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October 15, 1982
NLN-33

Ms. E. Adensam, Chief
Licensing Branch 4
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Puget Sound Power & Light Company
Skagit/Hanford Nuclear Project, Units 1 & 2
Docket Nos. 50-522 and 50-523
Preliminary Safety Analysis Report
Draft Amendment 28

Dear Ms. Adensam:

At the direction of and with the concurrence of Puget Power, we are transmitting to you six copies of the Final Draft of Amendment 28 to the S/HNP PSAR. This action is being taken at this time so that an expeditious review of the material can commence and the SER finalized upon formal submittal in late October. Although some minor work remains on the draft, the technical material contain therein and conclusions reached will not change.

This amendment consists of the responses to NRC Questions 231.5, 231.14 and 231.15; revisions to PSAR Section 2.5 and Appendices 2K and 2R incorporating recent work by the Supply System on the Southeast anticline and by NESCO on the May Junction monocline.

For the convenience of the reviewers, the current transmittal contains a complete copy of the relevant PSAR Sections 2.5.1 through 2.5.3 and Appendices 2K and 2R. The amended pages have been inserted into the above noted text and are marked "draft". "Change bars" in the right hand margin identify the location of the changes. The Final Draft has been printed on yellow pages so that it will be easily identified and not inadvertently inserted into the formal documentation.

The following distribution of this Final Draft is suggested:

1. Mr. Moon, Project Manager
2. Dr. Jackson, Chief Geosciences Branch
3. Dr. Brocoum, Geosciences Branch
4. Mr. Lefevre, Geosciences Branch
5. Dr. Ibrahim, Geosciences Branch
6. Ms. Alterman, Geosciences Branch

B001
1/6 Encls
Rec'd

Dist Per
C. Moon

Encls To:
C. Moon
R.E. Jackson
S. Brocoum
H. Lefevre
Ibrahim
I Alterman

Additional distribution of this Final Draft in the interest of time has also been made to the following reviewers in the U.S. Geological Survey.

1. Dr. Algermissen
2. Dr. Dickey
3. Dr. Morris

If there are any questions regarding this transmittal, please call Mr. Stimac of Puget Power or myself immediately.

Very truly yours,

F. A. Spangenberg
Project Manager

cc: Dr. Slemmons
M. V. Stimac - PSP&L
Dr. Algermissen
Dr. Dickey
Dr. Morris

affected the Site, the two highest intensities are estimated to have been IV-V (MM) from the December 14, 1872 earthquake and IV (MM) from the Milton-Freewater shock of July 15, 1936. The maximum acceleration at the Site resulting from historical or instrumental earthquakes is estimated to have been 0.015g (see Section 2.5.2.6 WNP-2 FSAR).

A Regulatory Guide 1.60 Spectrum anchored at a peak acceleration of 0.35g is assigned as the Safe Shutdown Earthquake (SSE). The requirements of this SSE exceed those for all potential earthquakes discussed in Section 2.5.2.4. 28

<u>1.2.2.1.2.7 Land use</u>. Natural physical characteristics of the Plant Site, which indicate that the area is ideally situated for and suited for operation of the Plant, include: favorable geographical, geological, and seismological characteristics; adequate water supply; ideal climatological characteristics; and remoteness from population centers or areas of special ecological concern. The Hanford Reservation has served as a nuclear industrial center since 1943 when it was selected by the Federal government as the location for construction of one of the world's first nuclear production reactors. Since 1943, nine plutonium production reactors and a number of test reactors have been constructed and operated at the Hanford Reservation.

<u>1.2.2.1.2.8 Population</u>. In 1980 approximately 280,000 people were living within a 50 mile radius of the S/HNP Site. Since the Site is situated within the Hanford Reservation, there are no significant concentrations of population within a 10-mile radius. The closest inhabitants occupy farms located east of the Columbia River, and are thinly spread over five compass sectors. The closest resident is about seven miles south of the Plant. The nearest population centers are the Tri-Cities area of Richland (15 miles to the south-southeast), Pasco (23 miles to the southeast), and Kennewick (23 miles to the SSE-SE); Benton City (16 miles to the south); Mesa (21 miles to the east-northeast); Prosser (24 miles to the southwest); and Othello (26 miles to the north-northeast).

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2.5 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING

The descriptions of the geologic, seismologic, and geotechnical engineering aspects of the S/HNP Site and surrounding areas are extensive and voluminous in this and other reports because of the detailed nature and long history of investigations in the region. Investigations described in this section of the PSAR have been coordinated and combined with work carried out for WNP-2 of Washington Public Power Supply System. The Supply System has been chiefly responsible for regional geology and seismology; Northwest Energy Services has been chiefly responsible for the S/HNP Site geology and investigation of the Umtanum Ridge-Gable Mountain structural trend. The essential investigations and results of this and previous studies (described in detail in other parts of Section 2.5) are summarized below to provide the reader with an abstract of the work and an overview of the geologic/seismic/geotechnical setting of the S/HNP Site.

Intensive studies of the area in which the S/HNP Site is located have shown that the area is suitable for siting the proposed facilities in terms of both geologic and seismologic conditions. These studies have spanned more 23
than 80 years and have, for the most part, been reviewed by the USNRC and USGS. Despite the exhaustive nature of investigations and the duration over which they have been conducted, little evidence has been found to indicate significant amounts of recent tectonic activity in the Columbia Plateau. On the contrary, new evidence continues to indicate a remarkably low degree of tectonic activity.

The S/HNP Site is located within the Hanford Reservation in the Pasco Basin, one of several physiographic and structural depressions in the Columbia Plateau underlain by sequences of Miocene basalt and sedimentary rocks, and partially filled by an assemblage of Plio-Pleistocene deposits of stream, lake, glacial and wind origin. Subsurface investigations conducted for S/HNP indicate that generally flat-lying basalt underlies the Site Area and is overlain by approximately 800-900 feet of dense to hard sand, gravel, and clayey silt. The Mio-Pliocene Ringold Formation immediately above the basalt is 500-600 feet thick and contains four stratigraphic units that have been traced by borings to indicate the presence or absence and nature of structural features. Flood gravels 200-300 feet thick overlie the Ringold Formation and provide competent foundation soils for the Plant facilities. Stabilized sand dunes thinly mantle the ground surface to depths of 1-10 feet. The groundwater table is at a depth of approximately 140 feet below the surface.

Deformation in the Columbia Plateau which affected the basalts and overlying sedimentary rocks occurred largely during the period 14 m.y. to 3 m.y. BP and resulted in major west- to northwest-trending assymetrical folds (the Yakima folds), subordinate and secondary faults, and minor upwarps and depressions. Deformation younger than 3 m.y. BP has been found in only a few locations and is typically very subtle. Although strain rates are not precisely known, geologic and seismologic evidence consistently indicate they must be small and, accordingly, are typical of intraplate tectonic environments. The absence of long faults and large earthquakes further indicates a relatively low degree of tectonic activity and a low seismic potential for the Site region.

The tectonic model that best explains the known geologic and seismologic conditions and their evolution is one in which the Yakima folds are shallow features which originated by buckling within the Plateau basalts in response to regional north-south compression. Some small component of northeast or northwest oriented shearing may have accompanied the buckling, but this shearing was accommodated along numerous and diffuse zones rather than concentrated along discrete faults. This implies that seismogenic structures which may exist in the Plateau have small dimensions and limited potential for earthquakes.

Site-specific investigations for the S/HNP were carried out under the direction of NESCO. The three prime contractors for geologic, seismologic, geophysical and groundwater investigations were Golder Associates, Weston Geophysical and Battelle. Responsibilities for the investigations were designated as shown below: 23

Golder Associates	-	Geology Foundation Engineering Groundwater (field testing)
Weston Geophysical	-	Seismology (review) Geophysics
Battelle	-	Groundwater (analysis)

All geotechnical work related to S/HNP Site investigations was reviewed and approved by a review panel composed of H. Coombs, R. Holt, G. Simmons and J. Vance.

On a regional scale, evidence favoring the area for nuclear power plant siting includes:

- An intraplate tectonic setting

- A lack of significant or pervasive faults
- Low rates of deformation
- Extensive and little-deformed sedimentary units of Pliocene and younger age
- Low rates of seismic activity and
- A lack of large-magnitude earthquakes.

Geologic knowledge of the Columbia Plateau and the Pasco Basin has evolved over nearly a century of investigations and has been reported in over 3000 publications (Ref 1). Ranging from regional-reconnaissance scale to very detailed site-specific and feature-specific scale, the studies have been conducted for a broad spectrum of purposes: academic, resource, facility construction and environmental protection. The investigations have yielded information that is impressive in amount and variety. Table 2.5-1 provides a chronology by category of some of the previous investigations that have formed the basis for the site-specific studies conducted for the S/HNP Site. It shows, together with the studies described below, that geologic, seismologic, and geotechnical investigations relevant to design and construction of S/HNP have been comprehensive and adequate. Furthermore, the table shows that the Hanford Reservation is virtually unequaled in the United States with regard to the quantity and quality of data applicable to design of critical facilities.

The approach to studies conducted for the S/HNP Site was based on the concept of verifying previously indicated suitable conditions in the Site Area and selected surrounding areas. The techniques employed to verify these conditions included: 23

- Field Mapping
- Trenching
  - Logging
  - Sampling
  - In-Situ Testing
- Rotary and Core Drilling
  - Logging
  - Sampling
  - In-Situ Testing
- Petrologic Analyses
  - Binocular and Petrographic Microscope

- o Downhole Geophysical Logging
  Neutron-Epithermal Neutron
  Natural Gamma
  Neutron-Gamma
  Gamma-Gamma

- o Ground Gravity and Magnetic Surveys

- o Seismic Surveys
  Seismic Refraction
  Downhole in-situ velocity measurements
  Crosshole in-situ velocity measurements

- o Laboratory Testing

- o Geochemical Analysis

Based on the investigations performed for the S/HNP Site, the Site has been found suitable for locating the proposed facilities in that it meets the criteria of Appendix A to 10 CFR 100. The investigations have also been adequate to satisfy the requirements of Regulatory Guide 1.70 and Standard Review Plans. Specifically, the investigations have shown:

- o There is no potential for ground rupture and no need to consider surface displacement in the Plant design.

- o The subsurface soils are competent to provide foundation support for Plant structures under both static and dynamic loading conditions, and there are no areas of active or potential subsidence, uplift or collapse.

- o The groundwater table in the Site Area will remain approximately 100 feet below foundation grade, and will not significantly influence, or be influenced by Site-facility water use.

The maximum acceleration at the Site resulting from historical or instrumental earthquakes is estimated to have been 0.015g (see Section 2.5.2.6 WNP-2 FSAR).

A Regulatory Guide 1.60 Spectrum anchored at a peak acceleration of 0.35g is assigned as the Safe Shutdown Earthquake (SSE). The requirements of this SSE exceed those for all potential earthquakes discussed in Section 2.5.2.4.

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2.5.1 BASIC GEOLOGIC AND SEISMIC INFORMATION

2.5.1.1 Regional Geology

Information regarding the geology and geologic hazards of the region surrounding the Skagit/Hanford Nuclear Project Site is described in Sections 2.5.1.1 through 2.5.1.2.6 of Amendment 18 (October, 1981) to the WNP-2 FSAR and the Washington Public Power Supply System's responses to WNP-2 Questions 361.16, 361.17, 361.20 through 361.25 and additional information transmitted to NRC by the Supply System on April 26, 1982 (Letter, Bouchey to Schwencer) and is incorporated herein by reference. This information is supplemented by Appendix 2S to the Skagit/Hanford Nuclear Project PSAR which synthesizes the presently available data bearing on the causative mechanism for deformation of the Yakima Fold Belt. 28

2.5.1.2 Site Geology

The Skagit/Hanford Nuclear Project (S/HNP) Site Area (2-mile radius) was studied in detail to determine the lithologic, stratigraphic, and structural geologic setting. The regional geologic setting, investigated in cooperation with the Washington Public Power Supply System, is described in Section 2.5.1.1 of the WNP-2 FSAR, Amendment 18. Investigative methods employed in the Site Area included surface geologic mapping, photogeologic analysis, drilling, borehole geophysical logging, sedimentary petrologic studies of drill core and cuttings, and gravity, magnetic, and seismic refraction studies.

These investigations supplemented previous investigations noted in the introduction to Section 2.5 of this PSAR. Data from the S/HNP investigations show that the basalt topography in the Site Area is generally flat, with some minor local warping. The late Miocene to early Pliocene Ringold Formation is deformed over bedrock highs; however, overlying late Pliocene(?) to late Pleistocene flood gravels are generally flat-lying, suggesting tectonic stability since post-Ringold time. The findings of the Site investigation are consistent with those from other local and regional investigations, generally affirming the regional data with respect to amount, nature, and rate of deformation. No evidence for faulting has been observed in the Site Area and no capable faults have been found within 5 miles of the Plant Site. Accordingly, there is no need to consider surface faulting in the design of the Plant.

The Skagit/Hanford Nuclear Project Site Area is in the east-central part of the Pasco Basin, a depression that is partially filled by alluvial and lacustrine sediments of the late Miocene to early Pliocene Ringold Formation. The

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Ringold Formation is underlain by a thick sequence of basalt flows of the Tertiary Columbia River Basalt Group and associated interbeds. Sediments overlying the Ringold Formation in the basin include the late Pliocene(?) to late Pleistocene Pre-Missoula and Missoula Flood Gravels (informal names) and Holocene eolian deposits. This stratigraphic assemblage provides the basis for evaluating the presence or absence and nature of geologic features important to Site safety, i.e., potential earthquake sources, zones of potential ground rupture, and foundation support conditions.

The regional context of the Site stratigraphy is described in Section 2.5.1.2.2 of the WNP-2 FSAR, Amendment 18.

The Plant facilities are near the axis of the buried Cold Creek syncline, a structural depression bounded on the north by the Umtanum Ridge-Gable Mountain structural trend and on the south by the Yakima Ridge and Rattlesnake Hills anticlines. The regional context of the Site Area structural geology is described in Section 2.5.1.2.4 of the WNP-2 FSAR, Amendment 18. Within the Cold Creek syncline, minor deformation of the basalt bedrock surface was initiated at least 14 million years (m.y.) ago (Ref 1) and appears to have continued into Ringold time (10.5 to 3.3 m.y. ago). Very minor deformation may have occurred in Post-Ringold time; however, the Site Area is characterized by relative structural stability, consistent with regional evidence for low pre-historic and historic seismicity. 23

The closest fault to the Plant facilities has been recognized in the subsurface on the Southeast anticline (informal name), 5.5 miles northeast of the Plant facilities (Appendices 2K, Section 5.3, and 2R, Section 6.2.1). The closest faults that are associated with the displacement of Pleistocene deposits are the Central and South faults on Gable Mountain (Appendix 2I, Section 6.1 and 6.2), 8 and 7.5 miles, respectively, northwest of the Plant facilities. The regional setting and tectonic evolution of faults are described in Section 2.5.1.2.4 of the WNP-2 FSAR, Amendment 18, and in Appendices 2K, 2N, and 2O of this PSAR.

2.5.1.2.1 Site Physiography

The Pasco Basin, a physiographic and structural depression within the Columbia Basin subprovince of the Columbia Plateau physiographic province, is a 2,000-square-mile, gently undulatory, semi-arid plain interrupted by low-lying hills and sand dunes dissected by intermittent streams. The regional setting of the Site Area physiography is described in Section 2.5.1.1.2 of the WNP-2 PSAR, Amendment 18. The

Pasco Basin is surrounded on three sides by pronounced topographic ridges: the Saddle Mountains form the northern boundary; Umtanum and Yakima Ridges plunge into the basin from the west; and the Rattlesnake Hills and Horse Heaven Hills form the southern boundary. The eastern edge of the basin is poorly defined topographically; it is characterized by relief formed only by sand dunes and coulees. The major drainage through the basin is the Columbia River, entering from the north at Sentinel Gap through the Saddle Mountains and exiting the basin through Wallula Gap in the south. The Yakima River enters the Columbia River from the west, south of Richland, and the Snake River joins the Columbia from the east at Pasco. The Site lies approximately 7 miles southwest of the Columbia River at its nearest approach.

The Site Area is in the east-central part of the Pasco Basin, a gently undulatory plain mantled with Pleistocene glaciofluvial flood deposits and Holocene eolian deposits. Figure 2.5-1 shows the topography of the Site Area (2-mile radius). Topographic relief of the Site Area averages approximately 20 ft, with an average elevation of 540 ft above mean sea level.

The Plant facilities are located in a stable sand dune area not subject to migration by wind. A small active dune field is present 1 mile to the north in section 28. A much larger active dune field, comprised mainly of transverse dunes, is located east-northeast of the Site and extends to the Columbia River. Prevailing dune migration direction is to the northeast, away from the Site. Several isolated patches of lag deposits, forming a desert pavement, are scattered throughout the dune deposits. 23

The physiographic development of the Pasco Basin was initiated by downwarping and folding of the Columbia River Basalts in late Cenozoic time, with anticlinal folds forming the prominent ridges and mountains of the region. The structural basin was filled by Ringold Formation sediments in late Miocene to early Pliocene time and by Pre-Missoula flood gravels in late Pliocene(?) to late Pleistocene time. Periodic catastrophic glacial flooding deposited Missoula glaciofluvial gravels in the basin in late Pleistocene time (Ref 2) and was largely responsible for forming the present topographic configuration of the basin. Aggradational landforms in the Site Vicinity resulting from the glaciofluvial flooding include sheet deposits, flood bars, and current ripples (Ref 1). Bergmounds, isolated mounds of till-like material deposited by grounded, debris-laden icebergs, occur locally in the Site Vicinity (Ref 3). Subsequent eolian processes have formed dune fields over most of the Pasco Basin. The present physiography of the Pasco Basin reflects a mature geologic environment undergoing very slow modification of the landscape.

2.5.1.2.2 Site Lithology and Stratigraphy

The geologic map of the Site Vicinity (5-mile radius. Figure 2.5-2), based on mapping published in Ref 1, Figure III-1, was verified by supplemental ground inspection and photogeologic studies. The subsurface geology in the region surrounding the Site was investigated in a total of 114 drillholes. The detailed analysis of the stratigraphy and structure of the Site Area (2-mile radius) was based on 25 rotary holes and two coreholes. The data from these drill holes were evaluated in concert with geophysical studies described in Appendices 2K and 2L of this PSAR, and in conjunction with regional studies described in Section 2.5.1.2.2 of the WNP-2 FSAR, Amendment 18. Previous work on the stratigraphy of the Pasco Basin is noted in the Introduction to Section 2.5 of this PSAR and in Appendix 2R. A complete description of the stratigraphic investigation of the Site Area and logs of all drillholes are included in Appendix 2R of the PSAR. Locations of the drillholes in the Site Area are shown in Figure 2.5-3.

The findings of this investigation correlate well with previous studies of regional stratigraphy and provide important details that contribute to an improved understanding of Site geology, particularly regarding stratigraphc subdivisions, contacts, age, and deformation. This understanding is the basis for confidence that the location and age of structural features important to the SSE determination are known (as described in Section 2.5.1.2.3), and that the geotechnical properties for foundation design have been defined (as described in Section 2.5.4 and Appendix 2Q). 23

<u>2.5.1.2.2.1 Stratigraphy.</u> The stratigraphic section of the S/HNP Site Area is illustrated on Figure 2.5-4. This stratigraphic section is equivalent to part of the previously defined section for the Pasco Basin (Ref 1, 4). Two basalt flows, the Pomona and Elephant Mountain Members of the Saddle Mountains Basalt Formation of the Columbia River Basalt Group, and the Rattlesnake Ridge interbed of the Ellensburg Formation were identified beneath the Site. These rocks are of middle to late Miocene age. Alluvial and lacustrine sediments of the late Miocene to early Pliocene Ringold Formation unconformably overlie the Elephant Mountain basalt. The Ringold Formation is mantled by late Pliocene(?) to late Pleistocene Missoula and Pre-Missoula Flood Gravels, which are, in turn, overlain by Holocene dune sands. The sedimentary section overlying the basalts has been further refined and subdivided in the area surrounding the Site to facilitate stratigraphic correlation and structural interpretation (see Appendix 2R).

Correlation of the geologic units at the S/HNP Site Area was made on the basis of stratigraphic position, lithology, and borehole geophysical characteristics. Basalt flow members were identified by means of geochemical (X-ray fluorescence) analysis (Appendix 2R, Section 5.1 and Table 2R-1). Stratigraphic correlations at the Site Area are shown on Figures 2.5-5 through 2.5-8.

2.5.1.2.2.2 Lithology

2.5.1.2.2.2.1 Columbia River Basalt Group. Based on interpretation of X-ray fluorescence (XRF) analyses, the uppermost basalt underlying the Ringold Formation in the Site Area is the Elephant Mountain Member of the Saddle Mountains Basalt Formation of the Columbia River Basalt Group. The Elephant Mountain Member has been dated as 10.5 m.y. (Ref 5). This flow is vesicular and commonly weathered to an olive-gray clay near the top, becoming non-vesicular and black to reddish-brown or brown with depth. Five drillholes that penetrated the Elephant Mountain Member indicate that the thickness in the Site Area ranges from 140 to 160 feet.

Underlying the Elephant Mountain flow is the Rattlesnake Ridge interbed of the Ellensburg Formation, a sedimentary unit which interfingers with flows of the Yakima Basalt 23
Subgroup. Sediments of the Rattlesnake Ridge interbed penetrated by five drillholes in the Site Area are comprised of sand to silty sand, silt, and clay. The unit has been correlated with the Rattlesnake Ridge interbed based on its position between the Elephant Mountain and Pomona flows. This interbed ranges in thickness from 50 to 85 ft in the Site Area.

The Rattlesnake Ridge interbed is underlain by the Pomona Member of the Saddle Mountains Basalt Formation of the Columbia River Basalt Group. The Pomona Member has been dated as 12 m.y. (Ref 5). This flow is commonly vesicular and weathered near the top.

2.5.1.2.2.2.2 Ringold Formation. The Ringold Formation unconformably overlies the Elephant Mountain basalt in the Site Area and, where measured, ranges from 305 to 570 ft in thickness. Table 2.5-2 shows the suggested correlation of the stratigraphic section of the Skagit/Hanford Nuclear Project Site Area with that of Ref 1 for the Pasco Basin. Myers and Price (Ref 1) recognized four textural facies within the Ringold Formation: (1) a basal gravel facies on top of the basalt surface, (2) a lower facies of silty sand

to sandy silt with gravel stringers, (3) a middle conglomeratic facies, and (4) an upper facies of silt, sand, and clay. For purposes of this study, the Ringold Formation has been subdivided within the Site Area into four units on the basis of detailed geophysical and lithologic analyses (Appendix 2R, Section 5.2). These units are referred to as I through IV, with Unit I being the oldest.

The maximum age of the Ringold Formation, limited by the age of underlying Elephant Mountain basalt, is 10.5 m.y. (late Miocene). However, Tallman, Lillie and Fecht (Ref 6) interpret the basal part of the Ringold Formation to be younger than the Ice Harbor Member of the Saddle Mountains Basalt Formation. The Ice Harbor Member has been dated as 8.5 million years old (Ref 5). The upper Ringold facies exposed in the White Bluffs contains vertebrate fossils which are 3.7 to 4.8 million years old (Ref 7). This indicates that the predominantly reversed magnetic section at the White Bluffs recognized by Packer and Johnston (Ref 8) represents the Gilbert Reversed Epoch (5.12 to 3.32 million years). The fine-grained sediments in the upper part of Unit IV in the Site Area are considered to be stratigraphically equivalent to the upper Ringold facies in the White Bluffs. Thus, the age range of the Ringold Formation in the Site Area is considered to be between 10.5 and 3.32 m.y. (late Miocene to early Pliocene).

The four units of the Ringold Formation each consist of a generally fining-upward sedimentary sequence, with gravel or sand at the base overlain by fine sand, silt, or clay at the top. The basal gravel of each unit is considered to represent a fluvial channel environment, possibly a pebbly braided stream, whereas the sands are interpreted to be flood plain deposits. The fine-grained sediments at the top are interpreted to be overbank and lacustrine flood plain deposits. The abundance of nonbasaltic clasts in the gravels indicates deposition from a through-flowing stream draining distant highlands. Cementation by calcite and clay in the Ringold Formation is variable, ranging from none to well-cemented. Each unit is interpreted to be bounded by erosional unconformities. The nature, thickness, extent, and age of the Ringold units are significant because they contribute information on the location and age of structural deformation during Ringold time (approximately 10.5 to 3.32 m.y. B.P.). The four units and their distinguishing characteristics are discussed below. 23

Unit I

Unit I is lowermost in the Ringold section and is subdivided into a basal gravel and an upper section of silty clay to clayey silt with some sand. The basal part is comprised of moderately well-cemented sandy gravels to gravelly sands

having dominantly basaltic clasts at the base, with increasing quartzite, granitics, and rare volcaniclastics higher up in the unit. Mafic grains in the matrix sand commonly have a distinct bluish color. Based on stratigraphic position and texture, these gravels are considered to be equivalent to the basal Ringold facies defined by Ref 1. The upper part of the unit is interpreted as a paleosol which is distinguished by its olive-gray to light-olive-gray color. Based on stratigraphic position and texture, the fines of upper Unit I are considered equivalent to the lower part of the lower Ringold facies defined by Myers and Price (Ref 1). Unit I ranges in thickness from approximately 118 to 177 feet in the Site Area.

Unit II

Unit II is composed of yellowish-gray to very-light-olive-gray clay, silt, and sand with a gravel horizon near the base. The clays commonly have a distinctive waxy luster. The gravel horizon is typically ferruginous-stained and contains stringers of sand, silt, and clay. Gravel clasts generally have a yellow-brown cementation rind with adhering sand grains. Clasts consist of basalt, quartzite, volcaniclastics, and granitics. Based on stratigraphic position and texture, Unit II is considered to be equivalent to the middle and upper parts of the lower Ringold facies defined by Myers and Price (Ref 1). Unit II ranges in thickness from approximately 116 to 146 feet in the Site Area.

Unit III 23

Unit III consists of interfingered sandy gravel and gravelly sand in the lower part of the unit, overlain by sand, silt, and clay in the upper part of the unit. Gravel clasts are basalt, quartzite, gneiss, granitics, and volcaniclastics, and commonly have yellowish cement rinds with adhering sand grains as in Unit II. Fine sediments in the upper part of the unit are interbedded yellowish-gray sand and silty sand with clayey silt or silty clay at the top. Based on stratigraphic position and texture, Unit III is considered to correlate with the gravels of the middle Ringold facies defined by Myers and Price (Ref 1). Unit III ranges in thickness from 0 to approximately 99 ft in the Site Area.

Unit IV

Unit IV consists of basal sandy gravel to gravelly sand overlain by interbedded yellow-gray to dusky-yellow silt, sand, silty sand, and sandy silt. Gravels in the basal part of Unit IV are lithologically like those in the base of Unit III. These gravels are also considered to correlate with the middle Ringold facies of Ref 1. Fine-grained sediments

in the upper part of Unit IV are considered to correlate with the basal part of the upper Ringold facies of Ref 1. A thick sequence of Upper Ringold sediments is exposed in the White Bluffs east of the Site. Most of this upper part of the Ringold section has been eroded from the Site Area. Thickness of Unit IV in the Site Area ranges from 0 to approximately 184 ft.

2.5.1.2.2.2.3 Pasco Gravels. The Pleistocene Pasco Gravels of the Hanford Formation (Ref 1, 4) have been subdivided in the Site Area into Pre-Missoula and Missoula Flood Gravels (informal names). Pre-Missoula Flood Gravels unconformably overlie the Ringold Formation in the Site Area and contain clasts that are dominantly composed of granite, quartzite, gneiss, and porphyritic volcanics derived in part from the Ringold Formation. The clasts are well-rounded and generally lack matrix. Weathering rinds on basalt clasts are thin and poorly developed. Thin, light-gray to white, well-sorted, medium- to coarse-grained sand beds are occasionally present within these gravels. Pre-Missoula Flood Gravels are generally uncemented, but some horizons are locally cemented with calcium carbonate or clay. These gravels form a channeled, sheet-like deposit across the Site Area. A flat-lying high-velocity seismic refracting layer (8,000-10,000 ft/sec) is present in the lower part of the Pre-Missoula gravels (Appendix 2L, Section 4.4.1.2). Although the provenance and age of the gravels have not been determined, their fabric, composition, and lateral extent suggest that they represent large-scale flood deposits, 23 possibly from late Pliocene flood episodes or early to late Pleistocene glaciofluvial flood episodes which were restricted to the Spokane River and Columbia River drainages. These gravels are equivalent to the basal part of the Pasco Gravels of the Hanford Formation defined by Myers and Price (Ref 1). Because the Pre-Missoula Flood Gravels can be distinguished from Ringold gravels by the lack of yellow cement rinds and from overlying Missoula Flood Gravels by greater than 50 percent nonbasaltic clasts, they are recognized as a separate stratigraphic unit in the Site Area. The age of these gravels is uncertain, but could be as old as 3.3 m.y. Thickness of the Pre-Missoula gravels in the Site Area ranges from approximately 93 to 223 ft. The Pre-Missoula gravels are widespread throughout the Site Area, and contribute to information on the location and age of structural deformation in post-Ringold time (3.32 m.y. to 17,500 years B.P.).

Missoula Flood Gravels are present across the Site Area. These gravels unconformably overlie the Pre-Missoula Flood Gravels and are capped by active or stabilized Holocene dune sands. They are uncemented pebble to cobble gravels which

commonly contain interbedded coarse sands. The gravels are characterized by a dominance of basalt, commonly 95 percent, with a few clasts of granitics and metamorphics. The sands are dark gray from the high basalt content, but also contain quartz, feldspar, and mica. Missoula flood gravels are distinguished from Pre-Missoula gravels by the presence of greater than 60 percent basalt in the gravels and sand. They formed as the result of large-scale catastrophic floods released from glacial Lake Missoula in Montana (Ref 9, 10, 11). Missoula flood deposits have been assigned an age range of 13,000 years B.P., based on the presence of St. Helens "S" ash near the top of the unit (Ref 12), to 17,500 to 18,000 years B.P., based on the age of the last major glacial advance in the northern United States (Ref 13). They are equivalent to the upper part of the Pasco Gravels of the Hanford Formation as defined by Myers and Price (Ref 1). Thickness of the Missoula Flood Gravels in the Site Area ranges from approximately 25 to 85 ft. Missoula flood gravels are the chief materials to be involved in the Site excavation. Their foundation engineering properties are good and are described in Section 2.5.4 and Appendix 2Q.

2.5.1.2.2.2.4 Surficial Deposits. Figure 2.5-2 shows the surface geology of the vicinity within a 5-mile radius of the Plant facilities. Surficial deposits include active and stabilized Holocene dune sands, Holocene alluvium, and Pleistocene glaciofluvial sediments. In the southwestern part of the map, the Touchet beds of Flint (Ref 14) represent fine-grained, slackwater sediments deposited distally from the main Pleistocene flood channels. 23

In the Site Area (2-mile radius), a thin mantle of active and stabilized Holocene dune sands blankets the Pleistocene Missoula Flood Gravels. These sands are fine- to medium-grained quartzose or basaltic sands which commonly contain silt (Ref 1). Sparse vegetation stabilizes most of the dunes. The eolian deposits range in thickness from 1 to 10 ft in the Site Area. Most of the surficial deposits will be removed or compacted during Site development and pose no problems for facility design and operation.

2.5.1.2.3 Site Structural Geology

The S/HNP Site Area is in the east-central part of the Pasco Basin, a structural sub-basin of the larger Columbia Basin. The Pasco Basin is partly surrounded by west- and northwest-trending anticlinal ridges, the Yakima Folds, which are separated by broad synclinal troughs. The Saddle Mountains form the northern boundary of the Pasco Basin, and

the Rattlesnake Hills and Horse Heaven Hills form the southern boundary. Umtanum Ridge and Yakima Ridge plunge eastward into the basin at the western boundary. The eastern boundary of the basin is formed by a gentle westward dip on the basalt surface. The Plant Site is near the axis of the Cold Creek syncline, a buried structural depression between Gable Butte-Gable Mountain-Southeast anticlines on the north and northeast, and the Yakima Ridge anticline on the west and southwest.

Investigations for S/HNP drew on previous knowledge of local and regional geologic structure (refer to Section 2.5.1.1 of the WNP-2 FSAR, Amendment 18) to develop specific information critical to identifying and characterizing all structures significant for seismic design.

Detailed photogeologic analyses, field mapping and subsurface stratigraphic studies have not identified any faulting within the Site Area. The closest fault to the Plant facilities is 5.5 miles to the northeast on the Southeast anticline, the buried easterly segment of the Umtanum Ridge-Gable Mountain structural trend. This fault was recognized on the basis of an anomalous thickness of the Elephant Mountain flow containing several thin zones of shearing in Corehole 125. Closely spaced coreholes were drilled by Golder Associates for the Washington Public Power Supply System to determine the attitude of this fault and the continuity of overlying Ringold units (Ref 22). The fault is a reverse fault. It strikes N39°W and dips 30°SW. The range of vertical displacement on the fault is 35 to 60 feet. Based on this small amount of displacement, the Southeast anticline fault appears to be a minor feature and probably does not extend any significant distance away from corehole 125.

The sediments overlying the projection of the fault plane have been penetrated by 11 holes spaced 30 to 100 feet apart along a line 450 feet long. These overlying sediments include the late Miocene lower Ringold Formation (approximately 10 million years old) and the Pleistocene Hanford Formation. Fine-grained units within the Pre-Missoula Gravels of the Hanford Formation near corehole 125 have been dated on the basis of paleomagnetic analyses as older than 730,000 years. Four stratigraphic contacts, ranging in age from approximately 10 million to at least 730,000 years in age, dip gently across the projection of the fault plane and show no abrupt changes in elevation. Based on these observations, the Southeast anticline fault has not been active for approximately 10 million years and is therefore not capable. 28

The South fault, 7.5 miles north on the south flank of Gable Mountain, is the closest known fault to the Plant facilities

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which is associated with displacement of Pleistocene sediments (Appendix 20, Section 6.2.3). The South fault is inferred to have moved in late Pleistocene time on the basis of deformation observed in clastic dikes present along the fault. The Central fault, 8 miles to the northwest on Gable Mountain, has displaced overlying Missoula glaciofluvial deposits (dated at 13,000-17,500 B.P.) in a reverse sense a maximum of 0.2 ft (Appendix 20, Section 6.1.3).

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Displacement in the glaciofluvial deposits has been observed over a lateral distance of approximately 1,100 ft, although the fault in the basalt bedrock extends over a greater distance. The origin of the displacements in the glaciofluvial deposits has not been determined. Several alternative mechanisms for the origin of the displacements have been considered, including tectonic activity, landsliding and flood-induced stress release (Appendix 2O, Section 7.2). Although some evidence supports nontectonic hypotheses for the origin of the displacements, insufficient data are available to demonstrate a nontectonic origin.

Figure 2.5-9 shows the structural geology of the Site Area based upon structural contours drawn on top of the uppermost basalt surface, identified by XRF analysis as the Elephant Mountain Member. The top of basalt was established by downhole geophysical logging techniques in combination with lithologic identification of core chips and rotary drillhole cuttings from 26 drillholes which encountered basalt. The resolution in establishing the flow top is estimated to be about ± 5 ft. Contours were extended beyond the limits of the drillhole data based on structural trends indicated on the gravity map of the Site region (Appendix 2L, Figure 2L-11).

The structure contour map (Figure 2.5-9) shows that the basalt surface underlying the Site Area is of generally low relief, with typical slopes on the order of 1 degree or less. The relief on the surface of the basalt is assumed to be the product of gentle warping that has formed two 23
distinguishable features in the basalt: the Cold Creek syncline in the central part of the Site Area, and a small east-west trending basalt high in the vicinity of drillholes S-6, S-8, S-9 and S-11 in the northwestern part of the Site Area. The Cold Creek syncline, a broad assymetrical trough with gently-sloping limbs (5 degrees maximum), trends northwest-southeast through the Site Area and plunges gently to the southeast. A local depression approximately 150 ft deep exists along the axis of the syncline in the vicinity of drillhole S-16. The small east-west basalt high exists on the northern limb of the Cold Creek syncline, rising approximately 100 ft above the surrounding bedrock surface. It is less prominent along its southeastern extent toward drillholes S-10 and S-11. The maximum gradient on this high is approximately 3.5 degrees and occurs on its northern side in the vicinity of drillholes S-6 and 15.

The east-west high (in the vicinity of drillholes S-6 to S-11), the southwestern limb of the Cold Creek syncline, and the depression in the vicinity of drillhole S-16 are locally reflected in the overlying Ringold units. Consistent thickness of Units I and II and reduced thickness of Units III

and IV suggest folding on these structures during Unit III and IV time. Slight changes in elevation of the base of the Pre-Missoula Flood Gravels across these features suggest minor warping during post-Ringold time.

There are no known capable faults within 5 miles of the Plant facilities and no structures have been identified which might influence the seismic design of the Plant facilities. The geologic structures that have been found in the Site Area are consistent with those of the region and with the seismic design described in Section 2.5.2.

2.5.1.2.4 Site Geologic History

Extrusion of the Columbia River Basalt Group into the Pasco Basin began between 14 and 16.5 million years ago (Ref 1). The Elephant Mountain basalt flow, the youngest flow in the Site Area, was extruded 10.5 million years B.P. (Ref 5). During intervals between lava extrusions, fluvial and lacustrine sediments were deposited on the basalt surface. This basalt and sedimentary interbed section may attain thicknesses of greater than 10,000 ft in some portions of the Pasco Basin (Ref 15). After extrusion of the Elephant Mountain flow, the area was subjected to a period of subaerial weathering. Subsequently, a series of four fining-upward sedimentary units were deposited over the basal Ringold gravels. These units (Units I-IV of the Ringold Formation) range in age from late Miocene to early Pliocene 23
and record cyclic depositional patterns reflecting interacting changes in the source area and base level for the Pasco Basin. Minor warping of the older Ringold units and the absence of the upper Ringold units over localized bedrock highs in the Site Area suggests that the Site deformation, which began at least 14 million years ago (Ref 1), continued into Ringold time.

The Pre-Missoula and Missoula Flood Gravels which overlie the Ringold Formation were deposited at least in part by catastrophic glacial floods which sculptured much of the Columbia Plateau. The youngest of these, the Missoula Flood Gravels, were deposited from flood waters emanating from glacial Lake Missoula in late Pleistocene time (approximately 13,000-17,500 years ago). The oldest of the flood gravels (Pre-Missoula Flood Gravels) may also have been deposited from similar Pleistocene glacial events or may have been deposited from much earlier (late Pliocene?) floods. Within the Site Area, the generally flat-lying contact at the base of the Pre-Missoula Flood Gravels show that no significant deformation has occurred since these sediments were deposited. Thus, geologic history of the

Site Area and the Columbia Plateau indicates that the region has been tectonically stable compared to other parts of the Pacific Northwest and western North America. In addition, recent geologic and seismic history are mutually consistent and indicate a low potential for earthquakes.

2.5.1.2.5 Engineering Evaluations of Local Geologic Features

Geotechnical investigations were performed to evaluate foundation conditions at the Plant facilities and to provide engineering data and analyses required for the design of foundations and subsurface walls under both static and dynamic loading conditions. The scope of the study included field and laboratory investigations, together with engineering evaluations for foundation design. The field program comprised subsurface borings, trenching, in situ deformation testing within boreholes and trenches, subsurface soundings, in situ density measurements and undisturbed sampling for laboratory testing. The details of the field program are discussed in Appendix 2Q of this PSAR. In addition, field seismic surveys were undertaken at the Plant facilities (Appendix 2L of this PSAR) and a groundwater monitoring system (water sampling and piezometric head monitoring) was established (Appendix 2P of this PSAR). Supplemental information was obtained from general observations during the geologic investigations. 23

There are no areas of actual or potential surface or subsurface subsidence, uplift or collapse at the Plant facilities. There exist no deformational zones, shears, joints, fractures or folds, zones of alteration, structural weakness or irregular weathering profiles which would have an influence on structural foundations. There is no evidence of faults or disturbances from past earthquakes within the foundation soils. Basalt bedrock is at a depth of approximately 700 feet at the Plant facilities, and unrelieved residual bedrock stresses would not impact structural foundations. The Plant facilities soils are derived from predominantly basaltic and silicic rock types that are chemically stable, and will not exhibit instabilities related to physical or chemical properties.

The Site Area has not been affected by subgrade mineral extraction and there are no known minerals of commercial value specific to the Site Area. Recent reports of possible commercial natural gas in an exploratory well north of Yakima may result in the Pasco Basin being classified as a gas-producing basin.

The Plant facilities are underlain by about 35 ft of medium dense to dense sand to approximately elevation 490 ft (MSL), about 170 ft of very dense sand and gravel to approximately elevation 320 ft, and about 520 ft of very dense sand and gravel with hard clayey silt down to basalt bedrock at about elevation -200 ft. The bearing capacities of the Plant facilities soils will be very large for the mat foundations of the major central plant structures, and settlements will be small. Because of the depth of the water table (approximately 100 ft below foundation grade) and the nature and strength of the soils below the water table, the foundation materials are not susceptible to instability associated with liquefaction or cyclic-strength deterioration. Accordingly, the subsurface soils at the S/HNP Plant facilities are competent to provide foundation support for the plant structures under both static and dynamic loading conditions. In general, overexcavation of soils at founding elevations and replacement with structural backfill will not be required beneath the central plant foundations. Details of the foundation engineering properties of the Plant facilities are described in Section 2.5.4 and Appendix 2Q. 23

2.5.1.2.6 Site Groundwater Conditions

Groundwater occurs at the Site Area under confined and unconfined conditions. Water exists in an unconfined state in the glaciofluvial deposits and in a confined state in the Ringold Formation and basalts. Water in the lower part of the Ringold Formation is under a slightly higher hydraulic head than water in the upper part of the Ringold Formation.

The water table at the Plant facilities occurs at approximately elevation 400 ft above mean sea level, which is about 100 ft below the base of Category I structures. Existing water-level data show that the elevation of the water table at the Plant Site has fluctuated in response to liquid waste disposal at the 200-Areas. Groundwater conditions of the Plant facilities are discussed in detail in Section 2.4.13.

2.5.1.2.7 Volcanic Hazards

Volcanic hazards at the S/HNP Site are the same as those at the Washington Nuclear Project No. 2 (WNP-2) site. Those hazards are discussed in WNP-2 FSAR (Amend 18), Section 2.5.1.2.6.1. The only potential volcanic hazard to the S/HNP Site is considered to be that resulting from ashfall from a major eruption of a Cascade volcano. The composite characteristics of such an ashfall would be as follows: 26

- Eruptive Sources: Mount Adams or Mount Rainier at a distance of 165 km and 180 km respectively.
- Estimated Ash Eruptive Volume: Mount St. Helens Layer Yn (4 km^3).
- Duration of Ashfall: Approximately 20 hours.
- Potential Thickness of Compacted Ashfall: 7.4 cm (3 inches)
- Estimated Percent Compaction of Ash: 20-40 percent.
- Average Rate of Ashfall: .37 cm/hr (0.15 in/hr). 26
- Average Density of Ash: 72 pcf (dry, loose)
  96 pcf (dry, compacted)
  101 pcf (wet, compacted

Estimated Average Grain Size:

98%	0.5 mm
91%	0.35 mm
76%	0.25 mm
57%	0.15 mm
50%	0.075 mm
40%	0.040 mm
27%	0.010 mm
20%	0.005 mm
11%	0.002 mm

Design criteria for the S/HNP meet or exceed all of the requirements of this postulated ashfall. Operating criteria and procedures addressing such an ashfall will be specified in the S/HNP FSAR.

2.5.2 VIBRATORY GROUND MOTION

The S/HNP Site is located approximately 5 miles west of WNP 1/4 and WNP-2 sites. Information on seismicity of the area within a 200 mile radius of the S/HNP Site and the maximum earthquake potential at the S/HNP Site is provided in 23
Sections 2.5.2.1, 2.5.2.2, 2.5.2.3 and 2.5.2.4 of Amendment 18 (October, 1981) to the WNP-2 FSAR and is incorporated herein by reference.

2.5.2.1 Seismicity

Reference Section 2.5.2.1, WNP-2 FSAR.

2.5.2.2 Geologic Structures and Tectonic Activity 23

Reference Section 2.5.2.2, WNP-2 FSAR.

2.5.2.3 Correlation of Earthquake Activity with Geologic Structure or Tectonic Provinces

Reference Section 2.5.2.3, WNP-2 FSAR.

2.5.2.4 Maximum Earthquake Potential

2.5.2.4.1 Potential Sources of Earthquakes

The earthquake potential at the S/HNP Site is defined in the following subsections, in accordance with parameters defined in the WNP-2 Draft SSER (June 29, 1982) for Section 2.5.2.

2.5.2.4.1.1 Swarm-Type Earthquake. A swarm-type earthquake (M_L = 4.0) is assumed to occur at the closest approach of major irrigation to the S/HNP Site. The Columbia River acts as a boundary to the water table influence from major irrigation to the north and east of the Hanford Reservation. To the south and west of the Hanford Reservation, the area under irrigation is limited. Thus, using the guidelines set forth in the WNP-2 SSER, a swarm-type earthquake is assumed to occur to the east of the S/HNP Site at a minimum hypocentral distance of approximately 8 kilometers from the S/HNP Site. 26

Irrigation currently taking place on the Hanford Reservation consists of (1) waste discharge to ponds, (2) waste discharge to surface cribs and (3) occasional and very minor surface irrigation of solid waste disposal sites for the purpose of establishing vegetative cover. The volumes of water associated with these usages have no significant effects on the groundwater table.

<u>2.5.2.4.1.2 Earthquakes Associated with Tectonic Provinces</u>. The largest earthquake within the Columbia Plateau Tectonic Province assumed to occur in the site vicinity is the 1936 July 16, Milton-Freewater earthquake. The magnitude of this earthquake has been determined to be 5.7-5.8 M_S (WNP-2 SSER, Section 2.5.2). The epicenter of the December 14, 1872 north-central Washington earthquake is located in the Northern Cascades tectonic province whose closest approach is approximately 140-150 kilometers north of the S/HNP Site. This event has been assigned a magnitude $M_S = 7.0$.

<u>2.5.2.4.1.3 Earthquakes Associated with Tectonic Structure</u>. The Rattlesnake-Wallula (RAW) alignment is the most significant structure to the S/HNP Site. The closest approach of RAW to the S/HNP Site is 15 kilometers. The maximum credible hypothetical earthquake for the RAW structure has been determined to be $M_S = 6.5$.

A number of faults and structural features are located in the vicinity of Gable Mountain. The closest approach of 26
Gable Mountain and its associated structural features to the S/HNP Site is approximately 10 kilometers. For licensing purposes, the maximum hypothetical earthquake assumed to be associated with Gable Mountain is $M_S = 5.0$ (WNP-2 SSER, Section 2.5.2).

2.5.2.4.2 Vibratory Ground Motion

<u>2.5.2.4.2.1 Ground Motion from Larger Earthquakes</u>. Peak accelerations from earthquakes associated with tectonic provinces (Section 2.5.2.4.1.2) or tectonic structures (Section 2.5.2.4.1.3) are estimated using attenuation relationships of Campbell (1981), Joyner and Boore (1981) and Woodward Clyde (Appendix 2.5K, WNP-2 FSAR). The highest acceleration values calculated are for the assumed 6.5 M_S earthquake on RAW, a distance of 15 kilometers from the S/HNP Site.

Of the three relationships cited above, it is believed that Campbell's relationship is most appropriate for estimating "close in" ground motion at the S/HNP Site. Neither the Joyner and Boore nor Woodward-Clyde relationships are as specific as Campbell's relationship to the "close in" distances being considered.

Campbell's attentuation relationship for a 6.5 M_S earthquake at 15 km yields acceleration values of .175g at the median level and .257g at the 84th percentile level. The average of the acceleration values calculated from the three attenuation relationships referred to above is 0.201g at the

median level (range of 0.175 to 0.237) and 0.316g at the 84th percentile level (range of 0.257 to 0.345).

Ground velocity values are estimated from the attenuation relationships of Joyner and Boore (1981) and Woodward-Clyde Consultants (1978). The average of the calculated velocity values is 22.19 cm/sec at the median level (values of 19.70 and 24.67) and 39.38 cm/sec at the 84th percentile level (values of 37.81 and 40.95).

Response spectra were developed using the above ground motion values and spectral amplification factors contained in NUREG/CR/0098 (Newmark and Hall, 1978). Median spectral amplification factors were used with the 84th percentile ground motion values, and 84th percentile spectral amplification factors were used with median ground motion values. The two response spectra for an $M_S = 6.5$ at a distance of 15.0 kilometers are shown on Figure 2.5-9a. For comparison purposes, a Regulatory Guide 1.60 Spectra anchored to 0.35g is also shown on Figure 2.5-9a. 26

2.5.2.4.2.2 Ground Motion from Swarm Earthquake. The ground motion predictions for a swarm-type earthquake of $M_L = 4.0$ were developed by Washington Public Power Supply System in response to Question 361.16 for WNP-2. The Supply System's consultant, Woodward-Clyde Consultants, used non-linear regression techniques to predict peak acceleration as a function of distance. The predicted 84th percentile corrected peak acceleration value for a M_L 4.0 event at a hypocentral distance of 8.0 kilometers (the closest approach of major irrigation to the S/HNP Site) is .115g.

The shape of the response spectrum associated with the swarm-type earthquake was also determined in the response to Question 361.16 (WNP-2 FSAR). This response spectrum shape anchored to the computed acceleration value of .115g is shown on Figure 2.5-9b. The resonse spectrum for the swarm earthquake is compared with the response spectra for the 6.5 M_S earthquake at 15 kilometers distance on Figure 2.5-9c.

2.5.2.5 Seismic Wave Transmission Characteristics of the Site

In-situ velocity measurements by crosshole and downhole techniques and surface refraction studies have been conducted in the vicinity of the S/HNP Site (Appendix 2L). 23 The velocity column beneath the S/HNP Site from ground surface to the Elephant Mountain Basalt is shown on Figure

2.5-10. The velocity column has been compiled from crosshole velocity measurements at the west reactor site to a depth of approximately 200 ft, from downhole velocity measurements to a depth of 570 ft in borehole S-15, and from surface refraction data for the basalts. Velocity values between a depth of 570 ft and the top of basalt at a depth of 704 ft have been estimated from downhole velocity measurements at other locations as correlated with the coarse and fine materials indicated by the geophysical logs. The coarse materials within the Ringold and lower pre-Missoula section are generally cemented, producing the high velocity (8,000 fps or greater) layers shown on Figure 2.5-10. Shear wave velocities within the Ringold section below a depth of 230 ft are estimated based on velocity measurements at other locations in the Hanford Reservation area. Compressional and shear wave velocities of the materials above basalt have also been measured at WNP-1/4 and WNP-2 (Appendix 2L of the WNP-1/4 PSAR). The changes in seismic wave velocities with depth at WNP-1/4 and WNP-2 are similar to those described above for the S/HNP. 26 24 23

The sonic velocities of the basalt flows and interbeds below the Elephant Mountain Basalt have been measured in the Rattlesnake Hills No. 1 well (Ref 16) to a depth of 3,230 m (10,600 ft). The sonic log from this well shows that the compressional wave velocity varies. Relatively high velocities of 5.0 to 5.7 km/s (16,400 to 18,700 fps) were measured for the competent basalt flows. Lower velocities of 4.0 to 4.5 km/s (13,000 to 14,800 fps) were measured for the interbeds. Shear wave velocities were not measured.

2.5.2.6 Safe Shutdown Earthquake

The maximum acceleration at the Site resulting from historical or instrumental earthquakes is estimated to have been 0.015g (see Section 2.5.2.6 WNP-2 FSAR).

A Regulatory Guide 1.60 Spectrum anchored at a peak acceleration of 0.35g is assigned as the Safe Shutdown Earthquake (SSE). The requirements of this SSE exceed those for all potential earthquakes discussed in Section 2.5.2.4. 26

2.5.2.7 Operating Basis Earthquake

A Regulatory Guide 1.60 Spectrum anchored at a peak acceleration of 0.175g, or one-half that of the SSE, is assigned as the Operating Basis Earthquake (OBE).

2.5.3 SURFACE FAULTING

All available geologic and geophysical information was evaluated to determine whether any evidence suggested that surface faulting might occur within 5 miles of the Site. Available information was supplemented with detailed, site-specific geologic and geophysical surveys extending beyond 5 miles in some directions and concentrated in a 2 mile radius of the Site. These surveys have included ground gravity and magnetic surveys along closely spaced lines and a seismic refraction survey. The results of the geophysical investigations are described in Appendices 2K and 2L. Geologic investigations undertaken specifically to supplement available information included photogeology, field mapping, rotary and core drilling, and stratigraphic analysis. The results of these investigations are described in Section 2.5.1.2 and Appendix 2R. 23

Geologic and geophysical studies have shown that the basalt bedrock underlying the Site within a radius of at least 2 miles shows slopes with only gentle relief (generally less than 5 degrees). Sedimentary units within the Miocene-Pliocene Ringold Formation which overlies bedrock are generally horizontal or show some minor warping (slopes less than 5 degrees). Sediments overlying the uppermost Ringold Formation (generally considered to be part of the Hanford Formation) are Pleistocene or older in age and contain a refracting horizon of 8,000 ft/sec velocity which is flat-lying within a radius of 2 miles of the Site. This velocity horizon has also been found to be flat-lying over an area of approximately 28 square miles within the vicinity of the Site. There are no photolinears within the Site Area which are structurally controlled. On the basis of these data, there is no evidence that suggests potential for surface faulting; therefore, Sections 2.5.3.1 through 2.5.3.8 do not apply.

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APPENDIX 2K

GEOPHYSICAL INVESTIGATIONS

UMTANUM RIDGE TO SOUTHEAST ANTICLINE

HANFORD SITE, WASHINGTON

prepared for

NORTHWEST ENERGY SERVICES COMPANY

October, 1981

(Amended October, 1982) | 28

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1.0 INTRODUCTION

As part of the investigations of the Umtanum Ridge-Gable Mountain structural trend, geophysical field studies were conducted for Northwest Energy Services Company (NESCO) from February 1980 to June 1981. The geophysical investigations were part of the overall siting study for the Skagit/Hanford Project. Amendment 28 updates Appendix 2K to reflect additional investigations conducted on the Southeast atnicline by the Supply System and the May Junction monocline by NESCO during 1982. 28

The geophysical investigation focused primarily on the bedrock configuration of the Hanford Site (Figure 2K-1). This report describes the geophysical investigations of the Umtanum Ridge-Gable Mountain structural trend, its associated structures, Gable Butte and Gable Mountain, and a buried ridge, informally named the Southeast Anticline, trending southeasterly from Gable Mountain.

The present area of study covers nearly 200 square miles of the Hanford Site, which is located in the central portion of the Yakima Fold Belt of the central Columbia Plateau of south-central Washington (Figure 2K-1). The bedrock units, the Miocene Columbia River Basalt Group, are overlain by as much as 700 feet of Late Tertiary and Quarternary sediments and sedimentary rocks.

The drilling performed by Golder Associates encountered the Elephant Mountain Member of the Saddle Mountains Basalt as the youngest bedrock unit in all boreholes. Consequently, the top of bedrock can be considered a structural surface on the top of the Elephant Mountain Member, except south of Vernita Bridge, where the Elephant Mountain Member is not present (Figure 2K-2); the older Pomona Member is the uppermost basalt unit in this area. These geologic conditions are favorable for the geophysical investigation of subsurface structure. The density contrast between the sediments and the basalt is 0.3-0.7 g/cm^3. The Bouguer gravity anomaly map for the Hanford Site is an approximate structural contour map with an arbitrary datum and a conversion factor of 150 feet of basalt elevation per 1 milligal of gravity relief. The conversion factor was determined from comparison of the profile of top of basalt (based on logging of drillholes and analysis of cuttings and core) with the gravity anomaly along the same profile. If no erosion of the Elephant Mountain basalt has occurred, then the top of basalt is a structural surface. However, some erosion has occurred. On the basis of the measured thickness of the Elephant Mountain basalt in all holes that extended through the unit, the erosion has removed differentially at most 80 feet of basalt. Therefore, the top of basalt is a structural surface within $\pm$40 feet

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(except in the area of Vernita Bridge where the unit is not present).

The conversion factor of 150 feet = 1 milligal is the average value determined for several profiles. It varies by approximately 20% over the study area as a result of the variation of the density of the Ringold Formation, which in turn is controlled by the relative thickness of coarse and fine units.

1.1 SCOPE OF INVESTIGATION

The geophysical investigations of the Umtanum Ridge-Gable Mountain structural trend were designed to delineate bedrock topography and examine specific structures within each area described below and shown on Figure 2K-2.

1.1.1 Umtanum Ridge-Gable Mountain Area

The Umtanum Ridge-Gable Mountain geophysical studies were designed to determine the structural continuity or discontinuity between Umtanum Ridge and Gable Mountain. Aeromagnetic and gravity data acquired for the Washington Public Power Supply System by Aeroservice, Inc. and Weston Geophysical Corporation, respectively, were interpreted by Weston Geophysical Corporation (1978a, 1978b, 1978c, Washington Public Power, 1977) as indicating possible structural continuity from Umtanum Ridge to Gable Mountain. Myers and Price (1979) concluded that the Gable Butte structure was a second-order fold on a continuous, primary fold linking Gable Mountain with Umtanum Ridge. Accordingly, gravity and land magnetic data were acquired and interpreted in order to analyze and characterize the structural continuity or discontinuity of the Umtanum Ridge to Gable Mountain trend.

1.1.2 Central Gable Mountain, DB-10, May Junction Areas

The Central Gable Mountain-DB-10 area was investigated to determine the structural relationships between this area and the Umtanum ridge structure as well as to augment geologic investigations of faulting. Corehole DB-10 encountered two zones of reverse faulting with a combined offset estimated to be 160 feet (Myers and Price, 1979). Weston Geophysical conducted a program of seismic

refraction, gravity and land magnetics to complement the geological studies of the faults.

Geophysical data were acquired on Gable Mountain to assist in the investigation of faults in the central Gable Mountain area. The geophysical program of seismic refraction, gravity and land magnetics was designed to assist in tracing the faults, as well as to investigate features believed related to the observed offset. Seismic refraction data were also utilized in feasibility studies for various trench localities on Gable Mountain.

The May Junction linear, initially defined on the basis of aeromagnetic data (Myers and Price, 1979), was investigated by seismic refraction and gravity data acquired by Weston Geophysical and drilling data collected by Golder Associates to characterize the structural relationships between this feature and the Umtanum Ridge-Gable Mountain structural trend.

1.1.3 Southeast Anticline

The third major area of investigation was the subsurface ridge informally named the Southeast Anticline. The aeromagnetic data acquired by Washington Public Power Supply System shows a magnetic high trending southeasterly from the eastern end of Gable Mountain. Extensive seismic refraction, gravity and land magnetic data were acquired and interpreted in order to characterize the Southeast Anticline and the structural relationships between the Southeast Anticline and the first-, second-, and third-order folds of the Umtanum Ridge-Gable Mountain structural trend.

2.0 SUMMARY AND CONCLUSIONS

2.1 SUMMARY

The results of the geophysical investigation implemented by Weston Geophysical for the Skagit/Hanford Project characterize the subsurface basalt topography of the Hanford Site. The basalt surface, based on geologic information, can be considered a structural surface, except in the area south of Vernita Bridge.

New geophysical data obtained for the Skagit/Hanford Project consist of approximately 10,700 closely spaced, surveyed, and high precision gravity stations; 500 line miles of land magnetic profiles; and 72 line miles of seismic refraction profiles. Previously acquired data utilized in this study include aeromagnetic data, gravity data, and seismic refraction data collected for Washington Public Power Supply System, as well as aeromagnetic data, gravity data, and seismic reflection data acquired by Rockwell Hanford Operations. | 28

Two principal structural features have been delineated by the geophysical investigations, the Gable Butte-Gable Mountain segment of the Umtanum Ridge-Gable Mountain structural trend and the Southeast Anticline. The Gable Butte-Gable Mountain segment of the Umtanum Ridge-Gable Mountain structural trend, is a broad, low amplitude anticline within the Hanford Site and is bounded on the east by the May Junction monocline. The various faults reported on Gable Mountain and in DB-10 are features within the Gable Butte-Gable Mountain segment.

A subsurface, bedrock ridge, the Southeast Anticline, has been defined as an 8-mile long, low amplitude anticlinal fold. The Southeast Anticline is separate from and extends 1 mile to the northwest of the eastern end of the Gable Mountain portion of the Gable Butte-Gable Mountain segment.

2.2 CONCLUSIONS

2.2.1 GABLE BUTTE-GABLE MOUNTAIN SEGMENT

The gravity anomaly associated with the Gable Butte-Gable Mountain segment of the Umtanum Ridge-Gable Mountain structural trend is a 5 milligal gravity high extending from the eastern end of Umtanum Ridge to the May Junction

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monocline. The Gable Butte-Gable Mountain segment, defined primarily by gravity data, is a segment of the Umtanum Ridge-Gable Mountain structural trend, although indicative of a change in structural style from the single anticlinal ridge of Umtanum Ridge to the broad, first-order fold with superimposed, second-order anticlines of the Gable Butte-Gable Mountain segment. This change in structural style occurs at the eastern end of Umtanum Ridge south of Vernita Bridge. The broad, first-order antiform is bounded on the east by the monoclinal flexure resulting in the May Junction linear.

2.2.1.1 DB-10 Area

The gravity and seismic refraction data are consistent with the geologic interpretation (Golder Associates, 1981, Figure 20-69) that the upper DB-10 fault strikes north-south and dips 30° to the west.

Based on seismic refraction velocity data, the length of the upper DB-10 fault appears to be 2,400 feet, limiting the fault to the small, northwest-trending, anticlinal fold south of Gable Mountain.

2.2.1.2 May Junction Monocline

The May Junction monocline trends north-south for a distance of 2 1/2 miles from the eastern end of Gable Mountain, has a maximum relief of 300 feet, and a maximum dip on the eastward sloping rock surface of 10°. An elongate gravity high indicative of an anticlinal fold extends across the southern portion of the May Junction monocline. | 28

The seismic refraction data for the May Junction and DB-10 areas indicate an anisotropic condition in the basalt. The bedrock velocities are higher in a north-south direction than in an east-west direction. The anisotropy suggests that fracturing is oriented north-south, parallel to the May Junction monocline.

2.2.2 SOUTHEAST ANTICLINE

The Southeast Anticlne is a separate structure from the first-order fold of the Gable Butte-Gable Mountain segment. The Southeast Anticline is also separate from the second-

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order fold, Gable Mountain, and extends 1 mile to the northwest beyond the eastern end of Gable Mountain.

The trend of the Southeast Anticline changes from northwest to east-northeast at its southeastern end and does not extend east of the Columbia River. 28

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3.0 GEOLOGIC SETTING

The study area is located in south-central Washington, within the central Columbia Plateau. The geophysical data were acquired primarily within the Hanford Site, which is situated in the central Pasco Basin. The underlying bedrock in the area of investigation is composed of the Columbia River Basalt Group. With the exception of several exposures of basalt ranging up to 600 feet in relief, the study area is underlain by as much as 700 feet of Late Tertiary and Quarternary alluvial and windblown sediments and sedimentary rocks.

The exposed basalts and those immediately underlying the overburden in the study area are members of the late Miocene Saddle Mountains Basalt of the Columbia River Basalt Group. The basalt is overlain by a Miocene to Pliocene series of alluvial sediments and sedimentary rocks composed of fanglomerates, poorly to well consolidated conglomerates, silts, sands and clays assigned to the Ringold Formation, whose type section is located within the area of investigation. The Ringold sediments are overlain by two sets of gravel units which are of glacial flood origin. The older set, immediately overlying the Ringold Formation, has been termed the pre-Missoula gravels. Although the pre-Missoula gravels within the study area have not been dated, possibly correlative gravels have been dated elsewhere as approximately 200,000 years old (Tallman, et al., 1978). The pre-Missoula gravels are overlain by the Missoula flood gravels which have been dated as young as 13,000 years old (Mullineaux, et al., 1977). The Missoula gravels in the study area are overlain by a veneer of loess and windblown sand.

The Hanford Site is located within the central and eastern portion of the Yakima Fold Belt, a series of linear and curvilinear anticlinal ridges which extends from the Cascade Mountains, 70 miles to the west, to an area east of the Columbia River, approximately 40 miles to the southeast. The anticlinal ridges and the broad, intervening synclines are all composed of Columbia River Basalts and the interbeds of the Ellensburg Formation. The ridges are generally asymmetric and trend from east-west to N60°W. Umtanum Ridge and Yakima Ridge plunge beneath the alluvial sediments at the western margin of the Hanford Site while the Rattlesnake Hills change trend and form the southwestern boundary of the Hanford Site.

Gable Butte and Gable Mountain, subsidiary structures superimposed upon the Umtanum Ridge-Gable Mountain structural trend, are the only outcropping folds of the

Yakima Fold Belt within the area of investigation. Information based upon drilling data acquired within the Hanford Site by Golder Associates (Appendix 2R) and Rockwell Hanford Operations (Myers and Price, 1979, Figure III-25a) indicates that the Elephant Mountain Member of the Saddle Mountains Basalt is the uppermost basalt unit within most of the area of investigation. Therefore, in the areas where the Elephant Mountain Member is the uppermost basalt unit, the bedrock surface is essentially a structural surface.

4.0 GEOPHYSICAL DATA BASE

4.1 DATA ACQUIRED FOR SKAGIT/HANFORD PROJECT

Seismic, gravity and land magnetic data were acquired for the Skagit/Hanford Project along surveyed traverse lines; horizontal and vertical survey control were established to the nearest 0.1 foot.

4.1.1 SEISMIC DATA

4.1.1.1 Seismic Refraction

Approximately 72 miles of seismic refraction data were acquired along the profile lines shown on Figure 2K-3. The seismic refraction method is utilized to determine the depth to a refracting horizon and the thickness of major seismic strata overlying a high-velocity refracting horizon. Interpretations are based on the measurement of the time required for elastic waves, generated at a point source, to travel to a series of geophones spaced at known intervals on the ground surface. Depth computations are based on the ratio of the velocities and the horizontal distance from the shot point where the refracted wave overtakes the direct wave (Figure 2K-4).

Seismic refraction is preferred over seismic reflection because the refraction technique is a direct measurement of the variable depth to bedrock and the highly variable near surface velocities. The variations in velocity and depth must be known in order to reasonably interpret any seismic reflection data.

4.1.1.1.1 Data Acquisition and Processing

Seismograms were obtained using a portable 24-trace seismograph system which allowed direct reading of seismic wave arrivals to 1 millisecond. Continuous profiling was accomplished by having the end shotpoint of one spread coincident with the end or intermediate position shotpoint of the succeeding spread.

The near-surface low velocity material and the underlying 6,000-10,000 ft/sec. refractor which occurs extensively throughout the project area were profiled using seismic spreads, generally of 800 feet in length and overlapped

every 400 feet. This allowed continuous datum control of a higher velocity refractor which generally occurs between elevations 350 and 400 feet above sea-level.

For profiling the basalt, shotholes were drilled to depths of 50 to 200 feet; detectors were spaced at 100-foot intervals to form 2,300-foot seismic spreads (see Figure 2K-4). Seismic energy for end and offset shots was generated with 50 to 200 pounds of dynamite placed below the water table for efficient energy generation.

Corrections were made for the near-surface low velocity material overlying the 6,000-10,000 ft/sec. refractor. This refractor provided a datum for reducing the deep refraction data using delay-time interpretation techniques described by Gardner (1967). The absolute delay times calculated from shallow refraction profiling were subtracted from the intercept values calculated from deep refraction. After applying this datum correction, a shothole correction was also applied to account for any variations in the depth of the shotholes with respect to the datum. Lines of best fit were placed through the corrected intercept values to form a continuous relative set of data from both directions along the seismic line. From the relative curves, an average curve was constructed from which the absolute delay times were calculated. Delay times were converted to depths to the 16,000 ft/sec. basalt refractor using an average velocity as determined by downhole velocity measurements.

4.1.1.2 Downhole-In-Situ Velocity Measurements

Since previous seismic studies in the Hanford Site (Washington Public Power Supply System, 1974) indicated at least one velocity inversion within the overburden material, downhole measurements were made in the overburden from the top of the near-surface high velocity refractor to approximately the top of basalt. The downhole velocity data were used to process the delay-time refraction data and obtain a profile of the top of basalt. Measurements were made in 52 boreholes within the study area (Figure 2K-3).

4.1.1.2.1 Data Acquisition and Processing

In the downhole technique, the seismic energy, generated by explosives in an adjacent shallow borehole (generally 50 feet in depth) is received by 24 geophones spaced at 10-

foot intervals in the monitoring hole (Figure 2K-5). Typically, multiple shots were used and the cable adjusted (overlapped) to obtain data at 5-foot intervals to various depths (usually the top of basalt).

The downhole data for each borehole were computer processed and an average velocity value determined for the overburden column. Time-distance plots of the data were also constructed in order to define the velocity interfaces. The downhole velocity data in profile form is presented in Attachment A.

The average velocities determined from downhole along a given seismic line were then used to convert the time profile of the 16,000 ft/sec. refractor to a depth profile (Section 4.1.1.1.1).

4.1.2 GRAVITY DATA

4.1.2.1 Data Acquisition and Processing

Approximately 10,700 gravity stations were established along traverse lines within the Hanford Site at the locations shown on Figure 2K-6. All data points were acquired utilizing Lacoste-Romberg Model G gravimeters, capable of 0.01 milligal reading precision. All gravity measurements were made in reference to local base stations established from the Washington gravity base station network (Pasco B Station, Nilson, 1976). 28

The gravity data were generally acquired at a 400-foot station interval along the traverse lines (Figure 2K-6). In areas where greater detail was required to more closely determine the location of a causative feature for an anomaly, additional stations were established at a 100-foot interval. Additional gravity stations were also established in Sections 32 and 33 of T13N, R27E, approximately one mile south of Gable Mountain (Figure 2K-6A) to investigate the May Junction monocline. The stations were located along eleven traverse lines (8A-8N, 8J and portions of Lines 8 and D) at 100-foot intervals. 28

Gravimeter dial readings were converted to milligal values utilizing conversion factors appropriate to the instrument (supplied by the manufacturer). The data were corrected for instrumental and tidal drift by means of base station reoccupations at intervals of three hours or less. The drift was considered linear over this time period.

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Subsequent to correcting the gravity observations for instrumental and tidal drift, the data were corrected for latitude as well as station elevation and assumed rock density (combined free air and Bouguer corrections). The gravity data were all reduced to a datum elevation of sea

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level utilizing a density of 2.67 g/cm^3. The resulting simple Bouguer gravity values, in the vicinity of Gable Mountain and Umtanum Ridge, were individually corrected for the surrounding variations in terrain according to Hammer (1939) and Douglas and Prahl (1971). The effects of variations in the terrain within a 13.6 mile radius were applied to each station in these two localities.

The resultant gravity data points were then processed and contoured to produce total, regional and residual Bouguer anomaly maps.

4.1.3 LAND MAGNETIC DATA

4.1.3.1 Data Acquisition and Processing

Land magnetic data were acquired along five hundred miles of traverse lines during this investigation. All data were acquired utilizing proton precession magnetometers and were recorded to the 1.0 gamma reading accuracy of the instruments. Local base stations were used for standard closure procedures to monitor the diurnal variations of the earth's magnetic field.

The magnetic data were acquired at 100-foot intervals for one-quarter to one-third of the data collected along the lines illustrated in Figure 2K-6. The remaining data were acquired at 50-foot intervals.

Subsequent to correcting the diurnal drift, the data for each line were plotted in profile form and evaluated collectively with the seismic refraction and the gravity data for the same line.

4.2 SUPPLEMENTAL GEOPHYSICAL DATA

4.2.1 DATA SUPPLIED BY WASHINGTON PUBLIC POWER SUPPLY SYSTEM

The Washington Public Power Supply System provided gravity, land magnetic, aeromagnetic and seismic refraction data to augment the data acquired for Northwest Energy Services Company. The Supply System data were used to assist in planning of the NESCO programs as well as combined with NESCO data to increase the data base available for interpretation.

The interpretations by Weston Geophysical (Weston Geophysical, 1978c; Washington Public Power Supply System, 1977, Appendix 2R-I) of both the gravity and land magnetic data provided guidelines for new programs.

The aeromagnetic data acquired by the Supply System (Figure 2K-7) were also utilized in the geophysical investigation of the Hanford Site. Details of the aeromagnetic survey, as well as previous interpretations, can be found in Washington Public Power Supply System (1977, Appendix 2R-I) and Weston Geophysical (1978a).

Seismic refraction data collected by Weston Geophysical in the vicinity of the Supply System sites (Washington Public Power Supply System, 1974) provided guidelines for data acquisition and processing techniques, as well as additional input concerning the seismic characteristics of the overburden of the Hanford Site.

Additional gravity and magnetic data in the vicinity of Line 4A (Figure 2K-7A) and gravity data on Savage Island and east of the Columbia River (Figure 2K-7B) acquired for the Supply System (Weston Geophysical, 1982) supplemented the NESCO data base for further evaluation of the Southeast anticline. 28

4.2.2 DATA SUPPLIED BY ROCKWELL HANFORD OPERATIONS

Rockwell Hanford Operations provided land magnetic and gravity data, aeromagnetic contour maps of a multi-level survey, and prints of processed reflection data. These data, acquired during Rockwell's siting program for a nuclear waste repository, were utilized in program planning and were evaluated relative to the data obtained for the Skagit/Hanford Project. The locations of the Rockwell reflection profiles and those Rockwell gravity data utilized in this study are shown on Figure 2K-8.

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5.0 RESULTS OF INVESTIGATIONS

5.1 REGIONAL GEOPHYSICAL SETTING

The Central Columbia Plateau of south-central Washington has been studied extensively during the past five to ten years. A large volume of geophysical data has been acquired by the United States Geological Survey (Swanson, et al., 1979 and Zietz, et al., 1971), by Rockwell Hanford Operations in their siting program for a waste repository (Myers and Price, 1979, and others), by various consultants to Washington Public Power Supply System (Weston Geophysical, 1978a; 1978b; 1978c; Washington Public Power Supply System, 1981, 1977) and through the present investigations for NESCO.

The gravity map for the Central Columbia Plateau (Figures 2K-9 and 2K-10) defines a north-northeast trending, semi-rectangular gravity high with two "lobes" extending from its southeastern and southwestern extremities. The rectangular high has been interpreted as defining a thick section of relatively high density material. The lower, high density body underlies 1-2 kilometers of Columbia River Basalts and has been modeled at 3-5 kilometers thick. The sides of the lower body dip inward at slopes ranging from 5°-45° (Washington Public Power Supply System, 1981, Appendix 2.5L). The present study area is located over the central portion of the rectangular high and is underlain by 5-7 kilometers of basalt and probable basaltic material. The generalized configuration of the subsurface basalt topography of the Hanford Site is depicted on the Hanford 1° gravity map (Figure 2K-12). The Gable Butte-Gable Mountain segment of the Umtanum Ridge-Gable Mountain structural trend is indicated by an elongate, 5 milligal gravity high trending N75°W, north of the Skagit/Hanford site.

Interpretations of aeromagnetic data for the Columbia Plateau also indicate an excess thickness of dense, magnetic rocks beneath the plateau. Zietz et al. (1971) interpreted a high-level (15,000 feet above sea level) survey and postulated the thickest section of basalt as underlying the region along the eastern margin of the Hanford Site. The interpretations of low-level surveys (Washington Public Power Supply System, 1977, Appendix 2R-I; Swanson et al., 1979; Weston Geophysical, 1978a) have characterized the prominent anticlinal ridges of the Yakima Fold Belt and defined the subsurface extensions of these ridges within the Hanford Site. Swanson et al. (1979)

postulated the existence of a dike swarm in the area east of the Hanford Site.

Two principal structural features, the Gable Butte-Gable Mountain segment and Southeast Anticline, have been delineated by the geophysical investigations for the Skagit/Hanford Project. These features are also in the aeromagnetic data provided by Washington Public Power Supply System (Figure 2K-14). Additional subsurface basalt highs, indicated by both gravity and aeromagnetic data, are located in the western and southwestern portion of the Hanford Site.

5.2 GABLE BUTTE-GABLE MOUNTAIN SEGMENT

The Gable Butte-Gable Mountain segment, defined by both gravity and magnetic data, extends from the eastern portion of Umtanum Ridge to the eastern end of Gable Mountain (Figures 2K-13 and 2K-14).

The east-west trending northern edge of the Gable Butte-Gable Mountain segment, is defined by a steep, linear gravity gradient (Figure 2K-15), which merges with the northern end of the May Junction linear at the eastern end of Gable Mountain. The eastern boundary of the first order antiform of the Gable Butte-Gable Mountain segment, defined by the May Junction monocline, trends 2½ miles southward from the eastern end of Gable Mountain. An elongate gravity high indicative of a small anticlinal fold extends across the southern portion of the May Junction monocline. The southern flank of the gravity high associated with the Gable Butte-Gable Mountain segment trends N65°-75°W from the southern end of the May Junction monocline; the gradients along the southern flank are not as steep as the northern or eastern flanks.

The aeromagnetic data in the vicinity of the Gable Butte-Gable Mountain segment exhibit characteristics similar to the gravity data (Figure 2K-14). The northern flank is defined by a magnetic low, the eastern boundary by the May Junction Linear (in Myers and Price, 1979). The internal components of the magnetically defined Gable Butte-Gable Mountain segment are zones of high frequency anomalies grouped in an en echelon pattern. The western portion of the Gable Butte-Gable Mountain segment is intersected by the Juniper Springs and Nancy lineaments (Washington Public Power, 1977, Appendix 2R-I; Weston Geophysical, 1978a).

The overall Gable Butte-Gable Mountain segment is characterized as a broad, low amplitude, east-west

trending, asymmetric antiform with internal features trending N65°-75°W and is bounded on the east by the May Junction monocline. The reflection data acquired by Rockwell Hanford Operations also indicate an asymmetry with bedrock slopes of up to 40° on the northern flank and up to 5° on the southern flank. The major components of the Gable Butte-Gable Mountain segment are discussed in Section 5.2.1 through Section 5.2.4.

5.2.1 UMTANUM RIDGE TO GABLE MOUNTAIN

5.2.1.1 Introduction

Gravity and ground magnetics were the geophysical techniques employed in the field investigation of the region between Umtanum Ridge and Gable Mountain. The gravity data were collected at 400-foot intervals along all profiles (Figure 2K-6) and at 100-foot intervals along selected portions of Lines 23 and 25 for additional detail over specific features discovered during this study. The ground magnetic data were acquired at 50-foot intervals along all gravity lines, as well as along four shorter lines flanking the northern portion of Line 25 (Figure 2K-16). In addition to the new geophysical data, the Washington Public Power Supply System's aeromagnetic data and Rockwell reflection data were analyzed.

5.2.1.2 Discussion of Results

5.2.1.2.1 Gravity Data

The Bouguer anomaly map depicting the configuration of the basalt topography is shown on Figure 2K-17. The gravity data for Lines 25-31 near the eastern end of Umtanum Ridge have been terrain-corrected.

The Bouguer anomaly map of the Umtanum Ridge to Gable Mountain area is characterized by several obvious features; the most prominent is an east-west trending, linear gradient. The steepest portions of the gradient, along Lines 13, 17, 19, and 21, result from bedrock relief of approximately 500 feet (utilizing a conversion of 150 feet/milligal) on a slope which dips 20° to the north.

A smaller east-west feature, not evident in the contour map as the amplitude of the anomaly is less than the contour

interval, occurs within the prominent east-west trending gradient. This gravity high is present on Lines 23 and 25 (Figure 2K-19) at the location shown on Figure 2K-16. A positive bedrock feature of erosional or structural origin on the northward sloping surface would produce this anomaly.

5.2.1.2.2 Land Magnetic Data

The land magnetic data indicate features very similar to those seen in the gravity data. The northern flank is characterized by magnetic anomalies exceeding 1500 gammas (Figure 2K-20). The higher frequency anomalies along the northern portions of Lines 23 and 25 coincide with gravity anomalies on the same lines (Figure 2K-19). Four short magnetic lines were acquired in the area flanking Line 25 (Figure 2K-16) and indicate that the causative feature is continuous for approximately 2 miles (Figure 2K-21).

5.2.1.2.3 Aeromagnetic Data

The aeromagnetic data provided by Washington Public Power Supply System show features similar to those indicated by the gravity and land magnetic data. A continuous, magnetic low extends eastward from the Umtanum Ridge area to the Gable Mountain area (Figure 2K-22) and corresponds spatially to the linear gravity gradient coincident with the northern flank of the Gable Butte-Gable Mountain segment. The aeromagnetic pattern of the Gable Butte-Gable Mountain area consists of numerous, high-frequency anomalies at a relatively higher intensity than surrounding areas. The northwesterly-trending regional aeromagnetic lineaments, Juniper Springs and Nancy (Weston Geophysical, 1978a; Washington Public Power, 1977, Appendix 2R-I) cross the Umtanum Ridge-Gable Mountain structural trend between Umtanum Ridge and the Gable Butte.

5.2.1.2.4 Seismic Reflection Data

Lines 4 and 5 of the seismic reflection survey (Figure 2K-8) performed by Seismograph Service Corporation for Rockwell Hanford Operations are located across the Gable Butte-Gable Mountain segment of the Umtanum Ridge-Gable Mountain structural trend. Line 5 is a north-south line coincident with gravity Line 21. Line 4 runs north toward Gable Butte, then northeasterly to the Columbia River along

Line 11A, passing between Gable Butte and the west end of Gable Mountain.

The reflecting horizons as interpreted qualitatively (Figure 2K-23) dip approximately 26° to the north along Line 4. When projected perpendicular to the anomaly, the dip is approximately 39°. The reflecting horizons on Line 5 are discontinuous, therefore the dip could not be determined.

5.2.1.3 Interpretation

The northern flanks of the Umtanum Ridge and Gable Butte-Gable Mountain segments are colinear, as defined by the geophysical data. The asymmetric gravity and magnetic highs associated with Umtanum Ridge trend east-west. The Gable Butte-Gable Mountain segment is a broad, low amplitude, east-west trending, asymmetric antiform with internal features trending N60°-75°W. The geophysical data are interpreted as indicating a change in style of folding from a single anticlinal structure along Umtanum Ridge to a broad, low-amplitude anticlinal high with smaller en echelon anticlines superimposed in the Gable Butte and Gable Mountain area.

The structural style changes in the area where the Juniper Springs and Nancy magnetic linears intersect the Umtanum Ridge structure. The Juniper Springs linear has been interpreted as indicative of a fault (Washington Public Power Supply System, 1977, Appendix 2R-I) which is younger than Umtanum Ridge. The Nancy linear (Weston Geophysical, 1978a), at the intersection of the Umtanum Ridge-Gable Mountain structural trend, is nearly coincident with the interpreted subcrop limit of the Elephant Mountain Basalt as defined by Myers and Price (1979) (Figure 2K-2).

Since the Elephant Mountain Basalt is absent in the area south of Vernita Bridge, the gravity anomaly map of this area cannot strictly be considered a structural contour map. Therefore the western boundary of the Gable Butte-Gable Mountain segment is only broadly defined by the geophysical data.

5.2.2 CENTRAL GABLE MOUNTAIN

5.2.2.1 Introduction

Geophysical studies on Gable Mountain consisted of ground magnetics and seismic studies in support of Golder Associates' investigations of the central Gable Mountain fault and possible "pull-apart" features. Ground magnetic studies were performed for the purpose of general characterization of the central Gable Mountain area. Seismic refraction studies were conducted to determine depths to bedrock for planning exploration trenches and to investigate the "pull-apart" feature on the high bluff to the southeast of the central Gable Mountain fault. Other seismic profiles were located to characterize the subsurface conditions within the saddle between the east and west anticlines on Gable Mountain.

5.2.2.2 Discussion of Results

5.2.2.2.1 Land Magnetic Studies

The locations of land magnetic profile lines on Gable Mountain are shown on Figure 2K-24 and the contour map of the total magnetic field is shown on Figure 2K-25. Significant features of the contour map are:

a. A linear east-west magnetic high G-1 to the west of the central Gable Mountain area. This high has steep gradients on both its north and south sides.

b. A northeast-trending magnetic feature G-2 in the approximate position of the scarp which forms the southeast side of the central Gable Mountain fault.

c. A magnetic high G-3 located on the south side of Gable Mountain on the saddle between the east and west anticlines on Gable Mountain.

d. The flank G-4 of a magnetic high located on the south side of Gable Mountain extending easterly from the magnetic high G-3.

There is no unique interpretation associated with these magnetic features; however, they are important geophysical data which serve to constrain geologic interpretations of

the observed structural features on Gable Mountain. Magnetic gradients and trends G-1, G-2, and G-4 are indicative of structural features or associated with bedrock topographic features such as a scarp. Geologic structural features which would cross these gradients would disrupt, offset, or in some way alter the magnetic contour patterns observed. In that manner, the geologic interpretation of larger structural features is constrained; it is recognized, of course, that small geologic features could be present and not be detected with the present grid spacing.

The magnetic high G-1 is coincident with the west anticline of Gable Mountain as mapped by Golder Associates (1981, Figures 20-51).

The magnetic gradient G-2 is related to basalt topography, specifically the edge effect of the northeasterly-trending basalt ridge on he eastern side of the saddle which overlies the central Gable Mountain fault. The trend of this magnetic feature, G-2, becomes more easterly and is no longer parallel to the scarp in the vicinity of Line GM-1. Seismic data in this area also show that the shallow high velocity basalt trends easterly in this area (the weathered basalt thickness increases), further supporting the interpretation that the magnetic gradient is related to basalt topography.

The magnetic high G-3 may be indicative of a basalt high. The magnetic feature G-4 extending easterly from the magnetic high G-3 appears to be indicative of bedrock topography, although a structural interpretation such as the edge of a fold is also permissible.

5.2.2.2.2 Seismic Refraction Surveys

The locations of seismic refraction profile lines in the central Gable Mountain area are shown on Figure 2K-26. Profiles for those seismic lines not individually discussed in this section are included in Attachment B. Seismic refraction surveys were initially conducted on Gable Mountain to determine the thickness of unconsolidated overburden materials above the bedrock at proposed trenching locations. As shown on the isopach map, Figure 2K-27, the thickness of the low velocity overburden material (less than 3,000 ft/sec.) increases in a southwesterly direction along the trend of the central Gable Mountain fault. A typical cross-section profile across this trend is shown on Figure 2K-28. Toward the northeast, where the loose overburden material is not

present, seismic velocities of approximately 6,000 ft/sec. were detected in the immediate vicinity of the fault zone. This velocity value is typical of the fractured rock that was excavated in the exploration trenches. Toward the southwest, the relatively narrow zone of 6,000 ft/sec. material becomes more difficult to define because of the increasing thickness of the overlying low velocity materials (see Profile Line 9A, Figure 2K-29). Thus a definitive tracing of the fault zone by seismic refraction techniques is not possible.

Other seismic refraction profiles were located in the saddle area between the east and west anticlines on Gable Mountain to obtain general subsurface information for planning trenching and drilling activities. In the northwestern region, a relatively extensive area and thickness (up to 80 feet) of 7,000 to 8,000 ft/sec. material was detected on Line 9 (Figure 2K-30). Golder Associates identified the material encountered in Borehole 107 along Line 9 as weathered and broken basalt.

Toward the southern part of the saddle, the thickness of the loose low velocity overburden material increases substantially (see Figure 2K-31, Profile for Line 9B and Figure 2K-27). Seismic refraction lines in the vicinity of the trenches which cross the South fault define a locally shallow ridge of 6,000 ft/sec. material.

Several seismic refraction lines were located southeast of the central Gable Mountain fault to investigate the hypothesis that the offset on the Central Gable Mountain fault was due to a nontectonic mechanism. The seismic lines were located across the postulated "pull-apart" feature, the head scarp of a possible gravity slide feature. The typical Gable Mountain cross section (Figure 2K-28) shows that the basalts which outcrop throughout much of this area have near-surface velocities of 8,000 to 11,000 ft/sec. However, in the vicinity of the "pull-apart" feature between Stations 10+00 and 14+00 (Figure 2K-28) lower velocity materials are present; these velocities are 4,000 to 6,000 ft/sec. and have been identified by trenching as fractured and weathered basalt. Although the geophysical data on Lines LS-1, LS-2, and LS-3 do not exhibit any specific feature which can be directly associated with the suggested "pull-apart", there is a generalized spatial correlation between these lower velocities and the suggested location of the "pull-apart" feature.

5.2.3 DB-10 AREA

5.2.3.1 Introduction

Several deep coreholes were drilled within the Hanford Reservation by Rockwell Hanford Operations during their geologic and geophysical investigations of the Pasco Basin. Corehole DB-10, located in the SW 1/4, sec. 29, T.13N., R.27E. (Figure 2K-32) intersected two zones of reverse faulting (Myers and Price, 1979) at depths of 400 feet and 575 feet. The combined vertical offset was estimated at 160 feet. Rockwell interpreted the faulting to be part of an anticlinal ridge. No other deep coreholes were located in the immediate vicinity to assist in defining the attitude of the faulting or of the basalt flows.

As part of the geologic and geophysical study of the DB-10 area, Weston Geophysical conducted a detailed program of seismic refraction, gravity and land magnetics to supplement drilling and geological studies by Golder Associates.

The seismic refraction data were collected along overlapping and reversed 800-foot spreads and gravity data were acquired at 100-foot station intervals. The land magnetic data for many of the lines in the DB-10 area were evaluated as not usable; three sets of power lines cross that area and limit the useful data to very short, inconclusive segments.

The initial refraction studies defined a northwest-trending zone across which the near-surface velocities differed significantly. Test pits were excavated by Golder Associates to investigate this anomalous zone.

Test pit 6 disclosed an outcrop of basalt six feet below the surface (Table 2K-1). The seismic coverage was subsequently expanded to the west to investigate this near-surface zone as well as apparently anomalous bedrock velocities. Upon completion of the borehole studies conducted by Golder Associates, several of the existing DB-10 lines were extended with seismic and gravity coverage, and Line DB-10-8 was located to intersect the projected outcrop of the faulting defined by Golder Associates.

5.2.3.2 Discussion of Results

5.2.3.2.1 Seismic Data

Seismic refraction Profiles DB-10-1 through DB-10-8 (Figures 2K-34 through 2K-36 and Attachment C generally show higher, near-surface overburden velocities than are found elsewhere in the Hanford Reservation; the typical 1,000-2,000 ft/sec. shallowest material is less than 20 feet thick and is underlain by material with velocities ranging from 3,000 to 8,000 ft/sec. An analysis of materials excavated from test pits (Table 2K-1) along the seismic refraction lines indicate a lateral variation in the composition of the gravels. These compositional changes define a northwest-trending transition zone which is indicated by the northwest-trending dotted line on Figure 2K-33. Lower velocities of 3,000-5,000 ft/sec. in the gravels found northeast of the transition zone correlate with a matrix of basaltic sand. The higher velocity material (6,000-8,000 ft/sec.) encountered southwest of the zone has a matrix of silt and clay with weak calcareous cementation.

The seismic refraction data in the DB-10 area clearly define the northwest-trending basalt ridge indicated by the gravity data, as well as the drillhole data obtained by Golder Associates. Top of basalt elevations in the area of seismic lines DB-10-1 through DB-10-8 are between 460 feet and 260 feet. The seismic velocities for bedrock vary from 10,000 to 14,000 ft/sec.

Seismic lines DB-10-3A, DB-10-5, DB-10-6 and DB-10-7 were located to explore the lateral extent of the 8,000 ft/sec. material that appear at the west end of Line DB-10-3. Shallow, competent basalt (12,000 - 14,000 ft/sec.) with a localized weathered zone (6,000-9,000 ft/sec.) in the vicinity of Test Pit 6 was found to extend across the entire DB-10 area.

Profile DB-10-4 (Figure 2K-34) shows an anomalous low velocity zone in the basalt bedrock between Stations 12+00 and 16+00. A low velocity zone in the bedrock was encountered between Stations 6+00 and 10+00 on Profile DB-10-8 (Figure 2K-35) and at Station 15+50 on Line DB-10-3 (Figure 2K-36).

Seismic Profiles 7 and 8 (Figures 2K-37 and 2K-38) show an overburden sequence of 2,000-4,500 ft/sec. material underlain by 8,000-10,000 ft/sec. material. Isolated zones within the overburden have intermediate velocities that

range from 5,000-8,000 ft/sec. The velocity of the basalt varies from 13,000 to 14,500 ft/sec. in areas overlain by 100 feet or more of the gravels. In areas where the basalt is less than 100 feet below the surface the velocities range from 11,000 to 13,000 ft/sec. The seismic refraction data were used to contour the bedrock surface (Figure 2K-39) and bedrock velocity values (Figures 2K-40).

5.2.3.2.2 Gravity Data

The Bouguer gravity map shown in Figure 2K-41 was processed with a density of 2.67 g/cm^3. Because of the contrast in density between basalt and sediments (0.2 to 0.5 g/cm^3), the map is controlled mainly by the topography of the basalt. The immediate DB-10 area is characterized by an elongate, northwest-trending, gravity high located approximately one mile south of Gable Mountain and one mile west of the north-south trending May Junction monocline.

The residual gravity map for the DB-10 area is shown in Figure 2K-42. It is characterized by two major features: a northwest-trending elongate gravity high and the gravity gradient indicating the location of the May Junction monocline. The elongate, gravity high, A, coincides with the bedrock ridge which trends through the site of the DB-10 drill hole. The crest of the bedrock ridge appears to be disrupted by a north-south to northeast-trending "saddle". The dips on the flanks of the ridge are less than 20°. 24

5.2.3.3 Interpretations

The bedrock high, A, was interpreted by Myers and Price (1979) to be an anticlinal ridge. Their interpretation was based upon a single drill hole, DB-10 and their aeromagnetic data. Subsequent drilling by Golder Associates across the southeastern nose of the bedrock ridge (Figure 2K-32) has confirmed the presence of anticlinal folding (Figure 2K-43). This drill hole profile crosses the northwest-trending ridge where it intersects the May Junction monocline. The structural section of Figure 2K-43 therefore contains interference from two different features, the DB-10 anticline and the May Junction monocline. The change in the elevations between DH-97 and DH-93 contains two components. Furthermore, the line of drill holes is oriented at 45° to the trend of the bedrock high.

The contour map of the top of basalt (Figure 2K-39), developed from the seismic refraction data, shows a northwest-trending bedrock ridge consistent with the gravity data. The southwest flank of the ridge is characterized by a steeper gradient than the northeast flank. The maximum slope of the bedrock surface on the southwest flank is 20°. To the northwest the ridge becomes more symmetrical and the slope decreases to 10°. The bedrock contours are disrupted 600 feet southeast and 800 feet west of corehole DB-10. Basalt elevations decrease from 460 feet to 400 feet along a north-south trend, and define saddles in the bedrock ridge.

The bedrock seismic velocity in the DB-10 and adjacent areas (Figure 2K-40) decreases as bedrock elevations increase. Variations in basalt velocity (from 9,000 to 15,000 ft/sec.) are probably caused by a combination of weathering and fracturing due to folding. The velocity of near-surface and exposed basalt is generally lower than the velocity of more deeply buried basalt. The lower velocities at the ridge crest may be evidence of fracturing that could have been produced by the folding of the basalt. Another aspect of the bedrock velocity contour map that appears to be structurally controlled is the 2,400-foot-long, north-south trending, low velocity zone located 800 feet east of corehole DB-10 (Figure 2K-40). The low velocity zone occurs at the intersection of the bedrock surface and the upper DB-10 fault as determined by Golder Associates (Figure 2K-44). The residual gravity map defines a disruption in the crest of the ridge indicating a break in the bedrock slope or a low density zone at this locality. No offset of the bedrock surface was observed within this low velocity zone. The abrupt change in velocities and the residual gravity anomaly are attributed to a zone of breccia, the length of which is probably confined to the north-south zone described above.

The bedrock velocities in the DB-10 and adjacent areas are indicative of anisotropic conditions in the basalt. They are consistently higher along north-south trending seismic profiles than on east-west profiles. The higher velocities (14,000-15,500 ft/sec.) approach the bedrock velocities measured in other areas (16,000 ft/sec.). The minimum values, however, are significantly lower (approximately 12,000 ft/sec.), and are likely caused by oriented fractures in the basalt.

The overburden velocities in the vicinity of DB-10 range from 3,000 to 8,000 ft/sec. The velocity of the overburden material generally decreases away from the shallow bedrock ridge, especially to the southwest. The 6,000 to 8,000

ft/sec. overburden is present on either side of the basalt ridge.

The flanks of the DB-10 anticlinal ridge dip at approximately 20°. This value is consistent with the value obtained from drill holes 96 and 92. Our interpretation of the seismic data along Line 8 (Figure 2K-38) indicates that the dip is due to anticlinal folding. This interpretation differs significantly from the interpretation by Seismograph Services Corporation of their Line 3-1, described in Myers and Price (1979) and shown in Figure 2K-45. Gravity, drilling and refraction data presented in this report do not support a fault in the vicinity of Station 476, of the magnitude and attitude shown in Figure 2K-45.

5.2.3.4 Summary

The gravity and seismic refraction data support the geologic interpretation that the upper DB-10 fault strikes north-south and dips 30° to the west.

The seismic refraction data limit the length of the upper DB-10 fault to 2,400 feet, confining the fault to the small, northwest-trending, anticlinal fold south of Gable Mountain.

5.2.4 MAY JUNCTION AREA

5.2.4.1 Introduction

The eastern boundary of the first order antiform of the Gable Butte-Gable Mountain segment is the May Junction monocline, originally defined as the May Junction linear by Myers and Price (1979) on the basis of aeromagnetic data obtained by Rockwell Hanford Operations. Data acquired during the study of the May Junction monocline included gravity, ground magnetic and seismic refraction. Seismic reflection data acquired by Rockwell were also used in the evaluation of the May Junction monocline. Geophysical surveys in the DB-10 area (Section 5.2.3) extended into the May Junction area and are discussed and/or cross-referenced where appropriate.

5.2.4.2 Discussion of Results

5.2.4.2.1 Aeromagnetic Data

The existing aeromagnetic data, those of Washington Public Power Supply System and Rockwell Hanford, exhibit similar features to those identified from the gravity data collected for Northwest Energy Services Company. The prominent north-south magnetic feature is the May Junction linear of Rockwell (Myers and Price, 1979). This north-south gradient (Figure 2K-46) intersects the northwest-trending magnetic anomalies to the west and bounds a large, regional magnetic low to the east. The May Junction linear indicates the location of a known bedrock gradient with up to 350 feet of relief based on drill hole and other geophysical data.

5.2.4.2.2 Gravity Data

The Bouguer gravity map of the May Junction area shown in Figure 2K-47 was processed with a density of 2.67 g/cm^3. Because of the contrast in density between basalt and sediments (0.3 to 0.7 g/cm^3), the map is controlled mainly by the topography of the basalt. The gravity data acquired along eleven east-west traverse lines intersecting the trend of the May Junction monocline (Figure 2K-6A) provide greater detail on the configuration of the top-of-basalt. The gravity anomaly contours, as illustrated on the detailed Bouguer gravity map of the area (Figure 2K-47A), are consistent with a north-south trending bedrock surface sloping gently toward the east. The north-south trending May Junction gradient is produced by the change in depth to the top of basalt of approximately 350 feet. 28

A model of the subsurface geology that satisfies both the results of drilling and the gravity along Line 8C is shown on Figure 2K-47B. The densities used for the units are 2.60 g/cm^3 for the basalt, 2.45 g/cm^3 for the Ringold Basal Unit I gravel, and 2.0 g/cm^3 for the Rattlesnake Ridge interbed and the remainder of the sedimentary section. The elevation of the basalt surface varies smoothly. The maximum slope of the basalt surface along the May Junction structure at Line 8C is 10° as determined by drilling data and gravity modeling. 28

5.2.4.2.3 Seismic Data

The north-south trending May Junction linear observed in the gravity and magnetic data is clearly present on seismic lines 7 and 8. Both lines show a steep rise of the bedrock surface from east to west with a maximum relief of 350 feet. As shown in the bedrock contour map (Figure 2K-48), the northwest-trending DB-10 ridge is not distinct at its projected intersection with Lines 7 and 8. The dominant north-south May Junction monocline interferes with the northwest trend of the DB-10 anticline. The bedrock surface on Line 8 is irregular at the intersection of the two trends.

The bedrock velocities in the DB-10 and May Junction areas are indicative of anisotropic conditions. They are consistently higher along north-south trending seismic profiles than on east-west profiles.

5.2.4.3 Interpretation

The May Junction monocline produces prominent anomalies in both the magnetic and gravity fields. The data indicate the presence of an eastward-dipping monocline about 2,000 feet wide that strikes north-south for a distance of approximately 2½ miles. This interpretation is consistent with the drill hole profile shown in Figure 2K-43 (provided that the interference of structures in the DH-97, DH-93 area is recognized) and the drilling data noted on Figure 2K47B. There is no evidence in the seismic refraction or the gravity data to support the fault near Station 435 as proposed on the basis of the seismic reflection data by Seismograph Services Corporation (in Myers and Price, 1979 and shown on Figure 2K-45). The change of Bouguer gravity anomaly across the May Junction monocline is due to the change of elevation of the top of basalt, change of density in the Ringold section and variation of the regional Bouguer gravity anomaly; the change in elevation of top of basalt accounts for at least 90% of the change. No evidence for offset is present. 28

In the DB-10 and May Junction areas, the bedrock velocities are higher in a north-south direction than in an east-west direction. The higher velocities (14,000 to 15,000 ft/sec.) approximate the bedrock velocities measured in other areas (16,000 ft/sec.). The minimum values, however, are significantly lower (approximately 12,000 ft/sec.) and could be caused by (1) primary features in the basalt, (2) anisotropic (horizontal) stress, and (3) open fractures

developed in the basalt and oriented north-south. Cause No. 1 is rejected because the same basalt unit is present elsewhere on the reservattion and does not exhibit anisotropy outside the DB-10 area. Cause No. 2 is rejected as the chief cause of anisotropy because of the magnitude of the stress difference that is required. Nur and Simmons (1969) showed that a stress difference of 400 bars produced 15% anisotropy in dry Barre granite. A much larger stress difference would be required for saturated or partially saturated rock. We attribute the cause of the anisotropy to cause number 3, fractures in basalt.

The broad, first-order antiform of the Gable Butte-Gable Mountain segment is bounded by the May Junction monocline. An elongate gravity high indicative of a small anticlinal fold extends across the southern portion of the May Junction monocline. The geometry does not imply an age relationship between the two features. This small northwest-trending anticline is separate and distinct from the Southeast Anticline.

5.3 SOUTHEAST ANTICLINE

5.3.1 INTRODUCTION

The aeromagnetic data acquired by Washington Public Power Supply System (Figure 2K-49) show a magnetic high trending southeasterly from the eastern end of Gable Mountain. Two aeromagnetic survey blocks are joined along the axis of this magnetic high. Those individual flight lines which overlap from one survey block to another have been evaluated and confirm that the magnetic high is real and not an artifact of merging the two aeromagnetic survey blocks. Rockwell's 1980 aeromagnetic survey of the Hanford Reservation area further confirms the existence of this aeromagnetic high. Extensive seismic refraction, gravity and land magnetic data were acquired to characterize this anticlinal ridge and to define the structural relationships between the Southeast Anticline and the first-, second-, and third-order folds of the Umtanum Ridge-Gable Mountain structural trend.

5.3.2 DISCUSSION OF RESULTS

5.3.2.1 Magnetic Data

An aeromagnetic high, generally symmetrical in shape, trends in a southeasterly direction from the eastern end of Gable Mountain to the vicinity of Line 4C. At this location the anomaly decreases in amplitude and appears to be offset to the southwest. This lower amplitude magnetic high continues trending southeasterly and then easterly in the vicinity of Lines 4E and 4F.

The individual land magnetic profiles (Figure 2K-50) indicate a feature which may be more complex than the aeromagnetic data would indicate. A sharp anomaly (A) trends in a S60°E direction from Line 3 to Line 1-A but is not traceable south of Line 1-A. The single peaked, magnetic anomaly on Line 1 broadens and divides into two more subdued peaks (B and b) in the vicinity of Line 4B. The northeasterly of the two southeast trends decreases in amplitude to a magnetic low (C) on Line 4D. The southwesterly of the two southeast-trending highs appears to continue southeast of Line 4D but is then offset in an en echelon manner, similar to the aeromagnetic data, to a southeasterly-trending lower amplitude magnetic high on Lines 4E and 4F (D).

Land magnetic data acquired for the Supply System in the immediate vicinity of Borehole 125 on Line 4A (Weston Geophysical, 1982) have been contoured and are shown on Figure 2K-50A. A small residual magnetic high of approximately 25 gammas, located just southwest of Borehole 125, is consistent with a small undulation in the top of basalt. 28

5.3.2.2 Gravity Data

The gravity data processed at a density of 2.67 g/cm3 (Figure 2K-51) define a gravity high trending southeasterly from the Gable Mountain area. Detailed gravity coverage (Figure 2K-6) shows that the northwest portion of this gravity feature is quite linear and appears to extend one mile northwest of the eastern end of Gable Mountain.

The southeast-trending gravity high is generally symmetrical in shape and decreases in amplitude toward the southeast. Assuming that 1 milligal gravity is equal to about 150 feet of basalt relief, the basalt surface slopes

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at angles ranging from 5 to 13 degrees. The gravity data clearly indicate that the southeast-trending feature changes trend to east-northeast in the vicinity of Lines 4C and 4D.

Gravity data acquired for the Supply System (Weston Geophysical, 1982) provide additional information on two aspects of the Souteast anticline. First, a detailed survey in the immediate vicinity of Borehole 125 on Line 4A (Figure 2K-7A) has delineated a small localized rise in the surface of basalt consistent with the results of the detailed drilling program in that area (Golder Associates, 1982). This localized rise is indicated as anomaly A on the residual Bouguer anomaly map for the area (Figure 2K-51A). Second, additional data acquired on Savage Island and east of the river (See Fig 2K-7B) constrain the extent of the Southeast anticline. The residual Bouguer gravity anomaly attributed to the Southeast anticline terminates in the vicinity of Savage Island (Figure 2K-51B). Therefore, the Southeast anticline does not extend east of the Columbia River. 28

5.3.2.3 Seismic Refraction Data

Seismic refraction data across the Southeast Anticline have been acquired and profiled along Lines 3 (Figure 2K-52), 1 (Figure 2K-54), 4A (Figure 2K-55), and 4B (Figure 2K-56) and on the southwesterly side of the feature on Line 2 (Figure 2K-53). Seismic data were also obtained for portions of Lines 4C (Figure 2K-57), 6 (Figure 2K-58), and 6A (Figure 2K-59) to provide more information on the configuration of the bedrock surface in the area where the gravity and magnetic data indicated a change in the orientation of the feature. Seismic data were acquired on Line 6B (2K-60) to explore the northeast flank of the Southeast Anticline.

Overburden seismic velocities in the area of the Southeast Anticline are, in general, typical of those encountered elsewhere in the Hanford Reservation. The low velocity (2,500-3,000 ft/sec.) overburden has a uniform thickness of approximately 100 feet except at the northeast limit of the area near the Columbia River where it thins to 50 feet. Higher velocity overburden materials (9,500-10,000 ft/sec.) underlie the lower velocity material southwest of the bedrock high. The seismic velocity of this material changes to 6,500-7,500 ft/sec. northeast of the bedrock ridge.

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The seismic velocity of competent basalt in the vicinity of the bedrock ridge is 15,000-16,000 ft/sec. Highly fractured basalt above a depth of 250 feet in Boring 125 (Line 4A, Figure 2K-55) correlates with a seismic velocity of 7,500 ft/sec. The higher velocity overburden materials also have a velocity of 7,200-7,500 ft/sec. over the anticline, precluding a determination of the lateral extent of the fractured basalt along Line 4A. To the southeast of Boring 125, the velocity of 9,000-9,500 ft/sec. is indicative of cemented overburden materials as identified in Boring 122A. In Boring 109, northeast of Boring 125, the 7,200-7,500 ft/sec. material has been identified as overburden.

The fractured basalt encountered on Line 4A in the vicinity of Boring 125 probably extends along strike of the ridge. Differences between the seismic top of rock elevations and borehole bedrock elevations also occur on Lines 1, 3 and 4B along the southwest side of the bedrock ridge. Basalt elevations in Boreholes 105 (Line 1) and 37 (Line 3) are 50 to 100 feet above the seismic top of high velocity bedrock (16,000 ft/sec.). The materials above the 16,000 ft/sec. horizon have a seismic velocity of 6,800-7,500 ft/sec. and are described in the boring logs as "weathered basalt." To the southeast, on Line 4B, "extremely weathered, fractured basalt" was logged in Boring 101 at elevation 234, 75 feet above the top of seismic high velocity basalt.

The profiles for Lines 1 (Figure 2K-54), 3 (Figure 2K-52), and 4A (Figure 2K-57) show slopes on the high velocity bedrock ranging from 5° to 9° on each side of the bedrock high. The profile of the southwestern side of the bedrock ridge on Line 2 (Figure 2K-53) also exhibits a bedrock slope of approximately 10°. All of the bedrock slopes described above are smooth.

The top of high velocity basalt contour map (Figure 2K-61) compiled from the seismic refraction data for the Southeast Anticline defines a southeast-trending, broadly asymmetrical anticline feature. The anticline extends from the vicinity of Line A to Line 4B where it changes trend from a southeasterly to an east-northeasterly direction. The southwest flank of the anticline has a slightly steeper gradient than the northeast flank. The feature becomes symmetrical as it changes trend to the east-northeast; the maximum slopes on either flank of the ridge decrease to 8°.

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5.3.3 INTERPRETATION

Gravity, seismic refraction, land magnetic and aeromagnetic data have defined a southeast trending anticlinal shaped feature extending from the vicinity of Line A to Line 4C where it changes trend to east-northeasterly but does not extend east of the Columbia River. Geochemical analysis of drill cuttings in this location identified the basalt surface as the same basalt unit. The anticlinal interpretation is based on the symmetry and broad shape of the aeromagnetic and land magnetic profiles across the feature, as well as the slope of the basalt surface as defined by the gravity and seismic data. Slopes on the basalt surface as determined from the seismic and gravity data range from 5 to 16 degrees. 28

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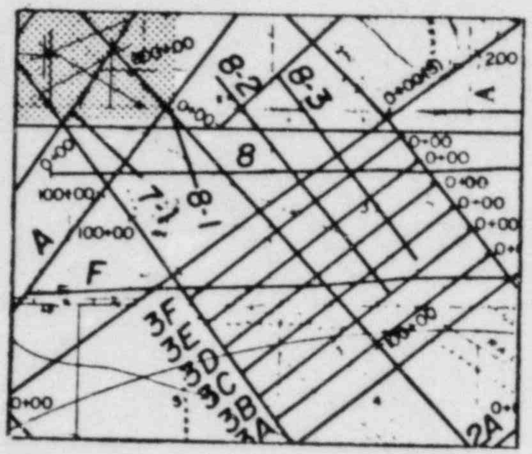

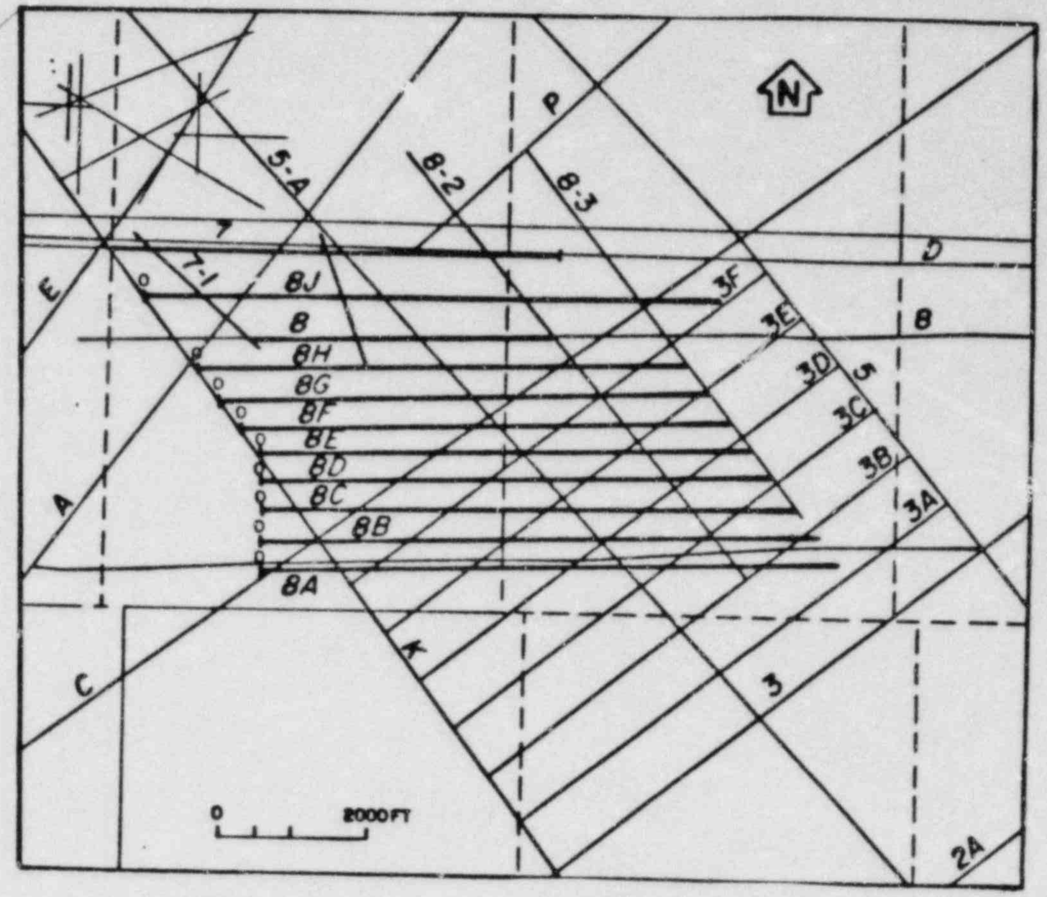

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FIG. 2K-6A

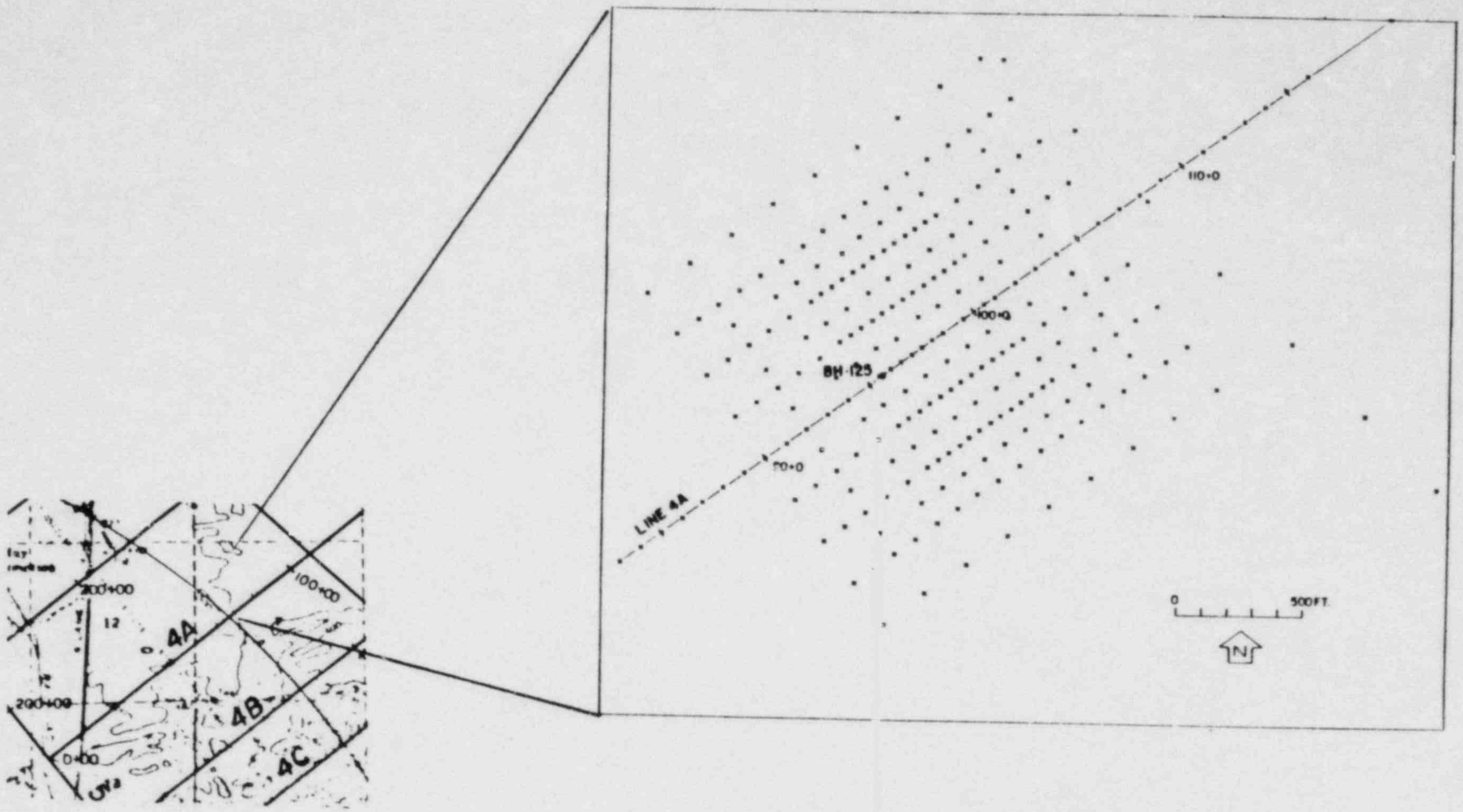

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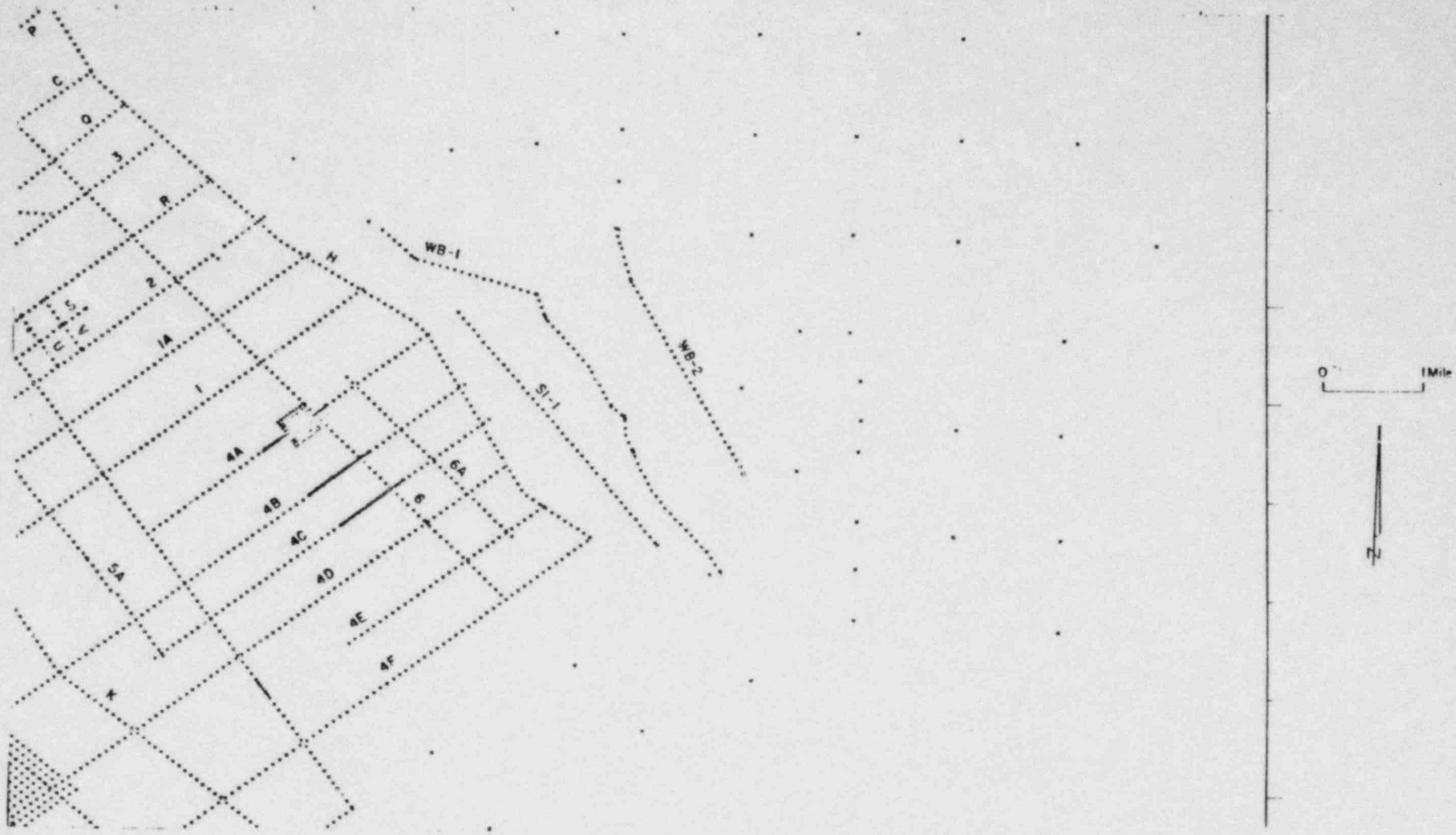
Fig. 2K-7A



THIS WILL HAVE A TOPO OVERLAY WITH THE SAVAGE ISLAND AREA STATIONS HIGHLIGHTED

Fig 2K-7B

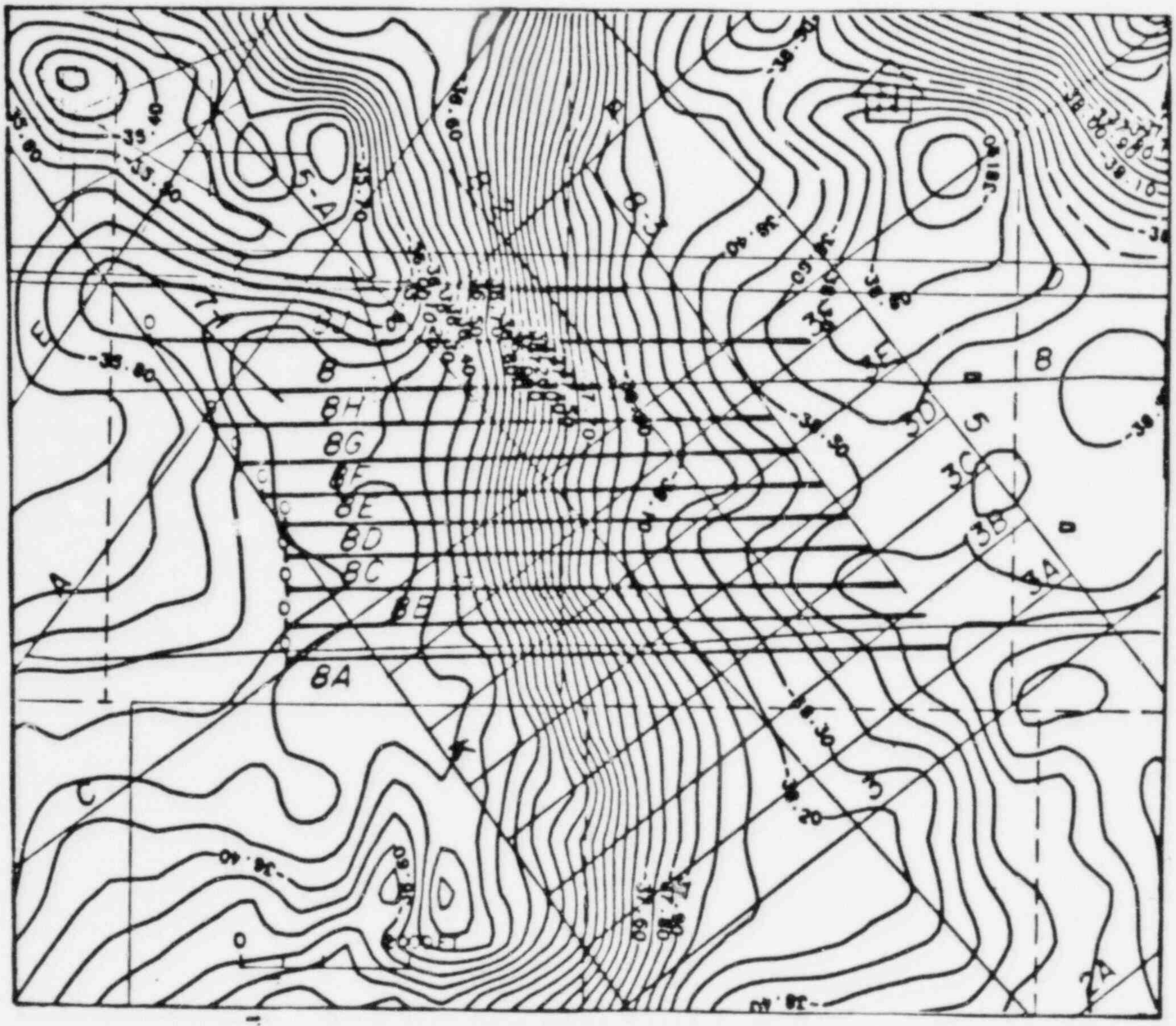
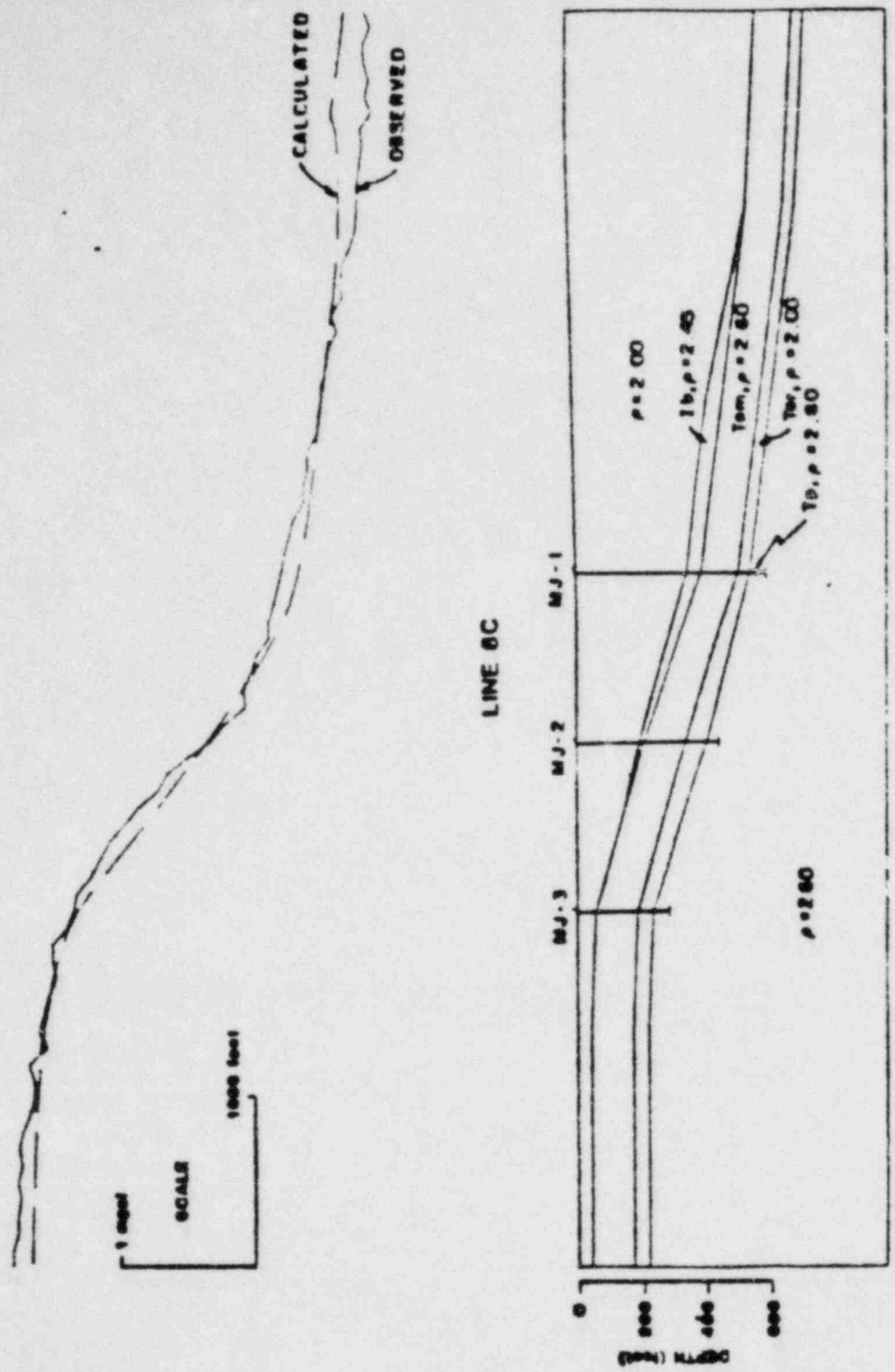


FIG 2K-47A



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GEOLOGIC MODEL OF GRAVITY LINE 8C

FIGURE ~~2.5.14-8~~ 2K-47B

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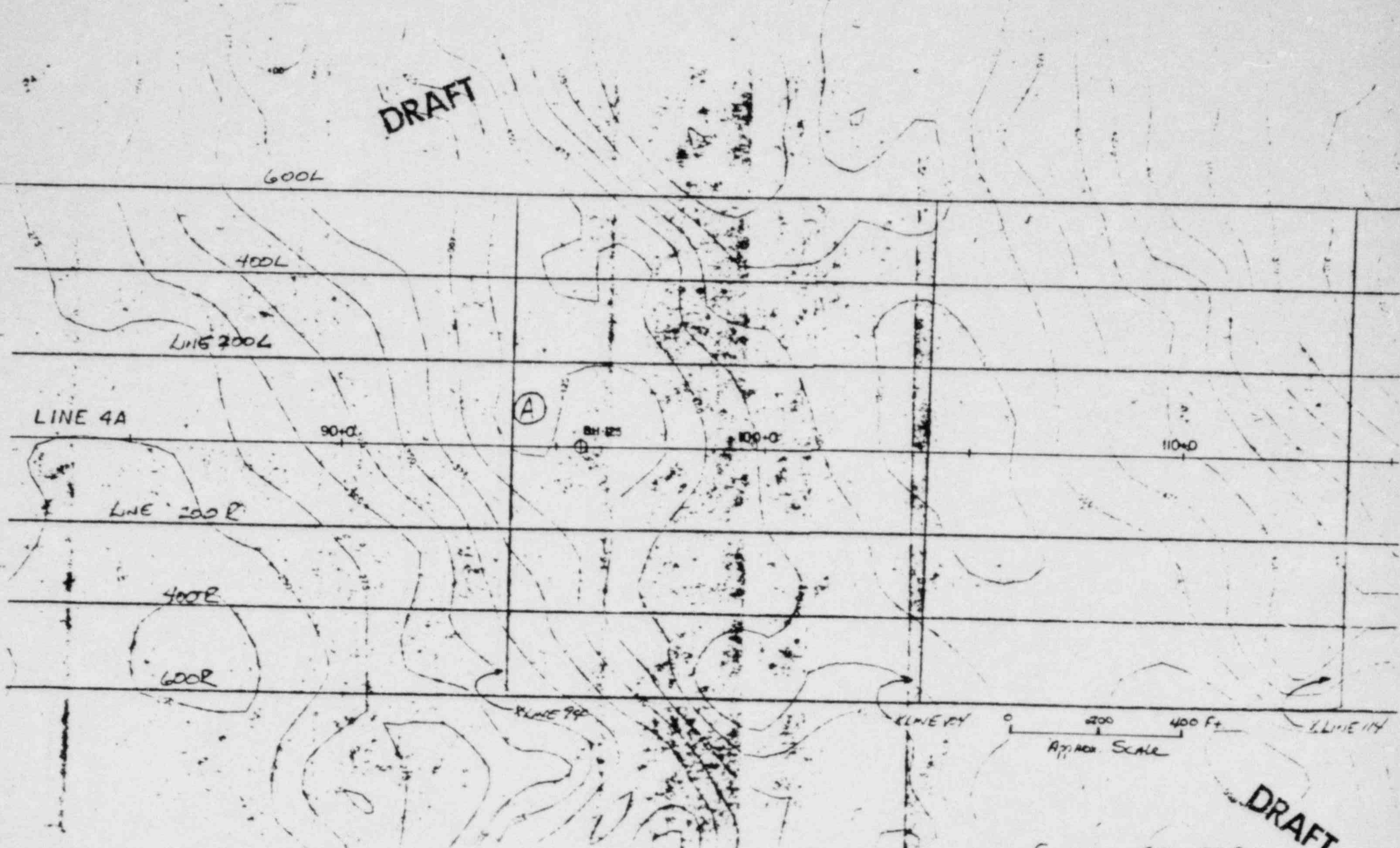

FIGURE 2K-50A
LAND MAGNETICS, SE Anticline

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FIGURE ZK-51A
RESIDUAL BOUGUER GRAVITY ANOMALY MAP,
BOREHOLE 125 AREA

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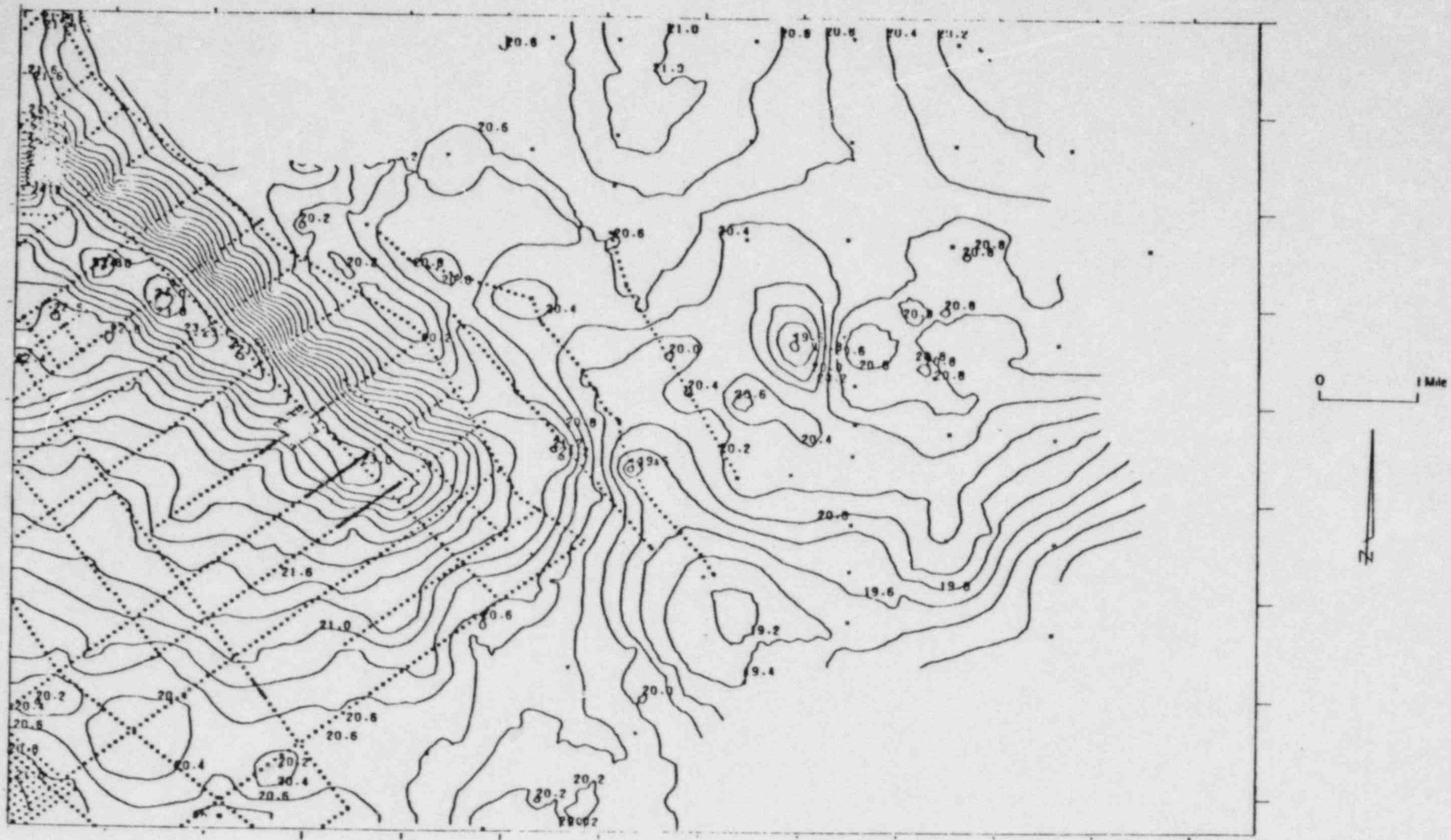

FIGURE ZK-51B
RESIDUAL BOUGUER GRAVITY ANOMALY MAP,
SAVAGE ISLAND AREA

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Appendix 2R

Stratigraphic Investigation of the Skagit/Hanford Nuclear Project

by

Gary D. Webster and James W. Crosby III

with
Golder Associates

Prepared for Golder Associates
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Geological Engineering Section
Washington State University
Pullman, Washington 99164
November, 1981

(Amended October, 1982) 28

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APPENDIX 2R

CONTENTS

APPENDICES

FIGURES

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NUMBER	TITLE
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2R-A-90	Interpretive Petrographic Log, Drillhole S-3
2R-A-91	Interpretive Petrographic Log, Drillhole S-4
2R-A-92	Interpretive Petrographic Log, Drillhole S-5
2R-A-93	Interpretive Petrographic Log, Drillhole S-6
2R-A-94	Interpretive Petrographic Log, Drillhole S-7
2R-A-95	Interpretive Petrographic Log, Drillhole S-8
2R-A-96	Interpretive Petrographic Log, Drillhole S-9
2R-A-97	Interpretive Petrographic Log, Drillhole S-10
2R-A-98	Interpretive Petrographic Log, Drillhole S-11
2R-A-99	Interpretive Petrographic Log, Drillhole S-12
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TABLES

1.0 SUMMARY

The Skagit/Hanford Nuclear Project Site is in the east-central part of the Pasco Basin, a structural sub-basin of the larger Columbia Basin (Figure 2R-1). The Pasco Basin is partly surrounded by west- and northwest-trending anticlinal ridges, the Yakima folds, which are separated by broad synclinal troughs. The Saddle Mountains form the northern boundary of the Pasco Basin, and the Rattlesnake Hills and Horse Heaven Plateau form the southern boundary. The eastern boundary, formed by a gentle westward dip on the basalt surface, extends slightly east of south from the eastern end of the Saddle Mountains to a point approximately 20 miles east of Pasco, then turns southwest to Wallula Gap. Umtanum Ridge and Yakima Ridge plunge eastward into the basin at the western boundary. The most prominent structural features within and adjacent to the study area are the Gable Mountain anticline, the Southeast anticline, and the Cold Creek syncline (Figure 2R-2). Of these, only the Gable Mountain anticline is expressed surficially. The Pasco Basin is underlain by flows of the Columbia River Basalt Group, and these basalt flows are overlain by alluvium of the Ringold Formation and Pre-Missoula and Missoula Flood Gravels.

This stratigraphic investigation encompasses approximately 47 square miles within the central part of the Pasco Basin. Because the youngest basalt flows are known to be deformed and faulted in some parts of the Pasco Basin, information regarding post-basalt deformation is important to evaluate the age and amount of youngest deformation in the study area. The investigation has been carried out to determine both the general areal stratigraphy and details of stratigraphic relationships.

In most of the study area, the basalt is overlain by three sedimentary formations: Pleistocene Pasco or Missoula Flood Gravels, Pre-Missoula Flood Gravels of late Pliocene(?) or Pleistocene age, and late Miocene-Pliocene Ringold Formation. These formations have a combined thickness of approximately 720 feet in the southwestern part of the study area. The Missoula Flood Gravels range in thickness from about 30 feet near May Junction to greater than 100 feet in the southeastern part of the study area. Pre-Missoula Flood Gravels are generally on the order of 100 feet thick. The Ringold Formation has a thickness generally greater than 200 feet except over the Southeast anticline. Surficial deposits consist of loess, dune sand, and alluvial sand of Recent or latest Pleistocene age.

The Ringold Formation is comprised of lacustrine and alluvial sediments. The age of the Ringold section in the study area was considered by Gustafson (1978) and Myers and Price (1979) to be Pliocene (5.12 to 3.32 million years B.P.). New information from a palynological study by Leopold and Nickmann (1981), however, indicates that the basal units of the Ringold Formation are of late Miocene age. The age of the Pre-Missoula Flood Gravels is not known. The Missoula Flood Gravels are reported to be 13,000 to 19,000 years old (Mullineaux and others, 1977; Fulton and Smith, 1978; and Waitt, 1980). However, a recent study by Clague and others (1980) suggests that the major advance of the last Pleistocene glaciation into northeastern Washington and northern Idaho did not occur until after 17,500 years B.P. This implies that the Missoula Flood Gravels, which are the result of floods associated with that glaciation, were deposited between 17,500 and 13,000 years B.P. The Ringold Formation has been the primary target of this stratigraphic investigation because of its age, overlying relationship to the Columbia River Basalt, and continuity of sedimentary units. A combination of borehole geophysical logging and sedimentary petrologic techniques has been used to investigate the stratigraphy of this formation. The borehole geophysical techniques involved downhole logging with four radiation devices: natural gamma, gamma-gamma, neutron-gamma, and neutron-epithermal neutron tools. The data were digitized, computer processed, and plotted to enhance stratigraphic relationships. Composite analysis of the four geophysical logs indicated zones in which recognizable geophysical or marker horizons occur which could be used in stratigraphic correlation. Sedimentary petrologic studies consisted of examining core samples and rotary cuttings under a binocular microscope to identify the geologic characteristics of the samples. Lithologic determinations based on texture, color, roundness, cementation, and luster were recorded on lithologic logs for each drillhole.

The use of the geophysical marker horizons in conjunction with lithologic identification from the petrologic studies has allowed the correlation of four sedimentary units within the Ringold Formation in the study area, each representative of a depositional unit. Although the contacts between the units are unconformable, the available evidence indicates that only minor erosion of the upper surfaces of the units has occurred. These surfaces are believed, therefore, to have been generally horizontal over distances measured in miles at the time that the overlying unit was deposited. Structural contour maps, isopach maps, and stratigraphic sections have been constructed using the contacts of these sedimentary units. These maps and sections have been used to interpret the nature of structural deformation during and

after deposition of the Ringold Formation in the study area. In general, all of the units within the Ringold Formation tend to thin or pinch out over the Southeast anticline and thicken toward the Cold Creek syncline to the southwest. Those Ringold units which continue across the Southeast anticline are warped, but younger units are less deformed than older units. The units within the Ringold section are interpreted to have been locally warped over basalt highs in the northwestern and southwestern parts of the study area. This warping reflects deformation which started at least 14 million years B.P. (Myers and Price, 1979) and continued into late Ringold time (early Pliocene). This agrees with the general understanding of Yakima fold development in the Pasco Basin, which indicates that folding started approximately 14 million years B.P. and became most intense between about 8 and 4 million years B.P. (Myers and Price, 1979). Deformation rates have decreased since that time according to Myers and Price (1979). No deformation is recognized in the Pre-Missoula Flood Gravels or Missoula Flood Gravels within the study area.

2.0 INTRODUCTION

This report describes a stratigraphic and structural investigation of a portion of the Hanford Site conducted for the Northwest Energy Services Company. The work was undertaken as a part of a broader investigation for a new reactor site at Hanford. The report integrates the results of support studies for Golder Associates, Inc., undertaken by Professor James W. Crosby III of the Geological Engineering Section, Washington State University, and Dr. Gary D. Webster, Consulting Geologist. The area of investigation is in south-central Washingtron within a large structural downwarp known as the Pasco Basin (see Figure 2R-1). Within this basin, stratigraphic correlations have been made in the Ringold Formation to determine the age and extent of post-basalt deformation. Stratigraphic correlations have been based on a combination of geophysical techniques employed by Professor Crosby and sedimentary petrological studies employed by Dr. Webster.

3.0 DEVELOPMENT OF THE INVESTIGATION

The investigation was initiated by drilling two coreholes approximately 1300 feet apart. These two coreholes, 1 and 3, were drilled to determine whether the stratigraphic section could be correlated on the basis of lithology over short distances. Examination of the cores showed that correlation of lithological characteristics was, in fact, possible. In addition, examination revealed that the sediments of the Ringold Formation accumulated during four major depositional cycles, herein referred to as units. Each of these units began with the deposition of relatively coarse-grained sediments (usually gravels) in a high-energy environment and ended with finer-grained sediments (typically silts) deposited in a low-energy environment.

The two coreholes were geophysically logged using a suite of four radiation tools. Twelve recognizable geophysical markers were initially identified and correlated between the coreholes. These markers on the geophysical logs compared well with the stratigraphic section observed in the cores and demonstrated that the geophysical markers could be directly related to lithologic characteristics. Geophysical markers corresponding to six lithologic contacts ultimately were selected for use in making correlations throughout the study area and for constructing maps and sections. These six contacts are those found at the top of the basalt, top of Basal Unit I, top of Upper Unit I (A-horizon), and at the tops of Units II, III, and IV, respectively. Figure 2R-3 shows five of these contacts that are present in coreholes 1 and 3.

Recognition of the correspondence between markers on the geophysical logs and lithologic contacts permitted lines of drillholes to be extended away from coreholes 1 and 3 without the need for continuous sampling. Therefore, rotary drilling techniques were used to advance additional drillholes, using either mud or air to cool the bit and remove cuttings. Cuttings from the rotary drillholes were sampled, and the drillholes were logged using the four radiation tools. Contacts determined lithologically and geophysically were traced throughout the study area using the geophysical markers observed in coreholes 1 and 3. Six additional coreholes were drilled during the later phases of the investigation to confirm contacts extended into areas distant from coreholes 1 and 3. Figure 2R-4 shows the location of all drillholes in the study area, and delineates areas which are discussed in detail in following sections of this report.

4.0 METHODOLOGY

4.1 PETROLOGIC ANALYSES: SAMPLING AND DESCRIPTIVE TECHNIQUES

Detailed lighologic descriptions were made from sample chips from coreholes 1, 3, 73, 78, 94, 101, 102, 103, 125, E-1, and E-19 and for drill cuttings of all rotary drillholes (Appendix 2R-A). Cores were sampled for laboratory analysis at 3-foot intervals and at lesser intervals where smaller lithologic changes occurred. Cuttings were sampled at 5-foot intervals from rotary drillholes. Cuttings were washed sufficiently to remove drilling mud or were used unwashed from drillholes drilled with air-cooled rotary tools. Lithologic descriptions were made on dry samples using a stereoscopic binocular microscope with magnifications to 100 power. Descriptions included lithologic type or types, color, grain size range and mode, roundness, character of mafics, degree of cementation, and where applicable, other characteristics such as luster, fissility, grain shape, or particular mineral abundance. Cuttings were compared to core chips to ensure the recognition of characteristic unit lithologies as contacts were traced laterally and to identify additional characteristics as they were observed in new drillholes.

Gravel sloughing is common in rotary drilling. As a result, some judgment is required to determine the lower contact of the gravels where they have sloughed into finer-grained samples below the contact. In some cases, sloughing has caused gravels to appear in samples as much as 10 to 20 feet below their actual occurrence. In coreholes, the gravel boundaries correspond directly to geophysical character changes. Therefore, where sloughing of gravels was suspected in rotary drillholes, the geophysical logs were used to pick the contact of gravels with underlying materials.

Lost circulation, change of rates of circulation of drilling fluids (mud or air), mechanical failure of equipment, the taking of incorrect samples from the shaker, improper sample washing, failure to take samples at specified times and intervals, and other human errors are possible explanations of why drill cuttings do not correspond exactly to drilling depths. Such differences which may vary from a few feet to several tens of feet generally increase with drilling depths and are referred to as indexing errors. The indexing error for cores is usually less than 5 feet and is commonly less than 1 foot. The indexing error for geophysical logs is usually less than 3 feet. Therefore, cuttings have been used to identify lithologies encountered in sequence in

drillholes, to provide tentative unit tops, and to verify identification of units determined geophysically. Stratigraphic contacts, on the other hand, are recognized best in cores, and, as has been stated previously, nearly direct correlations may be made between the cores and the geophysical logs. Because of this excellent correspondence, the geophysical logs have been used to establish contacts or other unique features within a stratigraphic unit and, in turn, have been used for correlation between drillholes and for construction of cross-sections and maps.

Contacts also have been determined approximately from cuttings and used for correlation purposes and map construction; however, whenever geophysical logs were available, the geophysical markers were used for consistency and accuracy.

4.2 GEOPHYSICAL TECHNIQUES

Test borings in the Ringold Formation require casing for support of the drillhole. Accordingly, the radiation group of geophysical tools was chosen for these studies, and the standard suite included natural gamma, gamma-gamma, neutron-epithermal neutron, and neutron-gamma tools. Of these, the neutron-epithermal neutron and natural gamma tools provided the more diagnostic logs. A brief description of the radiation devices and their modes of operation is given in Appendix 2R-B-I.

The geophysical logs initially revealed that there were at least twelve easily recognizable markers which could be correlated between the coreholes. Of these markers, those which were found to correspond to obvious contacts between the four lithologic units were selected as the basis for correlating and tracing interfaces within the Ringold Formation. The geophysical characteristics of each of the units are described in Appendix 2R-B-II.

The correspondence between geophysical responses and lithologic units observed in cores is obvious throughout most of the study area, including locations several miles distant from coreholes 1 and 3. However, some interpretation is required in relating lithology and geophysical markers in rotary drillholes and in correlating units between these drillholes. Unit boundaries are based in part on geophysical characteristics of the units (Appendix 2R-B-II) but also rely in large part on the recognition of a sequence of characteristic responses. Therefore, geophysical correlations cannot be made on sections removed from context, i.e., they are traceable only when they appear with their stratigraphic affinities.

In general, where a complete fining upward sequence (basal gravels and overlying sands and silts) is present, the units are sufficiently diagnostic on the geophysical logs that their correlation between drillholes is apparent. However, above the geophysical A-horizon of Unit I, where parts of the younger units are absent or poorly developed, unit boundaries cannot be determined uniquely by the borehole geophysical technique.

Figures 2R-5 and 2R-6 present comparisons between the gamma ray logs of coreholes 1 and 3 and the neutron-epithermal neutron logs of thise holes, respectively. The location of the top of the basalt and the top of each of the sedimentary units is shown. Although the Basal Unit I gravels are not present in coreholes 1 and 3, the top contact of these gravels is carried as a correlating horizon in holes in which they do appear. To be noted in the logs are the elevated gamma ray characteristics of the Ringold section, the reduction in gamma ray activity and porosity change at the basalt surface, and the gross similarity of the sections. Other than the A-horizon (top of Upper Unit I), there are few consistent gamma ray features, although some can be traced to nearby holes. Despite the lack of areally extensive gamma ray markers, the general gamma ray characteristics of the units can be seen to be similar.

In Figures 2R-5 and 2R-6, it is clear that gamma ray "spikes" or high count rates are commonly associated with materials that are obviously gravels on the neutron-epithermal neutron log. Although this observation is contrary to normal expectations, it was found to hold true uniformly for the Ringold deposits of the study area. It may be the result of higher gamma emissions from the clay rinds on the gravels (see Appendix 2R-B-I).

Unit II is somewhat discordant with the sedimentary cycle format in that its lower contact is arbitrarily established at the geophysical A-horizon, which in turn, appears to be genetically related to a paleosol at the top of Unit I. Units III and IV each may be composed of more than one fining-upwards sequence, and therein lies the difficulty in uniquely establishing the contact between the units from geophysical data. The problem is further complicated by a lack of distinguishing lithological characteristics of the units. Geophysical tracing of contacts, therefore, required sufficiently close spacing of holes to permit recognition of newly introduced facies or the loss of facies in the section. On occasion, definition of sub-sequences was possible but was not included.

4.3 INTERPRETIVE PROCEDURES

The Elephant Mountain Member of the Saddle Mountains Basalt Formation is the youngest basalt present throughout the study area (see Section 5.1 for details). This flow is assumed to have been extruded over a geologically short period of time (Shaw and Swanson, 1970; Swanson and others, 1973). The top of the flow probably had a nearly horizontal attitude in the Pasco Basin at the time that it crystallized. A sequence of vesicular basalt grading downward into non-vesicular porphyritic basalt is recognized in both cores and cuttings throughout the study area. Weathering of the top of the Elephant Mountain flow prior to the deposition of the overlying Ringold Formation is recognized in many cores and drill cuttings by the presence of a residual clay paleosol (B- and C-horizons) grading downward into unweathered vesicular basalt. The time duration for the formation of this clay paleosol is unknown but could have been a few hundred to several tens of thousands of years, depending upon climatic conditions. No major erosional relief is recognized on this surface throughout the Site, because the vesicular flow top is found in most drillholes penetrating the basalt. Thus, the top of the Elephant Mountain flow is judged to be a reliable horizon for stratigraphic and structural interpretations.

Unit boundaries determined on the basis of the petrologic and geophysical analyses have been used as markers of stratigraphic contacts. These contacts are interpreted as having formed generally planar subhorizontal surfaces at the time of deposition and as being approximately time-correlative. The subhorizontal surface interpretation is supported by the general presence of fine-grained sediments in the upper part of each unit. These sediments would have been removed by erosion if much topographic relief had developed throughout the area prior to burial by the overlying unit. The time-correlative interpretation is supported by the presence of volcanic ash in a paleosol near the top of Unit I in drillholes 1 and E-19. Although not shown to be the same lithologic unit, an ash has also been identified in the Unit I paleosol in drill cuttings from each of the three subareas of this study.

The geochemical nature of the A-horizon gamma ray spike is not presently known; however, it is consistently associated with the upper part of the paleosol of Unit I, and the two are believed to be genetically related. The paleosol consists of a light to dark olive gray mixture of clay, silt, and sand. It contains weathered organic debris as seen in some cores and has been bioturbated. It is interpreted to be an aggrading soil A-horizon, developed in an alluvial

environment. Independent identification of the top of the paleosol from the drill cuttings and the geophysical A-horizon gamma ray spike from the geophysical logs for 93 drillholes throughout the study area resulted in the markers being within plus or minus 10 feet of each other in 88 percent of the drillholes and within plus or minus 5 feet of each other in 60 percent of the drillholes. Statistically, therefore, and making allowance for indexing errors, the A-horizon and paleosol appear coincident within expected experimental error, and this lends considerable credence to the value of the A-horizon as a stratigraphic marker. For consistency in map construction, the geophysical A-horizon was selected as the top of Unit I. In five drillholes (47, 96, 97, and 99 and MJ-2), the top of Unit I was determined from cuttings at the top of the paleosol; the geophysical A-horizon was not recognized or geophysical logs were not available for these holes. 28

Other contacts used in the interpretation are those between Units II and III, III and IV, and between Unit IV and the Pre-Missoula Flood Gravels. Each unit is bounded on top and bottom by unconformities. The unconformities are recognized by the sharpness of the contact in cores and on the geophysical logs and by the abrupt change in lithology from silts and sands below into gravels above. Unconformities between the Ringold units were found to coincide with the contacts between coarse and fine depositional sequences that are well displayed on borehole geophysical logs. Variations were noted in the type of fine-grained sediment below the same gravel unit as these contacts were traced laterally. Although the boundaries might be expected to mark an irregular surface, they have been found to be laterally continuous and to lie on apparently subhorizontal and subplanar surfaces throughout most of the study area. The unconformities below Units I and II are developed upon paleosols. Paleosols are not found at the tops of Units II through IV. However, the upper, fine parts of each of these units are commonly present and suggest 1) that little erosion occurred on the tops of these units after deposition, and 2) that the time between deposition and burial of the units was insufficient for paleosols to develop. These factors indicate that these contacts provide markers useful for stratigraphic and structural interpretation where sufficient section is present to insure correlation of Ringold units.

The post-Columbia River Basalt history of the study area is based on an interpretation of structural contour maps (Figures 2R-7 to 2R-12), isopach maps (Figures 2R-13 to 2R-18), one-to-one scale cross-sections (Figures 2R-19 to 2R-28), and computer-drawn geophysical cross-sections (Figures 2R-B-1 to 2R-B-56, Appendix 2R-B-III). These figures have been generated from the drillhole lithologic

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data (Appendix 2R-A) and geophysical log suites on the basis of contacts picked from the lithologic and geophysical logs.

Structural contour maps were used to interpret the present structural configuration of the mapped unit. Isopach maps were used to determine thickness trends, distribution patterns, and paleoslopes. In addition, the isopach maps were used in conjunction with the structural contour maps and cross-sections to interpret paleostructure and paleotopography. Examples of these interpretive uses of isopach maps, which are important in reconstructing the stratigraphic and structural history of an area, follow.

An isopach map can be interpreted as a topographic reversal map of the underlying undeformed surface when the top of the isopach interval is an undeformed planar time-correlative surface and the basal surface is an unconformity. On such a map, the areas of greatest thickness reflect topographic depressions, and areas of least thickness reflect topographic highs of the underlying surface. If the underlying surface underwent deformation prior to or during deposition of the isopach interval, then the isopach map will reflect a combination of topographic and structural relief. The isopach maps of Units II through IV are considered examples of this type of map.

If the surface underlying an isopach interval is a deformed, uneroded, planar, time-correlative surface, then the isopach map reflects structural deformation prior to and during deposition of the isopach interval. An an example, assume that the basalt surface was deposited subhorizontally and that it was not extensively eroded prior to the deposition of Unit I. Then the isopach map (Figure 2R-13) of Basal Unit I (i.e., inverted topographic map of the basalt surface) may be used to interpret the structure developed between the time of deposition of the basalt and prior to the end of deposition of Unit I gravels. In this case, the structural relief on the basalt surface, which is here considered to equal the topographic relief, will approximate the total amount of thinning of the sedimentary unit (i.e., a minimum of 98 feet in the Site area and 124 feet in the May Junction area). The isopach map of Basal Unit I shows that the basal gravels are not present over the Southeast anticline nor the area along the May Junction linear in the May Junction area.

The isopach map (Figure 2R-14) of Upper Unit I (fines, including the geophysical A-horizon and paleosol) may be used for the area where the basal gravels are not present. It shows a minimum of 80 feet of relief in the Southeast anticline area. Data from these two maps (Figures 2R-13 and 2R-14) may be combined and provide a total minimum relief of

212 feet for Unit I between the Southeast anticline (zero thickness) and the southwestern part of the May Junction area (212 feet, drillhole 71). These combined maps give a calculated minimum of 168 feet of relief in the Site area.

4.4 STRATIGRAPHIC CORRELATIONS

Correlation of sedimentary units is based on the recognition of diagnostic lithologies and sequential order combined with the stratigraphic principles of superposition (older is deposited first, younger sediments above), original horizontality, and lateral continuity (sediments extend laterally until they pinch out, abut against a barrier, or interfinger into time-equivalent sediments). Several lithologies within the Ringold units, the Pre-Missoula Flood Gravels and Missoula Flood Gravels sequences, are easily recognized in both cores and cuttings. A preliminary stratigraphic sequence was established by observing the sediments in the cores of drillholes 1 and 3. Similar lithologies in the same sequential order are present in both cores, and bedding surfaces are horizontal, that is approximately normal to the long axis of the core. This stratigraphic sequence was confirmed and traced laterally by observing and correlating the sediments found in cores from drillholes 73, 78, 94, E-1, and E-19 and from cuttings from intervening drillholes. Coreholes 101, 102, 103, and 125 on the Southeast anticline show the lower part of this sequence; however, the stratigraphic section if considerably thinner in these coreholes than in coreholes 1, 3, 73, 78, or E-19.

In tracing the stratigraphic units through the study area, it was necessary to take into account lateral and vertical changes typical of an alluvial environment. Of the changes produced during deposition, most prevalent are those resulting from changes in the flow regime and those resulting from the topographic configuration of the surface upon which the sediments were deposited. Changes in the flow regime between high-energy flow and low-energy flow produced lateral facies changes and caused different lithologies to interfinger. This is especially apparent in Unit III where interfingering of sands and gravels is common. Relief on the various surfaces upon which the sediments were deposited also controlled the nature and distribution of lithologic types. Topographic highs were typically areas of non-deposition or deposition of only fine-grained sediments. Coarse-grained sediments tended to accumulate in areas of lower topographic relief and were then overlain by finer-grained sediments. Coarse-grained sediments are most prevalent in the southwestern and central parts of the study

area where they are well-developed in the basal parts of each of the units.

The distribution of the various lithologies and the configuration of structural contour and isopach maps do not support the existence of an integrated drainage network at any time during the deposition of the Ringold sediments. So, too, only in localized areas do individual or groups of geophysical logs indicate the existence of channels which cut tens of feet into underlying sediments. Therefore, the effects of channeling are not considered to have significantly altered the unit boundaries at the scale employed for mapping structural contours.

The effects of structural deformation on the stratigraphic section are seen in areas where the basalt surface and the overlying sediments have been up-warped. In these areas, units thin and often pinch out against the underlying warped surfaces. Recognition of this type of stratigraphic relationship has been a major means of interpreting structural deformation in the study area.

5.0 THE STRATIGRAPHIC SECTION

The stratigraphic section (Figure 2R-29) described in this report is based on initial description of cores from drillholes 1 and 3. This section was modified as other drillholes were investigated and lateral differences recognized. Although direct correlations have not been established, the stratigraphic section of the study area is believed to be equivalent to parts of the previously defined section for the Pasco Basin (Myers and Price, 1979; Tallman and others, 1979) as shown on Figure 2R-29. The subdivision of the Pasco and Ringold Formations used herein offers refinements of the stratigraphy for the Pasco Basin which Tallman (personal communication, October 1981) believes may be recognizable throughout a much larger area. These refinements have been made possible by the close spacing of drillholes in the study area. Earlier studies of the Hanford Site have included part or all of the Pasco Gravels in the Ringold Formation.

5.1 COLUMBIA RIVER BASALT GROUP

Drillholes used in this investigation were typically drilled at least 20 to 50 feet into the basalt. Samples of the basalt from selected drillholes throughout the study area were submitted to Dr. P. R. Hooper (Washington State University) for X-ray fluorescense (XRF) analyses. Analytical procedures used to determine oxide weight percentages are described by Hooper and others (1981), and the application of geochemical analysis to basalt identification by other workers on the Columbia Plateau is described in Wright and others (1973), Holden and Hooper (1976), McDougall (1976), Wright and Hamilton (1978), Swanson and others (1979), Myers and Price (1979), and Wright and others (1980).

X-ray fluorescence (XRF) analysis of samples from drillholes (Table 2R-1) shows that the basalt underlying the Ringold Formation in the study area is the Elephant Mountain Member of the Saddle Mountains Basalt Formation of the Columbia River Basalt Group. The Elephant Mountain Member has been dated as 10.5 million years B.P. (McKee and others, 1977). This flow has a vesicular flow top and is porphyritic and non-vesicular with depth. The upper parts of the flow are commonly weathered to an olive-gray clay paleosol up to 7 feet thick. The time required for formation of the clay is uncertain but suggests landscape stability in post-basalt to pre-Ringold time. Less-weathered basalt is black to reddish-brown or brown. Underlying the Elephant Mountain

Member is the Rattlesnake Ridge Interbed and the Pomona Member of the Saddle Mountains Basalt Formation. These units were penetrated by several deep drillholes in the study area and are readily identified on the geophysical logs.

As a result of the generally weathered condition of the upper parts of the Elephant Mountain Member, the geophysical characteristics of the basalt are gradational upwards to the base of the overlying Ringold Formation. In establishing the basalt contact with the Ringold on the geophysical logs, the selection has been made at the change in gamma ray activity. This change may be minimal where the basalt is overlain by the highly basaltic gravels of Basal Unit I. Below the reduction in gamma activity, basalt porosity may decrease sharply at additional depths of 5 to 20 feet. The intervening interval is interpreted to be clay or altered rock derived from weathering of the basalt. In some instances, the neutron logs demonstrate a higher porosity in the uppermost basalts than in the overlying Ringold strata. This probably occurs whenever the basalt flow top is vesicular and intensely weathered.

5.2 RINGOLD FORMATION

5.2.1 AGE RANGE OF THE RINGOLD FORMATION

Throughout the study area, the Ringold Formation is underlain by the Elephant Mountain Member, which is dated at 10.5 million years B.P. (McKee and others, 1977). Brown and Brown (1961) suggested a late Miocene age for the basal part of the Ringold Formation, which they incorrectly thought might be coeval with young interbeds in the basalts of the Saddle Mountains. Based on analyses of pollen and spores, Leopold and Nickmann (1981) also have suggested a late Miocene age for the lower part of the Ringold Formation. Tallman (personal communication, October, 1981) suggests that the Ringold in the Cold Creek syncline along the southeastern part of the Pasco Basin is younger than the Ice Harbor Member of the Saddle Mountains Basalt. The Ice Harbor Member has been radiometrically dated at 8.5 million years B.P. (McKee and others, 1977). Gustafson (1978) and Myers and Price (1979) suggested a Pliocene age for the Ringold Formation. Packer and Johnston (1979) have suggested an age of 5.12 to 3.32 million years B.P. (the time span of the Gilbert Reversed Magnetic Epoch) for sediments in part of the upper Ringold unit at White Bluffs. The Ringold section in the study area is considered to be bracketed by the 10.5 and 3.32 million year dates (late Miocene to early Pliocene age).

5.2.2 LITHOLOGIC CHARACTERISTICS OF THE RINGOLD CYCLES

Examination of the lithology of coreholes 1 and 3 indicated that the Ringold Formation could be subdivided into four units, each consisting of a sedimentary cycle generally fining upwards. Subsequent detailed studies have shown that these units, with some modifications in thickness and lithology, are also recognizable in cuttings from drillholes up to 7 miles from coreholes 1 and 3. Each unit commences with alluvial gravels or sands at the base which are overlain by fine sands, silts, and clays, probably overbank sediments, in the upper part. Subcycles are present locally within parts of each unit. The following summary of each unit, commencing with the basal part of Unit I, is based upon chips from coreholes 1, 3, 73, 78, 94, 101, 102, 103, 125, E-1, and E-19, and from cuttings from rotary drillholes. Logged core and cutting descriptions are given in Appendix 2R-A. Table 2R-2 summarizes the lithologic characteristics and criteria used to define the Units I through IV.

5.2.2.1 Unit I

The basal gravels of Unit I consist of light to medium bluish-gray to yellowish-gray, weakly to moderately well-cemented pebble to cobble gravel to conglomerate in a sand matrix. The gravels grade from sandy gravels (sand matrix filling in between touching gravel clasts) to gravelly sands (gravel clasts floating in a sand matrix), sometimes with thin sand stringers lacking gravel clasts. All grains and clasts are coated with a thin cement rind of clay with minor calcite (Simmons, personal communication, October, 1981). Sand grains are commonly cemented in the rind adjacent to gravel clasts. Cobbles are well-rounded, dominantly basaltic at the base, with well-developed weathering rinds or, in pebbles and some smaller cobbles, weathered throughout. Secondary pebbles and cobbles include quartzite, granitics, volcanics, and volcaniclastics. The matrix is fine- to coarse-grained, angular to subangular sand. Basalt grains are common, and, when coated with the cement rinds, have a distinct bluish color. Mafics may be up to 25 percent in these sands. Quartz, feldspar, and mica are the other most common minerals in these sediments. Cementation is sufficient to bind many sand grains together to form sand clasts found when disaggregation of the sediment is attempted. The gravels are well-developed in coreholes 73, 78, and E-19.

Unit I basal gravels occur along the southern edge of the Southeast anticline area, eastern part of the May Junction area, and throughout the Site area (Figure 2R-13). They are

absent on Line 8 and over the Southeast anticline. The basal contact is a nonconformity, and the gravels grade upward into the overlying fine sediments of Unit I. These gravels are considered equivalent to the basal Ringold unit as defined by Tallman and others (1979).

Upper parts of Unit I commonly consist of olive-gray to light olive-gray to gray, flakey silty clay, or clayey silt. Less common is sand, composed of angular to subrounded grains, medium- to coarse-grain size, with up to 30 percent mafics, rare fragments of carbonized wood, and moderate to no cement. Fine- to medium-grained, angular to subangular sand grains are commonly present floating in the clayey silt. Rarely, thin very fine- to medium-grained light gray sand beds or stringers occur interbedded with the silty clays and clayey silts. A thin ash horizon occurs in the upper part of Unit I fines in coreholes 1 and E-19. An ash was also noted in many of the rotary drillhole cuttings. Fine sediments in the uppermost part of Unit I, typically olive-gray micaceous sandy silty clay, form a paleosol of variable thickness marking the end of Unit I. An erosional unconformity forms the upper surface of the unit. The fines of Unit I are referred to as "blue clays" by drillers in the Pasco Basin and are believed to be equivalent to the lower part of the lower Ringold unit as defined by Tallman and others (1979). Pollen analyses by Leopold and Nickmann (1981) suggest a late Miocene age for the fines of Unit I.

5.2.2.2 Unit II

Gravels at the base of Unit II are generally thin, if present, and are typically pale yellowish-gray to yellowish-brown ferruginous sandy gravels to gravelly sands. Clasts are well-rounded pebbles to small cobbles of basalt, quartzite, volcaniclastics, and granitics. Weathering rinds on basalt clasts are well-developed. Gravel clasts generally float in fine- to coarse-grained, angular to subrounded sand grains of quartz, basalt clasts, feldspar, mica, and mafics (up to 10 percent). Commonly, the sand grains are coated with a very thin cement rind, but grains are easily disaggregated and friable. Gravel clasts generally have a yellowish-brown cementation rind (clay with some calcite; Simmons, personal communication, 1981) with adhering sand grains. Interbedded with the gravelly sands are laminated sands, silty sands, and silty clay beds which are light yellowish-gray with ferruginous staining in part. The basal gravel may be underlain by a yellowish-gray silty sand to clayey silt which is considered a subunit of Unit II. This subunit is thin and not present in all drillholes.

The upper part of Unit II is characterized by fine-grained sediments commonly containing greenish-gray to yellowish-gray silty clay and clay interbedded with yellowish-gray to light olive-gray sands and sandy silts. The silty clays and clays are platy to blocky, grayish-green to varicolored, have a high waxy luster, and occasionally are bentonitic. The waxy clays (Figure 2R-30) are distinctive but not as continuous as the fines of Unit I. The sands and sandy silts are often ferruginous and contain up to 25 percent mafics. Sand grains are sometimes coated with a thin cement rind and are very friable. Silts and fine sands of Unit II lacking the waxy clays are not distinguishable from silts and fine sands of Units III and IV, unless they are found in stratigraphic sequences underlain by Unit I. This is a common occurrence along the crest of the southeastern part of the Southeast anticline. Unit II sediments are founded by erosional unconformities. The exact age of Unit II sediments is uncertain, but pollen analyses by Leopold and Nickmann (1981) suggest a late Miocene age. They are believed to be equivalent to the middle and upper parts of the lower Ringold unit as defined by Tallman and others (1979).

5.2.2.3 Unit III

Gravelly sands to sandy gravels in the lower part of Unit III are yellowish-gray, and the well-rounded pebbles and cobbles commonly have yellowish cement rinds with sand grains adhering to the clasts. Clay cement rinds (Simmons, personal communication, October, 1981) are occasionally calcareous. Clasts tend to float in the sand matrix, but the matrix sand may be absent. Clasts consist of basalt, quartzite, gneiss, granitics, and volcaniclastics. Thick weathering rinds occasionally occur on basalt clasts. The sand matrix is fine- to coarse-grained, may be silty to rarely clayey in part, mostly angular to subangular, with some subrounded to well-rounded grains in the coarse-grained fraction. Grains are mostly quartz but may also be feldspar, mica, and up to 30 percent mafics. Gravels in Unit III are similar megascopically to those of Unit IV. However, they are thick and make good diagnostic correlation zones when used together with other lithologies present in the stratigraphic sequence.

Fine sediments in the upper part of Unit III are interbedded sand and silty sands with clayey silt or silty clay at the top of the sequence. Sediments are commonly yellowish-gray, and sands are generally well-sorted, subangular to sub-rounded, fine- to medium-grained, rarely coarse-grained, and lack cement. Although dominantly quartz, sands typically

contain mica and up to 20 percent mafics. Erosional unconformities occur at the base and top of Unit III.

Based on lithologic similarity, Unit III gravels and fines are believed to correlate with the lower gravels of the middle Ringold unit as defined by Tallman and others (1979). Middle Ringold gravels are exposed at the base of the bluffs along the eastern side of the Columbia River south of Ringold Flat, approximately 8 to 12 miles east of the study area.

5.2.2.4 Unit IV

Gravelly sands to sandy gravels in the basal part of Unit IV are lithologically like those in the base of Unit III and also grade upward into finer clastic sediments. Fine sediments in the upper part of Unit IV are interbedded yellowish-gray to dusky-yellow silts, sands, silty sands, and sandy silts. Grains are angular to subangular, moderately to well-sorted, contain up to 25 percent mafics, and commonly are uncemented. They are megascopically very similar to the fine-grained sediments in the upper part of Unit III.

Based on lithologic similarity, the gravels of Unit IV are believed to correlate with the upper gravels of the middle Ringold unit as defined by Tallman and others (1979). Fine sediments of Unit IV are considered to correlate with the basal part of the upper Ringold unit of Tallman and others (1979). Both middle and upper Ringold sediments are exposed along the bluffs on the eastern side of the Columbia between Taylor and Ringold Flats in the eastern part of the Pasco Basin.

5.2.3 BOREHOLE GEOPHYSICAL CHARACTERISTICS OF THE RINGOLD UNITS

Throughout most of the central and southern part of the study area, the Ringold sequence displays a uniform but somewhat atypical group of geophysical characteristics. They are atypical in that the natural gamma activity of many of the coarse clastic zones is greater than that of the associated fine clastics. This is contrary to the normal expectation for an alluvial environment, whereas the porosity and density responses, as indicated on the neutron logs, are generally typical of such settings. Individual fine and coarse clastic sequences commonly can be traced on the geophysical logs for considerable distances (to the limits of

the study area in the case of some fine-grained units). More detailed information on the geophysical characteristics of each stratigraphic unit and the resolution of the borehole geophysical responses is presented in Appendix 2R-B-II. Table 2R-3 summarizes the geophysical characteristics of each unit.

Source-detector spacing of the neutron-epithermal neutron tool used in these investigations moved the neutron response beyond the "cross-over" zone, so that increases in hydrogen, or water content, lowered the number of detectable epithermal neutrons. Accordingly, a high water content in the sediments causes a reduction in neutron flux or an excursion to the left on the logs. As fine-grained sediments characteristically have higher percentages of interstitial voids than do coarse sediments, they have higher porosities, contain more water, and display reduced neutron activity. Therefore, the sedimentary units can be seen on the neutron logs to represent generally fining-upwards cycles of deposition and to display typical neutron responses.

Comparison of logs from certain adjacent drillholes suggests the presence of minor local cut-and-fill structures within cycles. It is evident, too, that facies changes are common in some of the units, as would be anticipated in an alluvial depositional environment. Where facies change rapidly, some subtle geophysical markers probably cannot be followed with confidence in drillholes more than a few hundred feet apart.

In the southern part of the Southeast anticline area, in the eastern part of the May Junction area, and in the Site area (Figure 2R-13), drillholes commonly intercept the basal conglomeratic and gravel unit below the fine-grained sequence of sedimentary Unit I. This conglomeratic-gravel unit has been treated as though it were the basal unit of Unit I. However, the physical and chemical characteristics of these deposits as indicated by the geophysical logs are grossly different from the overlying Ringold section. The basal conglomerate of Unit I has a higher density and lower porosity than younger gravels in cores of drillholes 73 and 78 and could cause gravimetric determinations of depth to basalt to be in error.

Over the Southeast anticline and the May Junction monocline, the Unit I section thins, largely through the elimination of the gravel facies but also by thinning of the fine-grained clastic facies. In these areas, the characteristic geophysical signatures of the units on the logs are more subtle than in the remainder of the study area. | 28 | 28

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5.2.4 ENVIRONMENT OF DEPOSITION

The environment of deposition of the Ringold Formation has been interpreted as primarily fluvial with some contribution from floodplain and lacustrine environments (Tallman and others, 1979; Leopold and Nickmann, 1981). Sediments observed in the cores and cuttings from the study area are consistent with this interpretation. In addition, some of the well-sorted silts and very fine sands in the upper parts of Units II through IV probably represent loess deposits and sand dunes.

Coarse sediments at the base of each of the units are generally matrix-supported gravels or gravelly sands; only rarely are matrix-free gravels found in the cores. The matrix-free intervals in the cores represent higher energy depositional levels in which the finer sediments were retained in suspension as the pebbles and cobbles were deposited. As current velocity decreased, matrix-supported gravels were deposited and typically grade vertically and laterally into gravel-free sands. Thin sand lenses and interfingering of sand beds (especially in Unit III) in the gravels suggest a pebbly braided alluvial environment (Collinson, 1978) such as a large-scale alluvial fan or very wide braided stream channel. The abundance of non-basalt clasts in the gravels clearly indicates a source from outside the Pasco Basin.

The clean, fine- to medium-grained sands in the middle and upper parts of each of the units are interpreted as channel deposits formed in intermediate flow regimes. The very fine-grained, well-sorted clean sands are considered to represent lower-energy channel sands and floodplain dune sands. Fine-grained materials, ranging in size from clays to fine sands, are commonly very thinly bedded or laminated in the cores and are interpreted to be overbank and lacustrine floodplain deposits. The presence of plant fragments and pollen in samples of these finer-grained sediments from coreholes 1, 3, and 78 and the development of paleosols support this interpretation. The presence of other non-basalt-derived minerals in the finer sediments indicates a through-flowing fluvial medium bringing sediments into the Pasco Basin from highlands of non-basaltic composition.

The absence of most of the upper Ringold Formation in the study area is accounted for by post-Ringold Formation erosion or possibly non-deposition. Cyclic deposition in the Ringold Formation is obvious when the stratigraphic sequence is observed. However, the factors controlling the cyclical nature are unknown. They could include fluctuations in erosional conditions in the source areas and the influence of tectonic activity in the Pasco Basin.

5.3 PRE-MISSOULA FLOOD GRAVELS

Gravels unconformably overlying the Ringold Formation in the study area are dominantly clasts of granite, quartzite, gneiss, and rhyolite porphyry, with subordinate basalt clasts. Non-basalt clasts may have been derived in part from the Ringold Formation. Clasts are well-rounded and generally embedded in a sand matrix. Weathering rinds on the basalt clasts are thin and poorly developed. Thin, light gray to white, well-sorted, medium- to coarse-grained, angular to subangular sands with up to 10 percent mafics are occasionally present within these gravels. Gravels of the Pre-Missoula Flood Gravels are distinguished from Ringold gravels by a lack of yellow cement rinds and in some cores by a lack of matrix sand. In cores they have a white appearance. They are distinguished from Missoula Flood Gravels by the presence of up to 60 percent non-basalt clasts of quartzite, granitics, volcanics, and volcaniclastics. A high velocity seismic refracting layer (8,000 to 10,000 ft/sec) is present in the lower part of the Pre-Missoula Flood Gravels (Weston Geophysical Corp., 1981a). This layer is generally flat-lying throughout the study area and may be associated with materials having a clay matrix.

The Pre-Missoula Flood Gravels form a subsurface sheet-like deposit across the Hanford Reservation. Although the provenance and age of these gravels have not been determined, their fabric, composition, and lateral extent suggest that they probably represent pre-Missoula, large-scale flood deposits, possibly from late Pliocene(?) or early Pleistocene glaciations or early Missoula-type flood episodes which were restricted to the Spokane River and Columbia River drainages. These gravels are equivalent to the basal part of the Pasco Gravels of the Hanford Formation as defined by Tallman and others (1979). They are recognized as a separate stratigraphic unit in the study area because they are lithologically distinct from underlying and overlying units.

5.4 MISSOULA FLOOD GRAVELS

Missoula Flood Gravels are present across the Hanford Reservation either exposed on the surface or capped by loess, dune sands, or alluvium. These gravels unconformably overlie the Pre-Missoula Flood Gravels and formed as the result of large-scale floods released from Lake Missoula in Montana. Missoula flood deposits have been assigned an age range of 17,500 to 13,000 years B.P. based on the presence of St. Helens "S" ash near the top of the unit (Mullineaux

and others, 1977) and the ages of glaciation in southern Canada and the northwestern United States (Fulton and Smith, 1978; Clague and others, 1980).

The Missoula Flood Gravels are pebble to cobble gravels which may or may not contain interbedded coarse sands. The gravels are characterized by a dominance of basalt, commonly 95 percent, with a few clasts of granitics and metamorphics. The sands are dark gray from the high basalt content but also contain quartz, feldspar, and mica; they are uncemented. These gravels represent rapid deposition from sediment-laden water, which is generally reflected in their lack of matrix sand. They are equivalent to the upper part of the Pasco Gravels as defined by Tallman and others (1979).

5.5 LOESS, DUNE SAND, AND ALLUVIAL SANDS

Surficial sediments unconformably overlying the Missoula Flood Gravels are thin and were generally not sampled. These sediments are described in Myers and Price (1979, Table III-2, p. III-10). The loess, dune sand, and alluvial sand are intricately related and are all of Recent age or latest Pleistocene age.

6.0 RESULTS

6.1 STRATIGRAPHIC DEVELOPMENT OF THE POST-BASALT SEDIMENTS

Observations of the post-basalt sediments based on the lithologic and geophysical study of the sedimentary section show several depositional patterns or trends and marker horizons that are significant throughout much of the study area. These observations and their interpretations are as follows:

1. The Elephant Mountain flow forms the uppermost basalt throughout the study area, and the vesicular flow top is recognized in cores and cuttings. This suggests that:

    a. No significant erosion incised the area prior to deposition of the overlying Ringold Formation, and

    b. The Elephant Mountain Member is a good reference surface for mapping purposes.

2. An extensive residual clay paleosol up to 7 feet thick (corehole 78) and a weathered basalt interval up to 9 feet thick (corehole 125) are present on top of the Elephant Mountain flow throughout much of the study area. Development of a residual clay paleosol suggests landscape stability and low topographic relief for the area during the time of development of the paleosol. The time duration of development is unknown. If climatic conditions were like the arid climate of the Pasco Basin today, the paleosol would imply long periods of time, perhaps in the hundreds of thousands of years. Conversely, if warm, humid climatic conditions prevailed, then the paleosol could have developed in a few hundreds or a few thousands of years.

3. Ringold, Pre-Missoula, and fine-grained Missoula sediments contain a high percentage of non-basaltic particles, whereas Missoula coarse-grained sediments contain a low percentage of non-basaltic particles. This is interpreted to indicate that:

    a. The non-basaltic materials in the Ringold, Pre-Missoula, and Missoula sediments were derived from areas adjacent to the Columbia Plateau,

b. More sediment was transported into the Pasco Basin during Ringold, Pre-Missoula, and Missoula times than could be removed, or general subsidence of the Pasco Basin occurred during this time interval,

c. Coarse-grained sediments of the Missoula Flood Gravels were derived from different areas and were deposited by different processes than the coarse-grained Ringold sediments, and

d. Coarse-grained sediments of the Pre-Missoula Flood Gravels were derived from the same areas but were deposited by a different process than those of the Ringold sediments.

4. Gravels of Basal Unit I contain many non-basaltic clasts, thin to the northeast and northwest, and are confined to the central and southern parts of the study area. This suggests that: | 28

a. The Southeast anticline and May Junction monocline were low-lying positive area while the gravels of Basal Unit I were being deposited, and | 28

b. Offlap, pinchout, or infilling of structural lows in the study area to the south and west of the Southeast anticline and south and east of the May Junction monocline occurred during Basal Unit I time. | 28

5. Gravels of Basal Unit I thicken in the southern part of the May Junction area and thin to the east. Fine-grained sediments of Unit I are thin in the southwestern part of the May Junction area and thicken to the east. Basal gravels of Unit I are thinner (approximately 25 feet) in drillhole S-3 than in all surrounding drillholes. Fines of Unit I are considerably thicker (approximately 45 feet) in drillhole S-3 than in all surrounding drill-holes. This is interpreted in the following manner:

a. A change of facies is believed to occur in Unit I with the basal gravels interfingering into fine sediments in the southwestern to eastern part of the May Junction area and in the vicinity of drillhole S-3 in the Site area, and

b. The fine-grained sediments in the upper part of Unit I are a part of the same depositional cycle as the basal gravels but represent a decrease in the energy level.

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6. Sediments in Upper Unit I are composed of olive-gray to brownish-gray silts and clays with some very fine to fine sand. They are uncemented, contain organic fragments, are bioturbated in some areas, and may show thin laminations. They are present throughout the study area except along the northwestern part of the crest of the Southeast anticline and the crest of the subsurface ridge of basalt on the western side of the May Junction monocline in the May Junction area. These sediments are interpreted as:

   a. An aggrading paleosol, probably developing on a flood plain, and

   b. An indication of landscape stability for the late part of Unit I time.

7. Upper Unit I sediments are present throughout the study area except along the northwestern part of the crest of the Southeast anticline (drillholes 105, 34, 38, and 37) and the crest of the subsurface basalt ridge on the western side of the May Junction monocline (drillholes 92 and MJ-3). They thin around these structures and thicken to the southeast. This is interpreted in the following manner: | 28

   a. Paleoslopes existed to the southeast during Upper Unit I time, and

   b. The Southeast anticline and subsurface basalt ridge west of the May Junction linear were low-lying positive areas during deposition of the Upper Unit I sediments or were uplifted and stripped of Upper Unit I sediments prior to deposition of Unit II sediments.

8. Fine sediments of Unit II are characterized by varicolored to gray-green waxy clays throughout the study area to the south and west of the Southeast anticline. This suggests that:

   a. The area to the south and west of the Southeast anticline was the site of deposition of very fine-grained sediments during part of Unit II time, and

   b. These sediments reflect low energy environments or that source areas were providing only fine-grained sediments during this time.

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9. Sands and gravels of Unit III intricately interfinger throughout the study area. This is interpreted to mean that:

   a. The sediments of Unit III demonstrate the lateral and vertical variations and changes in deposition of sands and gravels in a fluvial environment, and

   b. Rapid lateral and vertical changes occurred in the fluvial conditions of the Pasco Basin during Unit III time.

10. Each of the four units recognized in the Ringold commonly commences with gravels or coarse-grained sediments and ends with silts and clays with a complexly interbedded sequence of silts, sands, and gravels present in any one core or drillhole where the entire unit is present. Each of the four units is interpreted to:

    a. Represent a major cycle (with subcycles) of deposition in the Pasco Basin,

    b. Represent a time period when more sediment was introduced into the basin than could be passed through or a time of general subsidence, and

    c. Reflect fluctuations in the amount and size of sediments introduced into the Pasco Basin or to tectonic pulses above, in, or below the outlet of the Pasco Basin.

11. Ringold units are well-defined in both the interpretive lithologic and geophysical logs and unit contacts are flat-lying throughout most of the Site area, suggesting tectonic stability during or until late in Ringold time.

12. Parts of the Ringold which might be expected to be present in drillholes 55, 98, 99, 101, 102, 109, and 110 are absent. In these drillholes, as throughout most of the study area, the Pre-Missoula Flood Gravels overlie the Ringold Formation. This suggests that:

    a. A channel in post-Ringold time was cut across the Southeast anticline, removing parts of the Ringold Formation, and

    b. The Pre-Missoula Flood Gravels unconformably overlie the Ringold Formation.

13. Pre-Missoula Flood Gravels are present throughout most of the study area, with the exception of the northwestern part of the Southeast anticline. This is interpreted to mean that the Southeast anticline was a structural high during Pre-Missoula time and was not completely covered by the Pre-Missoula Flood Gravels.

14. The Missoula Flood Gravels are present throughout the study area, suggesting that the Missoula Floods were extensive and covered the Southeast anticline.

6.2 STRUCTURAL FEATURES AND HISTORY

6.2.1 SOUTHEAST ANTICLINE AREA

The Southeast anticline, the easternmost segment of the Umtanum Ridge/Gable Mountain structural trend, is a subsurface structure buried beneath the glaciofluvial gravels. The top of basalt structural contour map (Figure 2R-7) shows that the Southeast anticline trends northwest, plunging southeast, for most of its length. Near the southeastern end, its trend turns easterly or slightly north of east.

Initial deformation of the basalts in the vicinity of the Southeast anticline commenced in post-Esquatzel Member time (older than 12.0 million years B.P.) and continued intermittently through upper Elephant Mountain Member time (10.5 million years B.P.) as reported by Myers and Price (1979). The area was then subjected to a period of subaerial weathering which resulted in the development of a residual clay paleosol on the upper part of the Elephant Mountain flow. Parts of the B- and C-horizons of this paleosol are present in drillholes 3, 101, 102, 103, and 125.

Ringold units thin along the flanks and across the Southeast anticline. Where a complete Ringold sequence is not present, geophysical and lithologic markers are more subtle, and correlations are less certain. These correlations are dashed and questioned on the maps and cross-sections. On the northeastern side of the Southeast anticline, four generally fining-upward sequences are recognized in the sediments, although few gravel beds are present. Because definite correlations could not be made with the Ringold units defined on the southwestern side of the anticline, units and contacts on the northeastern side of the anticline are questioned in the cross-sections.

Basal Unit I gravels are present to the southwest of the Southeast anticline area. They thin, pinch out, or have been removed by erosion across the anticline, suggesting that the structure was a positive area during Basal Unit I time. The Basal Unit I gravels are not present on the northeastern side of the structure. Structural and topographic relief on the Southeast anticline must have been low during Basal Unit I time or the clay paleosol on top of the basalt would have been removed by erosion.

Upper Unit I fine-grained sediments thin across the southeastern part of the Southeast anticline. The northwestern part of the crest of the structure lacks Upper Unit I sediments, suggesting that this part of the structure was either a positive area during Upper Unit I time or that post-depositional erosion removed the sediments. The presence of the paleosol at the top of Upper Unit I sediments across the southeastern part of the Southeast anticline indicates landscape stability in late Unit I time for the Southeast anticline area. Minor erosion of Upper Unit I sediments is interpreted in the vicinity of drillhole 99 on the southeastern end of the structure.

Within the Southeast anticline area, Unit II sediments are unconformable above Unit I, thin at least 132 feet toward the Southeast anticline, and are interpreted to cross the southeastern part of the structure. The gravel horizon occurring to the southwest in the lower part of Unit II pinches out toward the anticline. The varicolored and gray-green waxy clays common in the upper parts of Unit II in the southern and central parts of the study area are not present over the Southeast anticline. Loss of the basal gravels and waxy clays and thinning of Unit II sediments over the Southeast anticline suggests that the structure was a positive feature during Unit II time; some uplift and erosion could have occurred following deposition of these sediments. Channeling of Upper Unit II fines in the vicinity of drillhole 99 is believed to have occurred. Probable dune sand and find-grained fluvial sediments at the top of Unit II show no evidence of the development of a paleosol.

Units III and IV both thin toward the flanks but do not cross the crest of the Southeast anticline. Such behavior may be a result of erosion or non-deposition, and it is here interpreted that the Southeast anticline was a positive area during Units III and IV time.

Glaciofluvial sediments of the Pre-Missoula Flood Gravels unconformably overlie the Ringold across the Southeast anticline. Their presence, however, is uncertain over the northwestern part of the structure along Line 3 in drillholes 37 and 38 (Figure 2R-20). In the vicinity of

drillholes 54, 55, 68, 99, 101, and 103, Pre-Missoula Flood Gravels are noted to fill a channel cut into the Ringold sediments. Missoula Flood Gravels unconformably overlie the Pre-Missoula Flood Gravels throughout the Southeast anticline area, and surficial dune sands and fluvial deposits of Recent age are present over most of the area today. No deformation of any of the post-Ringold sediments is recognized in the southeast anticline area.

A fault was recognized on the southwestern flank of the Southeast anticline (Figure 2R-7) on the basis of fault breccia and an anomously thick section of the Elephant Mountain member in corehole 125. A study carried out by Golder Associates (1982) for Washington Public Power Supply System determined the attitude, displacement and capability of this fault. Eleven drillholes, spaced 30 to 100 feet apart, indicate that the fault has a reverse sense of movement, strikes N39°W and dips 30°SW. The range of vertical displacement on the fault is 35 to 60 feet, and the range of dip-slip displacement is 70 to 110 feet. Based on this small amount of displacement, the Souteast anticline fault is interpreted to be a minor feature which probably does not extent any significant distance away from corehole 125. Four stratigraphic contacts across the projection of the fault plane (Elephant Mountain basalt/Ringold Upper Unit I contact, the contact of a lower fine-grained and upper coarse-grained subunit of Ringold Upper Unit I, Ringold Upper Unit I/Ringold Unit II contact and Ringold Unit II/Pre-Missoula contact) showed no abrupt changes in elevation. Based on these observations, the Southeast anticline fault has not been active for approximately 10 million years. It has clearly not been active since Pre-Missoula time (730,000 years before present) and is, therefore, not capable. 58

Based upon the similarity of structural patterns in the cross-sections, structural contour, and isopach maps, and the amount of thinning of stratigraphic units displayed in these illustrations, the Southeast anticline is interpreted to have developed intermittently throughout Ringold time. Deformation may have been most intense during Unit II and Unit III time and diminished during Unit IV time.

6.2.2 MAY JUNCTION AREA

The May Junction area includes the May Junction monocline and the area between the monocline, the Southeast anticline, and the Site area. The north-south-trending May Junction monocline is defined by the eastern boundary of a gravity high associated with the Gable Butte/Gable Mountain segment of the Umtanum Ridge/Gable Mountain structural trend (Weston

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Geophysical Corp., 1981b). Relief on this feature is approximately 300 feet, with a slope of 10 degrees or less on the basalt surface. To the east, a gentle southward-slipping (less than 1 degree) surface forms the northern flank of a southeasterly-plunging syncline. The Ringold Formation thins over the basalt high to the west of the May Junction monocline as shown on the isopach map (Figure 2R-18) and the cross-sections (Figures 2R-22 to 2R-24). Because a complete stratigraphic sequence of Ringold sediments is not present, correlations over this structure are questioned. 28

Gravels of Basal Unit I are present throughout the area except where they pinch out or have been removed by erosion on the flank of the Southeast anticline and over the northern part of the May Junction monocline on Line 8. The interpretation that the Basal Unit I gravels overlie the structure on the southwestern end of Line 3 suggests that deformation of this structure occurred after the deposition of the gravels.

Upper Unit I fine-grained sediments in the May Junction area are interpreted to thin or interfinger with a thickened gravel interval in the southwestern part of the area.

A normal sequence of Unit II sediments is present in the eastern part of the May Junction area. To the southwest (Line 3) the gray-green waxy clays become varicolored. These sediments generally thin toward the May Junction monocline and are interpreted to pinch out or have been removed by erosion over the northern part of the structure in the vicinity of Lines 8 and 8C. Unit III and Unit IV sediments are interpreted to be present only on the flanks of the monocline. The absence of Units I through IV could be a result of erosion or non-deposition. Pre-Missoula and Missoula Flood Gravels overlie the Ringold sediments. 28

The shallow and uniform dip of the sediments and basalt units across the May Junction monocline, and the generally uniform and typical thickness of the Elephant Mountain member and Rattlesnake Ridge interbed encountered along Line 8 and 8C, indicate that the May Junction monocline is not fault controlled. The shallow dip of stratigraphic units (7 to 10 degrees) indicates that, although the monocline is a prominent geophysical feature, only minor deformation has taken place in the basalt or overlying sediments along the trend of the monocline. This minor deformation has clearly been accommodated by the warping which produced the monocline. 28

It is postulated that deformation of the May Junction monocline and fold commenced in post-Elephant Mountain Member time (less than 10.5 million years B.P.) and probably

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diminished in Unit IV time (early Pliocene). No deformation is recognized in the post-Ringold sediments in the May Junction area.

6.2.3 SITE AREA

The structural contour map on top of basalt in the Site area (Figure 2R-7) indicates that the basalt surface underlying the Site area is of generally low relief, with typical slopes on the order of 1 degree or less. The relief on the basalt surface is interpreted to be the result of gentle folding which has produced three dominant features. These are the Cold Creek syncline in the southern part of the Site area, an unnamed gentle east-west trending anticline in the

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central part of the Site area, and a syncline along the northern edge of the Site area.

The Cold Creek syncline trends northwest and plunges gently to the southeast through the Site area (Myers and Price, 1979). A local depression occurs along the axis of the syncline in the vicinity of drillhole S-16. The bedrock surface in the lowest portion of this depression is approximately 150 feet below the surrounding bedrock surface. The syncline is asymmetrical, with the steeper southwestern limb formed by a northwest trending flexure in the Site area (Weston Geophysical Corp., 1981a). The maximum slope on the southwestern flank of the syncline is approximately 5 degrees.

Along Line X-1 (Figure 2R-28), which generally parallels the axis of the syncline, Ringold Units I through III maintain a constant thickness and parallel the basalt surface; however, the upper fine-grained part of Unit IV is thinner in drillhole S-17 than elsewhere on Line X-1. This reduced thickness is due either to erosion or non-deposition and suggests uplift of the basalt underlying the Ringold section in this area during or after the deposition of Unit IV sediments. Ringold Units III and IV are interpreted to be absent in drillhole S-24 on Line 4D (Figure 2R-26) on the southwestern flank of the Cold Creek syncline. The absence of these units suggests similar uplift and erosion after Unit II time and possibly during or after Unit IV time.

A small, generally east-west trending anticlinal feature occurs on the bedrock surface on the northern limb of the Cold Creek syncline. The relief across this flexure is 250 feet on the southern flank and 100 feet on the northern flank, with the northern flank sloping more steeply (maximum of 3.5 degrees). The Ringold formation is warped over the anticline, and the upper, fine-grained part of Ringold Unit IV is thinner over the structure along Line 1 (Figure 2R-25), Line M (Figure 2R-27), and Line W (Figure 2R-28). The reduced thickness of Unit IV may be interpreted to suggest that upwarping of the anticline and consequent thinning of Unit IV by erosion or non-deposition occurred during or shortly after Unit IV time.

With the exception of drillhole S-24 on Line 4D, the entire Ringold section is present in the Site area. Thinning or elimination of Unit IV occurs only over bedrock highs, suggesting that deformation in the Site area occurred during or after Unit IV time (early Pliocene). Uplift and erosion along Line 4D clearly occurred after Unit II time, probably during or after Unit IV time, to be consistent with the time of deformation of the surrounding structures. No deformation is recognized in the post-Ringold sediments which are present throughout the Site area.

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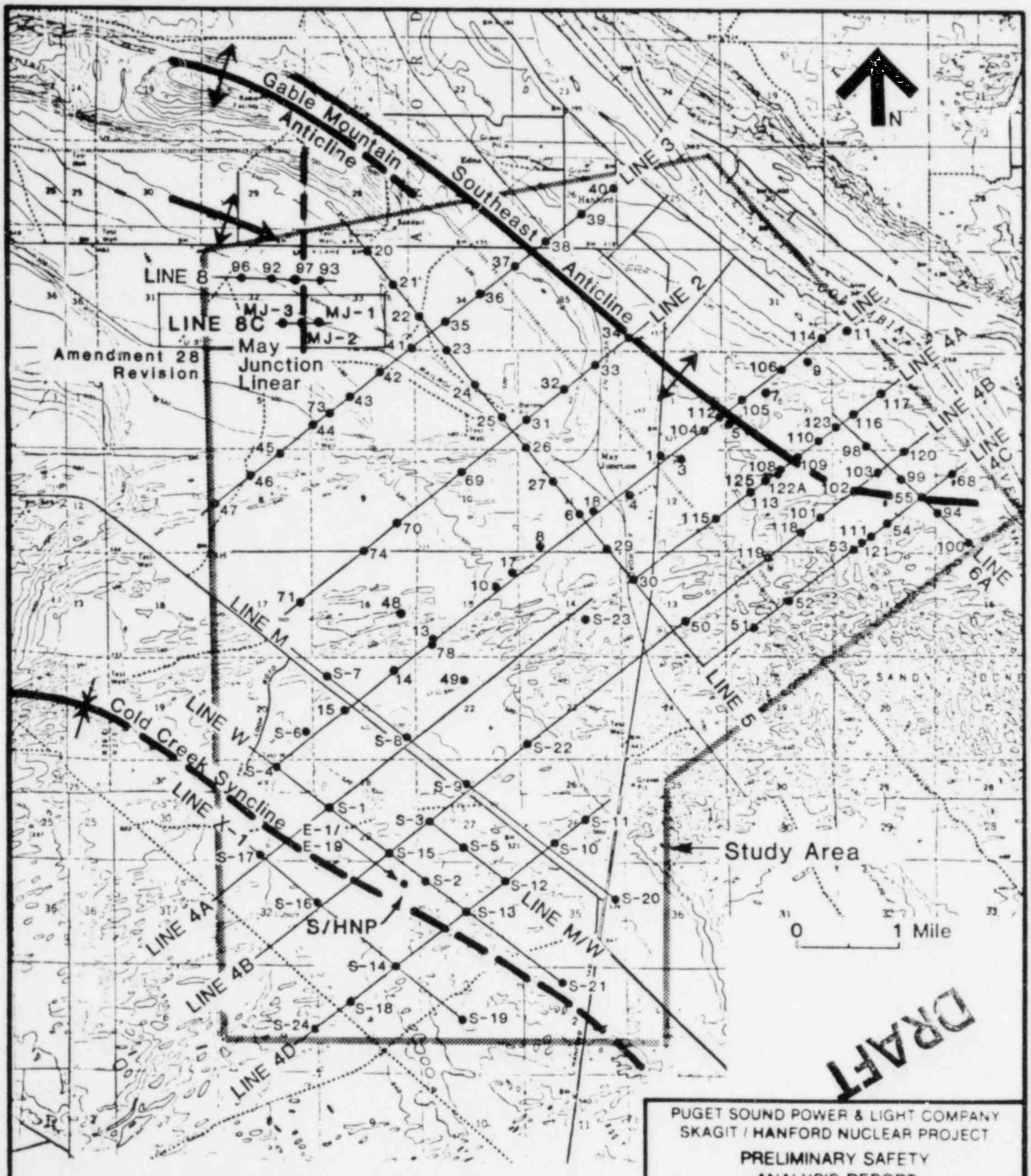

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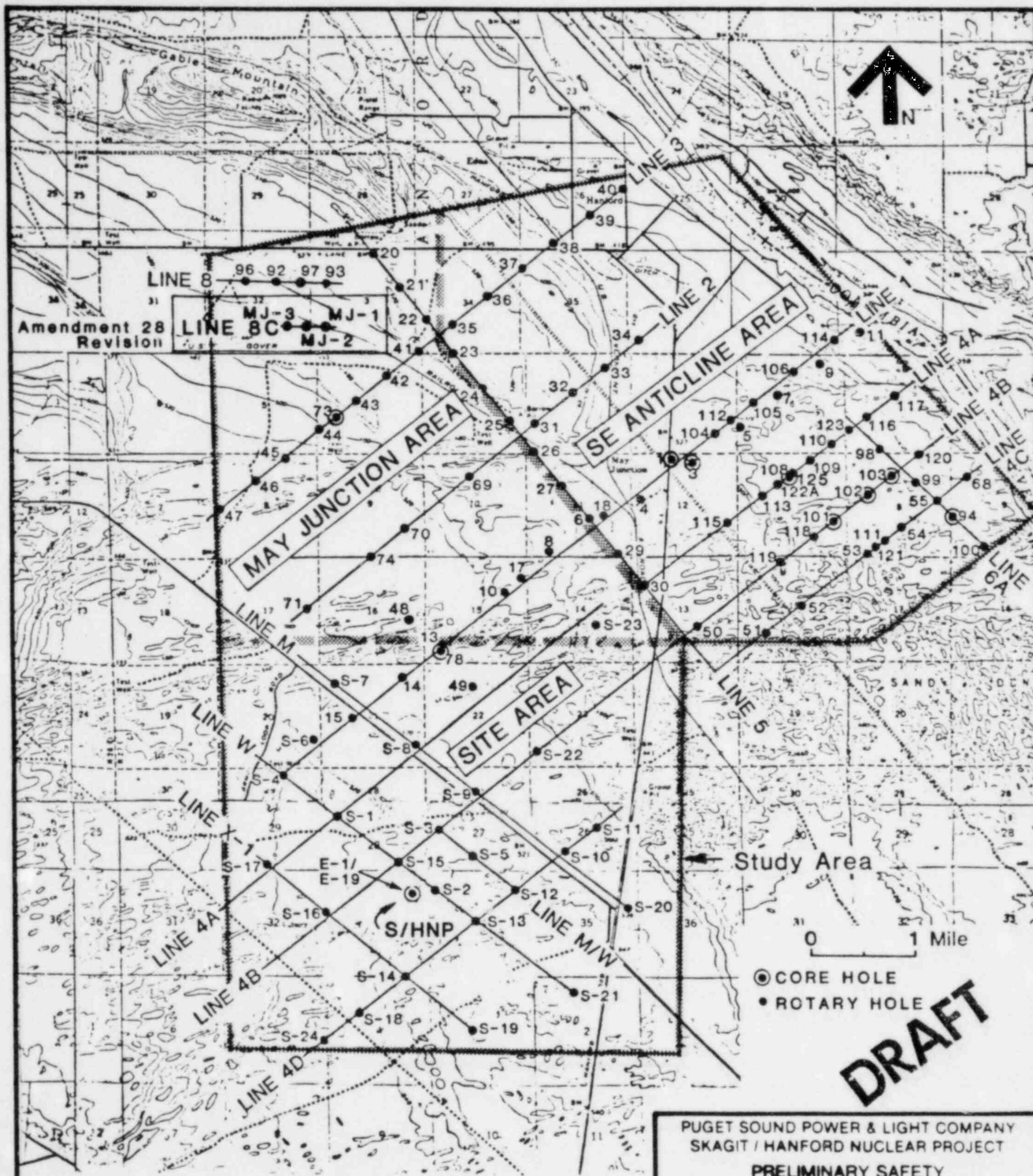
PRELIMINARY SAFETY ANALYSIS REPORT

MAJOR STRUCTURAL FEATURES IN STUDY AREA

FIGURE 2R-2



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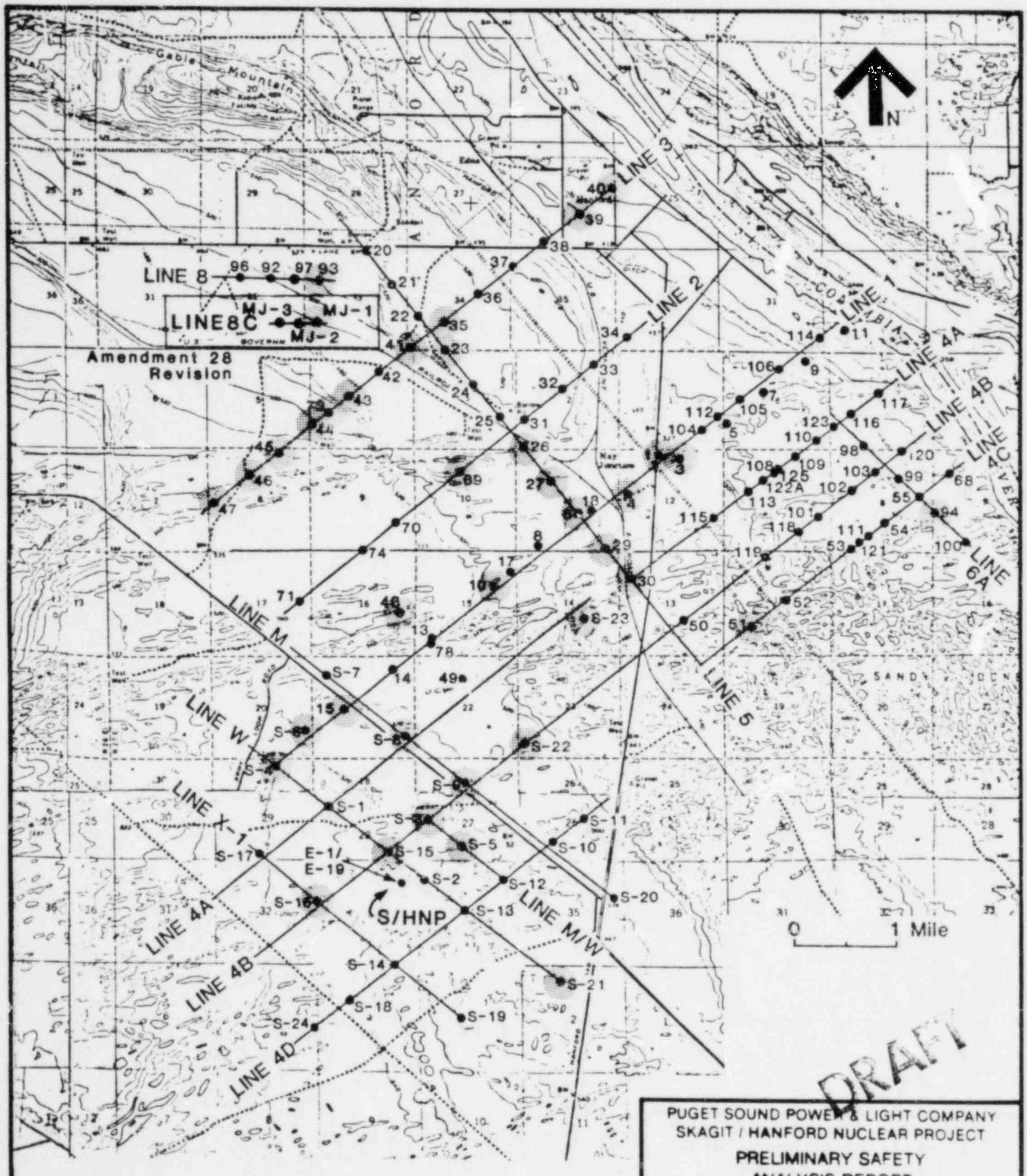
DRILL HOLE LOCATION MAP SHOWING AREAS DISCUSSED IN TEXT

FIGURE 2R-4

Insert Oversized figures 2R-7
2R-8
2R-9
2R-10
2R-11
2R-12
2R-13
2R-14
2R-15
2R-16
2R-17
2R-18
AND 2R-23.



Drillhole in which green waxy Clay present in Unit II

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DISTRIBUTION OF UNIT II GREEN WAXY CLAYS

FIGURE 2R-30

10/15/82

DRILL HOLE 97

Project No : 803-1701H
Elevation : 513.2 ft.
Total Depth : 339 ft.
Coordinates : N453,790.15, E263,334.42
Date Completed : 9/18/80

SAMPLE TYPE

- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C 2015 XRF, With Sample Number. Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area:

M - Missoula
PM - Pre-Missoula

IV - Ringold, Unit IV
III - Ringold, Unit III
II - Ringold, Unit II
I-u - Ringold, Unit I-upper
I-b - Ringold, Unit I-basal

Columbia River Basalt Group
Tem - Elephant Mountain Member
Ter - Rattlesnake Ridge Interbed
Tp - Pomona Member
B - Basalt, Undifferentiated

Elevation (MSL): 510, 500, 490, 480, 470, 460, 450, 440, 430, 420, 410, 400, 390
Depth (ft.): 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

Sampled Interval / Graphic Log	Lithologic Description	Unit
	Gravelly silty SAND. Light-olive-brown. Very-fine- to fine- and coarse- to very-coarse-grained. Gravel 85% basalt clasts.	M
	Silty sandy GRAVEL. 70% basalt clasts. Sand coarse- to very-coarse-grained; angular to subrounded.	M
	Sandy GRAVEL. 70% basalt clasts. Sand very-fine- to coarse-grained; angular to subangular; 35% mafics.	M
	Silty GRAVEL. 80-90% basalt clasts.	M
	Silty sandy GRAVEL. 80% basalt clasts. Sand coarse- to very-coarse-grained, some medium-grained; angular to subrounded.	M
	Gravelly silty SAND. Fine- to very-coarse-grained, mostly medium-grained. 20% mafics. Silt adheres to grains.	PM
	Silty GRAVEL. 40% basalt clasts. Silt adheres to clasts. No cement.	PM
	Silty sandy GRAVEL. 35% basalt clasts. Sand medium- to very-coarse-grained, fining downward; angular to subrounded; 20-30% mafics, decreasing with depth. Silt adheres to grains. No cement.	PM
	SILT. Yellowish-gray. Subrounded fragments.	II?
	Sandy SILT. Yellowish-gray. Subrounded fragments. Sand very-fine-grained.	II?
	Silty CLAY. Light-brown. Subrounded fragments.	II?
	CLAY. Light-brown. Subrounded fragments.	II?
	Sandy CLAY to clayey SAND. Moderate-brown. Sand very-fine-grained.	II?

28

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LOG OF DRILL HOLE 97

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FIGURE 2R-A-59

10/15/82

DRILL HOLE MJ-1

Project No : 823-1036
Elevation : 476.3 ft.
Total Depth : 573.0 ft.
Coordinates : N451,449.33; E264,631.23
Date Completed : 9/15/82

SAMPLE TYPE
- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C2015 XRF, With Sample Number
  Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

M - Missoula	III - Ringold, Cycle III	B - Basalt, Undifferentiated
PM - Pre-Missoula	II - Ringold, Cycle II	EM - Elephant Mountain Member
IV - Ringold, Cycle IV	I - Ringold, Cycle I	RR - Rattlesnake Ridge Interbed
		P - Pomona Member

Elevation (ft.MSL): 470, 460, 450, 440, 430, 420
Depth (feet): 10, 20, 30, 40, 50, 60

Sampled Interval / Graphic Log	Lithologic Description	Unit
	Gravelly silty SAND. Light-olive-brown. Medium- to very-coarse-grained.	M
	Gravelly silty SAND. Olive-gray. Very-fine- to very-coarse grained, fining with depth. 60 to 75% basalt grains. Angular to subrounded.	M
	Gravelly silty SAND. Medium-dark-gray grading to medium-gray at 30 to 35 ft. 55 to 80% basalt grains, decreasing with depth. Very-fine- to very-coarse-grained. Angular to subrounded. Gravel 75% basalt clasts.	M
	Silty GRAVEL to gravelly SILT. Light-olive-gray. Ferruginous stain. Gravel basaltic; possibly caved.	PM
	Gravelly SILT to silty GRAVEL light-olive-gray.	PM
	Gravelly sandy SILT to silty sandy GRAVEL. Light-olive-gray. Spotty ferruginous stain. Sand very-fine- and medium- to coarse-grained.	PM
	Silty sandy GRAVEL. 30 to 50% basalt clasts, decreasing with depth. Sand very-fine- to very-coarse-grained; mostly coarse- to very-coarse grained; 20% basalt grains.	PM
	Gravelly SAND. Yellowish-gray. Fine- to medium-grained. 10% mafics. Angular to subangular. Trace silt.	PM

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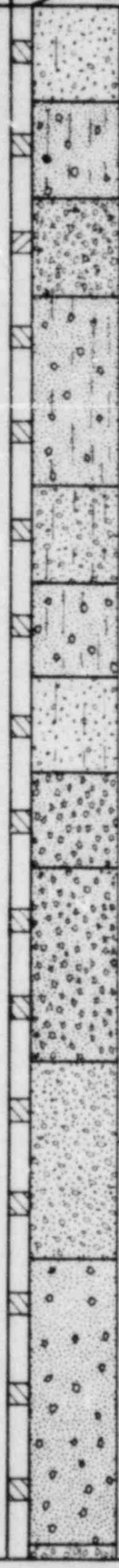
LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
410			Sandy GRAVEL. 20% basalt clasts. Sand fine- to coarse-grained; 10 to 15% mafics; angular. Trace silt.	
	70		Gravelly silty SAND. Yellowish-gray to light-olive-gray. 20 to 25% mafics. Very-fine- to coarse-grained. Angular to subangular.	
400			Gravelly SAND to sandy GRAVEL. Yellowish-gray to light-olive-gray. Fine- to very-coarse-grained; mostly very-coarse-grained. 30% basalt grains.	
	80		Gravelly silty SAND. Yellowish-gray to light-olive-gray. Very-fine- to very-coarse-grained. Grain size decreases and sorting is poorer with depth. 25 to 30% basalt grains. Silt increases with depth.	
390	90		Silty sandy GRAVEL to gravelly silty SAND. 45% basalt clasts. Sand as above.	PM
380			Gravelly silty SAND. Yellowish-gray to light-olive-gray. Very-fine- to medium-grained; mostly medium-grained. 15 to 20% mafics. Local ferruginous stain.	
	100		Silty sandy GRAVEL. Matrix as above. Local ferruginous stain. No sandy cement rinds.	
370			Gravelly silty SAND to silty sandy GRAVEL. Yellowish-gray. Very-fine- to coarse-grained. 10 to 15% mafics. No sandy cement rinds.	
	110		Gravelly SAND to sandy GRAVEL. Yellowish-gray. Fine- to medium-grained. 7 to 10% mafics. Angular to subangular. Clean. Gravel 15% basalt clasts; no sandy cement rinds.	
360	120		Sandy GRAVEL to gravelly SAND. Sand as above. Some pebbles with yellow sandy cement rinds (reworked Ringold?).	
350	130		Gravelly SAND. Yellowish-gray to dusky yellow. Fine- to medium-grained; mostly medium-grained. 7-10% mafics. Angular to subangular. Abundant gravel clasts with yellow sandy cement rinds.	IV
340	140			



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LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1 Page 3 of 8

Elevation (feet-MSL): 330, 320, 310, 300, 290, 280, 270, 260

Depth (feet): 150, 160, 170, 180, 190, 200, 210, 220

Sampled Interval / Graphic Log	Lithologic Description	Unit
	Silty sandy GRAVEL. Matrix yellowish-gray to dusky yellow. Sand fine- to medium-grained; mostly medium-grained; 5 to 7% mafics; angular to subangular. Yellow sandy cement rinds on gravel clasts.	IV
	Gravelly SAND. Yellowish-gray grading downward to dusky yellow. Very-fine- to medium-grained; mostly medium-grained. 5 to 7% mafics. Angular to subangular. Abundant yellow sandy cement rinds.	IV
	Silty SAND. Yellowish-gray to dusky yellow. Very-fine to medium-grained; mostly fine- to medium-grained. 5 to 7% mafics. Trace gravel.	IV
	Silty SAND to sandy SILT. Dusky yellow. Very-fine-grained.	IV
	SAND. Yellowish-gray. Fine- to medium-grained; mostly medium-grained. 7 to 10% mafics. Angular to subangular. Trace silt from 180 to 190 ft. Micaceous at 185 to 190 ft. and 195 to 200 ft. Trace gravel with yellow sandy cement rind at 195 to 200 ft.	IV
	Sandy GRAVEL to gravelly SAND. Yellowish-gray to dusky yellow. Abundant yellow sandy cement rinds.	IV
	Gravelly SAND. Dusky yellow. Local ferruginous stain and cement.	III
	Gravelly SAND. Light-olive-gray. Fine- to medium-grained; mostly medium-grained. 15 to 20% mafics. Wood fragments. Micaceous. Sandy cement rinds.	III
	SAND. Light-olive-gray. Very-fine- to medium-grained; mostly medium-grained. 20% mafics. Micaceous.	III
	GRAVEL. Trace sand. 15 to 20% basalt clasts. Trace sandy cement rinds.	III

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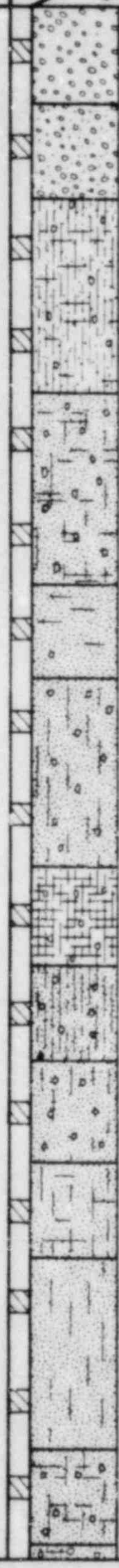
LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
250			GRAVEL, as above. Pyrite on some clasts.	III
	230		Sandy GRAVEL. 35% basalt clasts. Local pyrite. Minor yellow sandy cement rinds. Sand matrix fine- to medium-grained.	
240	240		Gravelly sandy SILT, with CLAY and ash-like fragments. Very-light-gray, olive-gray, and light-olive-gray. Gravel and sand probably caved. Pyrite fragments. Some silt and clay fragments laminated.	
230	250		Gravelly silty SAND, with CLAY fragments. Light-olive-gray. Very-fine- to medium-grained.	II
220	260		SAND, with clay and white ash-like fragments. Yellowish-gray. Very-fine to fine-grained. Mostly fine-grained. 5 to 7% mafics. Trace gravel.	
210			Gravelly silty SAND with SILT fragments. Yellowish-gray. Very-fine- to medium-grained. 10% mafics. Angular to subangular.	
	270		Gravelly sandy SILT to CLAY. Yellowish-gray. Slight waxy luster to clay.	
200			Gravelly sandy SILT to gravelly silty SAND. Yellowish-gray. Sand very-fine-grained.	
	280		Gravelly silty SAND. Yellowish-gray. Very-fine- to fine-grained; mostly very-fine-grained. 3% mafics. Angular to subangular.	
190			Silty SAND, with CLAY fragments. Dark yellowish-brown. Sand as above.	
	290		Silty SAND, with silty SAND to sandy SILT fragments. Yellowish-gray. Very-fine- to medium-grained. 2 to 3% mafics.	
180	300		Gravelly silty SAND, with CLAY fragments. Sand yellowish-gray. Clay dark-yellowish-brown. Very-fine- to medium-grained.	

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LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1

Elevation (feet-MSL): 170, 160, 150, 140, 130, 120, 110, 100

Depth (feet): 310, 320, 330, 340, 350, 360, 370, 380

Lithologic Description	Unit
Gravelly SAND, with dark yellowish-brown CLAY fragments. Yellowish-gray. Fine- to coarse-grained;mostly medium-grained. 3% mafics.	
Gravelly silty SAND, with silty clayey sand fragments. Light-olive-gray. Very-fine- to medium-grained; mostly fine-grained. 2 to 3% mafics. Angular to subangular.	1-u
Sandy clayey SILT. Olive-gray.	1-u
Gravelly clayey SAND. Olive-gray. Medium- to coarse-grained.	1-u
Gravelly silty SAND, with SILT and CLAY fragments. Light-olive-gray. Very-fine- to coarse-grained. 3% mafics. Local ferruginous stain.	1-u
Gravelly SAND, with SILT fragments. Light-olive-gray. Fine- to medium-grained; mostly medium-grained. 5% mafics. Local ferruginous stain.	1-u
SAND. Light-olive-gray. Medium-grained. 5 to 7% mfaics. Micaceous. Trace gravel.	1-b
Sandy GRAVEL. 20% basalt clasts increasing downward to 40 to 45% basalt clasts. Some sandy cement rinds. Blue cast to some basalt clasts. Local ferruginous stain and cement.	1-b
GRAVEL. Trace sand. 30 to 40% basalt clasts. Sandy cement rinds. Blue cast to some basalt clasts.	1-b
Silty sandy GRAVEL. 30 to 40% basalt clasts. Sand very-fine- to medium-grained; yellowish-gray.	1-b
Basalt. Dark-gray. Caved gravel clasts.	Tem

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LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
90			
		BASALT, as above. Some vesicles.	
	390		
		BASALT. Dark-gray. Weathered. Vesicular. Some vesicles filled with green and white clay.	
80			
	400		
70			
	410	BASALT. Dark-gray. Vesicular. Moderately fresh. Some caved gravel.	
60			
	420	BASALT sand. Grayish black. Fresh. Ground to sand size by drill bit.	Tem
50			
	430	BASALT. Brownish-gray to grayish black. Fresh. Trace vesicles. Local pyrite mineralization at 430 to 435 ft.	
40		BASALT. Dark-gray to grayish black. Fresh. Nonvesicular.	
	440		
		BASALT. Olive-gray to olive-black. Vesicular. Some vesicles filled with green clay. Some brecciated clay fragments.	
30			
		BASALT. Dark-gray. Fresh. Nonvesicular. Trace silt from 450 to 460 ft.	
	450		
20			
	460		
		BASALT. Olive-gray. Fresh. Trace silt. Nonvesicular.	

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DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
10 to -19	~465 to ~495	BASALT, as above. Local calcite mineralization at 465 to 470 ft.	Tem
-19 to -24	~495 to ~500	BASALT. Olive-gray. Moderately weathered. Vesicular. Vesicles filled with yellowish-green clay.	Ter
-24 to -29	~500 to ~505	Sandy clayey SILT to sandy silty CLAY. Light-olive-gray.	Ter
-29 to -34	~505 to ~510	Clayey silty SAND. Light-olive-gray. Local pyrite cement. Very-fine- to medium-grained. Angular to subangular.	Ter
-34 to -49	~510 to ~525	SAND. Light-olive-gray to yellowish-gray. Fine- to coarse-grained; mostly coarse-grained. 3 to 5% mafics. Angular to subangular.	Ter
-49 to -54	~525 to ~530	SAND, as above, with pinkish-gray to light-greenish-gray CLAY fragments.	Ter
-54 to -59	~530 to ~535	SILT, with CLAY fragments and SAND. Light-olive-gray; pinkish-gray and light-greenish-gray. Silt tuffaceous. Clay with waxy luster.	Tp
-59 to -66	~535 to ~545	BASALT. Brownish-black. Highly vesicular. Many vesicles filled with clay. Caved sand, silt, and clay fragments	Tp

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LOG OF DRILL HOLE MJ-1

FIGURE 2R-A-112

DRILL HOLE MJ-1

Elevation (feet-MRL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
-70					
	550			BASALT, as above.	
-80					
	560				Tp
-90				BASALT. Dark-gray. Fr-sh. Nonvesicular from 560 to 570 ft. Minor vesicles at 570 to 573 ft.	
	570				
-96.7			EOH 573'		

DRILL HOLE MJ-2

Project No : 823-1036
Elevation : 470.2 ft.
Total Depth : 425 ft.
Coordinates : N451,412.95; E263,630.25
Date Completed : 9/3/82

SAMPLE TYPE
- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C 2015 XRF, With Sample Number Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

M - Missoula
PM - Pre-Missoula
IV - Ringold, Cycle IV
III - Ringold, Cycle III
II - Ringold, Cycle II
I - Ringold, Cycle I
B - Basalt, Undifferentiated
EM - Elephant Mountain Member
RR - Rattlesnake Ridge Interbed
P - Pomona Member

Elevation (ft.MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
470				Gravelly silty SAND. Medium-light-gray. 75% basalt grains. Coarse- to very-coarse-grained.	
				Gravelly silty SAND to silty sandy GRAVEL. Medium-light-gray. 75% basalt grains. Coarse- to very-coarse-grained.	
460	10			Gravelly silty SAND. Medium-light-gray. 75% basalt grains. Medium- to very-coarse graine1; mostly medium-grained.	M
				Gravelly sandy SILT. Medium-gray. Gravel 60% basalt clasts.	
450	20			SAND. Medium-dark-gray. Medium- to very-coarse-grained; mostly coarse-grained. 70% basalt grains. Trace silt.	
440	30			Gravelly silty SAND. Moderate yellowish-brown grading downward to yellowish-gray. Moderately well to poorly sorted. 5 to 10% mafics, increasing with depth. Micaceous. Angular to subangular.	
430	40			Gravelly SAND. Yellowish-gray. Very-fine- to fine-grained. 5-7% mafics. Angular to subangular. Gravel 20% basalt clasts. Trace silt at 45 to 50 ft.	PM
420	50			Gravelly silty SAND to silty sandy GRAVEL. Light-olive-gray. 10 to 15% mafics. Fine- to coarse-grained. Gravel 25 to 30 % basalt clasts.	
				Silty sandy GRAVEL. Moderate olive-brown. No cement rinds. Silt adheres to clasts. Sand fine- to medium-grained.	
410	60			Gravelly silty SAND. Dark yellowish-brown. Fine- to medium-grained. 15% mafics. Silt adheres to grains. Subangular to subrounded.	

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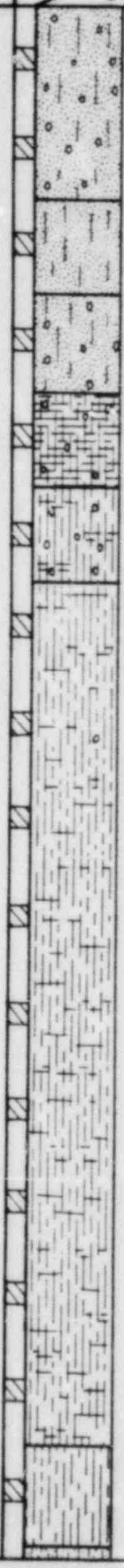
LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
400	70		Gravelly silty SAND, as above. Micaceous. Ferruginous stain. Fine- to medium-grained; mostly medium-grained. No cement rinds on gravel clasts.	PM
			Silty SAND. Dusky yellow. Very-fine- to medium-grained, mostly medium-grained. 5 to 7 % mafics. Large muscovite flakes.	
390	80		Gravelly silty SAND. Dusky yellow. Very-fine- to medium-grained; mostly very-fine-grained. 2 to 3% mafics. No cement rinds on gravel clasts.	
			Gravelly clayey SILT to gravelly silty CLAY. Yellowish-gray to dusky yellow. Gravel probably caved.	II?
380	90		Gravelly SILT, with CLAY fragments. Yellowish-gray. Sand very-fine-grained.	
370	100		SILT, with CLAY fragments. Yellowish-gray to 130 ft.; yellowish-gray to dusky yellow from 130 to 140 ft. Trace gravel at 100 to 105 ft. Clay fragments decrease with depth.	
360	110			
350	120			
340	130			
330	140		SILT. Yellowish-gray to dusky yellow.	

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LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

DRILL HOLE MJ-2

Lithologic Description	Unit
Sandy SILT. Yellowish-gray to dusky yellow. Sand very-fine-grained. Trace clay fragments.	II?
Silty SAND to sandy SILT. Dusky yellow. Very-fine- to fine-grained 2-3% mafics. Angular to subangular.	
Silty SAND. Dusky yellow grading downward to light-olive-brown. Very-fine- to medium-grained; mostly very-fine- to fine-grained. 3 to 5% mafics. Angular to subangular.	
Sandy SILT to silty SAND. Dusky-yellow. Sand very-fine-grained. Clayey in part.	
Sandy SILT. Yellowish-gray. Sand very-fine-grained.	
Gravelly SAND. Light-olive gray. Fine- to coarse-grained; mostly fine- to medium-grained. 15 to 20% mafics. Sandy cement rinds on some gravel clasts. Trace silt at 185 to 190 ft.	1-u?
Sandy GRAVEL to gravelly SAND. 45 to 50% basalt clasts. Sandy cement rinds on some clasts. Sand yellowish-gray; mostly medium-grained; 7 to 10% mafics.	1-b?
Gravelly SAND. Light-olive-gray. Medium-grained. Micaceous. Sandy cement rinds on some gravel clasts.	
Sandy clayey GRAVEL. Clay light-olive-gray; possibly weathered basalt clay.	
BASALT. Olive-gray. Weathered and vesicular at 205 to 210 ft.	Tem
BASALT. Dark gray. Moderately fresh. Vesicular. Some yellowish-green clay in vesicles.	

Elevation (feet-MSL)	Depth (feet)
320	150
310	160
300	170
290	180
280	190
270	200
260	210
250	220

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LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

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DRILL HOLE MJ-2

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Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
240	230			BASALT. Medium-dark-gray to 255 ft. Weathered. Vesicular. Some vesicles filled with yellowish-green to white clay.	
230	240				
220	250			BASALT. Dark-gray. Fresh. Minor vesicles to 265 ft. Minor clay (caved?).	
210	260				Tem
200	270			BASALT. Dark-gray. Fresh. Nonvesicular. Local pyrite or calcite mineralization on some surfaces. Minor vesicles from 270 to 280 ft. and from 290 to 300 ft.	
190	280				
180	290				
170	300				

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LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
160	310			BASALT. Dark-gray. Fresh. Nonvesicular. Local calcite or pyrite on some surfaces from 320 to 330 ft.	Tem
150	320				
140	330			BASALT. Dark-gray. Vesicular. Vesicularity increases with depth. Vesicles at 335 to 340 filled with green clay.	
130	340			Clayey SILT to silty CLAY. Light-olive-gray.	Ter
120	350			SILT to clayey SILT. Grayish-yellow-green. Tuffaceous.	
110	360			Clayey SILT, with CLAY and tuffaceous fragments. Pale olive.	
100	370				
90	380				

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LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
80	390		Clayey SILT, as above. Pale-olive to grayish-olive. Vesicular basalt clasts in sample at 395 to 400 ft.	Ter
70	400			
60	410		BASALT. Dark-gray. Moderately fresh. Vesicular. Some vesicles filled with green clay. Caved material from Rattlesnake Ridge interbed from 405 to 420 ft. Basalt extremely vesicular from 415 to 420 ft.	Tp
50	420			
45.2		EOH 425'		

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LOG OF DRILL HOLE MJ-2

FIGURE 2R-A-113

DRILL HOLE MJ-3

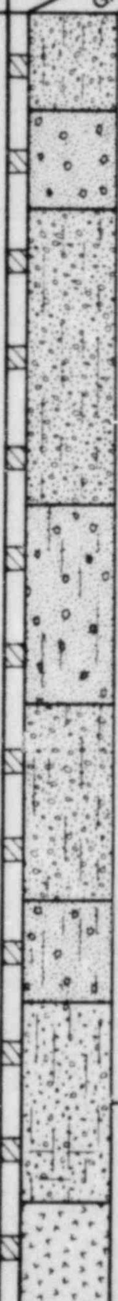
Project No : 823-1036
Elevation : 468.5 ft.
Total Depth : 273 ft.
Coordinates : N451,378.18; E262,629.38
Date Completed : 8/26/82

SAMPLE TYPE
- ▨ Cuttings
- 95 ■ Core, Number Indicates % Core Recovery
- C2015 ⊡ XRF, With Sample Number Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

M - Missoula	III - Ringold, Cycle III	B - Basalt, Undifferentiated
PM - Pre-Missoula	II - Ringold, Cycle II	EM - Elephant Mountain Member
IV - Ringold, Cycle IV	I - Ringold, Cycle I	RR - Rattlesnake Ridge Interbed
		P - Pomona Member

Elevation (ft.MSL): 460, 450, 440, 430, 420, 410
Depth (feet): 10, 20, 30, 40, 50, 60



Lithologic Description	Unit
Silty sandy GRAVEL to gravelly silty SAND. 50 to 55% basalt clasts. Sand yellowish-gray; very-fine-grained; angular to subangular.	M
Gravelly SAND. 75% basalt grains. Very-coarse-grained. Angular to subangular.	M
Silty sandy GRAVEL to gravelly silty SAND. 50 to 75% basalt clasts. Sand poorly sorted; very-fine- to very-coarse-grained; 45 to 60% basalt grains; angular to subangular.	M
Gravelly silty SAND. Yellowish-gray to dusky yellow. Very-fine-grained. <1% mafics. Angular to subangular. Gravel <45% basalt clasts.	PM
Silty sandy GRAVEL to gravelly silty SAND. 20-25% basalt clasts. No cement rinds. Sand moderately to poorly sorted; 5-7% mafics; subangular to subrounded; yellowish-gray to dusky yellow.	PM
Gravelly silty SAND. Yellowish-gray to dusky yellow. 7-10% mafics. Very-fine to medium-grained. Angular to subrounded. Gravel 25% basalt clasts; no cement rinds.	PM
Silty sandy GRAVEL. <50% basalt clasts. No cement rinds Matrix light-olive-gray to moderate-olive-brown. Clay at 55 to 60 ft; possibly weathered basalt clay.	PM
BASALT. Oive-gray. Weathered. Nonvesicular.	Tem

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LOG OF DRILL HOLE MJ-3

FIGURE 2R-A-114

DRILL HOLE MJ-3

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
400	70			BASALT. Olive-gray. Weathered. Silt and clay at 70 to 75 ft.	
390	80			BASALT. Medium-dark-gray at 75 to 80 ft. Dark-gray from 80 to 135 ft. Fresh, vesicular to 135 ft. Some vesicles filled with yellowish-green or white clay.	
380	90				
370	100				Tem
360	110				
350	120				
340	130				
330	140			BASALT. Dark-gray. Fresh. Nonvesicular. Calcite on fracture surface at 140 to 145 ft.	

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DRILL HOLE MJ-3 — Page 3 of 4

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
320	150		BASALT. Dark-gray. Fresh. Nonvesicular. Calcite on fracture surface at 170 to 175 ft.	
310	160			Tem
300	170			
290	180		BASALT. Medium- dark-gray from 175 to 185 ft. Fresh. Minor vesicules at 180 to 185 ft.	
280	190		Clayey SILT to silty CLAY. Light-olive-gray. Caved vesicular basalt clasts.	
270	200		Clayey SILT. Light-olive-gray. Tuffaceous.	
			Clayey SILT to silty CLAY. Light-olive-gray. Tuffaceous.	Ter
260	210		Silty CLAY to clayey SILT. Grayish-yellow-green. Tuffaceous.	
			Sandy clayey SILT to sandy silty CLAY. Grayish-yellow-green. Tuffaceous.	
250	220		Sandy silty CLAY to sandy clayey SILT. Grayish-yellow-green. Tuffaceous.	
			Sandy clayey SILT. Grayish-yellow-green. Tuffaceous. Sand very-fine-grained.	

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LOG OF DRILL HOLE MJ-3

FIGURE 2R-A-114

DRILL HOLE MJ-3

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
240	230			Sandy clayey SILT, as above.	Ter
230	240			BASALT. Medium-gray grading downward to medium-dark-gray. Moderately fresh. Vesicular. Some vesicles filled with green or white clay.	
220	250			BASALT. Dark-gray from 245 to 260 ft. fresh. Vesicles decreasing. Calcite crystals at 250 to 255 ft.	Tp
210	260			BASALT. Grayish-black from 260 to 270 ft. Fresh. Large vesicles at 265 to 270 ft. Increase in size of plagioclase phenocrysts at 260 to 265 ft.	
200	270				
195.5			EOH 273'		

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LOG OF DRILL HOLE MJ-3

FIGURE 2R-A-114

INSERT OVERSIZED FIGURES 2R-B-10

2R-B-10A

2R-B-24

2R-B-24A

2R-B-38

2R-B-38A

2R-B-52

AND 2R-B-52A

QUESTION 231.5 (Regulatory Staff Position):

Additional investigations may be required of the Applicant to confirm the presence or absence of potentially hazardous geologic structure which may have been identified through existing data utilized in the response to RAI 231.4 but which lacks sufficient resolution for determination of capability or noncapability.

RESPONSE:

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Subsequent to the Applicant's response to RAI 231.4 and a meeting with the NRC staff on July 8 and 9, 1982, the staff determined that some additional investigations were required in one area for which there was not, in their judgment, sufficient information to confirm the presence or absence of hazardous geologic structure. Their request for additional information was forwarded to the Applicant in the form of Question 231.14. The Applicant's response to this request for additional information is provided in Amendment 28 to the PSAR.

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QUESTION 231.14

The Applicant will conduct a core boring program of sufficient scope to determine if the May Junction monocline is fault controlled. If fault controlled, this program should provide sufficient new subsurface evidence demonstrating that the fault is not capable. This may include other subsurface techniques and information to supplement the core borings. This program should be of sufficient scope to define the attitude, sense of movement and age of last movement of the fault and be designed to carefully recover and define the overlying formations in this area.

RESPONSE:

In response to this question, the Applicant undertook a program of exploration using gravity measurements and rotary-wash borings. This program developed sufficient evidence to demonstrate that the May Junction monocline is not fault controlled. Thus, core borings were not required.

<u>Definition of May Junction Monocline</u>

The May Junction monocline is defined by the 2000-foot wide, north-south gravity gradient extending 2.5 miles through sections 28, 29, 32 and 33 of T13N, R27E, and sections 4 and 5 of T12N, R27E (S/HNP PSAR, Appendix 2K, Figure 2K-15). It was first recognized on the basis of aeromagnetic data (Myers and Price, 1979) and termed the May Junction linear (Magnteic Features Map, RHO-BWI-ST-4, Plate 111-6d). Investigations for the S/HNP PSAR, including gravity surveys and drilling, showed that the aeromagnetic linear was produced by a gentle easterly slope on the buried bedrock surface. On the basis of this bedrock structure, indicated both by gravity surveys and drilling, the feature was interpreted to be a gentle monoclinal fold and termed the May Junction monocline.

<u>Exploratory Program</u>

In a meeting with the NRC staff and representatives of the USGS on July 21, 1982, a program of investigations to address Question 231.14 was proposed by Applicant. The program contemplated three steps. First, a gravity survey would be performed to characterize the May Junction monocline in greater detail so that locations for rotary-wash borings could be selected. Next, rotary-wash

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QUESTION 231.14 (Cont'd)

borings would be drilled to evaluate the bed rock structure. And, finally, core borings would be drilled to determine the characteristics of any faults that might be discovered. NRC staff agreed that the program was responsive to their request for additional information (NRC Letter, Novak to Myers dated August 4, 1982) and the program was implemented.

New gravity stations were established in sections 32 and 33 of T13N, R27E, approximately 1 mile south of Gable Mountain (Figure 231.14-1), along nine new traverse lines (8A-8H, 8J) and portions of Lines 8 and D at 100-foot station intervals. All gravity stations were surveyed and both vertical and horizontal control provided to the nearest 0.1 foot. The newly acquired data were evaluated in profile. They were also combined with the NESCO data set (S/HNP PSAR, Appendix 2K) to produce a total Bouguer gravity anomaly map (Figure 231.14-2). The gravity anomaly contours on the May Junction monocline are consistent with a north-south trending bedrock surface sloping gently and uniformly downward toward the east.

Line 8C was chosen as a drilling location because of the typical character of the gravity profile (Figure 231.14-3) and the anticipation of a thick section of Ringold. Three rotary-wash boring locations, spaced equidistantly across the steepest part of the gravity anomaly, were selected and discussed with the NRC and USGS staff. 28

The rotary method of drilling was used because the most important contacts in the section for determining the bedrock structure are the basalt/sediment contacts, which are easily recognized from data generated by this drilling technique. The elevations of these contacts were determined from detailed examination of the lithologic characteristics of the drill cuttings (Figures 231.14-4A, B and C) combined with interpretation of four down-hole geophysical logs for each hole (Figures 231.14-5A, B, C and D). The elevations of these contacts, particularly the Ringold Formation/Elephant Mountain member contact, the Elephant Mountain member/Rattlesnake Ridge interbed contact and the Rattlesnake Ridge interbed/Pomona member contact, were used to determine the thickness and dip of the various units along the line of section. Table 231.14-1 shows the thickness of the several units encountered in the three holes. Figure 231.14-6 shows the correlation between stratigraphic units recognized in borehole MJ-1 on Line 8C and holes drilled on Line 8 to

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QUESTION 231.14 (Cont'd)

the north and Line 3 to the south, thus demonstrating the continuity of stratigraphic units along the strike of the monocline. Figure 231.14-7 shows the geologic cross section across the monocline at Line 8C.

Results:

The above investigation has shown the following:

1. Gravity anomaly and top-of-basalt contours are consistent with those drawn from earlier data and portray a gentle (7°-10°) continuous slope without abrupt irregularity.

2. Borehole intercepts of the top-of-basalt lie along a nearly straight line.

3. The Elephant Mountain basalt/Rattlesnake interbed/Pomona basalt contacts are nearly parallel and define unit thicknesses that vary slightly but which are well within the range of normal thickness for these units throughout the Hanford Reservation.

4. The entire Ringold section is present in the most downslope boring (MJ-1) and correlates well with other borings along strike.

Interpretation of Results

There are four lines of evidence which indicate that the May Junction monocline is not fault controlled. These are:

- the smooth surface of the basalt as defined by drilling and gravity (Figure 231.14-7 and -8),
- the shallow (7° to 10°) dip of the stratigraphic units which form the monocline,
- the uniform dip (±3°) of the stratigraphic units between the drill holes and
- the generally uniform and typical thicknesses of the Elephant Mountain member encountered along the line of section.

The shallow dip of the units across the strike of the monocline has been recognized from previous geologic and

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QUESTION 231.14 (Cont'd)

geophysical studies (S/HNP PSAR, Appendices 2R and 2K). Results of the present investigation have confirmed this observation and have specifically shown that the units do, in fact, have a shallow dip (7° to 10°) along Line 8C (Figure 231.14-2). The units for which this shallow dip has been confirmed along Line 8C include Ringold Unit I, Elephant Mountain member, Rattlesnake Ridge interbed and the Pomona member. The shallow dip of these units indicates that, although the monocline is a prominent geophysical feature, only minor deformation has taken place in the basalt or overlying sediments along the trend of the monocline. This minor deformation has clearly been accommodated by the warping which produced the monocline.

In addition to the very gentle dip of the sediments and basalt units across the monocline, the fact that the dip of the units remains nearly constant between the drill holes indicates an absence of fault control. If the feature were fault controlled, and some offset of the basalt and overlying sedimentary units had occurred, such an offset would be reflected by variations in dip across the feature. Since there are no significant (>5°) variations in dip and contacts across the feature lie along nearly straight line projections, there can be no significant fault offset between the drill holes. There is certainly no offset of the type that might be associated with a fault presumed to have caused nearly 300 feet of relief on the bedrock surface over a distance of only 2.5 miles.

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Table 231.14-1 shows the elevations of contacts and thicknesses of units encountered in the three rotary holes. The Elephant Mountain member, in particular, is shown to have a very uniform thickness along the line of section. Some thickening is observed in MJ-2 in the Rattlesnake Ridge interbed; however, it is well within the normal range of variability in thickness of this unit observed elsewhere in the Pasco Basin where faults are known to be absent. None of the units show changes in thickness which could be interpreted to result from thinning or thickening due to displacement on a fault.

Upon completion of the rotary drilling program, a model of the subsurface geology that satisfies both the results of drilling and the gravity along Line 8C was constructed (Figure 231.14-8). The densities used for the units are 2.60, g/cm^3 for the basalt, 2.45 g/cm^3 for the Ringold Basal Unit I gravel, and 2.0 g/cm^3 for the Rattlesnake

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QUESTION 231.14 (Cont'd)

Ridge interbed and the remainder of the sedimentary section. The modelled basalt surface varies smoothly. The change of Bouguer gravity anomaly across the May Junction monocline is due to the change of elevation of the top of basalt, change of density in the Ringold section and variation of the regional Bouguer gravity anomaly. The change in elevation of top of basalt accounts for at least 90% of the change. No evidence for offset is present.

Conclusions

Based upon all the available data, the following conclusions are drawn:

1. The May Junction monocline is a broad, gently-sloping fold in the basalt/interbed sequence;

2. No evidence of irregularities in the basalt surface or in subjacent or suprajacent units has been found to suggest fault offset;

3. Cumulative evidence indicates an absence of evidence for faulting or "fault control."

Based on these investigations and the other data available, investigations on the May Junction monocline have been adequate to provide reasonable assurance that the feature is not fault controlled. No further investigative work is needed to confirm this conclusion.

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TABLE 231.14-1

ELEVATIONS OF CONTACTS AND THICKNESSES OF UNITS
ENCOUNTERED IN DRILLHOLES ALONG LINE 8C

	MJ-3	MJ-2	MJ-1
Top IV			
Depth	NP	NP	124
Elevation	NP	NP	352
Thickness IV	0	0	82
Top III			
Depth	NP	NP	206
Elevation	NP	NP	270
Thickness III	0	0	36
Top II			
Depth	NP	85	242
Elevation	NP	385	234
Thickness II	0	95	66
Top I-u			
Depth	NP	180	308
Elevation	NP	290	168
Thickness I-u	0	10	33.5
Top I-b			
Depth	NP	190	341.5
Elevation	NP	280	135
Thickness I-b	0	14.5	39.5
Top Tem			
Depth	55	204.5	381
Elevation	413.5	266	95
Thickness Tem	127.5	127	113.5
Top Ter			
Depth	182.5	331.5	494.5
Elevation	286	139	-18
Thickness Ter	46	65.5	35

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TABLE 231.14-1

	MJ-3	MJ-2	MJ-1
Top Tp			
Depth	228.5	397	529.5
Elevation	240	73	-53
Thickness Tp	-	-	-

NP = Not Present
IV = Ringold Unit IV
III = Ringold Unit III
II = Ringold Unit II
I-u = Ringold Upper Unit I
I-b = Ringold Basal Unit I
Tem = Elephant Mountain Member
Ter = Rattlesnake Ridge Interbed
Tp = Pomona Member

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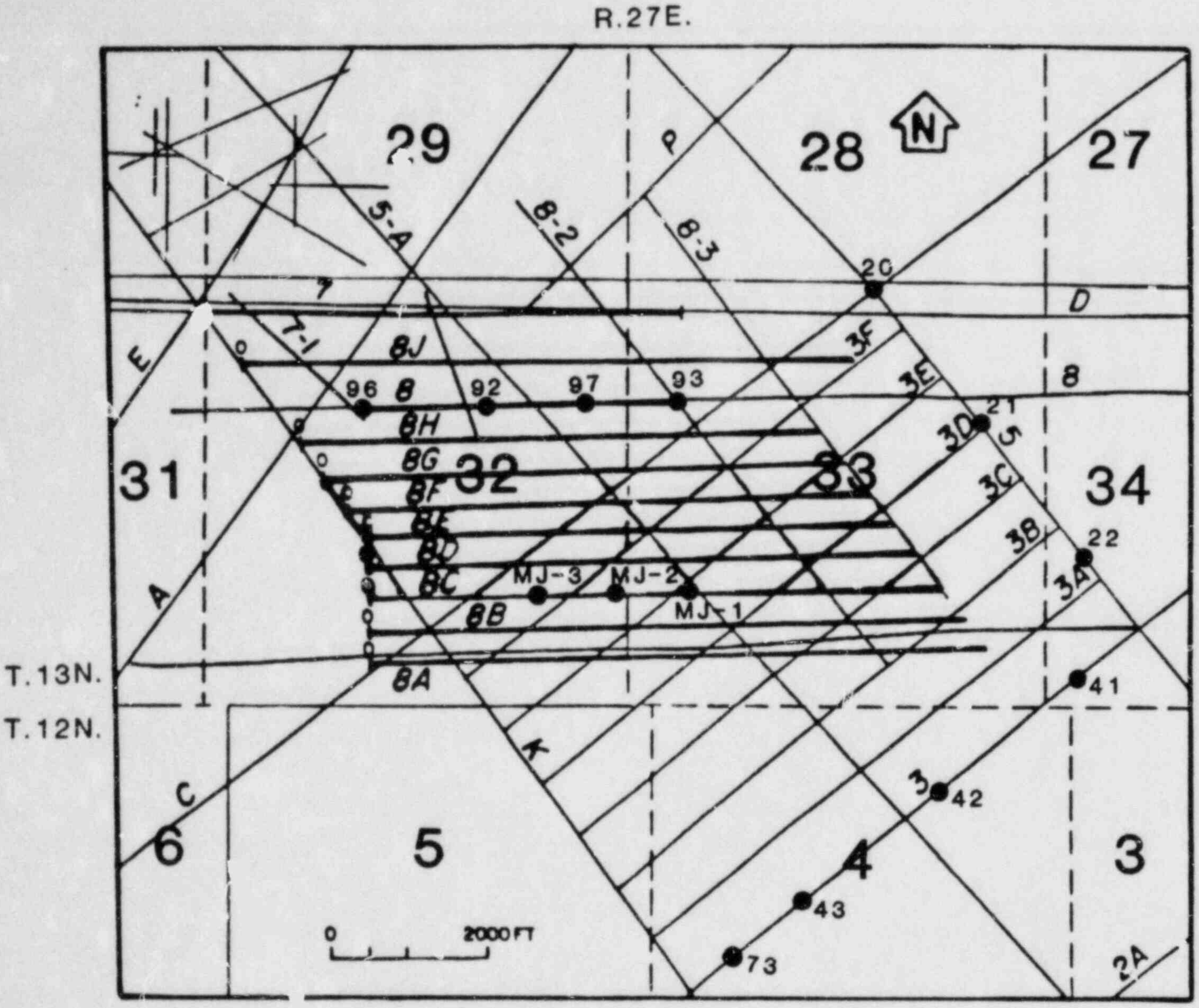

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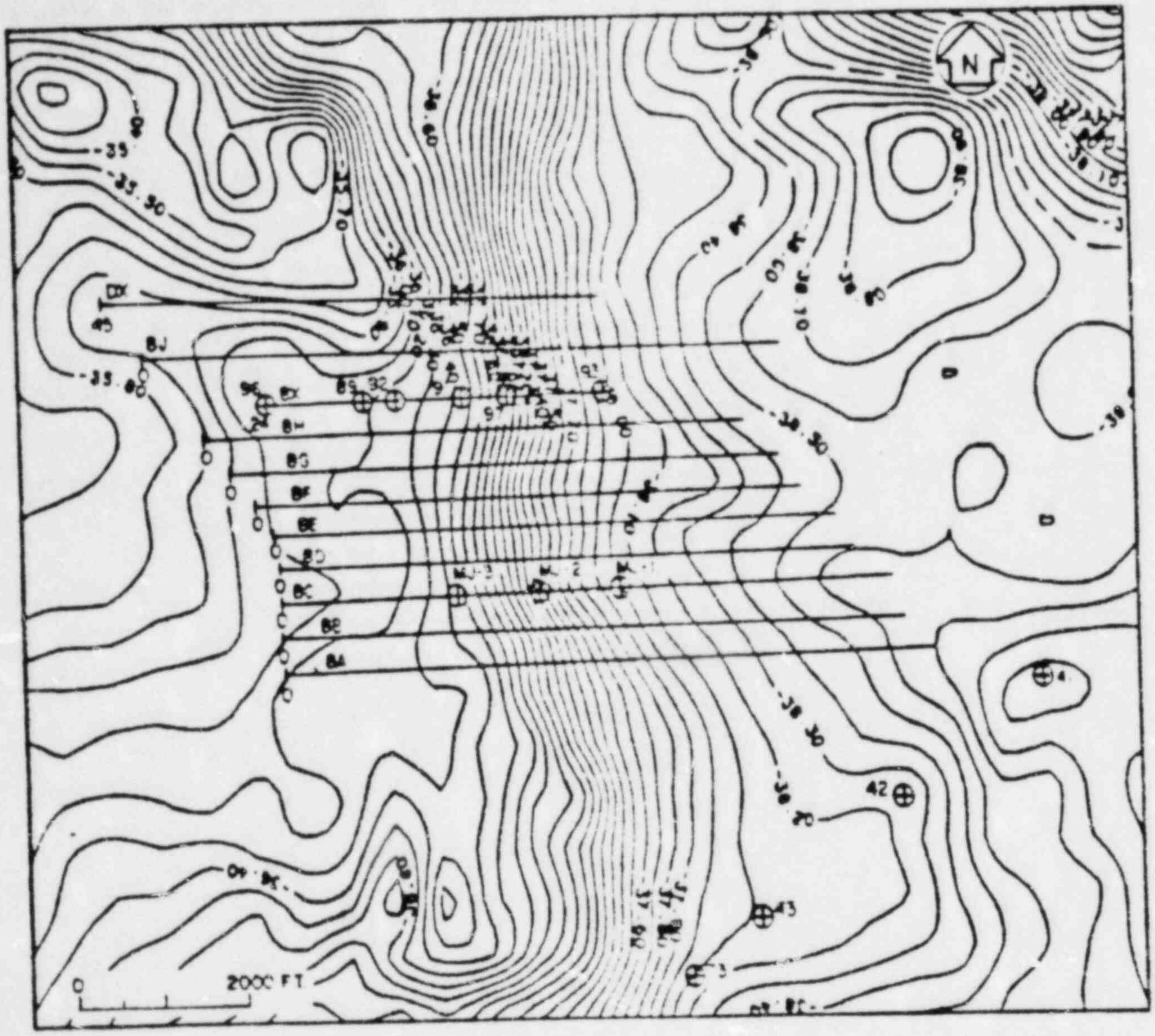
LOCATION MAP

Figure 231.14-1



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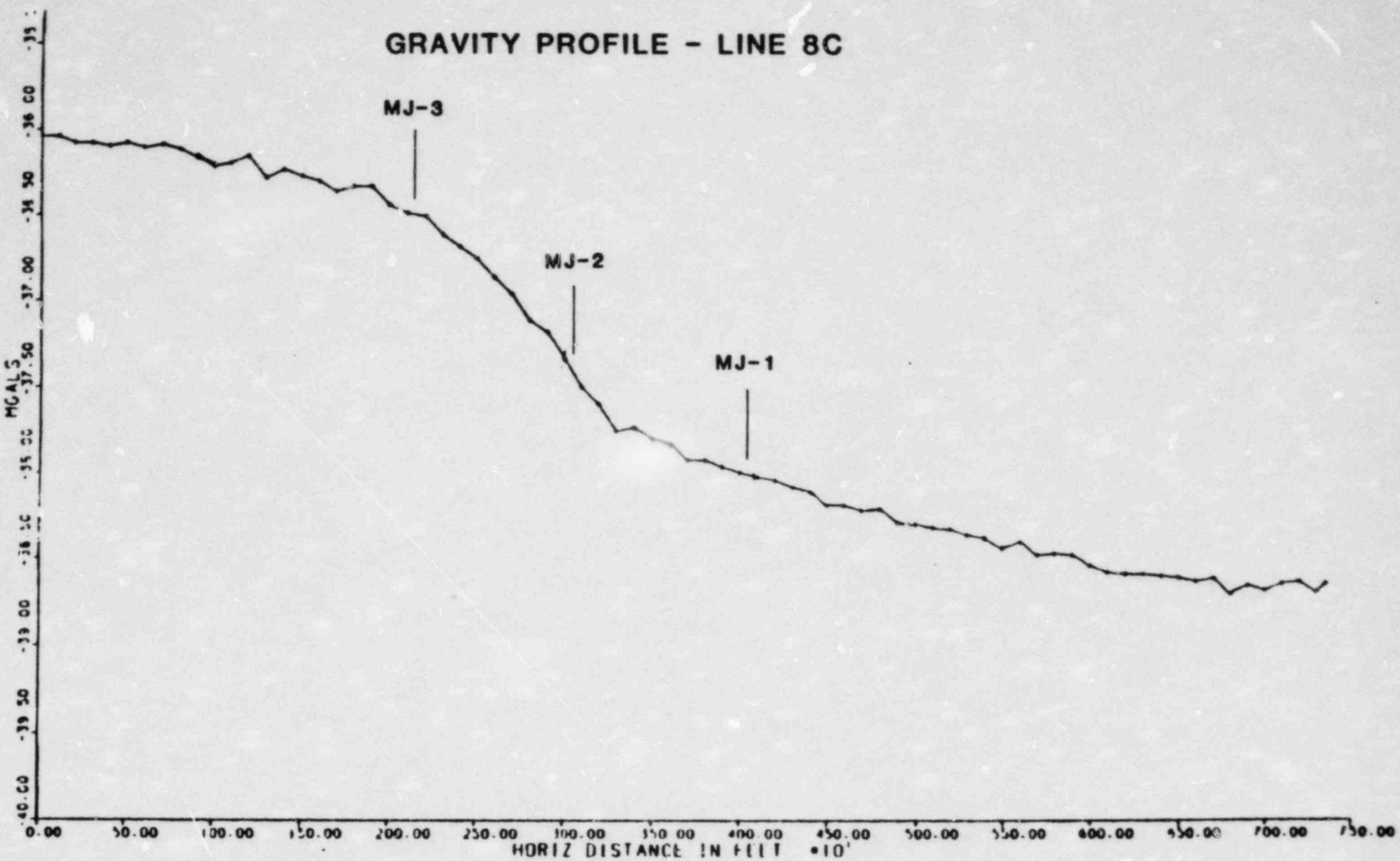
PRELIMINARY SAFETY ANALYSIS REPORT

TOTAL BOUGUER GRAVITY ANOMALY MAP MAY JUNCTION AREA

FIGURE 231.14-2



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GRAVITY PROFILE OF LINE 8C

Figure 231.14-3

DRILL HOLE MJ-1

Project No : 823-1036
Elevation : 476.3 ft.
Total Depth : 573.0 ft.
Coordinates : N451,449.33; E264,631.23
Date Completed : 9/15/82

SAMPLE TYPE
- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C 2015 XRF, With Sample Number. Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

- M - Missoula
- PM - Pre-Missoula
- IV - Ringold, Cycle IV
- III - Ringold, Cycle III
- II - Ringold, Cycle II
- I - Ringold, Cycle I
- B - Basalt, Undifferentiated
- EM - Elephant Mountain Member
- RR - Rattlesnake Ridge Interbed
- P - Pomona Member

Elevation (ft.MSL)	Depth (feet)	Lithologic Description	Unit
		Gravelly silty SAND. Light-olive-brown. Medium- to very-coarse-grained.	
470		Gravelly silty SAND. Olive-gray. Very-fine- to very-coarse grained, fining with depth. 60 to 75% basalt grains. Angular to subrounded.	
	10		
460			M
	20	Gravelly silty SAND. Medium-dark-gray grading to medium-gray at 30 to 35 ft. 55 to 80% basalt grains, decreasing with depth. Very-fine- to very-coarse-grained. Angular to subrounded. Gravel 75% basalt clasts.	
450			
	30		
440		Silty GRAVEL to gravelly SILT. Light-olive-gray. Ferruginous stain. Gravel basaltic; possibly caved.	
	40	Gravelly SILT to silty GRAVEL light-olive-gray.	
430		Gravelly sandy SILT to silty sandy GRAVEL. Light-olive-gray. Spotty ferruginous stain. Sand very-fine- and medium- to coarse-grained.	
	50		PM
		Silty sandy GRAVEL. 30 to 50% basalt clasts, decreasing with depth. Sand very-fine- to very-coarse-grained; mostly coarse- to very-coarse grained; 20% basalt grains.	
420			
	60	Gravelly SAND. Yellowish-gray. Fine- to medium-grained. 10% mafics. Angular to subangular. Trace silt.	

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LOG OF DRILL HOLE MJ-1

FIGURE 231.14-4A

Elevation (feet-MSL): 410, 400, 390, 380, 370, 360, 350, 340

Depth (feet): 70, 80, 90, 100, 110, 120, 130, 140

Sampled Interval	Graphic Log	Lithologic Description	Unit
		Sandy GRAVEL. 20% basalt clasts. Sand fine- to coarse-grained; 10 to 15% mafics; angular. Trace silt.	
		Gravelly silty SAND. Yellowish-gray to light-olive-gray. 20 to 25% mafics. Very-fine- to coarse-grained. Angular to subangular.	
		Gravelly SAND to sandy GRAVEL. Yellowish-gray to light-olive-gray. Fine- to very-coarse-grained; mostly very-coarse-grained. 30% basalt grains.	
		Gravelly silty SAND. Yellowish-gray to light-olive-gray. Very-fine- to very-coarse-grained. Grain size decreases and sorting is poorer with depth. 25 to 30% basalt grains. Silt increases with depth.	
		Silty sandy GRAVEL to gravelly silty SAND. 45% basalt clasts. Sand as above.	PM
		Gravelly silty SAND. Yellowish-gray to light-olive-gray. Very-fine- to medium-grained; mostly medium-grained. 15 to 20% mafics. Local ferruginous stain.	
		Silty sandy GRAVEL. Matrix as above. Local ferruginous stain. No sandy cement rinds.	
		Gravelly silty SAND to silty sandy GRAVEL. Yellowish-gray. Very-fine- to coarse-grained. 10 to 15% mafics. No sandy cement rinds.	
		Gravelly SAND to sandy GRAVEL. Yellowish-gray. Fine- to medium-grained. 7 to 10% mafics. Angular to subangular. Clean. Gravel 15% basalt clasts; no sandy cement rinds.	
		Sandy GRAVEL to gravelly SAND. Sand as above. Some pebbles with yellow sandy cement rinds (reworked Ringold?).	
		Gravelly SAND. Yellowish-gray to dusky yellow. Fine- to medium-grained; mostly medium-grained. 7-10% mafics. Angular to subangular. Abundant gravel clasts with yellow sandy cement rinds.	IV

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DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
330	150		Silty sandy GRAVEL. Matrix yellowish-gray to dusky yellow. Sand fine- to medium-grained; mostly medium-grained; 5 to 7% mafics; angular to subangular. Yellow sandy cement rinds on gravel clasts.	IV
320	160		Gravelly SAND. Yellowish-gray grading downward to dusky yellow. Very-fine- to medium-grained; mostly medium-grained. 5 to 7% mafics. Angular to subangular. Abundant yellow sandy cement rinds.	
310			Silty SAND. Yellowish-gray to dusky yellow. Very-fine to medium-grained; mostly fine- to medium-grained. 5 to 7% mafics. Trace gravel.	
	170		Silty SAND to sandy SILT. Dusky yellow. Very-fine-grained.	
300 / 290 / 280	180 / 190		SAND. Yellowish-gray. Fine- to medium-grained; mostly medium-grained. 7 to 10% mafics. Angular to subangular. Trace silt from 180 to 190 ft. Micaceous at 185 to 190 ft. and 195 to 200 ft. Trace gravel with yellow sandy cement rind at 195 to 200 ft.	
	200		Sandy GRAVEL to gravelly SAND. Yellowish-gray to dusky yellow. Abundant yellow sandy cement rinds.	
270			Gravelly SAND. Dusky yellow. Local ferruginous stain and cement.	III
	210		Gravelly SAND. Light-olive-gray. Fine- to medium-grained; mostly medium-grained. 15 to 20% mafics. Wood fragments. Micaceous. Sandy cement rinds.	
260			SAND. light-olive-gray. Very-fine- to medium-grained; mostly medium-grained. 20% mafics. Micaceous.	
	220		GRAVEL. Trace sand. 15 to 20% basalt clasts. Trace sandy cement rinds.	

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LOG OF DRILL HOLE MJ-1

FIGURE 231.14-4A

DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
250			GRAVEL, as above. Pyrite on some clasts.	
	230		Sandy GRAVEL. 35% basalt clasts. Local pyrite. Minor yellow sandy cement rinds. Sand matrix fine- to medium-grained.	III
240			Gravelly sandy SILT, with CLAY and ash-like fragments. Very-light-gray, olive-gray, and light-olive-gray. Gravel and sand probably caved. Pyrite fragments. Some silt and clay fragments laminated.	
	240		— — — — — — — — — —	
230			Gravelly silty SAND, with CLAY fragments. Light-olive-gray. Very-fine- to medium-grained.	
	250			
220			SAND, with clay and white ash-like fragments. Yellowish-gray. Very-fine to fine-grained. Mostly fine-grained. 5 to 7% mafics. Trace gravel.	
	260		Gravelly silty SAND with SILT fragments. Yellowish-gray. Very-fine- to medium-grained. 10% mafics. Angular to subangular.	
210	270		Gravelly sandy SILT to CLAY. Yellowish-gray. Slight waxy luster to clay.	II
200			Gravelly sandy SILT to gravelly silty SAND. Yellowish-gray. Sand very-fine-grained.	
	280		Gravelly silty SAND. Yellowish-gray. Very-fine- to fine-grained; mostly very-fine-grained. 3% mafics. Angular to subangular.	
190			Silty SAND, with CLAY fragments. Dark yellowish-brown. Sand as above.	
	290		Silty SAND, with silty SAND to sandy SILT fragments. Yellowish-gray. Very-fine- to medium-grained. 2 to 3% mafics.	
180	300		Gravelly silty SAND, with CLAY fragments. Sand yellowish-gray. Clay dark-yellowish-brown. Very-fine- to medium-grained.	

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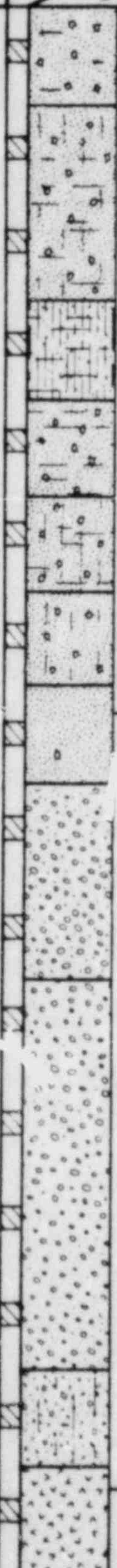
LOG OF DRILL HOLE MJ-1

FIGURE 231.14-4A



Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
170		Gravelly SAND, with dark yellowish-brown CLAY fragments. Yellowish-gray. Fine- to coarse-grained; mostly medium-grained. 3% mafics.	1-u
	310		
160		Gravelly silty SAND, with silty clayey sand fragments. Light-olive-gray. Very-fine- to medium-grained; mostly fine-grained. 2 to 3% mafics. Angular to subangular.	1-u
	320	Sandy clayey SILT. Olive-gray.	1-u
150		Gravelly clayey SAND. Olive-gray. Medium- to coarse-grained.	1-u
	330	Gravelly silty SAND, with SILT and CLAY fragments. Light-olive-gray. Very-fine- to coarse-grained. 3% mafics. Local ferruginous stain.	1-u
140		Gravelly SAND, with SILT fragments. Light-olive-gray. Fine- to medium-grained; mostly medium-grained. 5% mafics. Local ferruginous stain.	1-u
	340	SAND. Light-olive-gray. Medium-grained. 5 to 7% mfaics. Micaceous. Trace gravel.	1-b
130	350	Sandy GRAVEL. 20% basalt clasts increasing downward to 40 to 45% basalt clasts. Some sandy cement rinds. Blue cast to some basalt clasts. Local ferruginous stain and cement.	1-b
120	360		
110	370	GRAVEL. Trace sand. 30 to 40% basalt clasts. Sandy cement rinds. Blue cast to some basalt clasts.	1-b
100		Silty sandy GRAVEL. 30 to 40% basalt clasts. Sand very-fine- to medium-grained; yellowish-gray.	1-b
	380	Basalt. Dark-gray. Caved gravel clasts.	Tem

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LOG OF DRILL HOLE MJ-1

FIGURE 231.14-4A

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
90				BASALT, as above. Some vesicles.	
	390				
80				BASALT. Dark-gray. Weathered. Vesicular. Some vesicles filled with green and white clay.	
	400				
70					
	410			BASALT. Dark-gray. Vesicular. Moderately fresh. Some caved gravel.	
60					
	420			BASALT sand. Grayish black. Fresh. Ground to sand size by drill bit.	Tem
50					
	430			BASALT. Brownish-gray to grayish black. Fresh. Trace vesicles. Local pyrite mineralization at 430 to 435 ft.	
40				BASALT. Dark-gray to grayish black. Fresh. Nonvesicular.	
	440			BASALT. Olive-gray to olive-black. Vesicular. Some vesicles filled with green clay. Some brecciated clay fragments.	
30					
	450			BASALT. Dark-gray. Fresh. Nonvesicular. Trace silt from 450 to 460 ft.	
20					
	460			BASALT. Olive-gray. Fresh. Trace silt. Nonvesicular.	

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Elevation (feet-MSL)	Depth (feet)
10	
	470
0	
	480
-10	
	490
-20	
	500
-30	
	510
-40	
	520
-50	
	530
-60	
	540

Lithologic Description	Unit
BASALT, as above. Local calcite mineralization at 465 to 470 ft.	Tem
BASALT. Olive-gray. Moderately weathered. Vesicular. Vesicles filled with yellowish-green clay.	Ter
Sandy clayey SILT to sandy silty CLAY. Light-olive-gray.	Ter
Clayey silty SAND. Light-olive-gray. Local pyrite cement. Very-fine- to medium-grained. Angular to subangular.	Ter
SAND. Light-olive-gray to yellowish-gray. Fine- to coarse-grained; mostly coarse-grained. 3 to 5% mafics. Angular to subangular.	Ter
SAND, as above, with pinkish-gray to light-greenish-gray CLAY fragments.	Ter
SILT, with CLAY fragments and SAND. Light-olive-gray; pinkish-gray and light-greenish-gray. Silt tuffaceous. Clay with waxy luster.	Tp
BASALT. Brownish-black. Highly vesicular. Many vesicles filled with clay. Caved sand, silt, and clay fragments.	Tp

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DRILL HOLE MJ-1

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
-70	550			BASALT, as above.	
-80	560				Tp
-90	570			BASALT. Dark-gray. Fresh. Nonvesicular from 560 to 570 ft. Minor vesicles at 570 to 573 ft.	
-96.7			EOH 573'		

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LOG OF DRILL HOLE MJ-1

FIGURE 231.14-4A

DRILL HOLE MJ-2

Project No : 823-1036
Elevation : 470.2 ft.
Total Depth : 425 ft.
Coordinates : N451,412.95; E263,630.25
Date Completed : 9/3/82

SAMPLE TYPE
- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C 2015 XRF, With Sample Number
  Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

M - Missoula
PM - Pre-Missoula
IV - Ringold, Cycle IV
III - Ringold, Cycle III
II - Ringold, Cycle II
I - Ringold, Cycle I
B - Basalt, Undifferentiated
EM - Elephant Mountain Member
RR - Rattlesnake Ridge Interbed
P - Pomona Member

Elevation (ft.MSL)	Depth (feet)	Lithologic Description	Unit
470		Gravelly silty SAND. Medium-light-gray. 75% basalt grains. Coarse- to very-coarse-grained.	
		Gravelly silty SAND to silty sandy GRAVEL. Medium-light-gray. 75% basalt grains. Coarse- to very-coarse-grained.	
460	10	Gravelly silty SAND. Medium-light-gray. 75% basalt grains. Medium- to very-coarse grained; mostly medium-grained.	M
		Gravelly sandy SILT. Medium-gray. Gravel 60% basalt clasts.	
450	20	SAND. Medium-dark-gray. Medium- to very-coarse-grained; mostly coarse-grained. 70% basalt grains. Trace silt.	
440	30	Gravelly silty SAND. Moderate yellowish-brown grading downward to yellowish-gray. Moderately well to poorly sorted. 5 to 10% mafics, increasing with depth. Micaceous. Angular to subangular.	
430	40	Gravelly SAND. Yellowish-gray. Very-fine- to fine-grained. 5-7% mafics. Angular to subangular. Gravel 20% basalt clasts. Trace silt at 45 to 50 ft.	PM
420	50	Gravelly silty SAND to silty sandy GRAVEL. Light-olive-gray. 10 to 15% mafics. Fine- to coarse-grained. Gravel 25 to 30 % basalt clasts.	
		Silty sandy GRAVEL. Moderate olive-brown. No cement rinds. Silt adheres to clasts. Sand fine- to medium-grained.	
410	60	Gravelly silty SAND. Dark yellowish-brown. Fine- to medium-grained. 15% mafics. Silt adheres to grains. Subangular to subrounded.	

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LOG OF DRILL HOLE MJ-2

FIGURE 2R.14-4B

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
400	70	Gravelly silty SAND, as above. Micaceous. Ferruginous stain. Fine- to medium-grained; mostly medium-grained. No cement rinds on gravel clasts.	PM
		Silty SAND. Dusky yellow. Very-fine- to medium-grained, mostly medium-grained. 5 to 7 % mafics. Large muscovite flakes.	
390	80	Gravelly silty SAND. Dusky yellow. Very-fine- to medium-grained; mostly very-fine-grained. 2 to 3% mafics. No cement rinds on gravel clasts.	
		Gravelly clayey SILT to gravelly silty CLAY. Yellowish-gray to dusky yellow. Gravel probably caved.	II?
380	90	Gravelly SILT, with CLAY fragments. Yellowish-gray. Sand very-fine-grained.	
370	100	SILT, with CLAY fragments. Yellowish-gray to 130 ft.; yellowish-gray to dusky yellow from 130 to 140 ft. Trace gravel at 100 to 105 ft. Clay fragments decrease with depth.	
360	110		
350	120		
340	130		
330	140	SILT. Yellowish-gray to dusky yellow.	

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DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
			Sandy SILT. Yellowish-gray to dusky yellow. Sand very-fine-grained. Trace clay fragments.	
320	150		Silty SAND to sandy SILT. Dusky yellow. Very-fine- to fine-grained 2-3% mafics. Angular to subangular.	
310	160		Silty SAND. Dusky yellow grading downward to light-olive-brown. Very-fine- to medium-grained; mostly very-fine- to fine-grained. 3 to 5% mafics. Angular to subangular.	II?
300	170		Sandy SILT to silty SAND. Dusky-yellow. Sand very-fine-grained. Clayey in part.	
			Sandy SILT. Yellowish-gray. Sand very-fine-grained.	
290	180		Gravelly SAND. Light-olive-gray. Fine- to coarse-grained; mostly fine- to medium-grained. 15 to 20% mafics. Sandy cement rinds on some gravel clasts. Trace silt at 185 to 190 ft.	1-u?
280	190		Sandy GRAVEL to gravelly SAND. 45 to 50% basalt clasts. Sandy cement rinds on some clasts. Sand yellowish-gray; mostly medium-grained; 7 to 10% mafics.	
			Gravelly SAND. Light-olive-gray. Medium-grained. Micaceous. Sandy cement rinds on some gravel clasts.	1-b?
270	200		Sandy clayey GRAVEL. Clay light-olive-gray; possibly weathered basalt clay.	
			BASALT. Olive-gray. Weathered and vesicular at 205 to 210 ft.	
260	210		BASALT. Dark gray. Moderately fresh. Vesicular. Some yellowish-green clay in vesicles.	
				Tem
250	220			

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LOG OF DRILL HOLE MJ-2

FIGURE 231.14-4B

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
240	230	BASALT. Medium-dark-gray to 255 ft. Weathered. Vesicular. Some vesicles filled with yellowish-green to white clay.	
230	240		
220	250	BASALT. Dark-gray. Fresh. Minor vesicles to 265 ft. Minor clay (caved?).	Tem
210	260		
200	270	BASALT. Dark-gray. Fresh. Nonvesicular. Local pyrite or calcite mineralization on some surfaces. Minor vesicles from 270 to 280 ft. and from 290 to 300 ft.	
190	280		
180	290		
170	300		

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LOG OF DRILL HOLE MJ-2

FIGURE 231.14-4B

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
160	310	BASALT. Dark-gray. Fresh. Nonvesicular. Local calcite or pyrite on some surfaces from 320 to 330 ft.	Ter
150	320		
140	330	BASALT. Dark-gray. Vesicular. Vesicularity increases with depth. Vesicles at 335 to 340 filled with green clay.	
130	340	Clayey SILT to silty CLAY. Light-olive-gray.	Ter
120	350	SILT to clayey SILT. Grayish-yellow-green. Tuffaceous.	
110	360	Clayey SILT, with CLAY and tuffaceous fragments. Pale olive.	
100	370		
90	380		

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LOG OF DRILL HOLE MJ-2

FIGURE 231.14-4B

DRILL HOLE MJ-2

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
80	390		Claye, SILT, as above. Pale-olive to grayish-olive. Vesicular basalt clasts in sample at 395 to 400 ft.	Ter
70	400			
60	410		BASALT. Dark-gray. Moderately fresh. Vesicular. Some vesicles filled with green clay. Caved material from Rattlesnake Ridge interbed from 405 to 420 ft. Basalt extremely vesicular from 415 to 420 ft.	Tp
50	420			
45.2		EOH 425'		

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LOG OF DRILL HOLE MJ-2

FIGURE 231.14-4B

DRILL HOLE MJ-3

Project No : 823-1036
Elevation : 468.5 ft.
Total Depth : 273 ft.
Coordinates : N451,378.18; E262,629.38
Date Completed : 8/26/82

SAMPLE TYPE
- Cuttings
- 95 Core, Number Indicates % Core Recovery
- C2015 XRF, With Sample Number. Chemical Results Listed in Table 2R-1

Unit Column Refers to General Stratigraphic Divisions Identified Within the Site Area :

- M - Missoula
- PM - Pre-Missoula
- IV - Ringold, Cycle IV
- III - Ringold, Cycle III
- II - Ringold, Cycle II
- I - Ringold, Cycle I
- B - Basalt, Undifferentiated
- EM - Elephant Mountain Member
- RR - Rattlesnake Ridge Interbed
- P - Pomona Member

Elevation (ft.MSL)	Depth (feet)	Lithologic Description	Unit
		Silty sandy GRAVEL to gravelly silty SAND. 50 to 55% basalt clasts. Sand yellowish-gray; very-fine-grained; angular to subangular.	M
460	10	Gravelly SAND. 75% basalt grains. Very-coarse-grained. Angular to subangular.	M
450	20	Silty sandy GRAVFL to gravelly silty SAND. 50 to 75% basalt clasts. Sand poorly sorted; very-fine- to very-coarse-grained; 45 to 60% basalt grains; angular to subangular.	M
440	30	Gravelly silty SAND. Yellowish-gray to dusky yellow. Very-fine-grained. <1% mafics. Angular to subangular. Gravel <45% basalt clasts.	PM
430	40	Silty sandy GRAVEL to gravelly silty SAND. 20-25% basalt clasts. No cement rinds. Sand moderately to poorly sorted; 5-7% mafics; subangular to subrounded; yellowish-gray to dusky yellow.	PM
420	50	Gravelly silty SAND. Yellowish-gray to dusky yellow. 7-10% mafics. Very-fine to medium-grained. Angular to subrounded. Gravel 25% basalt clasts; no cement rinds.	PM
410	60	Silty sandy GRAVEL. <50% basalt clasts. No cement rinds. Matrix light-olive-gray to moderate-olive-brown. Clay at 55 to 60 ft; possibly weathered basalt clay.	PM
		BASALT. Oive-gray. Weathered. Nonvesicular.	EM

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LOG OF DRILL HOLE MJ-3

FIGURE 231.14-4C

DRILL HOLE MJ-3

Elevation (feet-MSL)	Depth (feet)	Sampled Interval / Graphic Log	Lithologic Description	Unit
400	70		BASALT. Olive-gray. Weathered. Silt and clay at 70 to 75 ft.	
390	80		BASALT. Medium-dark-gray at 75 to 80 ft. Dark-gray from 80 to 135 ft. Fresh, vesicular to 135 ft. Some vesicles filled with yellowish-green or white clay.	
380	90			
370	100			Tem
360	110			
350	120			
340	130			
330	140		BASALT. Dark-gray. Fresh. Nonvesicular. Calcite on fracture surface at 140 to 145 ft.	

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LOG OF DRILL HOLE MJ-3

FIGURE 231.14-4C

DRILL HOLE MJ-3

Elevation (feet-MSL)	Depth (feet)	Lithologic Description	Unit
320	150	BASALT. Dark-gray. Fresh. Nonvesicular. Calcite on fracture surface at 170 to 175 ft.	
310	160		Tem
300	170		
290	180	BASALT. Medium- dark-gray from 175 to 185 ft. Fresh. Minor vesicules at 180 to 185 ft.	
280	190	Clayey SILT to silty CLAY. Light-olive-gray. Caved vesicular basalt clasts.	
270	200	Clayey SILT. Light-olive-gray. Tuffaceous.	
		Clayey SILT to silty CLAY. Light-olive-gray. Tuffaceous.	Ter
260	210	Silty CLAY to clayey SILT. Grayish-yellow-green. Tuffaceous.	
		Sandy clayey SILT to sandy silty CLAY. Grayish-yellow-green. Tuffaceous.	
250	220	Sandy silty CLAY to sandy clayey SILT. Grayish-yellow-green. Tuffaceous.	
		Sandy clayey SILT. Grayish-yellow-green. Tuffaceous. Sand very-fine-grained.	

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LOG OF DRILL HOLE MJ-3

FIGURE 231.14-4C

DRILL HOLE MJ-3

Elevation (feet-MSL)	Depth (feet)	Sampled Interval	Graphic Log	Lithologic Description	Unit
240	230			Sandy clayey SILT, as above.	Ter
230	240			BASALT. Medium-gray grading downward to medium-dark-gray. Moderately fresh. Vesicular. Some vesicles filled with green or white clay.	Tp
220	250			BASALT. Dark-gray from 245 to 260 ft. fresh. Vesicles decreasing. Calcite crystals at 250 to 255 ft.	
210	260			BASALT. Grayish-black from 260 to 270 ft. Fresh. Large vesicles at 265 to 270 ft. Increase in size of plagioclase phenocrysts at 260 to 265 ft.	
200	270				
195.5			EOH 273'		

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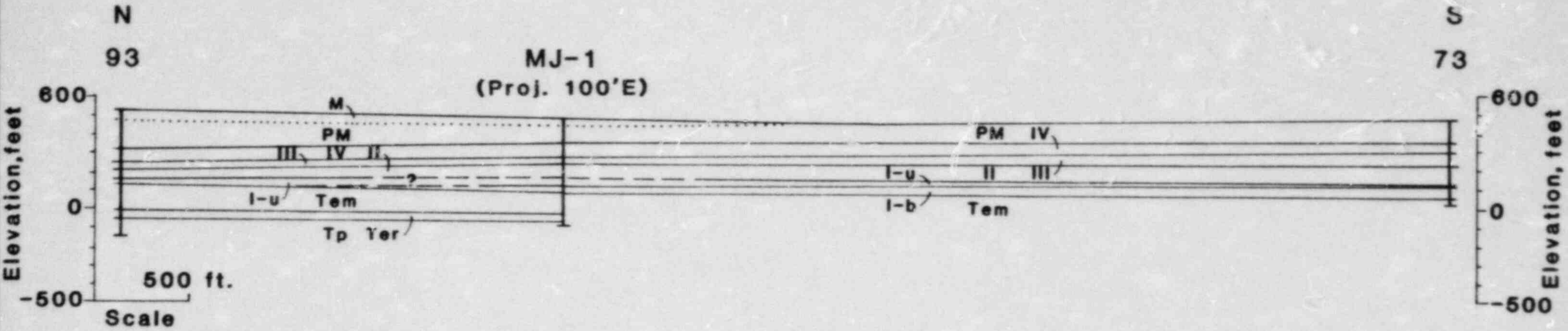
LOG OF DRILL HOLE MJ-3

FIGURE 231.14-4C

INSERT OVERSIZED FIGURES 231.14 - 5A
231.14 - 5B
231.14 - 5C
AND 231.14 - 5D



EXPLANATION

M	MISSOULA FLOOD GRAVELS
PM	PRE-MISSOULA FLOOD GRAVELS
	RINGOLD FORMATION
IV	UNIT IV
III	UNIT III
II	UNIT II
I-u	UNIT I - upper
I-b	UNIT I - basal
	COLUMBIA RIVER BASALT GROUP
Tem	ELEPHANT MOUNTAIN MEMBER
Ter	RATTLESNAKE RIDGE INTERBED
Tp	POMONA MEMBER
....	Gradational contact between Missoula and Pre-Missoula Flood Gravels
— —?— —	Inferred or indeterminate contact

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NORTH-SOUTH GEOLOGIC CROSS SECTION - DRILLHOLE 93 TO 73

Figure 231.14-6

GEOLOGIC CROSS SECTION LINE 8C

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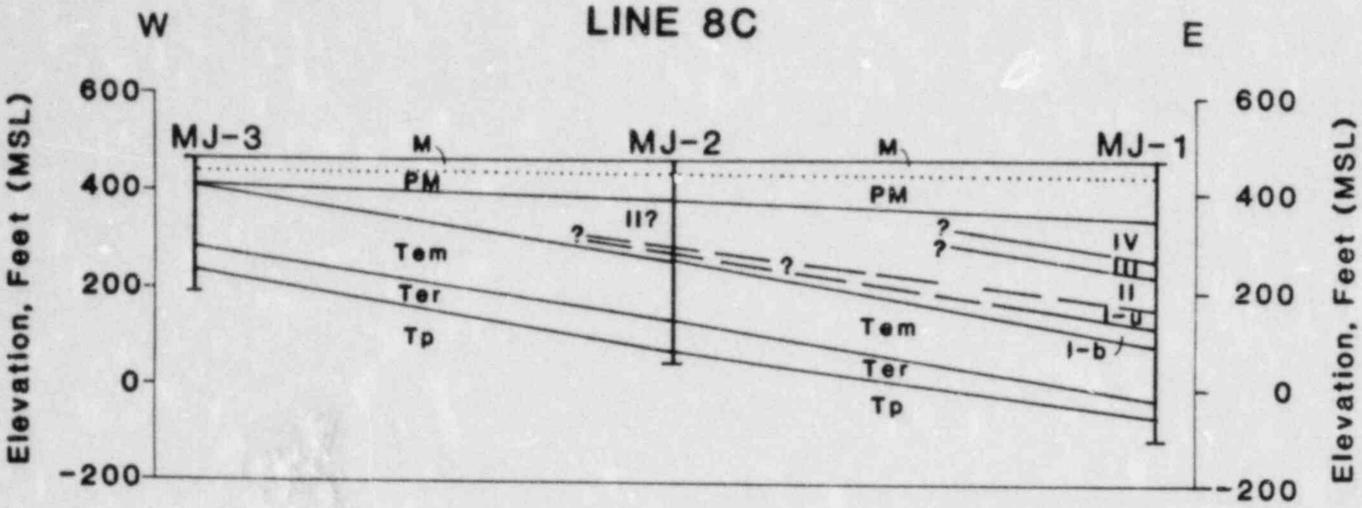
Figure 231.14-7



0 400

Scale, Feet

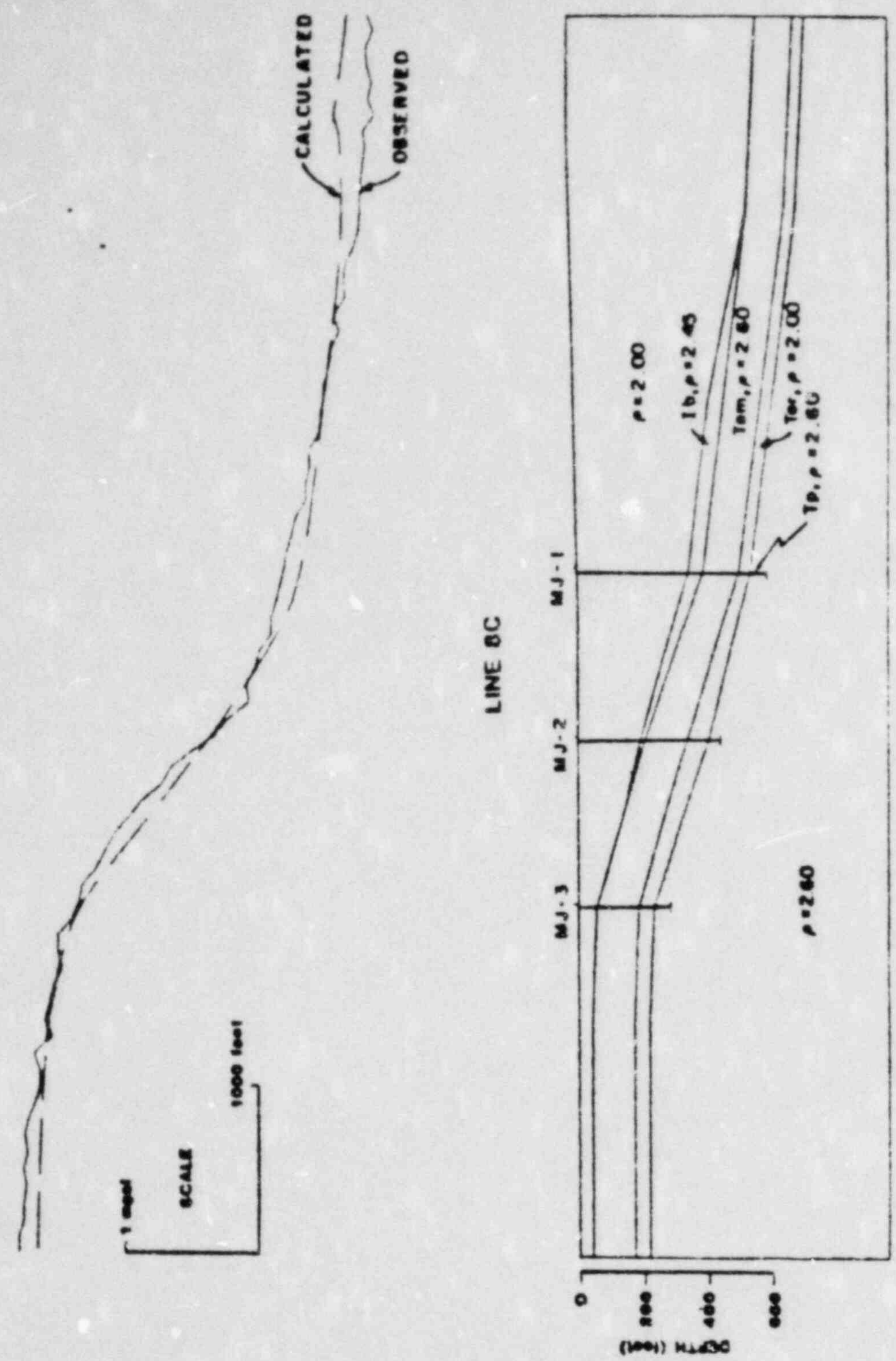
Horizontal = Vertical

EXPLANATION

M	MISSOULA FLOOD GRAVELS
PM	PRE-MISSOULA FLOOD GRAVELS
	RINGOLD FORMATION
IV	UNIT IV
III	UNIT III
II	UNIT II
I-u	UNIT I - upper
I-b	UNIT I - basal
	COLUMBIA RIVER BASALT GROUP
Tem	ELEPHANT MOUNTAIN MEMBER
Ter	RATTLESNAKE RIDGE INTERBED
Tp	POMONA MEMBER
....	Gradational contact between Missoula and Pre-Missoula Flood Gravels
– –?– –	Inferred or indeterminate contact

NOTE: Unit designations are questioned where identification of unit is uncertain

Rev. ____ Dwg. No. ____ Date ____ Eng. ____



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GEOLOGIC MODEL OF GRAVITY LINE 8C

FIGURE 231.14-8

QUESTION 231.15

Provide a table and/or other device showing the relationship between the various site area lithologies and velocities (downhole, crosshole and refraction).

RESPONSE:

The downhole velocity profiles presented in Appendix 2K and 2L have been annotated to indicate seismic velocities for the near-surface layers as determined from surface refraction and crosshole measurements together with the identification of the stratigraphic horizons as obtained from the boring logs prepared by Golder Associates and presented in Appendix 2R. The correlations observed on the enclosed annotated velocity profiles (Figures 1 through 6) are shown schematically on Figure 7. 28

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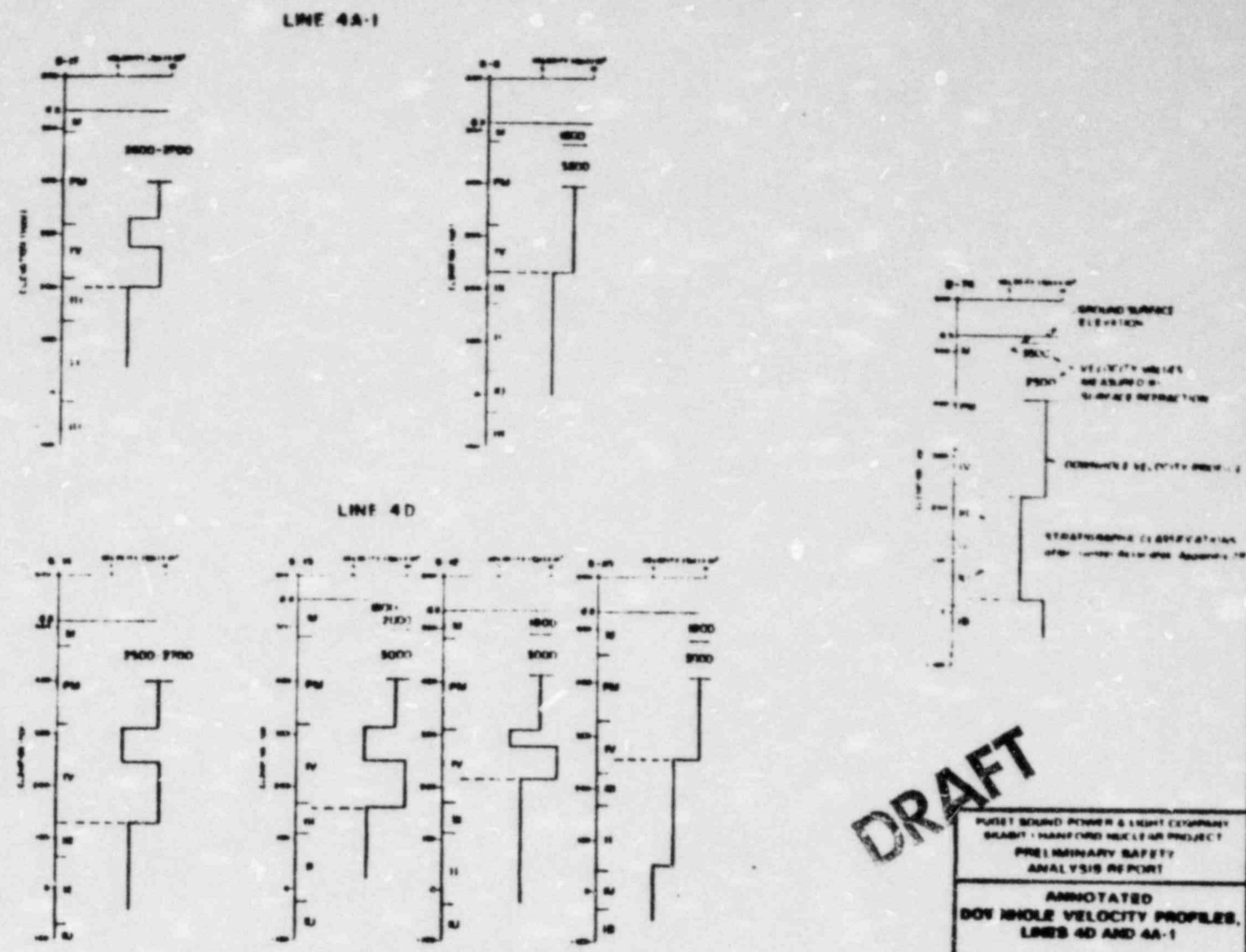

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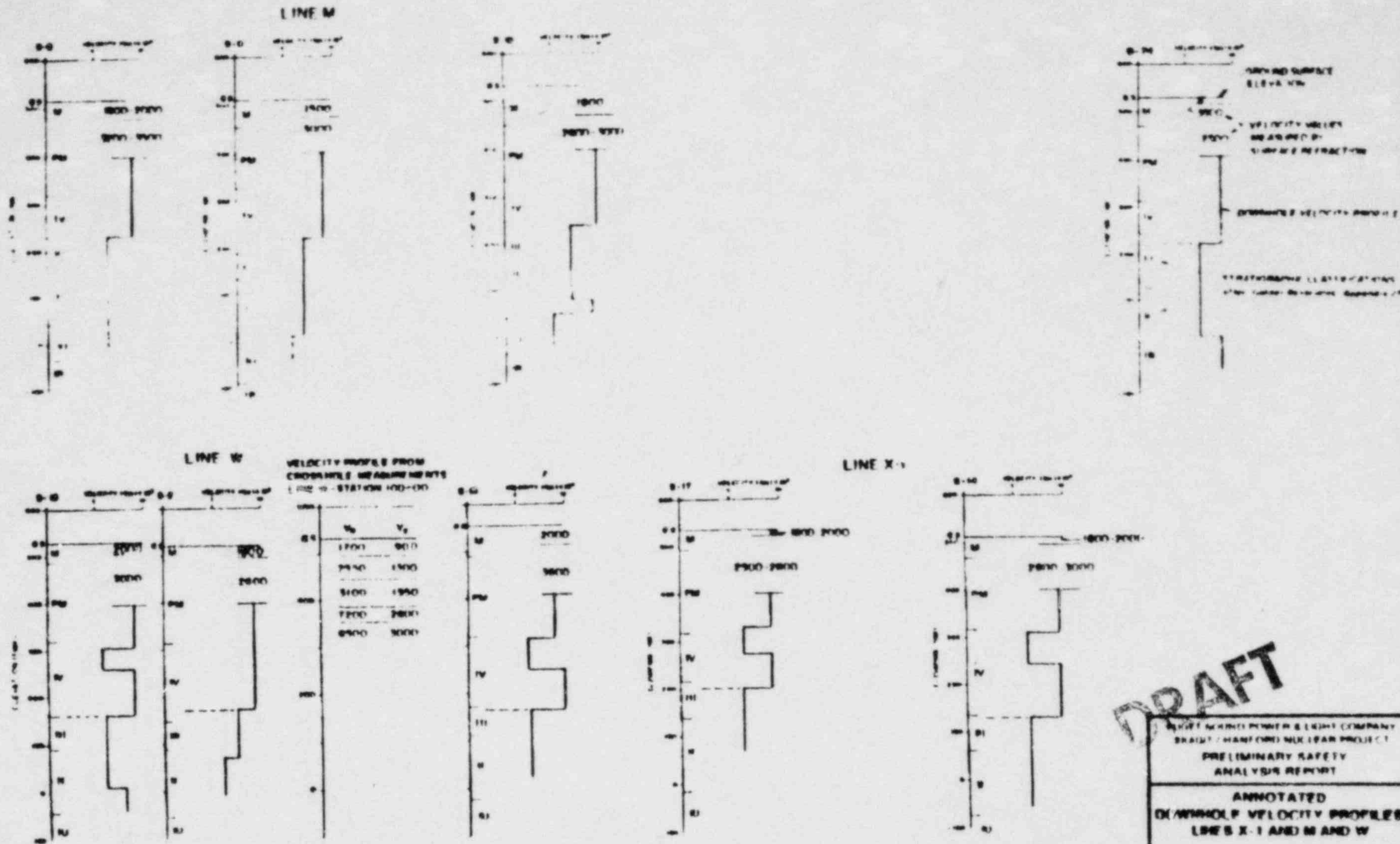
ANNOTATED DOWN HOLE VELOCITY PROFILES, LINES 4D AND 4A-1

FIGURE 2R1.10-1



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ANNOTATED
DOWNHOLE VELOCITY PROFILES,
LINES X-1 AND M AND W

FIGURE 2.5.1-19-2

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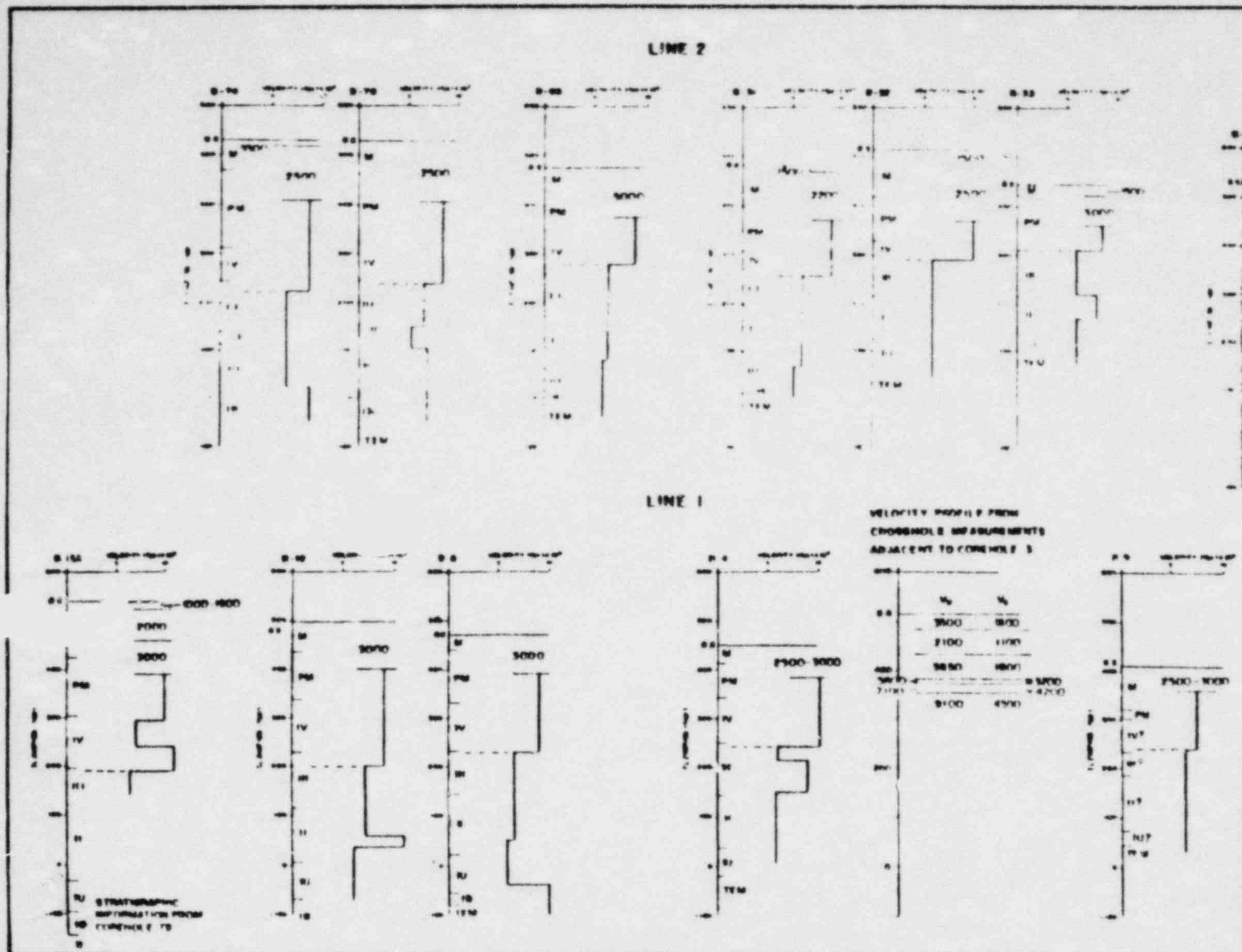

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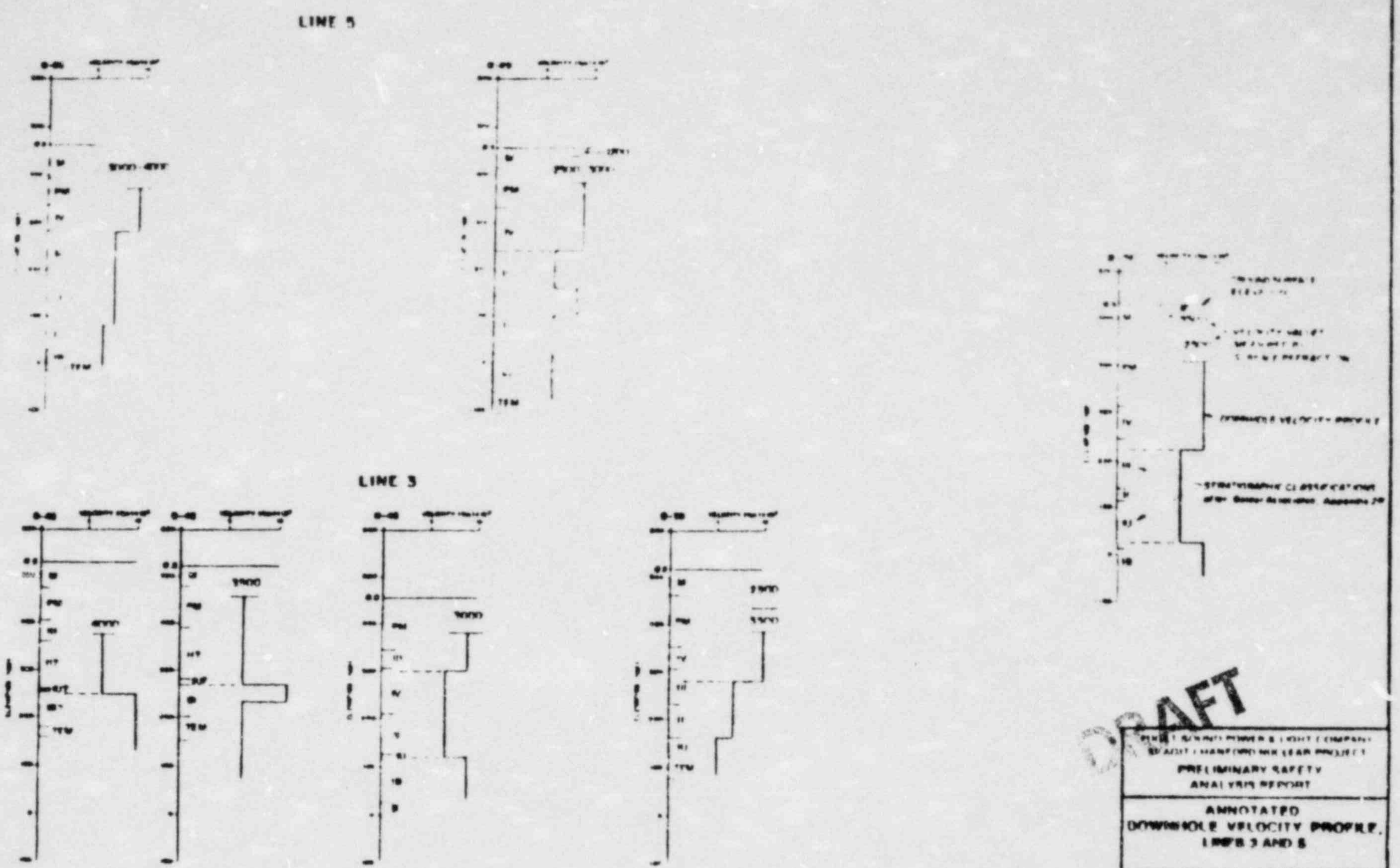
ANNOTATED DOWNHOLE VELOCITY PROFILE, LINES 1 AND 2

FIGURE 2.5.1-18-5



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ANNOTATED
DOWNHOLE VELOCITY PROFILE,
LINES 3 AND 5

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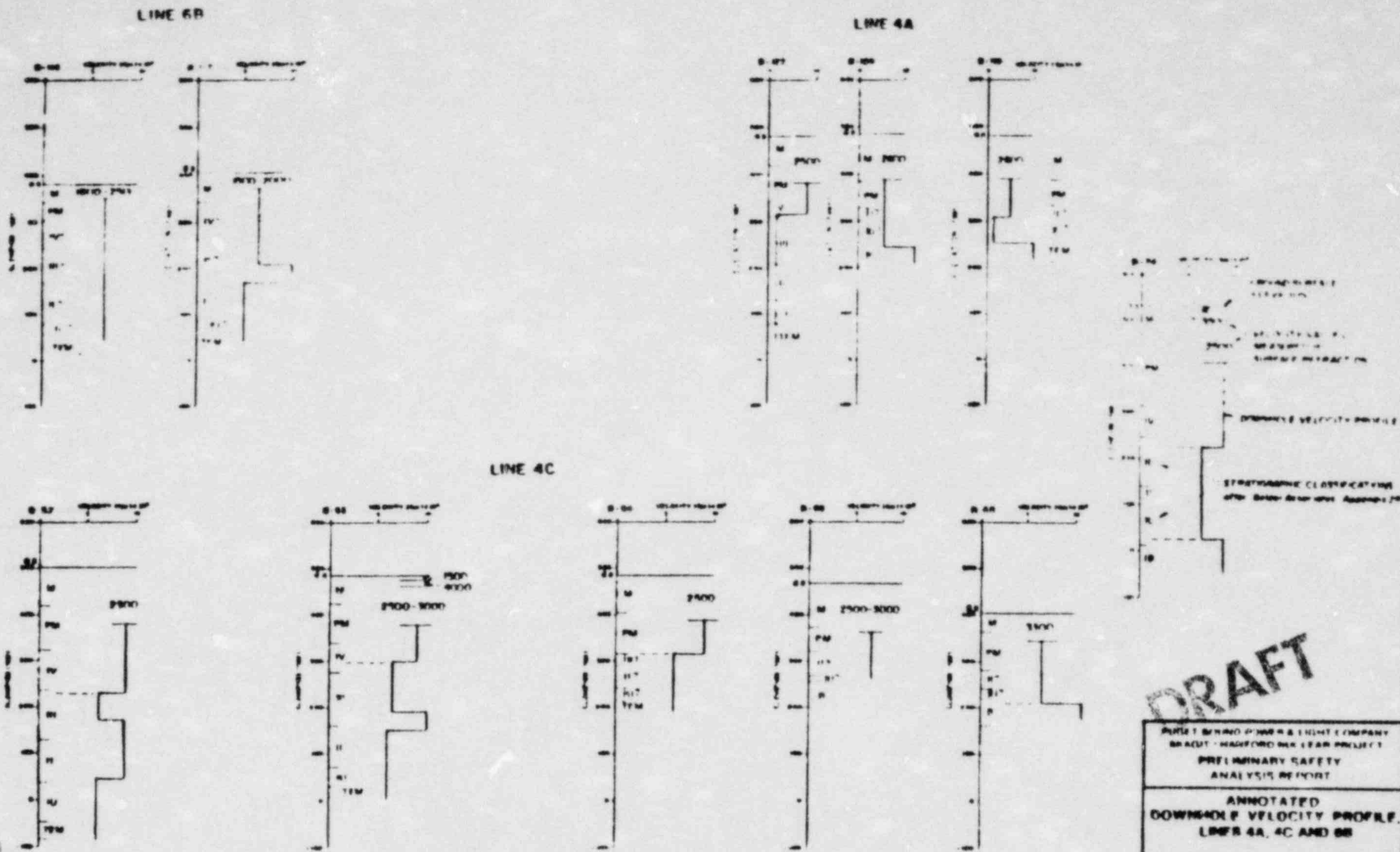

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ANNOTATED DOWNHOLE VELOCITY PROFILE, LINES 4A, 4C AND 6B

FIGURE 2.5.16-9

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ANNOTATED
DOWNHOLE VELOCITY PROFILE,
LINES 6 AND 6A

FIGURE 2R1 10-8

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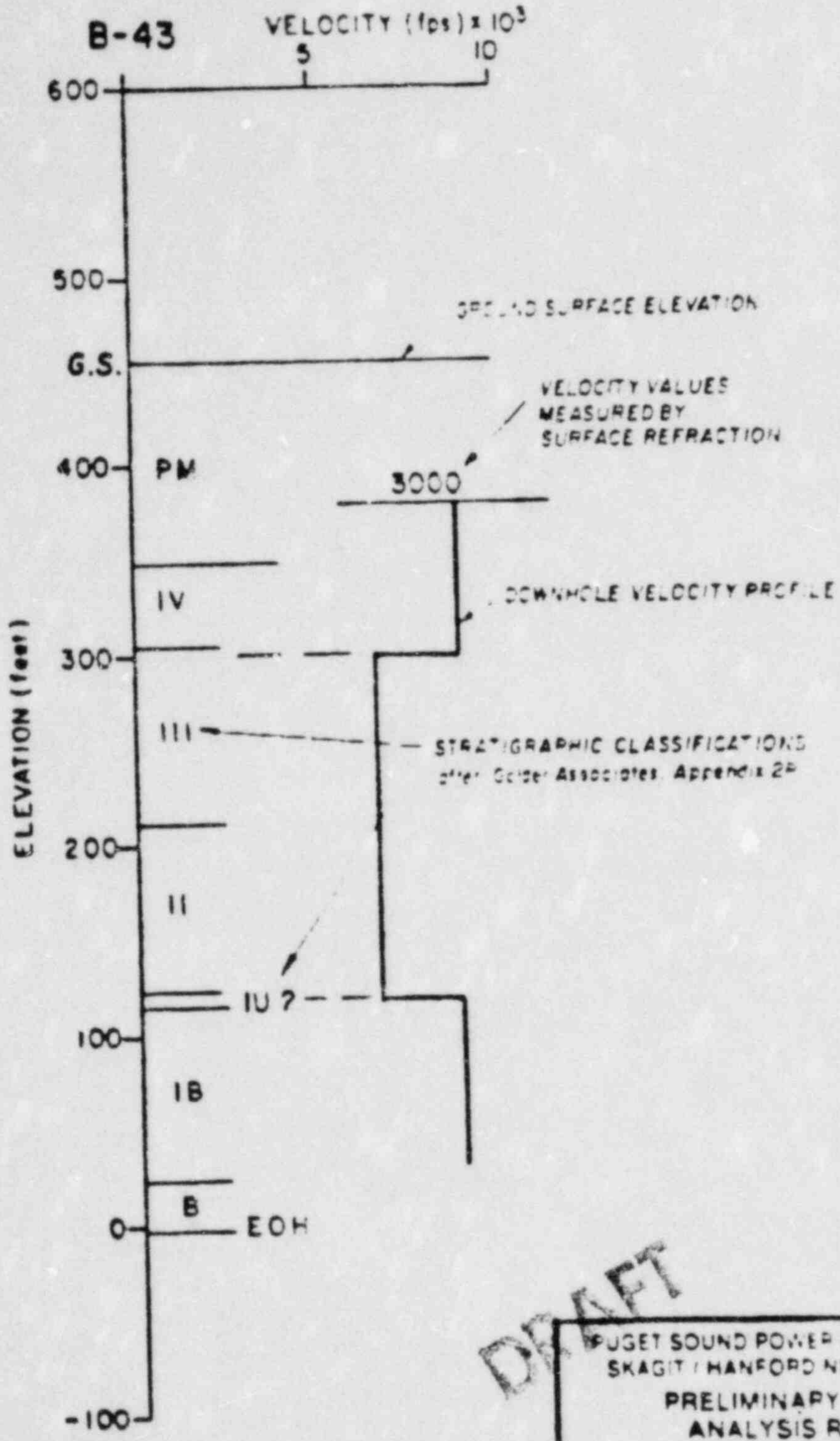

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TYPICAL VELOCITY/STRATIGRAPHIC CORRELATION

FIGURE 231.15-7

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