec (685 m/sec). The results of the uphole and seismic refraction surveys for compressional wave velocities range from 12,500 ft/sec to 14,000 ft/sec for the upper 100 feet of bedrock (3810 m/sec to 4270 m/sec for 31 m of bedrock). Figure 6 illustrates the results of the shockscope tests. This

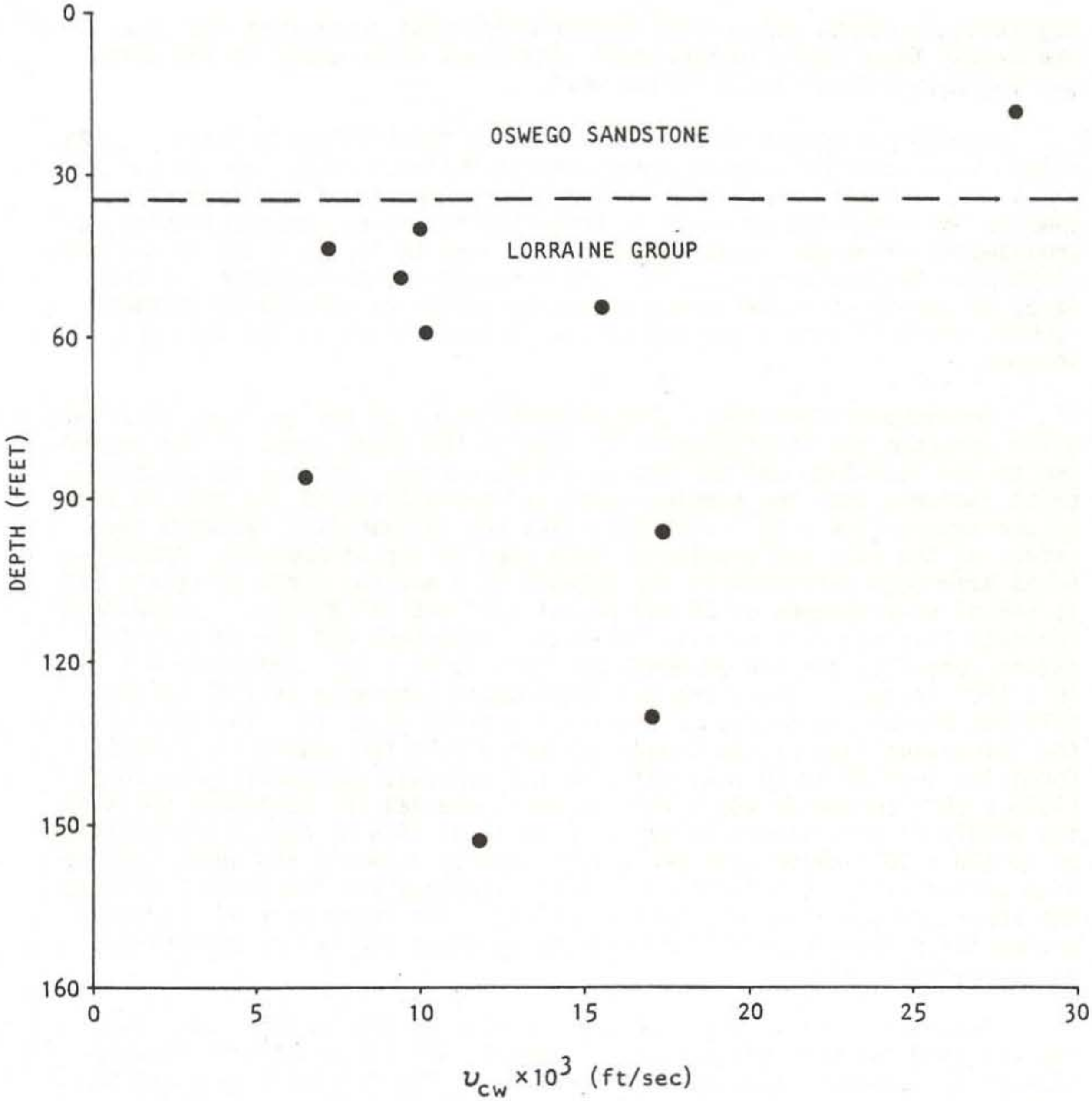

Figure 6. Shockscope tests showing compressional wave velocity measurements versus depth.

figure demonstrates that the Oswego Sandstone has a seemingly higher compressional wave velocity than rocks of the underlying Lorraine Group.

ENGINEERING HYDROLOGY

Surface Water Hydrology: There are no natural perennial streams located at Nine Mile Point. Precipitation which falls in this area is discharged into Lake Ontario via intermittent streams, groundwater flow, and artificially constructed drainage channels. The study area is bordered regionally by three major river basins which also drain into the lake: the Oneida River Basin to the south, the Black River Basin to the east, and the Oswego River Basin to the west.

Hydrologic budget studies of Nine Mile Point (Niagara Mohawk, 1972a, 1972b) show that the average annual precipitation is approximately 36 in (91.5 cm). Stream-flow runoff accounts for one-half of this amount, whereas the remaining one-half is accounted for by evapotranspiration and groundwater recharge. Evapotranspiration uses 16 in (40.6 cm) of the precipitation leaving only 2 in (5.1 cm) for groundwater recharge. Therefore, it can be seen that there is a high annual percentage of surface runoff, which is attributed to the low permeabilities of the soil and bedrock.

Groundwater Hydrology: The permeabilities of the geologic materials, which comprise the stratigraphic section in the study area, differ according to the lithology and the degree of fracturing. Surface percolation tests indicate that the average vertical permeability of the soil is 10^{-5} cm per second (0.4×10^{-7} in/sec). This low permeability reflects the nature of the till and proglacial lake clay on top of bedrock. Packer tests have been performed in the bedrock to a maximum depth of nearly 150 ft (45 m) at pressures of 25 and 50 psi (173 and 345 kN/m^2). These tests indicate that the rock mass in the Oswego Sandstone and the Pulaski Formation generally has low permeability (1.5 to 45×10^{-6} cm/sec or 0.5 to 18×10^{-6} in/sec). There are two zones which typically exhibit permeabilities one or two orders of magnitude greater (Fig. 7). The contact of the Transition Zone of the Oswego Sandstone with the underlying Pulaski Formation (~35 ft or 10.7 m) exhibits the greatest permeability measured (1000×10^{-6} cm/sec or 400×10^{-6} in/sec), whereas the sandstone units in the middle of the Pulaski Formation (~85 ft or 25.9 m) have a permeability up to 600×10^{-6} cm/sec (or 240×10^{-6}in/sec). Clearly the upper zone of high permeability is a function of both lithology and fracturing, because the upper bedrock is more highly fractured. The lower zone of increased permeability is related to the contrasting sandstone layers surrounded by impervious shales.

The static water levels in the vicinity of the nuclear facilities are the same for both the surficial deposits and the underlying bedrock indicating a seeming hydrologic connection. The hydraulic gradient at Nine Mile Point averages about 2 ft per 100 ft (2 m/100 m), and slopes toward Lake Ontario, its natural base discharge. This local gradient is greater than the regional hydraulic gradient of 40 ft/mi (0.75 m/100 m). When surface water percolates down to the watertable in the soil, it will flow toward the lake at a local rate of less than 2×10^{-5} cm/sec (or 8×10^{-6} in/sec). If a liquid were discharged below the bedrock surface, it would flow horizontally toward the lake at an estimated rate of less than 2×10^{-4} cm/sec (or 8×10^{-5} in/sec) in the upper 20 ft or 6 m of bedrock.

Domestic water well discharges in the area are characteristically low. For wells completed in soil, the discharges range from 5 to 8 gal/min (19 to 30 l/min). For wells completed in bedrock, the discharges average 10 gals per minute (38 l/min). Because the upper zone of bedrock is more highly fractured than at depth, few domestic wells extend deeper than 75 ft (23 m).

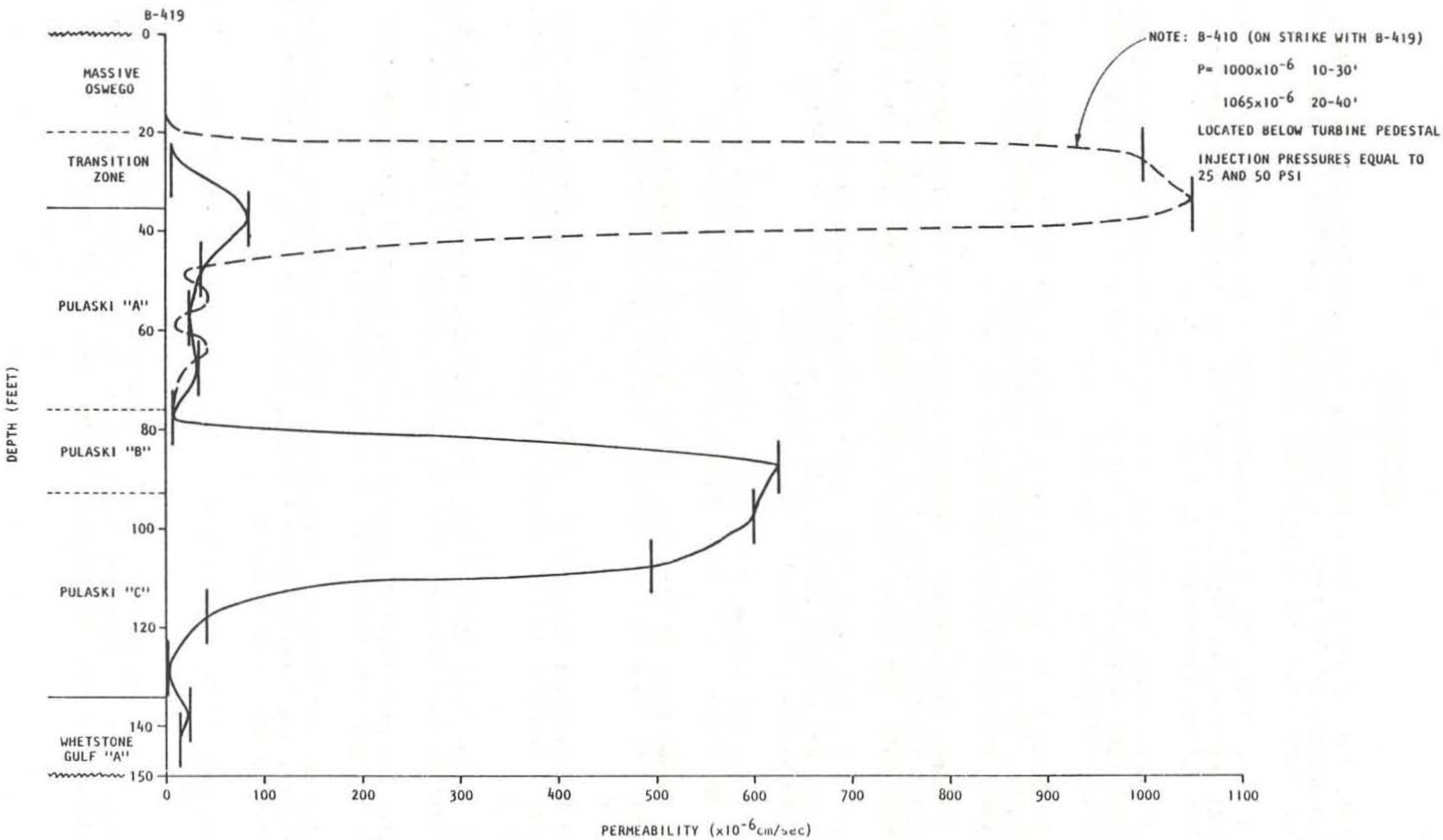

Figure 7. In situ permeability of rock mass at reactor, NMP-2.

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