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SUBJECT: Forwards specific discussions supplementing FSAR w/addl geologic info,per Geosciences Branch verbal requests.

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April 26, 1982
G02-82-400

Docket No. 50-397

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US NUCLEAR REGULATORY COMMISSION

Mr. A. Schwencer, Chief
Licensing Branch No. 2
Division of Licensing
U.S. Nuclear Regulatory Commission
Washigngton, D.C. 20555

Dear Mr. Schwencer:

Subject: NUCLEAR PROJECT NO. 2
TRANSMITTAL OF ADDITIONAL
GEOLOGIC INFORMATION FOR WNP-2

In response to verbal requests from the Geosciences Branch, we are providing additional geologic information to assist the staff with their timely review of the WNP-2 project. Attached to this letter are eight (8) specific discussions supplementing our FSAR. A number of other geologic and ground motion subjects will be responded to in a similar manner in the near future.

Some of the attached discussions relate to the geologic assessment of potential seismic sources and sensitivity tests performed on a random earthquake site specific response spectra. We do not agree with the philosophy of using a response spectra generated from a random event. Nonetheless, information is provided to supplement your staff's thorough review. Specifically, the following topics are attached:

1. Summary and evaluation of geologic and geophysical data on the Cold Creek Lineament.
2. Report on the nature and genesis of the Rattlesnake Northeast Lineaments.
3. Evaluation of faulting in Moxee Valley and Wenas Valley.
4. Segmentation.
5. Review of RHO-BWI-ST-14.
6. Evaluation of Cochran's geophysical data in the vicinity of the Butte and Game Farm Hill.
7. Supplement to response to Question 361.17.
8. Review of the magnitude of the July 16, 1936, Walla Walla area earthquake.

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Mr. A. Schwencer
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We trust that the above listed items can now be closed out. For additional information, please contact the Supply System's Mr. W.A. Kiel.

Very truly yours,

G. D. Bouchey
Deputy Director, Safety and Security

CDT/jca
Attachment

cc: R Auluck - NRC
WS Chin - BPA
R Feil - NRC Site

EVALUATION OF FAULTING IN MOXEE VALLEY AND WENAS VALLEY

1.0 INTRODUCTION

Photogeologic studies by Glass (Washington Public Power Suppply System, 1977b) concluded that scarps in recent alluvium occurred in Moxee Valley and Wenas Valley near Yakima, Washington. Glass (Washington Public Power Suppply System, 1977b) called these the Moxee Valley fault and the Wenas Valley fault, and this terminology is retained here. The scarps are located within the northwestern part of the Yakima fold belt, a region referred to as domain I of the Cle Elum Wallula lineament (CLEW) (Figure 1). If the scarps have been produced by recent tectonic surface faulting, they have the potential to provide information on earthquake recurrence, slip rate, earthquake magnitude, stress orientation and tectonic models. For these reasons, the faults at Moxee and Wenas Valleys have been re-examined. The present evaluation is based on a review of published literature; photogeologic interpretation of aerial photographs with scales ranging from 1:24,000 to 1:125,000; and field reconnaissance geologic mapping.

The following discussion presents 1) a review of previous and present interpretations of the Moxee Valley and Wenas Valley faults, 2) a review of tectonic models for domain I of CLEW, and 3) a discussion of the significance of these features to the assessment of the capability and earthquake potential of faults within CLEW and potential ground motions at the WNP-2 site.

2.0 MOXEE VALLEY FAULT

2.1 Previous Investigations

Remote Sensing

The Moxee Valley fault was first identified by Glass (Washington Public Power Suppply System, 1977b) from an analysis of aerial photographs and LANDSAT imagery. Glass (Washington Public Power Suppply System, 1977b) defined eastern and western branches (Figure 1). The eastern branch trends north-northwest and was interpreted to extend a distance of approximately 20 km from the axis of Rattlesnake Ridge on the south to just across the axis of Yakima Ridge on the north. Glass (Washington Public Power Supply System, 1977b) interprets the fault to displace the anticlinal structure of Rattlesnake Ridge in a left-lateral sense on the basis of an apparent deflection in the structural trend of the anticline. Although he could not trace the fault to the north across the Selah Creek Valley, Glass (Washington Public Power Supply System, 1977b) states that the topographic axis of Umtanum Ridge is displaced along the approximate projection of the fault. The eastern branch does not appear to displace recent alluvial material (Washington Public Power Suppply System, 1977b).

The western branch of the Moxee Valley fault occurs almost entirely within the Yakima Firing Center. It is defined by Glass (Washington Public Power Supply System, 1977b) as an approximately 3-km-wide, 25-km-long zone that trends generally N40W. The zone contains scarps and fissures that "appear to displace young alluvium" (Washington Public Power Suppply System, 1977b). The scarps interpreted to represent displaced alluvium were identified at two locations near the southeastern end of the zone (Washington Public Power Suppply System, 1977b). These are shown as localities 1 and 2 in Figure 2.

Geologic Mapping

Reconnaissance geologic mapping of the Yakima Ridge area by Bentley (Washington Public Power Suppply System, 1977a) and Kienle (Washington Public Power Suppply System, 1977c) and did not reveal the presence of faulting in the locations of Glass' (Washington Public Power Suppply System, 1977b) western and eastern branches of the Moxee Valley fault. However, regional geologic mapping reported in Myers and Price (1979) shows a right-lateral strike-slip fault having a down-to-the-east dip slip component, coincident with the eastern branch of the Moxee Valley fault. The right-lateral fault of Myers and Price (1979) is approximately 24 km long. It is confined to the bedrock of Yakima and Rattlesnake Ridges and is concealed beneath Holocene alluvium of Selah Creek Valley and Moxee Valley. The right-lateral fault coincident with the eastern branch is mapped as displacing the Wanapum and Saddle Mountains basalt members on the southern flank of Yakima Ridge approximately 300 to 500 m laterally, but does not displace the anticlinal axis of Yakima Ridge or the basalt stratigraphy on Rattlesnake Ridge (Myers and Price, 1979).

The mapping of Myers and Price (1979) shows that there are no faults coincident with the western branch, and also shows that intracanyon basalt flows of the Pomona and Esquaztel members of the Saddle Mountains basalt are parallel and subparallel to the scarps interpreted by Glass (Washington Public Power Supply System, 1977b).

2.2 Results of Present Evaluation

Based on photogeologic interpretation and reconnaissance geologic mapping, the eastern branch of the Moxee Valley fault is interpreted to be a bedrock fault that appears to be confined to the Yakima Ridge anticline. It is approximately 14 km long and

strikes about N25W (Figure 2). At its closest approach it is approximately 65 km west of the site. Apparent right-lateral offset of basalt stratigraphy as well as apparent down-to-the-east dip-slip displacement can be measured at two locations along the fault. At one location (Sec. 3, T12N, R21E), the contact between the intracanyon flow of the Pomona member and the underlying Frenchman Springs or Roza member is displaced an apparent 300 m in a right-lateral sense and about 60 m down-to-the-east. At the other location (Sec. 24, T12N, R21E), the Mabton interbed exhibits about 600 m of apparent right-lateral offset based on outcrop projections. The apparent vertical displacement is up-to-the-east, opposite of that observed across the intercanyon flow, but the amount of vertical displacement is uncertain.

The topographic crest of Yakima Ridge shows no apparent lateral offset where the fault is projected across it. However, there is an approximately 65 m down-to-the-east topographic step in the ridge. Linear features indicative of faulting are not observed in the bedrock along the southern projection of the eastern branch on the north flank of Rattlesnake Ridge. There appears to be continuity in the basalt stratigraphy across this projection as interpreted from aerial photographs. Because of the well-defined displacement and geomorphic expression of the eastern branch on the southern flank of Yakima Ridge, and the lack of similar expression on Rattlesnake Ridge, the fault is interpreted to be confined to Yakima Ridge. Features such as vegetation alignments, topographic scarps in alluvium or alluvial fans, and offset streams are not apparent in the Holocene alluvium of Moxee Valley along the southern projection of the eastern branch, nor along its northern projection across Selah Creek Valley.

As discussed above, Glass (Washington Public Power Supply System, 1977b), on the basis of photogeologic interpretation, concluded that active southwest-facing scarps occurred in alluvium at two

locations along the southeastern end of the western branch of the Moxee Valley fault (locations 1 and 2, Figure 2; Figure 2RK-18 of Washington Public Power Suppply System, 1977b). Interpretation of aerial photographs shows that in the area covered by Figure 2RK-18 (Washington Public Power Suppply System, 1977b) there are numerous, generally regularly-spaced, parallel to sub-parallel lineaments trending aoout N45W to N55W that occur in a zone about 2 to 3 km wide (Figure 2). A sub-parallel but less extensively developed set of lineaments trending about N35W to N40W is also observed. The lineaments occur almost entirely within gullied, gently south-dipping bedrock mapped as the Priest Rapids member by Myers and Price (1979) and appear to be more common in the older, stratigraphically lower basalts and less pervasive in the overlying flows. The lineaments are expressed as faint to strongly developed linear color contrasts and alignments of vegetation. The more prominent lineaments are expressed locally as subdued southwest-facing topographic scarps and shallow topographic trenches (fissures) that are highlighted by the concentration of vegetation along their lengths.

The localities where scarps in alluvium were identified by Glass (Washington Public Power Suppply System 1977b; Figure 2RK-18) were examined in the field. At locality 1 (Figure 2) a southwest-facing scarp is developed not in alluvium, but in a bedrock dip slope that dips approximately 10 degrees southwest. At this location the scarp varies in height from approximately 1/2 m to 1-1/2 m. The scarp becomes more subdued and disappears to the east and west where crossed by transverse streams. At locality 2 (Figure 2) a subtle southwest-facing break-in-slope occurs across a dip slope that is mantled by a thin (<1 m thick) deposit of loess and/or residual soil overlying basalt. The scarp is approximately 1/3 m high and locally is as broad as 5 m. The scarp does not extend to the northwest or southeast of locality 2 even though the linear color contrast and vegetation alignment with which it is coincident on the aerial photographs

extends in both directions. Discontinuous exposures of basalt in streams crossing the northwest projection of the scarp from locality 2 are highly jointed but do not expose any faults.

2.3 Summary and Interpretation

The Moxee Valley fault has an eastern and western branch. The eastern branch is a right-lateral strike-slip fault having some dip-slip component. It obliquely crosses the trend of, and appears to be confined to, the Yakima Ridge anticline. Cumulative right-slip may be on the order of 300 m to 600 m and cumulative dip-slip appears to be approximately 60 to 65 m. Based on the mapped relationships of Myers and Price (1979), the major displacement along the eastern branch is interpreted to post-date the Pomona intracanyon basalt flow but to pre-date the youngest folding of the Yakima Ridge anticline. The orientation of this fault relative to the Yakima Ridge anticline is similar to cross faults observed along other Yakima folds. No evidence could be detected for Holocene displacement along this branch.

Based on their geometry, pattern, and surface expression, the lineaments that define the western branch are interpreted to represent a pervasive N35W to 55W-trending conjugate joint system in the Priest Rapids and Pomona members. Although some localized minor displacement may have occurred, the topographic breaks in slope are most probably the result of differential erosion along the joints. At locality 1, a scarp occurs in bedrock and not alluvium. If the scarp at locality 2 is a fault in the basalt and not the result of differential erosion, the available field relationships do not provide information on the age of the most recent displacement. If the scarps associated with the western branch are assumed to represent tectonic faulting, then the faults would be interpreted as normal faults on the basis of the geometry and geomorphic expression of the scarps.

3.0 WENAS VALLEY FAULT

3.1 Previous Investigations

Remote Sensing

The Wenas Valley fault was first identified by Glass (Washington Public Power Supply System, 1977b) from analysis of aerial photographs and LANDSAT imagery. Glass (Washington Public Power Supply System, 1977b) interpreted the fault as a 25 km-long zone of southwest facing topographic scarps whose pattern suggested normal-slip with a right-oblique component. The zone was mapped as extending northwest from the Cottonwoods (20 km north of Yakima) along the base of the southwest flank of Umtanum Ridge. Glass (Washington Public Power Supply System, 1977b) notes that the scarps in Wenas Valley appear "nearly as fresh as the Moxee fault zone".

Geologic Mapping

Geologic mapping by Bentley (1977a), Kienle and others (Shannon and Wilson, 1978) and Myers and Price (1979) has not identified faults in bedrock coincident with the scarps identified by Glass (Washington Public Power Supply System, 1977b). The mapping by these authors indicates a syncline (Wenas syncline) within the Ellensburg Formation that is parallel to and occurs approximately 1 km to the southwest of the scarps (Figure 3).

3.2 Results of Present Evaluation

The present analysis, which is based on photointerpretation and field reconnaissance, indicates that the zone of scarps in Wenas Valley that could represent recent faulting has a length of approximately 9 km, rather than the 25 km length identified by Glass (Washington Public Power Supply System, 1977b). The scarps

occur discontinuously from just north of Kelley Hollow on the southeast to Horse Trough Canyon on the northwest (Figure 3) along a trend of approximately N50W. This is the section of the zone that Glass (Washington Public Power Supply System, 1977b) noted as having fresh-apppearing scarps. At its closest approach, the Wenas Valley fault is approximately 105 km northwest of the site. The geologic and geomorphic observations made along the scarps in this zone are summarized below.

The scarps occur along, and are parallel to, the base of the south flank of the Umtanum Ridge anticline. Bedrock along this flank dips to the southwest at angles up to 75 degrees (Shannon and Wilson, 1978). The scarps occur in late Quaternary, possibly Holocene, alluvial fans. The fans appear to be overlying the Ellensburg Formation, which has been mapped as filling Wenas Valley (Myers and Price, 1979). Mapped dips in the Ellensburg Formation range from 2 to 18 degrees to the southwest on the north flank of the Wenas syncline and 15 to 30 degrees to the northeast on the south flank of the syncline (Shannon and Wilson, 1978). The scarps are parallel to the Wenas syncline and do not appear to extend beyond the mapped length of the syncline.

The scarps are down-to-the-valley (southwest) and generally range in height from 3 to 5 m. The highest scarp, up to 10 m, occurs along the segment northwest of Black Canyon. The longest individual scarp is continuous for 4 km in Sec. 27, 28, and 20, T16N, R17E (Figure 3). A 500-m long graben is developed along a segment of the scarp in Sec. 27, T16N, R17E (Figure 3). The graben varies in width from 5 to 10 m. The net displacement across the graben is approximately 2 m. In the NW 1/4, Sec. 28, T16N, R17E the scarp is between 5 and 10 m high and a distinct inflection and steepening of the scarp profile is noted approximately 1-1/2 to 2-1/2 m above the base of the scarp. Also in Sec. 28, T16N, R17E, a northeasttrending, northwest-facing scarp intersects the main scarp to produce an apparent

downdropped block (Figure 3). This perpendicular scarp is less than 1 km long and decreases in height to the southwest.

The scarps occur uphill of extensive landslide topography. This landslide topography occurs along both sides of Wenas Creek Valley and is most prominent between Kelley Hollow on the southeast and Horse Trough Canyon on the northwest. Mapped locations of clearly defined landslide topography are shown as Qls in Figure 3 and the spatial relationship between landslide topography and the scarps can be observed on Figure 2RK-19 of Glass (Washington Public Power Supply System, 1977b).

Lineaments to the southeast of the scarps in Wenas Valley, which are included by Glass (Washington Public Power Supply System, 1977b) as part of the Wenas Valley fault, are expressed as linear color changes and vegetation alignments. These are coincident with strike ridges in the Ellensburg Formation, which generally strikes northwest and dips to the southwest in this area. Scarps having similar geomorphic characteristics of those observed in Wenas Valley are not observed in this area.

3.3 Summary and Interpretation

The Wenas Valley fault is defined by N50W-trending, southwest-facing scarps developed in Quaternary alluvium. The zone along which the scarps occur is approximately 9 km long. As discussed above, the morphology of the fault scarps and the occurrence of a graben indicate that the scarps are extensional features. There is no evidence of a component of right-oblique slip. The data permit two major interpretations for the origin of the scarps. These are: 1) tectonic normal faulting, and 2) gravitational failure resulting from landsliding in the Ellensburg Formation or underlying basalt.

If the scarps in Wenas Valley are tectonic, their geometry and morphology are typical of active normal-slip faults such as those in the Basin and Range. The height of the scarps, which locally is as high as 10 m, and the 1-1/2 to 2-1/2 m-high inflection in the scarp profile along one segment of the scarp, are observations suggestive of multiple displacements that could be on the order of a couple meters per event. The major inconsistency between the field observations and the interpretation of tectonic normal faulting is the relationship between the postulated displacement per event and the length of the fault. Typically, surface displacements of a couple of meters per event are associated with fault rupture lengths of 30 to 65 km, which greatly exceed the 9km-long zone observed in Wenas Valley. In addition, the fault would represent an extensional structure within the compressional environment expressed by the Wenas syncline and the Umtanum anticline.

As discussed above, widespread landsliding of the Ellensburg Formation towards Wenas Creek is observed on both sides of Wenas Valley. The Wenas Valley fault scarps are best developed and most continuous where they occur approximately 1 km northeast of, and parallel to, the well-developed landslide topography in the Ellensburg Formation. The landslide topography and scarps occur along, and appear to be restricted to, the N45W to 50W-trending segment of Wenas Valley. These observations, plus the sense and style of displacement across the scarps, are consistent with scarp formation by gravitational sliding to the southwest.

4.0 SIGNIFICANCE OF THE MOXEE AND WENAS VALLEY FAULTS TO CLEW TECTONICS AND SITE GROUND MOTIONS

4.1 Tectonic Models and Deformation Within Domain I of CLEW

The Moxee Valley and Wenas Valley faults occur within the region referred to as structural domain I of CLEW (Figure 1). As part of the evaluation of the way in which these faults provide information for assessing the tectonics of CLEW and potential ground motions at the site, the proposed tectonic models and the relationship between the surface deformation and the underlying structure in domain I are summarized below.

The northwestern domain of CLEW, domain I, consists of a broad zone of folds and associated faults within the Yakima fold belt. Domain I is distinguished from the rest of the Yakima fold belt by the more northerly trend of the fold axes within CLEW compared to the generally east-west trend of the folds outside of CLEW (Laubscher, Appendix 2.5-O). However, boundaries of CLEW in domain I are very diffuse and many of the fold trends within CLEW are similar to those outside of CLEW. Many of the folds that cross the postulated boundary of CLEW do not show any change in trend (e.g., Umtanum Ridge, Rattlesnake Hills, Yakima Ridge). This indicates that there is no sharp structurally defined boundary to CLEW in domain I and raises questions about its existence in this area. There is no evidence for a throughgoing fault at the surface in domain I.

The proposed tectonic models for CLEW differ in the causal mechanism for the strain pattern at the surface. Laubscher (Appendix 2.5-O) postulated a pre-existing fault or structural flaw in the crust of the Columbia Plateau. According to Laubscher (Appendix 2.5-O), CLEW is the consequence of "deep-seated right-lateral shear that drives a deformable sequence of partially decoupled more superficial layers." Based on studies of wrench-fault

deformation, Laubscher concludes that the depth to the driving structure is about half the width of the deformed belt that develops above it. From Laubscher's analysis, the driving structure beneath domain I would lie at a depth of 15 to 20 km. These depths are at or near the maximum depths of seismicity in the Columbia Plateau and lie within the lowermost crust and/or upper mantle. Thus, if a fault exists at depth beneath domain I of CLEW, it is beneath the brittle crust and is, therefore, not capable of generating moderate to large earthquakes.

Davis (Appendix 2.5N) presents an alternative explanation for the style of "basement" deformation along CLEW. He proposes that the greater width of CLEW in domain I is not a result of the controlling wrench structure being deeper there, but occurs because the zone of basement wrenching becomes broader and more diffuse to the northwest. This model implies that domain I, which is the widest part of CLEW, is the least likely domain to be underlain by a throughgoing fault. Therefore, it is unlikely that a major seismogenic source exists beneath the surface structures of domain I.

From the proceeding discussion it is apparent that neither Laubscher (Appendix 2.5-O) nor Davis (Appendix 2.5N) propose a throughgoing fault at depth in domain I that may be a potential seismic source. Therefore, the potential seismic sources within this domain are the faults at the surface, if they are capable. None of these faults are as long or as close to the site as the faults associated with the Rattlesnake-Wallula alignment (RAW). For this reason, the assessment of maximum earthquake magnitudes for faults within CLEW (Response to Q360.14) is limited to the Rattlesnake Mountain fault and the Wallua Gap fault, which are the longest and closest faults to the site.

4.2 Summary of Observations on the Moxee Valley and Wenas Valley Faults and Comparison with CLEW Structures

The eastern branch of the Moxee Valley fault strikes approximately N25W, oblique to the N50W trend of Yakima Ridge to which it appears to be restricted. The sense of displacement is right-slip with a down-to-the-east dip slip component. The eastern branch differs from many of the faults in domain I, such as the fault along the north side of Umtanum Ridge, which are reverse faults that parallel the folds. Geomorphic observations along the eastern trace suggest that Holocene displacement has not occurred, but the data are not available to demonstrate that the fault is not capable in accordance with 10CFR100, Appendix A.

Scarps associated with the western branch of the Moxee Valley fault trend N35W to N55W, generally parallel to the axis of Yakima Ridge. Two scarps were interpreted by Glass (Washington Public Power Supply System, 1977b) as evidence of recent faulting. One scarp occurs completely in bedrock (locality 1, Figure 2) and the other occurs across a bedrock dip-slope covered by a thin veneer of loess and/or residual soil (locality 2, Figure 2). The scarps are associated with a pervasive joint set and most probably represent localized differential erosion, although it has not been demonstrated that minor displacement along some joints, or involvement of the loess and/or soil in possible faulting at locality 2, has not occurred. If the scarps of the western branch are faults, they are southwest-facing normal faults. This style and sense of displacement differ from most mapped faults throughout CLEW, which are generally reverse, reverse-oblique, or strike-slip with a reverse component.

The Wenas Valley fault trends N50W, parallel to the Umtanum Ridge and Cleman Mountain anticlines. It is defined by southwest facing scarps in Quaternary, possibly Holocene, alluvial fans. The origin of the scarps is uncertain at present. They either

represent gravitational sliding or tectonic normal-slip faulting. Assuming that they are tectonic, the style and sense of displacement observed along the scarps differs markedly from most other faults mapped along CLEW or RAW. In addition, the occurrence of a normal fault that is parallel to the axes of the major adjoining folds, and that is located within and parallel to the axis of the Wenas syncline, is not consistent with the deformation expected from proposed regional tectonic models and is not characteristic of fold and reverse fault relationships observed throughout the CLEW zone.

In summary, the available data do not provide a basis for conclusively determining the capability of the Moxee Valley and Wenas Valley faults with regard to 10CFR100, Appendix A. However, the present evaluation suggests that late Quaternary faulting along the western branch of the Moxee Valley fault has not occurred, and provides observations consistent with a non-tectonic origin for the scarps that define the Wenas Valley fault. In addition, the sense and style displacement along both sets of scarps, assuming they are tectonic faults, is normal-slip down to the southwest along a N40- to 50W trend. This is not consistent with the general north-south compression proposed for the Columbia Plateau. It is also not characteristic of most of the mapped faults within CLEW, which are predominantly reverse and reverse-oblique. On this basis, the Moxee Valley and Wenas Valley faults are not considered to characterize either the behavior or the capability of the faults within CLEW.

4.3 Significance of Moxee Valley and Wenas Valley Faults to Site Ground Motions

The tectonic models proposed for CLEW have been summarized in terms of their implications to earthquake potential, and the relationships of the Moxee Valley and Wenas Valley faults to CLEW have been presented. From these discussions the significance of

these faults to the site ground motions may be assessed. As discussed previously, there is no evidence of a throughgoing fault at the surface along domain I of CLEW and the tectonic models for CLEW do not postulate a throughgoing crustal fault at depth in domain I that is a potential seismic source. Therefore, the earthquake potential of domain I is related to capable faults at the surface. The capability of the Moxee Valley and Wenas Valley faults is uncertain and for purposes of estimating earthquake potential, they may be assumed to be capable. However, the Moxee Valley and Wenas Valley faults are too short (14 km and 9km, respectively) and are too far from the site (65 km and 105 km) to be of equal or greater significance to the site than the Rattlesnake Mountain fault and the Wallula Gap fault, which are assumed to be capable.

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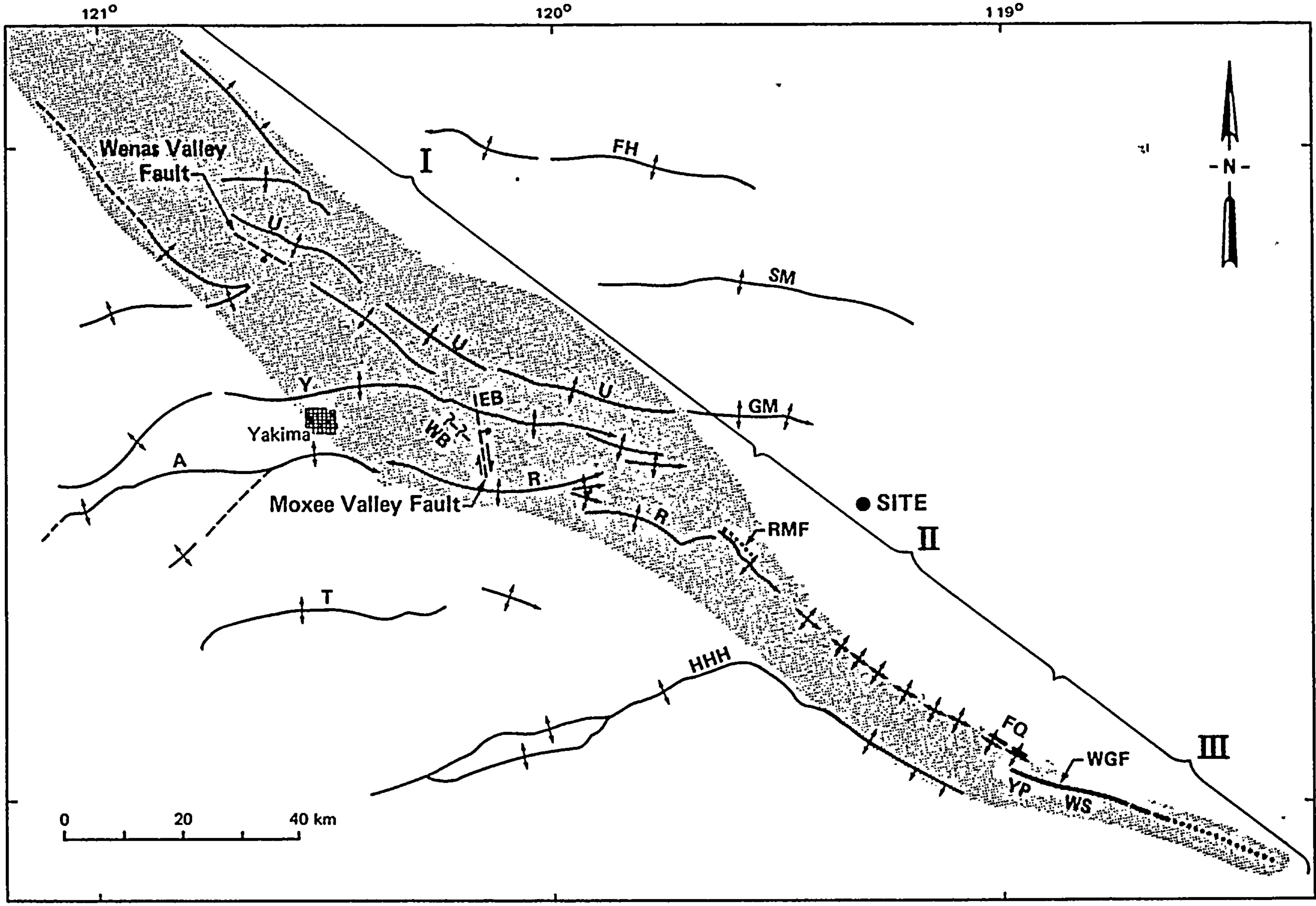
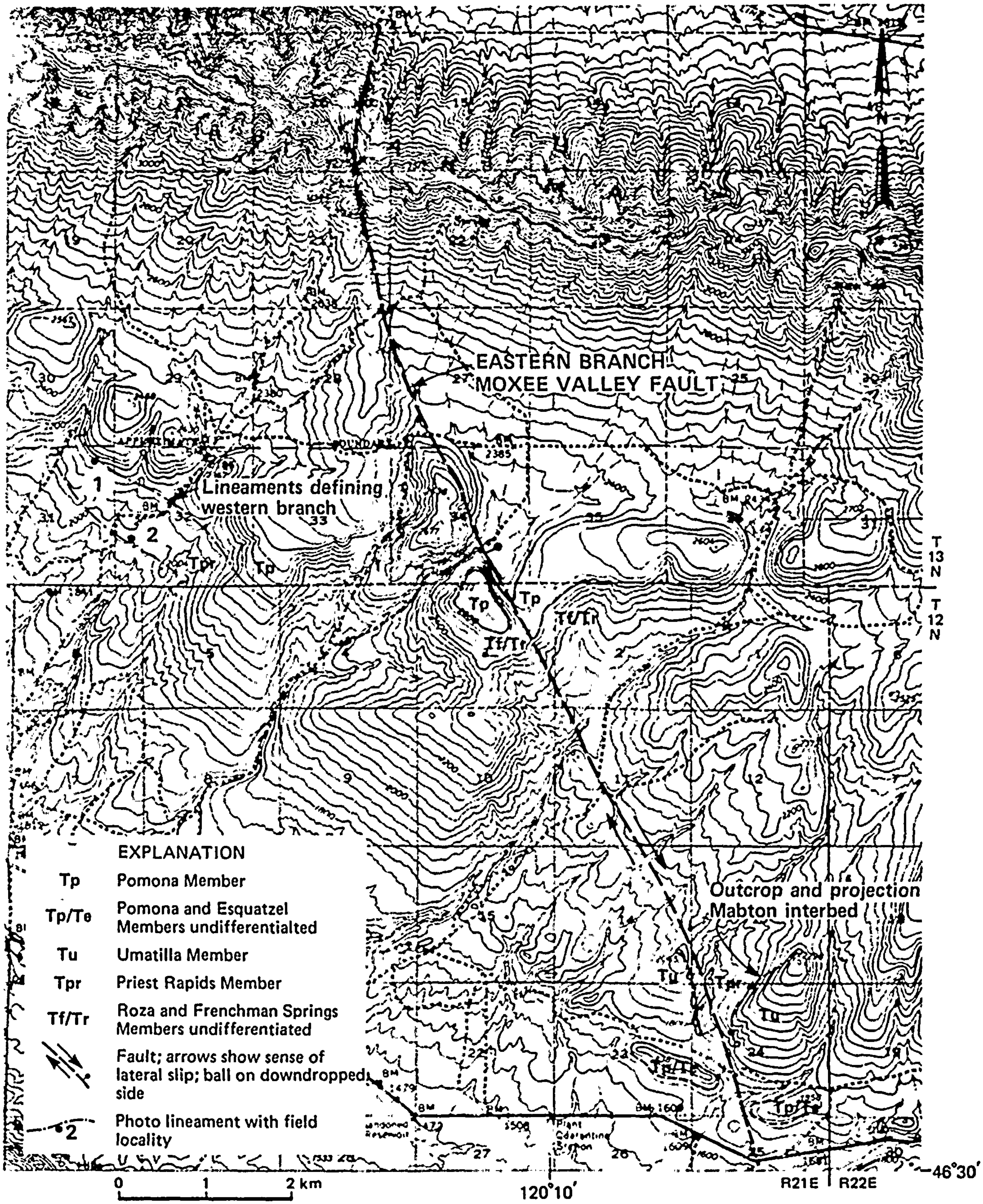
WASHINGTON PUBLIC POWER SUPPLY SYSTEM
Nuclear Project No. 2

MAP OF THE CLE ELUM-WALLULA LINEAMENT (CLEW) AND LOCATIONS OF MOXEE VALLEY AND WENAS VALLEY FAULTS

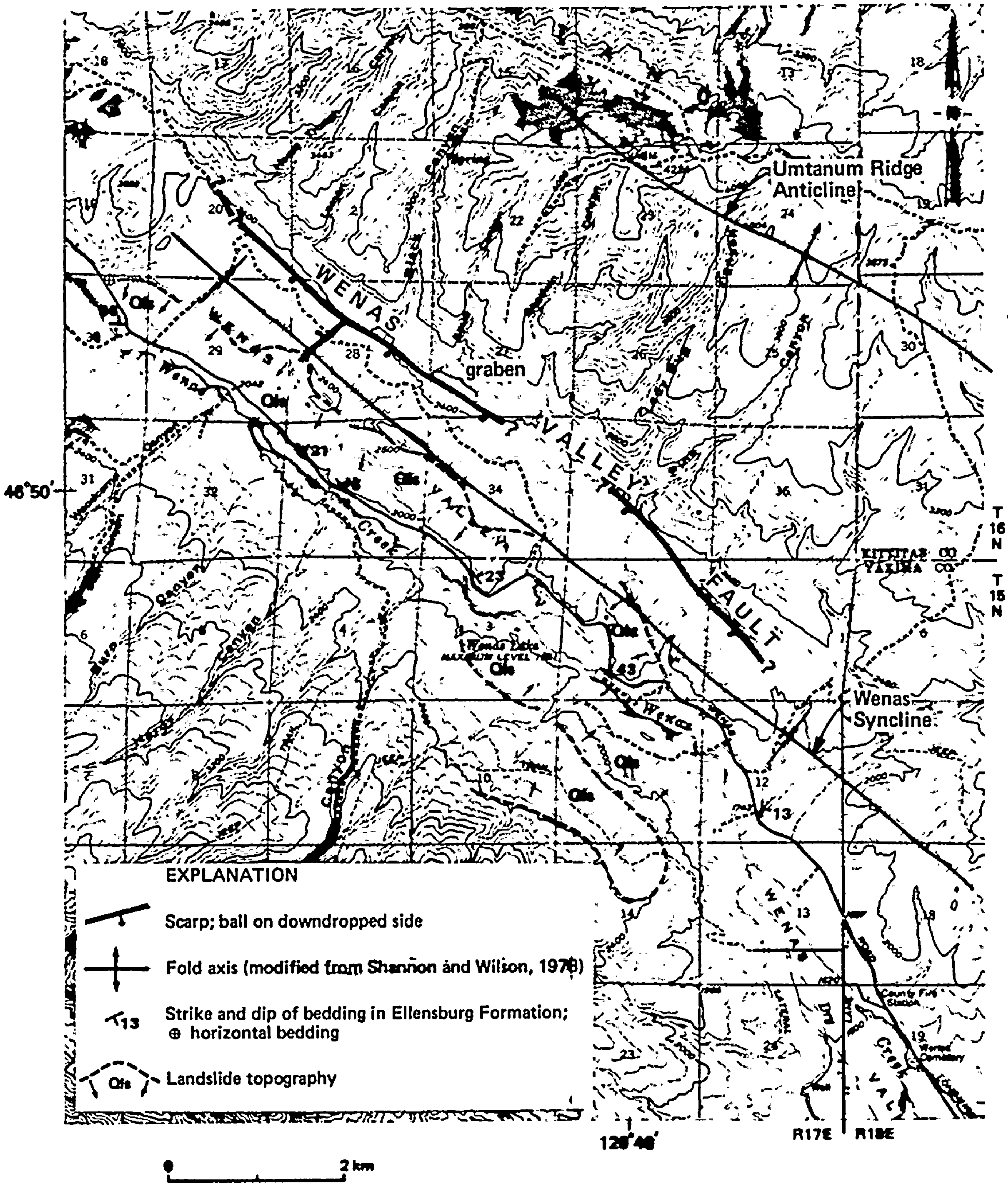
Figure 1



Map of the Cle Elum-Wallula Lineament (CLEW) showing structural domains I,II, and III with locations of the Moxee and Wenas Valley faults in domain I. EB and WB are the eastern and western branches, respectively, of the Moxee Valley fault. Names of anticlinal ridges are: A, Ahtanum Ridge; FH, Frenchman Hills; GM, Gable Mountain; HHH, Horse Heaven Hills; R, Rattlesnake Hills; SM, Saddle Mountains; T, Toppenish Ridge; U, Umtanum Ridge; Y, Yakima Ridge. Localities along domains II and III are: FQ, Finley Quarry; YP, Yellepit; WS, Warm Springs; RMF, Rattlesnake Mountain fault; WGF, Wallula Gap fault..



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	MAP OF MOXEE VALLEY FAULT, EASTERN AND WESTERN BRANCHES	Figure 2



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	MAP OF SCARPS, FOLD AXES, AND LANDSLIDE TOPOGRAPHY IN WENAS VALLEY	Figure 3

SUMMARY AND EVALUATION OF GEOLOGIC AND GEOPHYSICAL DATA ON THE COLD CREEK LINEAMENT

1.0 INTRODUCTION

During the 10 February 1982 review meeting, the NRC Geosciences Staff postulated that the Cold Creek lineament could be coincident with a continuous through-going fault and they requested a summary of the available information on the lineament. This report summarizes the available geologic and geophysical data on the Cold Creek lineament. These data are evaluated to assess whether or not the lineament is coincident with a major bedrock structure. A description of the lineament and a summary of the available geologic information are presented in section 2. The available geophysical data are evaluated in section 3, and the summary and conclusions are presented in section 4.

2.0 EVALUATION OF GEOLOGIC DATA

The Cold Creek lineament consists of an alignment of discontinuous topographic features. As defined by the NRC Staff, the lineament extends for a distance of 55 to 60 miles from the vicinity of Wallula Gap northwestward to the eastern end of Umtanum Ridge (Figure 1). The postulated fault is based on the topographic lineaments observed on U-2 photographs and on an inferred ground-water barrier. From southeast to northwest, these features include: 1) the Kennewick lineament; 2) the relatively straight part of the Columbia River between Kennewick and Richland; 3) the northwest-trending straight part of the Yakima River at Horn Rapids; 4) the valley of Cold Creek; 5) a vegetation lineament that connects the northwestward-trending part of Cold Creek Valley to the eastern end of Umtanum Ridge; and 6) a ground-water barrier reported by Gephart and others (1979). These features are discussed separately below.

The Kennewick Lineament

The Kennewick lineament is coincident with a well-developed slightly arcurate northeast-facing scarp that extends for a distance of approximately 10 miles from the vicinity of Wallula Gap to the city of Kennewick. It trends N60W in the south and approximately N40W in the north. The scarp has a maximum height of approximately 100 feet at its north end, and the scarp height decreases gradually to the southeast. Glass (Washington Public Power Supply System, 1977, WNP 1/4 PSAR, Appendix 2RK) conducted a remote sensing study of the plateau, which included an evaluation of the Kennewick Lineament. He concluded that it was an eroded terrace edge. He considered the possibility that streams had been displaced 3000 m in a right lateral sense, but rejected this hypothesis because "offsets of this magnitude . . . seem incredible for a feature which can only be traced 16 km."

Farooqui (Washington Public Power Supply System, 1977 WNP 1/4 PSAR, Appendix 2RH) and Farooqui and Thoms (Shannon and Wilson, 1980) analyzed the Kennewick lineament and in both analyses concluded that it was an erosional feature produced by late Wisconsin flood waters. They suggested there was no displacement across the lineament by correlating a terrace southwest of the lineament with one to the northeast, and noting that there was no elevation difference between the terraces. There are several problems with their analysis and the reader should refer to Figure 8 of Farooqui and Thoms (Shannon and Wilson, 1980) and to Figure 2 of this report. Farooqui and Thoms suggest a correlation between terrace T_3 to the southwest of the Kennewick lineament and T_3 to the northeast. The northeastern terrace underlies a hill identified as triangulation point "Junk". The first problem is one of labeling. On Cross-section C-C' (Figure 2) the terrace just southwest of the Kennewick lineament is identified as terrace T3, however, on the geologic map (Figure 8, Farooqui and Thoms, 1980) the same terrace is identified as T3 + T4.

There is no explanation of this discrepancy. In addition there is no evidence presented to demonstrate that the terraces are truly correlative. Finally, along the line of section C-C' (Figure 2), the correlated terraces are not at the same elevation. The terrace to the southwest of the lineament dips towards the northeast at an average angle of approximately 1-1/2 degrees and hence ranges in elevation between approximately 480 and 540 feet. The elevation of the surface of the proposed correlative terrace at "Junk" hill ranges from approximately 420 feet to 436 feet. In addition, if the sloping surface of the terrace southwest of the lineament is projected northeastward it projects below the proposed correlative at hill "Junk".

A reconnaissance was made of exposures in two quarries adjacent to the Kennewick lineament. These quarries lie within 200 to 300 feet of the lineament and expose massive and bedded coarse gravels and medium-grained sands. Gravels in the northernmost of the quarries are capped by a 1 to 3 foot thick caliche, suggesting an age for the gravel of greater than about 128,000 years B.P. (older than Oxygen isotope Stage 5). Although locally poor exposures and massive units make it impossible to preclude faulting in some parts of these quarries, no displacements were observed where bedding is present.

On aerial photographs parts of the Kennewick lineament are defined by a well-developed linear vegetation contrast. This vegetation lineament was observed on the ground between Finley Road and Nine Canyon Road, approximately 1/2 mile southwest of the town of Finley. Springs commonly emerge at or near the vegetation contrast and the ground is commonly marshy downslope of the boundary.

Near Nine Canyon Road, the linear vegetation contrast is discontinuous and has a left step of approximately 200 feet. The line of springs and the associated vegetational lineament could result

from either a steeply pipping ground water barrier or impermeable units within the sediments that underlie the Kennewick lineament.

To assess if the top of basalt is displaced along the Kennewick lineament, contours on top of basalt surface were drawn from water well data presented by Myers and Price (1979). These data (Figure 3) show that between Kennewick and Game Farm Hill the change in elevation of the top of basalt across the Kennewick lineament is less than the height of the topographic scarp that defines the lineament.

If the lineament is tectonic, it shows a down-to-the-northeast sense of displacement, and, hence, thickness of preserved sediments should be greater on the northeast side of the proposed fault. Sediments show the reverse sense of thickening, ranging from 22 to 40 feet thick northeast of the lineament to between 96 and 150 feet thick southwest of the lineament.

Given these data, the Kennewick lineament cannot be a purely tectonic feature. It must be either purely erosional, or the result of a fortuitous alignment of a pre-existing fault scarp with a later erosional scarp. There is no evidence that suggests there is a bedrock fault coincident with the Kennewick lineament. If a fault is hypothesized to exist, the vertical separation of the Miocene basalts along the northern part of the lineament is less that 60 feet.

The Columbia River Bridge

The northwestward projection of the Kennewick lineament intersects the Columbia River near its confluence with the Yakima River. Between the confluence and a point just east of Richland the river trends northwesterly with a southern segment oriented approximately N40-45W and a northern segment oriented N70W. A new freeway bridge is under construction at Columbia Point near

the bend in this northwest-trending part of the river, and drill core from the foundation investigations were analyzed. Five holes penetrated the upper part of the Columbia River Basalt and they showed as much as 140 feet of coarse gravels, silts, and sands overlying the basalt (Figure 4). The river is approximately 1160 feet wide at this location and holes penetrated basalt from the southwest bank of the river to a point approximately 300 feet from the northeast bank. In all the holes that penetrated the basalt, the basalt was texturally identical and a vesiculated flow top was present in the upper part of the basalt core. Chemical analyses were performed on core from hole H-19 and H-2. The results are shown in Table one. Rock from both holes is from the Goose Island basalt, which is the uppermost flow of the Ice Harbor member.

The uppermost 10 to 20 feet of basalt exhibits abundant clay and silt filled fractures, and in some of the holes the recovered rock consists of sediments mixed with small fragments of basalt. At a depth of greater than 20 feet these sediment filled fractures are generally absent. Because they are only present near the top of the basalt, these fractures are interpreted to be related to weathering and/or the late Pleistocene floods.

Two of the cores, H-5A and H-1, have thin mineral filled veins. These veins are generally less than 1/4 inch thick and range from nearly parallel to nearly perpendicular to the long axes of the cores. They are filled with a dark green aphanitic mineral, probably a smectite clay. Where fractured, the veins have shiny undulatory surfaces that parallel the fracture surface in the basalt. These veins are not characteristic of fault zones observed elsewhere in the plateau basalts and they probably are not related to faulting. The fault zones observed elsewhere in the plateau are characterized by massive finely pulverized basalt that encloses angular basaltic fragments. The previously mentioned surfaces are interpreted to be clay filled fractures

produced by weathering. The polished surfaces are thought to represent cleavage surfaces.

Chemical analyses and textures demonstrated that Goose Island basalt, the youngest Columbia River flow in the area, is present beneath the river at the Columbia River Bridge. The presence of vesiculated zones at the top of all of the basalt sections in the core establishes that the top of basalt approximates the depositioned top of the Columbia River basalt. Top of basalt is, therefore, approximately equivalent to a bedding plane and can be used to assess vertical displacements. A plot of the data from the core (Figure 4) shows that the top of basalt ranges from an elevation of 211 feet near the southwest bank to 204 feet. The base of the flow top ranges from 185 to 187 feet. A combination of the small variation in the elevation of both the depositional top of basalt and the base of vesiculated flow top indicates that faulting is either not present or that displacements must be very small in the southwestern 870 feet of the river. No bedrock data are available across the northeastern 300 feet of the river.

Horn Rapids Lineament

The northwestward trending section of the Columbia River between Kennewick and Richland projects approximately to the N50W trending section of the Yakima River near Horn Rapids. A reconnaissance of bedrock outcrops was carried out in the vicinity of Horn Rapids. At Horn Rapids the Ice Harbor member of the Saddle Mountain Formation is exposed at approximately river level on both sides of the river (Figure 5). Columnar joints within the Ice Harbor are also exposed on both sides of the river and are near vertical. No faults were observed in these exposures.

There is no evidence for faulting across the Horn Rapids segments of the Cold Creek lineament. However, the Yakima River covers a 500 foot wide area between the outcrops of Ice Harbor Basalt and

it is not possible to evaluate the relationships beneath the river. Regional studies by Woodward-Clyde Consultants and by Reidel and others (1980) provide information that constrains the maximum displacement that could be inferred across the Yakima River. Geologic mapping by both Reidel and others (1980) and Woodward Clyde Consultants have shown that the northern edge of the Ice Harbor flow is just north of Horn Rapids (Figure 6), and that the flow in this area should be less than one hundred feet thick. Because the Ice Harbor is present on both sides of Horn Rapids any vertical displacement across the river must be less than the thickness of the flow, or less than 100 feet. In addition if a significant right lateral displacement has occurred across the Cold Creek lineament at Horn Rapids the zero edge of the Ice Harbor member might be expected to show right lateral offset. Within the resolution of existing data no such offset is observed.

Cold Creek Valley

Lying along the northwest projection of the Horn Rapids section of the Yakima River, the valley of Cold Creek trends approximately N50W for a distance of approximately 10 miles, and lies just northeast of the contact between the gently northeast dipping top of the Elephant Mountain basalt and late Pleistocene flood deposits.

Farooqui and Thoms (Shannon and Wilson, 1980) investigated the origin of this part of the Cold Creek Valley and concluded that the alignment of the valley "is not surprising, as it runs counter to the slope of the Rattlesnake Hills Pediment exactly as it should. Such situations are the rule in the arid cycle of erosion." (p. 14)

Along most of its length, no bedrock exposures are present to the northeast of Cold Creek Valley and, hence, it is not possible to use surface exposures to evaluate if faults are present beneath the valley. However, at its southern end, just north of Horn Rapids, John Blume and Associates (1971) performed a refraction seismic survey and drilling to establish if a fault was present. The seismic data are discussed in section 3. The drill hole data are discussed below.

The geology in the vicinity of the drill holes is poorly exposed but existing outcrops (Figure 5) show that to the west of Cold Creek, the Elephant Mountain basalt strikes approximately N10-15W and dips 1 to 2 degrees to the east. Approximately 3/4 mile east of Cold Creek, a low hill is underlain by Elephant Mountain. This hill has been interpreted by Washington Public Power Supply System (1974, p. 2D-23) as being a dome structure having gently dipping flanks. Existing outcrops suggest the southern end of Cold Creek is underlain by a broad open northerly striking syncline having gently dipping limbs.

The locations of the drill holes are shown in Figure 5. They lie along an east-west line approximately one mile long that lies across the projection of the valley of Cold Creek. Six borings were drilled to depths of between 85 and 145 feet. Precise locations of the holes is difficult to determine because their locations are given on a 1/62,500 scale map that does not show topography. Measurements were made from this map and drill hole locations were transferred to the 7-1/2 minute topographic map.

All six holes penetrated an interbed and a flow that underlies the interbed and displays a vesiculated flow top (Fig. 7). Holes DDH 1, 4, 5, and 6 also penetrated a flow above the interbed. In hole DDH 2 and 3, the upper flow had been removed by erosion. John Blume and Associates (1971) interpreted this sequence to be, in descending stratigraphic order, the Elephant Mountain basalt,

Rattlesnake interbed, and Pomona basalt. This interpretation is consistent with surface exposures and was confirmed with chemical analyses on four elements (Table 2).

The cross section in Figure 7 was derived from an inspection of the core and from original well logs provided by John Blume and Associates. Because of the uncertainty in the location of the wells, there is an uncertainty in their elevation and, hence, an uncertainty in the precise elevation of contact within the holes. However, between hole DDH 1 and DDH 4, the top of the Pomona basalt declines 47 feet at an average angle of 1.4 degrees, or at approximately the angle that would be expected by projecting the dip observed to the west. From DDH 4 to DDH 6, the same contact climbs 80 feet at an average angle of 1.2 degrees. The structure inferred from the well data is consistent with that inferred from surface exposures. No evidence for faulting was found in the core. However, because of the wide spacing of the holes and the lack of surface outcrops, the drilling data cannot be used to preclude faulting. It can be used to constrain the total vertical displacement if a fault is assumed to exist. The Cold Creek lineament projects between holes DDH-4 and DDH-5 the maximum vertical displacement that could exist between these holes is 76 feet.

The Umtanum Lineament

An aerial photograph analysis by NRC Staff identified a color change extending discontinuously from Cold Creek to the east end of Umtanum Ridge. In addition, hydrologic studies (Gephart and others, 1979) have identified hydraulic head differences within the Wanapum basalt. The location of the feature or features that controls the hydraulic head change is poorly controlled (Figure 8) but existing data permit it to be placed in the vicinity of the lineament as defined on aerial photographs. On this basis it was suggested that a fault had produced both the aerial photo

lineament and the barrier that produced the differences in hydraulic head. To evaluate this possibility three approaches were used: 1) air photos and geologic maps were studied; 2) the hydrologic data presented by Gephart and others (1979) were reviewed; and 3) the structural interpretations of Myers (Myers and Price, 1981) were reviewed to establish if they are consistent with a structure coincident with the aerial photo lineament.

The northern part of this lineament is more prominently developed and more linear than the southern part. It is developed in a relatively flat terrace surface that is underlain by Pasco Gravels deposited during late Pleistocene flooding (Myers and Price, 1979, Geologic Map Sheet 4). The terrace lies at an elevation of approximately 800 feet and is bordered on the northeast by a scarp that trends northwestward and faces northeast, and to the south by an east-west-trending south-facing scarp. The terrace lies just south of the saddle between Umtanum Ridge and Gable Butte. The gravel that underlies these terraces was deposited in the lee of Umtanum Ridge during late Pleistocene floods.

The lineament trends N35W and, on U-2 photos, appears as a prominent but slightly irregular color contrast. On 1/50,000 color aerial photographs it is the most prominent of several similar lineaments that radiate southeastward from the east end of Umtanum Ridge. The northernmost of the features is associated with the northwest trending scarp that borders the terrace. As will be discussed later, these lineaments are interpreted to be depositional features related to the late Pleistocene floods.

The southern part of the lineament, between the southern end of the terrace surface and well DB-14, consists of a highly irregular color contrast that has a generally northwest trend. The color contrast appears to correspond to the depositional edge of Holocene alluvium overlapping the Pasco Gravels and Touchet Formation.

Hydraulic Head Differences in the Northern Pasco Basin

Gephart and others (1979) reported on hydraulic heads within confined aquifers in the Columbia River Basalt of the Pasco Basin. Within the Wanapum basalt between Yakima and Umtanum Ridge they identified an area that had hydraulic heads higher than those observed in two holes (DC-1, DC-8) in the Wanapum Formation 8-1/2 and 15-1/2 miles to the east and east southeast (Figure 8). Gephardt and others (1979) report:

> "information does indicate that an area of pronounced artesian head exists in Cold Creek Valley. Maximum head elevations in DB-11, 699-50-112, 699-52-111, and 699-52-115 are between 913 and 943 feet. The head elevations in Cold Creek Valley are approximately 450 feet greater than those found on the north side of the Umtanum-Gable Mountain anticline at DC-12 or farther east in DC-1 and DC-8. The location and orientation of the structural or stratigraphic barrier responsible for the high artesian heads conditions in the Cold Creek Valley are unknown at this time." (p. III-103)

The observed differences in hydraulic head could be due to:
1) lateral variation in permeability within the basalt; and/or
2) the presence of a structural barrier.

Gephardt and others (1979, p. 111-193) indicate that "the principal water-bearing or yielding portions of the basalt occur along flow contacts. Here vesicularity and flow brecciation form networks of interconnected vesicles and fissures through which ground water moves." Lateral variations in flow tops (changes in thickness, amount of brecciation, vesiculation, or fracturing), or stratigraphic pinch-outs could produce differences in permeability and hence differences in heads.

To assess the effects of lateral variations in permeability, data from holes that are not separated by significant structures was plotted and head differences were analyzed to assess if lateral variations in permeability are sufficient to produce the head differences observed within the Wanapum Formation.

Hydraulic head data are available from two kinds of rocks within the Pasco Basin. From the Saddle Mountain Formation information is available from sedimentary interbeds, while from the Grand Ronde and Wanapum Formation data are available from selected intervals within basalt flows. Data presented by Gephart and others (1979) suggest that there is greater variability in hydraulic conductiveness within basalt interflows than within sedimentary interbeds. They report sixteen measurements of hydraulic conductiveness of interbeds within the Saddle Mountain Formation. These values range from 0.1 to 181 feet per day. Five measurements from interflows within the Wanapum basalt show hydraulic conductivities of between 4.2 x 10-2 and 1.1 x 104 feet per day. Because of these differences a direct comparison of data from interbeds and interflows is probably not warranted. However, given the greater variability of hydraulic conductiveness in interflows it would be expected that under similar conditions greater head differences would be observed in basalt than in sediment. Regardless of this difficulty the data from various rock types are presented in the following discussion. All of these show a decline in head from the vicinity of DB-14 towards the east and north. The greatest head change in the interbeds is within the Rattlesnake Ridge interbed. Over a distance of approximately 14-1/2 miles there is a 69-foot head decrease between holes DB-14 and WPPSS-3. This produces hydraulic gradient of approximately 4.8 feet per mile, or approximately 8 percent of those described from the Wanapum.

Data from the Grande Ronde Formation should be more analogous to that of the Wanapum, unfortunately hydraulic head data are avail-

able from only 3 wells within the Pasco Basin. Two of these (DC-1 and DC-2) are within 60 feet of one another, whereas the third (DC-6) is on the opposite side of the Gable Mountain structure. Therefore, it was not possible to directly test the hypothesis that head differences observed within basalts are produced by lateral variations in permeability.

The effect of structures on head varies from structure to structure. Some structures produce head differences similar to those reported in the Wanapum, whereas others have little effect on hydraulic head. Hydraulic heads within the Mabton, Selah, and Rattlesnake interbeds show little difference across the Gable Mountain-Gable Butte structure. Heads in these units as reported from hole DB-12 and DB-9 (north of Gable Mountain-Gable Butte), are generally within ten feet of those reported to the south. Somewhat more variation is seen within the Grand Ronde across the Gable Mountain-Gable Butte structure. Although there is considerable uncertainty about the precision of the head measurements within the Grande Ronde the maximum difference across the Gable Mountain-Gable Butte Structure is approximately 100 feet.

On the other hand, data from hole RSH-1 shows that over a distance of 20 to 25 miles across the Rattlesnake Mountain structure there is a 500 to 1600 foot difference in head within the Grand Ronde Formation. This produces an average hydraulic gradient of 20 to 80 feet per mile. Although it is not known if the head differences are the result of a uniformly steep gradient or the Rattlesnake Mountain structure, Gephart and others (1979) believe it results from a "major interruption in the regional hydraulic gradient created by the Rattlesnake Hills anticline and associated faulting." (p. III-109)

Myers reported on recent studies of the structure of the area adjacent to the Cold Creek lineament (Myers and Price, 1981). His methodology for defining bedrock structure in areas where

surface exposures are not present consists of contouring the top of basalt and assuming variations in elevations are the result of structure. In addition "a deliberate attempt was made to have the pattern of contours on top of basalt closely reflect the structural fabric and structural style revealed by surface mapping..." (Myers, in Myers and Price, 1981, p. 8-11). This procedure should produce no significant problems in defining large scale structures; however, erosional channels on the top of basalt could be misinterpreted as small scale structures.

Myers (Myers and Price, 1981) identified structures in the vicinity of the proposed surface trace of the Cold Creek lineament. Since publication of Myers and Price (1981) additional geophysical studies by Rockwell's Basalt Waste Isolation Group have identified a sixth structure within the area. These six structures are plotted and numbered on Figure 9. Structures 1, 2, and 3 (see Figure 9) are defined on a variety of geophysical and geologic grounds (Myers in Myers and Price, 1981, p. 8-17 through 8-19). If the hydraulic head differences in the Wanapum Formation are structurally controlled, structures 1 and 2, which lie across the valley of Cold Creek and seperate the wells with high and low hydraulic head, could be responsible for the head differences. Structure 3 is a short structure that may not affect the Saddle Mountain Formation. It is too limited in lateral extent to produce the ground-water barrier.

Structure 4 lies approximately 3 miles west of the aerial photo lineament as well as west of some of the wells that show the high hydraulic head, therefore, it cannot be the ground water barrier report by Gephart and others (1979). Structure five is defined by "steep dips and...dip reversals on the top of basalt (Myers in Myers and Price, 1981). A Werner deconvolution solution in the southern part of the 200 west area coincides with the top of basalt dip reversals. Myers (Myers and Price, 1981) interprets

this feature to be a small anticline-syncline pair. The northwest-southeast strike of the structure is inferred because it is "more consistent with the regional structural trend (Myers and Price, 1981, p. 8-19)."

Structure 6 is not shown in Myers and Price (1981); however, gravity, magnetic, and seismic work completed since publication of ST-14 suggests there is a north-south trending feature located 1/2 mile or less to the east of the Yakima Barricade. BWIPS personnel favor the interpretation that this is an eastward facing monocline, however, given existing data they cannot rule out a fault (personal communications, T.D. Ault, Geophysicist for Rockwell, March 22, 1982). The lateral extent of the structure is not yet well defined but currently available geophysical data shows steep gradients over a distance of 1-1/2 to 2 miles. The structure makes an angle of 35 degrees with the inferred trace of the Cold Creek lineament. It could be the source of the anomalous hydraulic heads in Cold Creek Valley.

Existing data are inadequate to establish if stratigraphic factors are sufficient to produce the head change observed within the Wanapum. If the head change is the result of structure several structural features identified by Myers and Price (1981) are located in positions that could produce the head change. However, none are coincident with the aerial photo lineament southeast Gable Mountain. In addition, the lineament is one of a number of similar lineaments that lie in a unique geomorphic position. Late Pleistocene floods swept around the east end of Umtanum Ridge and deposited gravels in the lee of the ridge. The vegetation lineaments that radiate from the south edge of the water gap between Umtanum Ridge and Gable Butte are probably the result of the flood processes that deposited the gravel bar.

3.0 EVALUATION OF GEOPHYSICAL COVERAGE OF THE COLD CREEK LINEAMENT

Sources of Geophysical Data

All available geophysical data that, to our knowledge, cover the Cold Creek lineament are listed in Table 2, together with the sources of the data. The locations of geophysical profiles and seismic reflection and refraction lines that cross the Cold Creek lineament are shown on Figures 10 and 11.

Data Evaluation

Except as specified below, the data listed in Table 2 have been collected and carefully examined for any expression of the Cold Creek lineament in the form of geophysical anomalies and linear features. Each type of data is discussed separately below. Because of the large amount of data, only those items that show features of possible interest are discussed; items that are omitted from the following discussions do not contain any pertinent information.

Aeromagnetic Data

Detailed aeromagnetic coverage of the Cold Creek lineament is provided by the surveys flown at 1000 feet (300 m) terrain clearance by the Supply System (Item 1, Table 3) and at 2500 and 4000 feet (760 and 1220 m) by Rockwell (Item 3). The flight-line spacing for these surveys is 1/2 mile. The survey published by Swanson and others (1979) (Item 8) was flown at 500 feet (150 m) terrain clearance with a flight-line spacing of 1 mile. Because the survey reported by Raymond and McGhan (1963) (Item 7) was flown at the same altitude and with the same line spacing as the latter, Item 7 was not evaluated. The survey reported by Zietz and others (1971) (Item 6) is a reconnaissance flown at high

altitude (15,000 feet), and hence, contains information about only very large-scale crustal features. The Blume (1971) survey (Item 5) was flown at altitudes of 900 and 1500 feet (275 and 460 m) and a flight-line spacing of 2 miles (3.2 km) but covers only part of the Cold Creek lineament. The aeromagnetic maps published by the Northwest Energy Services Company (NESCO) (1981) (Item 4) are the same as the Supply System map except that they are plotted at a larger scale.

Detailed examination of the aeromagnetic contour maps reveals no continuous aeromagnetic feature or alignment of anomalies coincident with the Cold Creek lineament. The lineament generally crosses perpendicular or at an oblique angle to the trends of magnetic gradients within the Hanford Reservation. For 8 miles (13 km) northwest of Wallula Gap, the lineament parallels the contours defining a steep magnetic gradient but this gradient is definitely associated with the brachyanticlines, as discussed below. The only striking aeromagnetic anomaly apparent on these maps along the length of the lineament is a prominent magnetic "high" centered approximately 3 miles northwest of Horn Rapids. This anomaly has steep gradients that are elongated in a direction of N25W, which is oblique to the trend of the lineament and is only approximately 4 miles long. Myers and Price (1981, Appendix B) calculated a "dike-like" Werner deconvolution solution for this anomaly. The top of basalt map of Myers and Price (1979) suggests that the anomaly represents the north-northwesterly continuation of a small anticline.

In addition to the aeromagnetic maps, total field intensity profiles, which cross the lineament every 2 miles were obtained for the Washington Public Power Suppply System's (1977) survey flight lines. The locations of these profiles are shown on Figure 10. Because the survey was flown along flight lines oriented southwest-northeast, which is approximately perpendicular to the trend of the lineament, these profiles are ideal for identifying

anomalies that may be associated with the lineament. Total field intensity profiles crossing the lineament parallel to the Supply System profiles are also available for the John Blume and Associates (1971) survey. The two sets of profiles were compared and found to be closely similar.

There is no consistent magnetic signature where the profiles cross the lineament; in most cases the characteristics of each magnetic profile in the vicinity of the lineament are significantly different from those of neighboring profiles. Three of the profiles have prominent anomalies at the position of the lineament. On profile 910, a large positive anomaly corresponds to the magnetic high northwest of Horn Rapids, discussed above. A relatively steep magnetic gradient on profile 1160 corresponds to an elongated magnetic "high" that trends east-west, oblique to the lineament, through Rattlesnake Springs. Myers and Price (1981, Appendix B) calculate a "dike-like" Werner solution (D-35) for this anomaly, which is identified, based on well and outcrop data, as corresponding to the buried eastern extension of Yakima Ridge (Myers and Price, 1981, Appendix C). A similar steep gradient on profile 1280 corresponds to a northeast-southwest-trending magnetic feature on the contour maps.

As noted above, the southeastern end of the lineament trends parallel to the contours defining a steep magnetic gradient. The profiles confirm that this gradient corresponds to the northwestward-trending line of prominent, negative magnetic anomalies associated with the brachyanticlines; the trend of these anomalies on profiles 320 through 860 gradually diverges from the trend of the lineament, mimicking the trend of the brachyanticlines. Modeling of the magnetic profiles in this area (Item 2) has also shown that these anomalies are satisfactorily accounted for by the anticlines. Only one of these models requires a significant subsurface structure coincident with the Cold Creek lineament to provide a reasonable fit to the shape of the

observed magnetic profile. This is model "Pasco East" (Figure 11) in which a secondary magnetic low superimposed upon the topographically-related magnetic anomaly is modeled as a narrow dike of Pomona basalt (Weston Geophysical, 1980). The magnetic anomaly corresponding to this modeled feature is not evident on profiles 380 or 430 (Figure 10) immediately to the northwest.

Gravity Maps

The most detailed gravity coverage of the entire Cold Creek lineament is shown on the 1 mgal contour map published by Washington Public Power Supply System (Item 9). More detailed gravity coverage of the northwestern end of the lineament is provided by the NESCO (1981) maps (Item 10), which cover the Umtanum-Gable Butte/Gable Mountain area with a contour spacing of 0.2 mgal. Between Kennewick and a point 7 miles northwest of Horn Rapids the lineament parallels the overall northwesterly trend of the gravity contours. At this point, the gravity contours curve to the west, roughly paralleling the trend of Rattlesnake Hills. The gravity gradient is relatively steep over the Rattlesnake Hills, becoming more gentle towards the center of the Pasco Basin. The steep gradient probably represents the Rattlesnake Hills anticline, and the more gentle gradient to the northeast the deepening of the basalt surface towards the center of the Cold Creek syncline. Continuing to the northwest, the lineament cuts across the trends of the gravity contours and of anomalies that are associated with the buried extension of Yakima Ridge and the Umtanum-Gable structure, without perceptibly disrupting the contours. Therefore, throughout its length, the Cold Creek lineament appears to have no expression on the one-degree contour gravity map, which suggests that it is not related to a large-scale bedrock feature. The lack of expression of the lineament in the gravity data is confirmed along its northwestern end by the NESCO (1981) 0.2 mgal contour map (Item 10).

Gravity and Ground Magnetic Profiles

High-resolution gravity and ground magnetic traverse profiles are capable of revealing more subtle, shallow crustal features than are generally evident on contour maps such as those described above. A total of 10 gravity traverses and 11 ground magnetic traverses cross the Cold Creek lineament, as itemized in Table 2 (Items 11, 13, and 14) and shown on Figures 10 and 11. Magnetic profiles 25, 27, 29 and D, and gravity profiles 25 and D only of Item 13 were examined because these data provide adequate coverage of the extreme northwestern end of the lineament. Of the total of 15 gravity and magnetic profiles examined, only 5 show anomalies approximately coincident with the lineament, as discussed below:

Gravity Profile G02 (Item 11): The Cold Creek lineament crosses profile G02 at the apparent beginning of a steep gravity gradient on this profile. However, this is also the point at which this profile bends abruptly from southeast, parallel to the lineament, to south. The apparent anomaly on profile G02 at the location of the lineament is most probably an artifact of this bend in the profile. A similar north-south gradient begins approximately 2 miles (3.2 km) southwest of the lineament on profile G03, and can also be seen on profile G01 east of Wallula Gap (Washington Public Power Supply System, 1977, Figures 2RI-53 and 2RI-54) The alignment of the anomalies on the latter profiles suggests that the causative structure trends west or west-northwest across Wallula Gap, and may be the mapped Wallula Gap fault.

Gravity Profile Rattlesnake 1 (Item 14): The Cold Creek lineament crosses this profile in the middle of a relatively steep gravity gradient. A model based on topography and known stratigraphy (Rockwell, unpublished, 1981) very closely fits the observed gravity profile, without requiring a bedrock structure at the position of the Cold Creek lineament.

Ground Magnetic Profile 27 (Item 13): Where this profile crosses the northwestern end of the Cold Creek lineament there is a sharp, 300 gamma, positive anomaly. This is the southernmost of a band of high-frequency anomalies on this profile; similar bands of anomalies can also be seen on neighboring lines. This band of anomalies corresponds to the prominent, north-south gravity gradients associated with the east-west-trending Umtanum-Gable structure (NESCO, 1981, Appendix 2K). Because similar features are not observed where the lineament crosses profiles 25 and 29, the anomaly on profile 27 is not associated with the Cold Creek lineament.

Magnetic Traverses II and IV (Item 15): Because the plotting of these preliminary, unpublished Rockwell data has not yet been finalized, the positions at which the lineament crosses the profiles can be determined only to within about 500 feet. On traverses II and IV the lineament appears to be coincident with a negative magnetic anomaly having an amplitude of 150 to 250 gammas and a width of approximately 250 feet. On both profiles this anomaly occurs towards the northeastern end of a band of similar, high-frequency anomalies. A similar band of anomalies is also present on Traverse I (Item 15); on this profile the position of the lineament appears to be northeast of the end of the band of anomalies but, within the constraints of the available distance control, it could be correlated with an anomaly similar to those on traverses II and IV. Magnetic traverse I is coincident with the Rattlesnake 1 gravity profile. As discussed above, modeling of this profile does not require a bedrock structure in the vicinity of the lineament. All of the ground magnetic traverses are very close to, and parallel to, basalt outcrops exposed in stream channels and on adjacent ridges on the lower slope of Rattlesnake Hills, and the Cold Creek lineament is just to the northeast of the ends of these outcrops. Therefore, the

bands of high-frequency anomalies most probably correspond to the irregularly eroded surfaces of the basalt in the stream channels and on adjacent ridges.

Seismic Reflection

As shown on Figure 11, Rockwell seismic reflection lines 3, 4, and 5 (Item 16) cross the northwestern part of the Cold Creek lineament, and line 8 ends close to the intersection of the lineament with reflection line 5. Copies of the original seismic sections were evaluated (copies of these sections are reproduced in Myers and Price (1981) at reduced scale). As discussed by NESCO (1982), the quality of these data is variable. Prominent reflections that at first sight appear to correspond to the top of basalt have been found in certain areas not to be well correlated with top of basalt defined by other techniques. The velocities of sediments overlying the basalt exhibit large lateral variability that can result in apparent anomalies in deeper reflection horizons that are artifacts of the data processing. Therefore, although the reflection data adequately portray the gross structure in or near the top of basalt, interpretation of more subtle smaller-scale features is subject to a considerable degree of uncertainty.

Seismic lines 3 and 8 have cleanly developed reflection horizons that show no structural features related to the lineament. Line 5 ties with the eastern end of line 8 at the location of the lineament. At this location, there is a slight irregularity in the essentially continuous reflections between travel-times (two way) 0.15 and 0.30 seconds. This may be due to a slight flexure in the basalt flows at this location. However, Myers and Price (1981, Appendix B) state that reprocessing of this section using different stacking velocities tended to smooth this undulation, indicating that it is probably the result of lateral variations in the velocities of the overlying sediments. Along the

southernmost 1 mile of section 4, strong, continuous reflections that appear to correspond to the upper basalt section rise steeply to the south. This north-south slope corresponds to the northern flank of the buried extension of Yakima Ridge. Where line 4 crosses the lineament (SP140, Myers and Price, 1981, Appendix B, Figures B-2, B-20) there is a flexure in the reflections. Although the possibility that this feature corresponds to a bedrock structure at this location cannot be precluded, it is again more probably an artifact of lateral variations in the velocities of the sediments.

Seismic Refraction

The only seismic refraction lines that cross the lineament are line SW-5 and traverse I (Figure 11). Line SW-5 (Item 17) was shot for John Blume and Associates (1971). Only the interpretation of the refraction line from John Blume and Associates (1971) is considered in this evaluation. The initial interpretation of refraction line SW-5 produced questionable results that involve an abrupt irregularity in the basalt surface 900 feet from the western end of the line and lesser irregularities elsewhere (John Blume and Associates, 1971). To resolve these structural complexities, 3 boreholes were drilled near the large irregularity and 3 additional holes were drilled between this locality and the middle of the line. The results of the drilling program are described in the section of this report dealing with the Cold Creek Valley. These results indicate that a seismic velocity inversion between the uppermost Elephant Mountain basalt flow and the underlying Pomona flow was responsible for the irregularities apparent in the initial seismic interpretation. Subsequent reanalysis of the refraction data with control provided by the drilling results produced a more reasonable interpretation. This revised profile shows an essentially flat-lying basalt surface at very shallow depths that

outcrops at either end of the profile. There is no evidence for a bedrock structure in the vicinity of the Cold Creek lineament on either the final profile or on the initial profile.

4.0 SUMMARY AND CONCLUSIONS

Based on the presence of a series of discontinuous but aligned topographic features, the NRC Staff postulated that the Cold Creek lineament could be coincident with a throughgoing fault having a minimum length of 55 to 60 miles. Detailed analyses were made at a number of places along the lineament. No evidence has been found that indicate there is a bedrock fault conincident with the Cold Creek lineament. Although the available geologic data are insufficient to absolutely preclude the existence of a bedrock fault, the available data at a number of locations constrain the maximum amount of apparent vertical displacement that could exist if a fault is hypothesized to exist. Near the confluence of Cold Creek and the Yakima River, outcrop and bore hole data constrain the total possible vertical displacement to less than 100 feet and less than 80 feet, respectively. Although the zero edge of the Ice Harbor basalt is not well constrained, no evidence of lateral displacement is present. At the Columbia River Bridge, drill data shows a vesiculated flow top that varies less than 2 feet in elevation over a distance of 870 feet. At the Kennewick lineament, topographic relief is greater than relief on the top of basalt, suggesting the Kennewick lineament is erosional. Total relief on top of basalt beneath the northern part of the Kennewick lineament is less than 60 feet. An aerial photo lineament at the east end of the Untanum Ridge is not coincident with any of the structures identified by Myers (Myers and Price 1981), which suggests the air photo lineament is not the resultof faulting. It is unlikely that a major throughgoing fault would consistently show vertical displacements of less than 100 feet.

The Cold Creek lineament is covered by a variety of geophysical data types, including; aeromagnetic contour maps and profiles, gravity contour maps and high-resolution profiles, high-resolution ground magnetic profiles, and seismic reflection and refraction profiles. Evaluation of all known, available geophysical data that cover the lineament indicates that it has no identifiable geophysical expression. In particular, the lineament is not associated throughout its length with a linear feature or series of anomalies on the contour maps, or with a consistent signature on profiles that cross it that would suggest that it represents a continuous bedrock structure. Anomalies that are coincident with the lineament on individual geophysical profiles are not normally evident on adjacent profiles. Most of these anomalies can be satisfactorily explained by features that are unrelated to a northwest-trending structure.

Based on this review of the available geologic and geophysical data, it is concluded that the Cold Creek lineament is not coincident with a major throughgoing bedrock structure. The available data support the previous interpretations that the lineament is formed by a series of topographic erosional features produced by the late Pleistocene floods in the Pasco Basin.

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TABLE 1

Chemical Analyses From Columbia River Bridge Core

Chemical	Percentage		Goose Island
	Drill Hole H-19	Drill Hole H-2	Basalt Average*
S_iO_2	47.28	47.10	47.50
Al_2O_3	12.82	12.82	12.50
T_iO_3	3.71	3.82	3.79
FeO	15.13	15.12	17.53
MNO	0.28	0.29	0.27
CaO	8.65	8.87	8.80
MgO	4.36	4.22	4.41
K_2O	1.26	1.14	1.23
Na_2O	2.96	3.15	2.44
P_2O_5	1.55	1.56	1.54

*From Swanson and others (1979)

TABLE 2

Chemimcal Analyses from Blume and Associates (1971)

Percentage

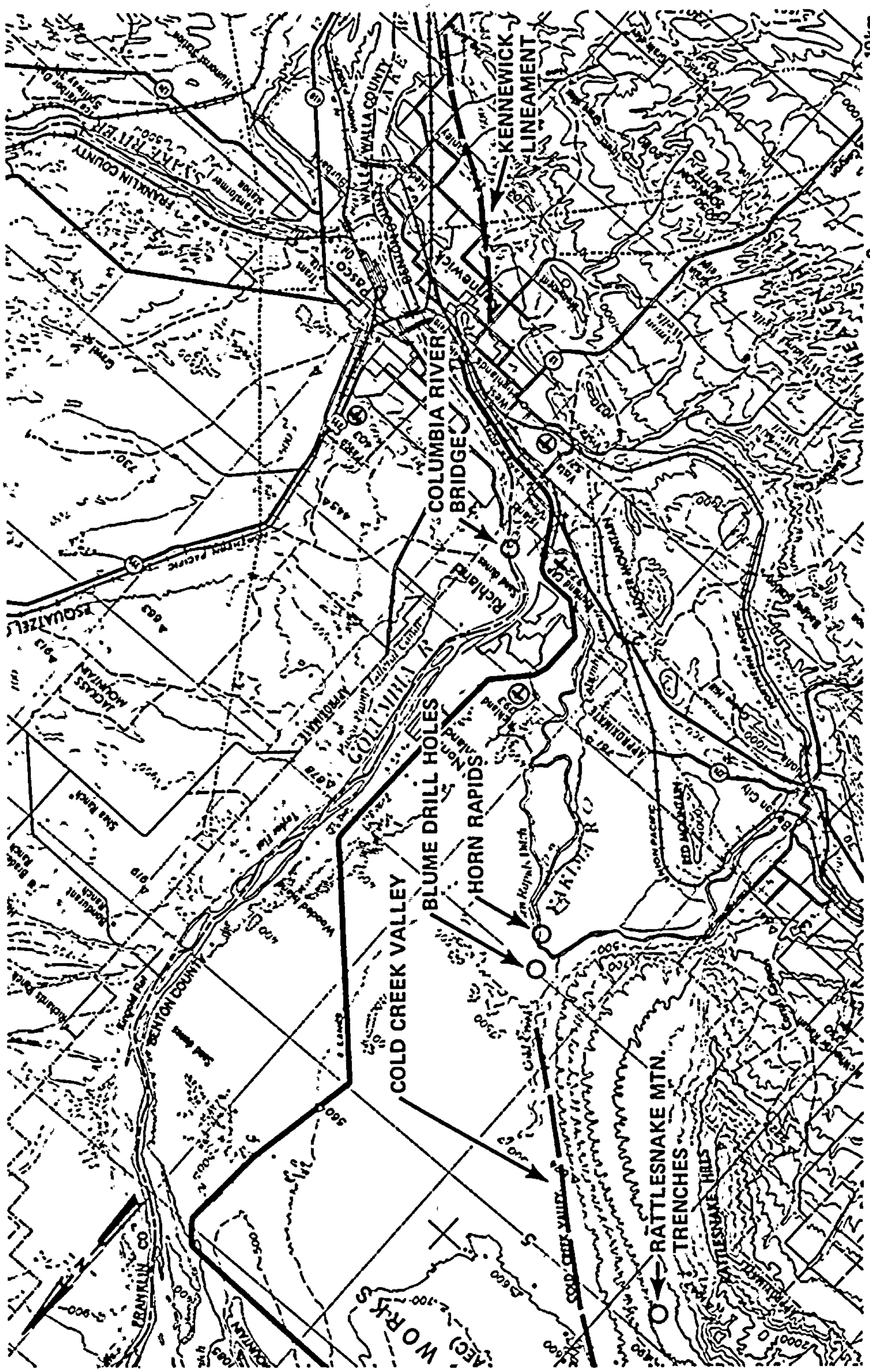
	Drill Hole	FeO	CaO	K_2O	TiO_2
Elephant Mountain Basalt Average*		14.75	8.34	1.25	3.52
Upper Basalt	DDH-1	14.8	8.2	1.0	2.9
"	DDH-4	14.0	8.0	1.0	
	DDH-5	8.8	7.3	1.7	
	DDH-6	15.0	7.7	1.2	
	Quarry (Approx. 1000 ft. north of DDH-1)	13.5	7.7	1.0	2.7
Pomona Basalt Average*		10.55	10.67	0.64	1.62
Lower Basalt	DDH-1	10.3	10.5	0.55	1.8
	DDH-2	10.5	10.5	0.55	1.8
	DDH-3	9.9	10.5	0.60	3.0
	DDH-4	10.5	10.0	0.60	3.3
	DDH-5	10.0	11.0	0.55	3.3
	DDH-6	12.0	10.5	0.65	2.7

*From Swanson and others (1979)

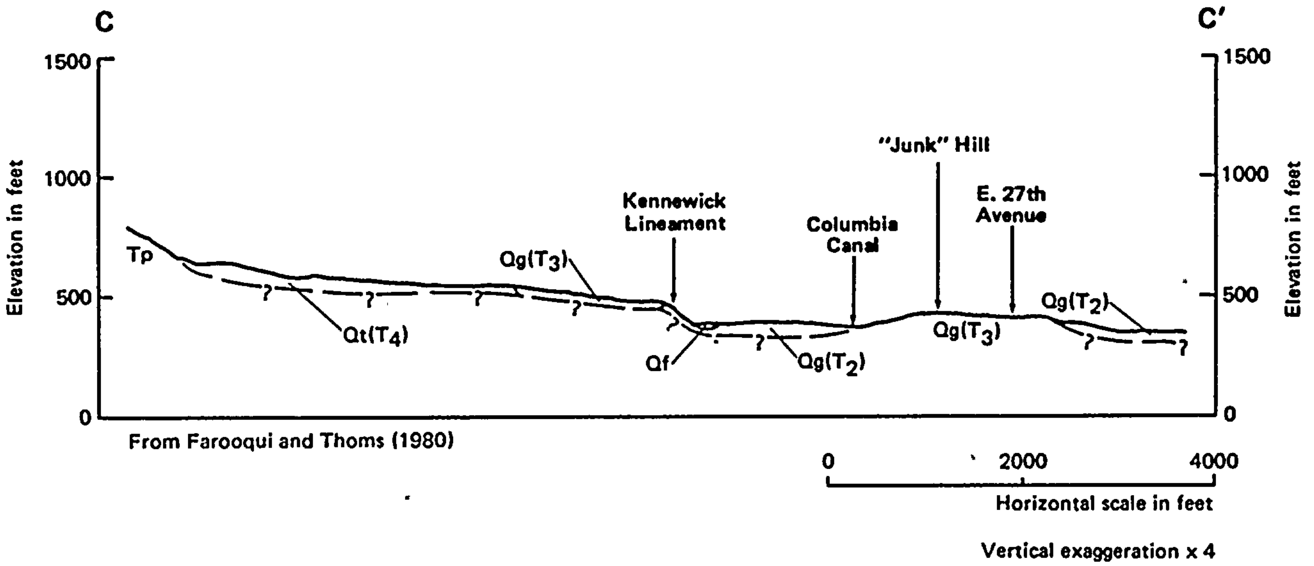
TABLE 3

GEOPHYSICAL COVERAGE OF THE COLD CREEK LINEAMENT

No.	Data Type	Map/Profile Identification	Source
1.	Aeromagnetic	Map: Block A	Washington Public Power Supply System (1977), Appendix 2RI, Figures 12, 12A
2.	Aeromagnetic Modeling	Profiles: E-E'; F-F'; I-I'	Weston Geophysical (1978), Figures 1, 6, 7, 10
		Profiles (Flight Lines): 370, 450, 510, 570	Washington Public Power Supply System (1980), Figures 1, 8-12
		Profile: "Pasco East"	Weston Geophysical (1980), Figures 1-3
3.	Aeromagnetic	Map: 4000' Terrain Clearance	Myers and Price (1979), Plate III-6a
		2500' Terrain Clearance	Myers and Price (1981), Appendix B, Figure 8
4.	Aeromagnetic	Maps: Hanford Site Umtanum Ridge to Gable Butte Area	Northwest Energy Services Company (1981), Appendix 2K, Figures 14, 22
5.	Aeromagnetic	Maps: 1500' Flight Altitude 900' Flight Altitude	Blume and Associates (1971), Figures 5 and 6
		Profiles: B-H, C', K f, h, m, n	Figures 7, 8, 10-18
6.	Aeromagnetic	Map: 15,000' Flight Altitude	Zeitz and others (1971), Figure 1
7.	Aeromagnetic	Map: 500' Flight Altitude	Raymond and McGhan (1963)
8.	Aeromagnetic	Map: 500' Terrain Clearance	Swanson and others (1979)
9.	Gravity	Map: 1-degree Hanford	Washington Public Power Supply System (1981), Appendix 2.5L, Figures 2, 5
10.	Gravity	Maps: Hanford Site Umtanum Ridge - Gable Mountain Area	Northwest Energy Services Company (1981), Appendix 2K, Figures 13, 15, 17, 18
11.	Gravity	Profiles: G02 G03	Washington Public Power Supply System (1977), Appendix 2RI, Figures 53, 56, 57
		G-C	Washington Public Power Supply System (unpublished)
12.	Gravity Modeling	Profile: C-C'	Washington Public Power Supply System (1981) Appendix L, Attachment 1, Figures 5, 6
13.	Gravity/ Magnetics	Lines: 25, 27, 29, D	Northwest Energy Services Company (1981), Appendix 2K, Figures 6, 19, 20 and Weston Geophysical (1981, unpublished)
	Magnetics	33,35	
14.	Gravity	Lines: SI-1 (44500) Rattlesnake 1	Northwest Energy Services Company (1981), Appendix 2K, Figure 8 and Myers and Price (1981), Appendix C, Figures 1, 2, 5, 6
	Gravity/ Magnetics	104	
15.	Magnetics	Traverses: II, III, IV	Rockwell Hanford Operations (unpublished)
	Magnetics/ Seismic Refraction	I	
16.	Seismic Reflection	Lines: 3, 4, 5, 8	Myers and Price (1981), Appendix B, Figures 2, 19-22
17.	Seismic Refraction	Line: SW-5	Blume and Associates (1971), Figures 4, 22, 23



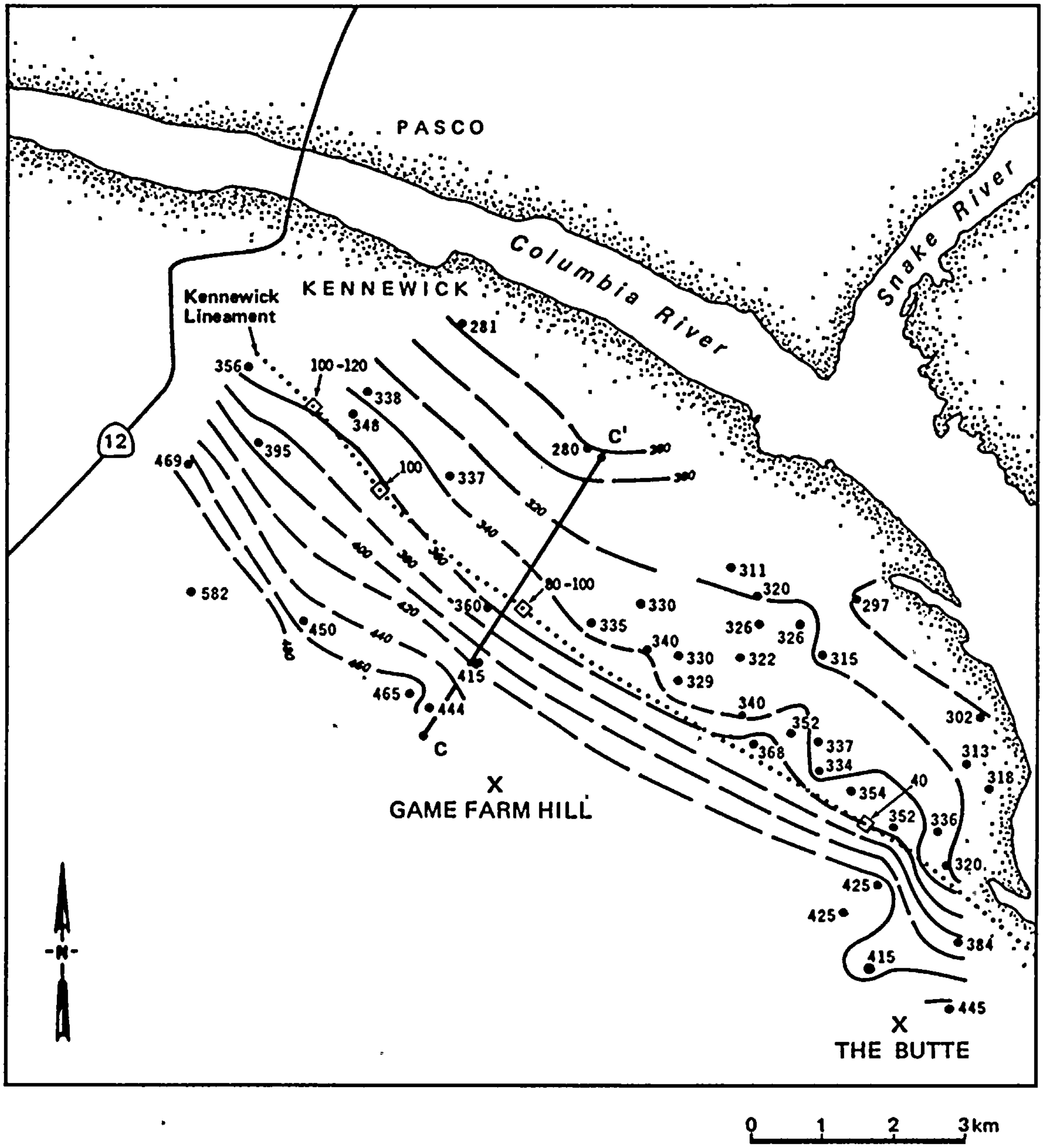
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	MAP OF LOCALITIES ALONG COLD CREEK LINEAMENT	Figure 1



EXPLANATION

Qt	Touchet beds
Qg	Pasco gravel
Qf	Alluvial fan deposits
$(T_1) - (T_4)$	Terraces developed on Qt and Qg
Tp	Pomona Member

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	CROSS SECTION ACROSS THE KENNEWICK LINEAMENT	Figure 2



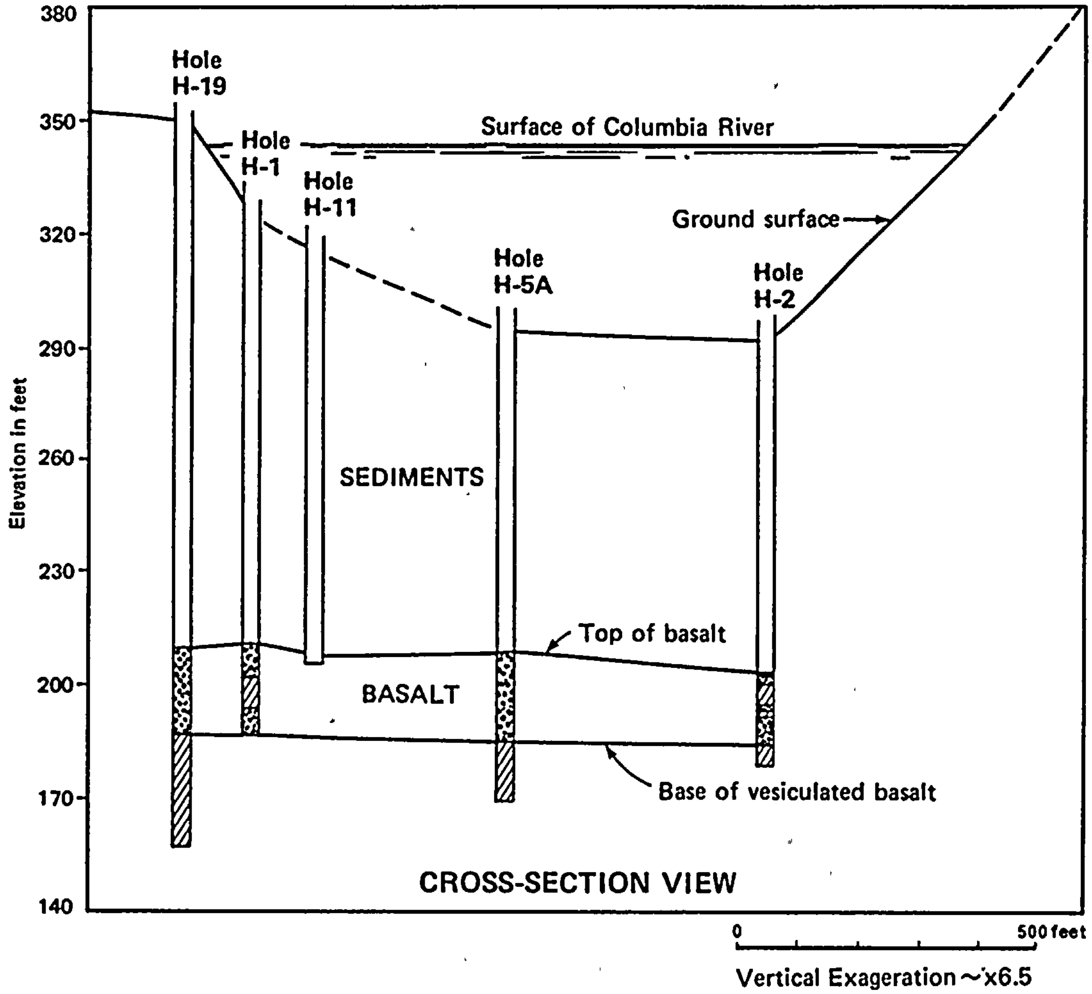
EXPLANATION

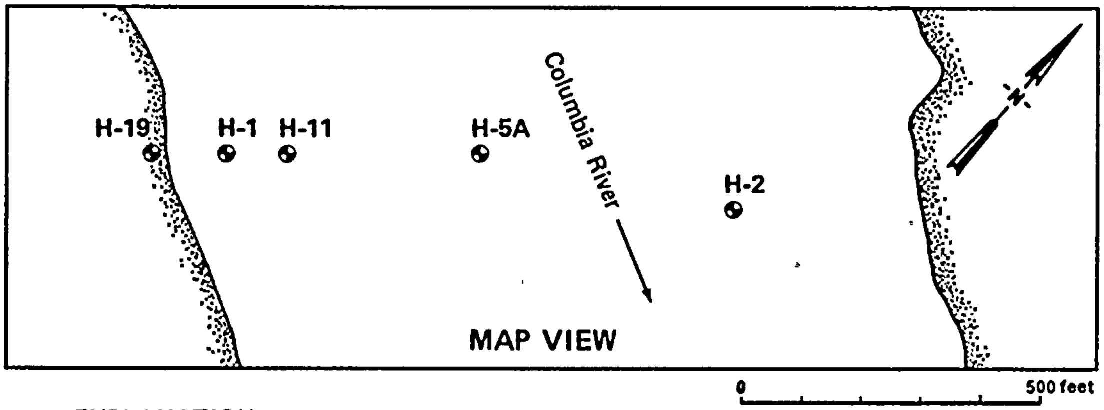
• 340 Elevation in feet on top of basalt. Data from Meyers and Price (1979).

□ 80 Topographic relief on Kennewick Lineament in feet.

C-C' Location of cross-section shown in Figure 2

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	CONTOURS ON TOP OF BASALT	Figure 3

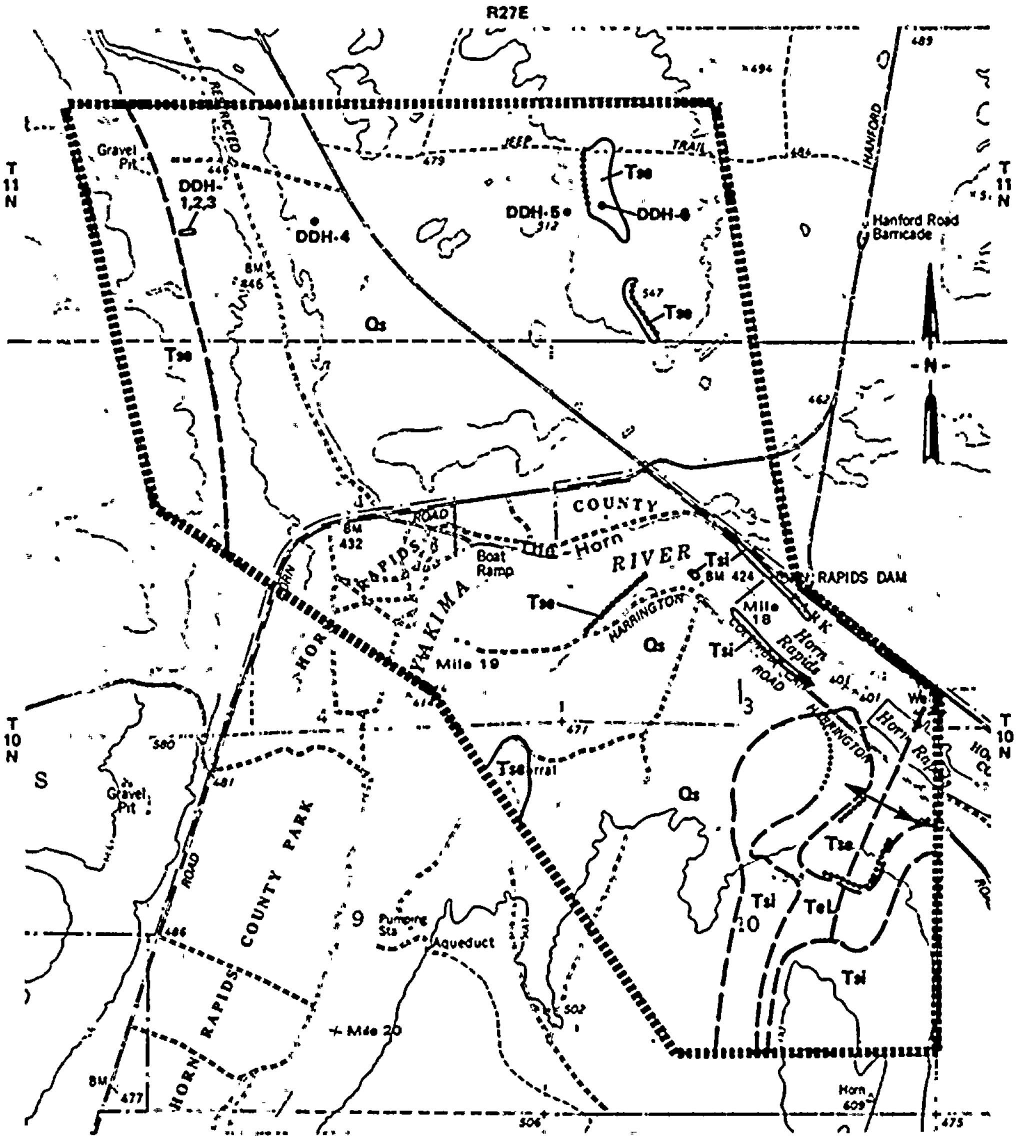




EXPLANATION

- Vesiculated basalt
- Unvesiculated basalt
- Borehole

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	CROSS SECTION AT THE COLUMBIA RIVER BRIDGE	Figure 4

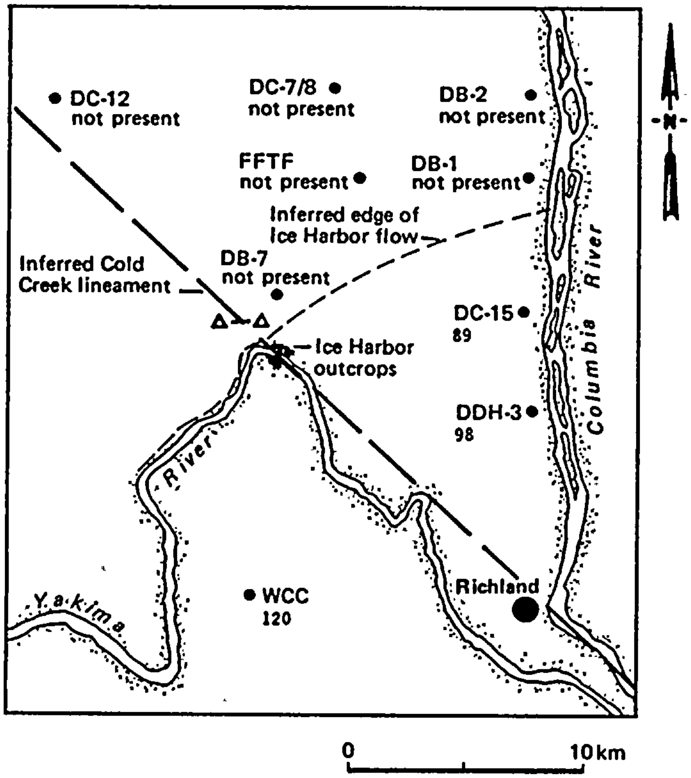


EXPLANATION

Qs	Undifferentiated Quaternary Sediments	Tsə	Elephant Mountain Basalt
Tsl	Ice Harbor Basalt	••••••••	Vesiculated Basalt
TeL	Levey Interbed	DDH-6	Location of Blume Drill Holes
		▮▮▮▮▮▮▮	Map Boundary

0 .5 1.0 km

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC MAP OF THE HORN RAPIDS AREA	Figure 5



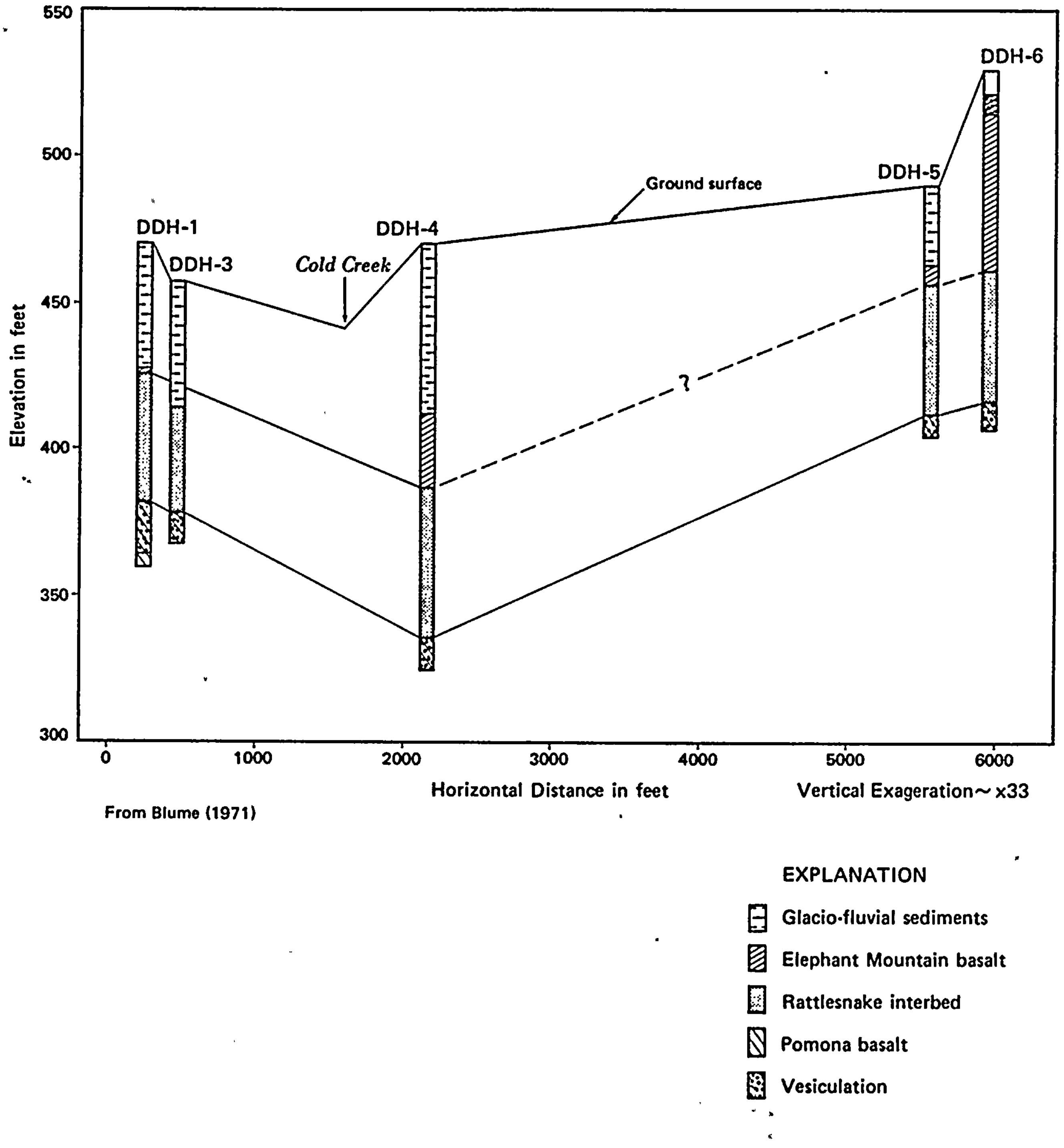
EXPLANATION

● DDH-3 98	Borehole with thickness of Ice Harbor in feet
● WCC 120	Location of surface measurement of thickness of Ice Harbor. Thickness given in feet
Δ—Δ	Line of drill holes from Blume (1971)

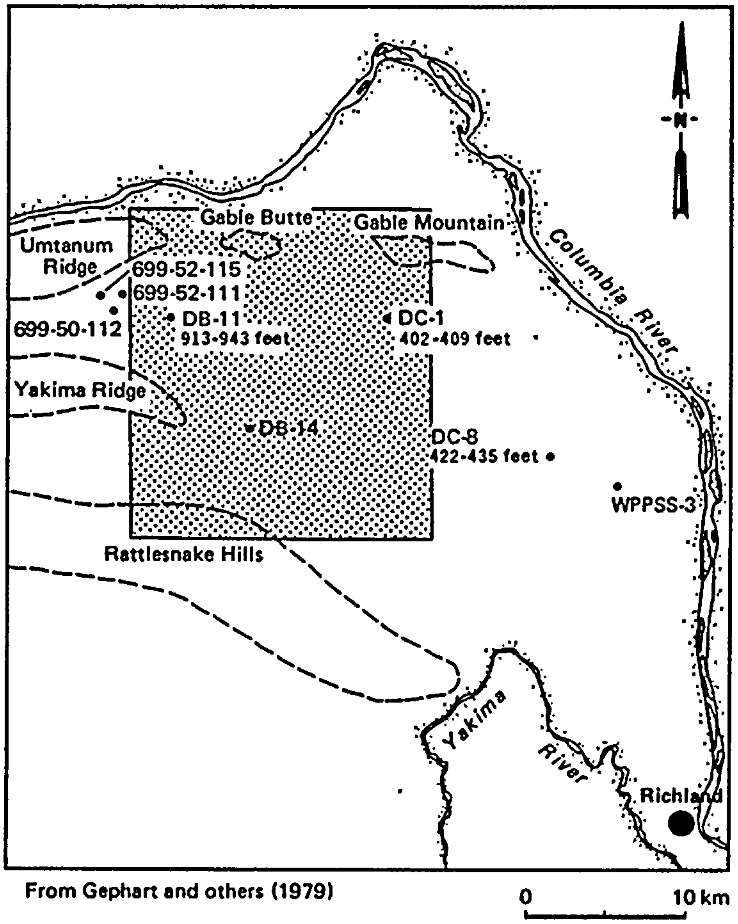
NOTE: Borehole location and lithologic data from boreholes from D. J. Moak in Meyers and Price (1981).

WCC thickness data from studies for The Washington Public Power Supply System

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	INFERRED DISTRIBUTION OF ICE HARBOR MEMBER	Figure 6



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	DRILL HOLES ACROSS COLD CREEK LINEAMENT	Figure 7



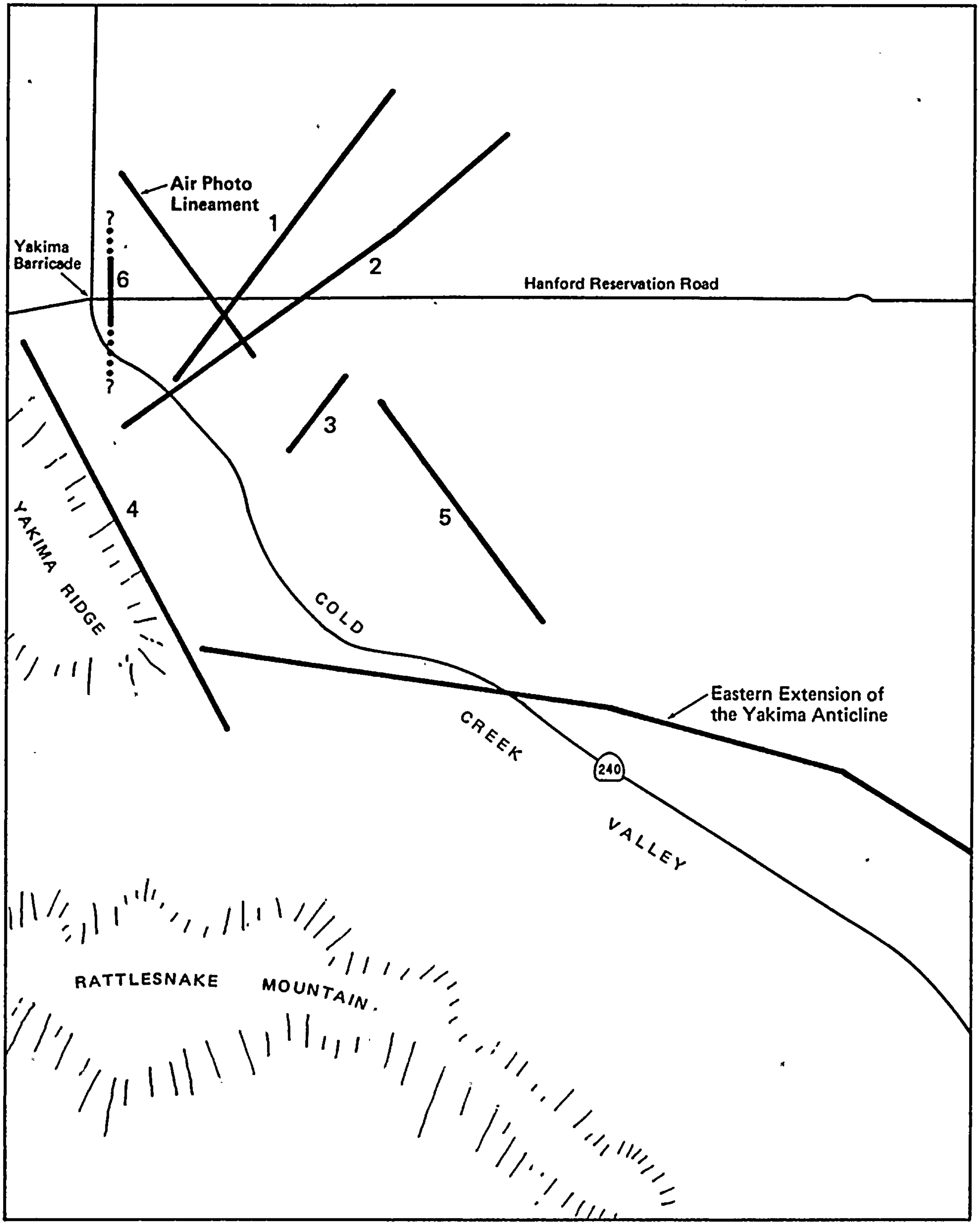
From Gephart and others (1979)

EXPLANATION

DC-1 • Borehole location
422-435 feet ← (hydraulic head measured in the Wanapum Formation)

Approximate area shown in Figure 9

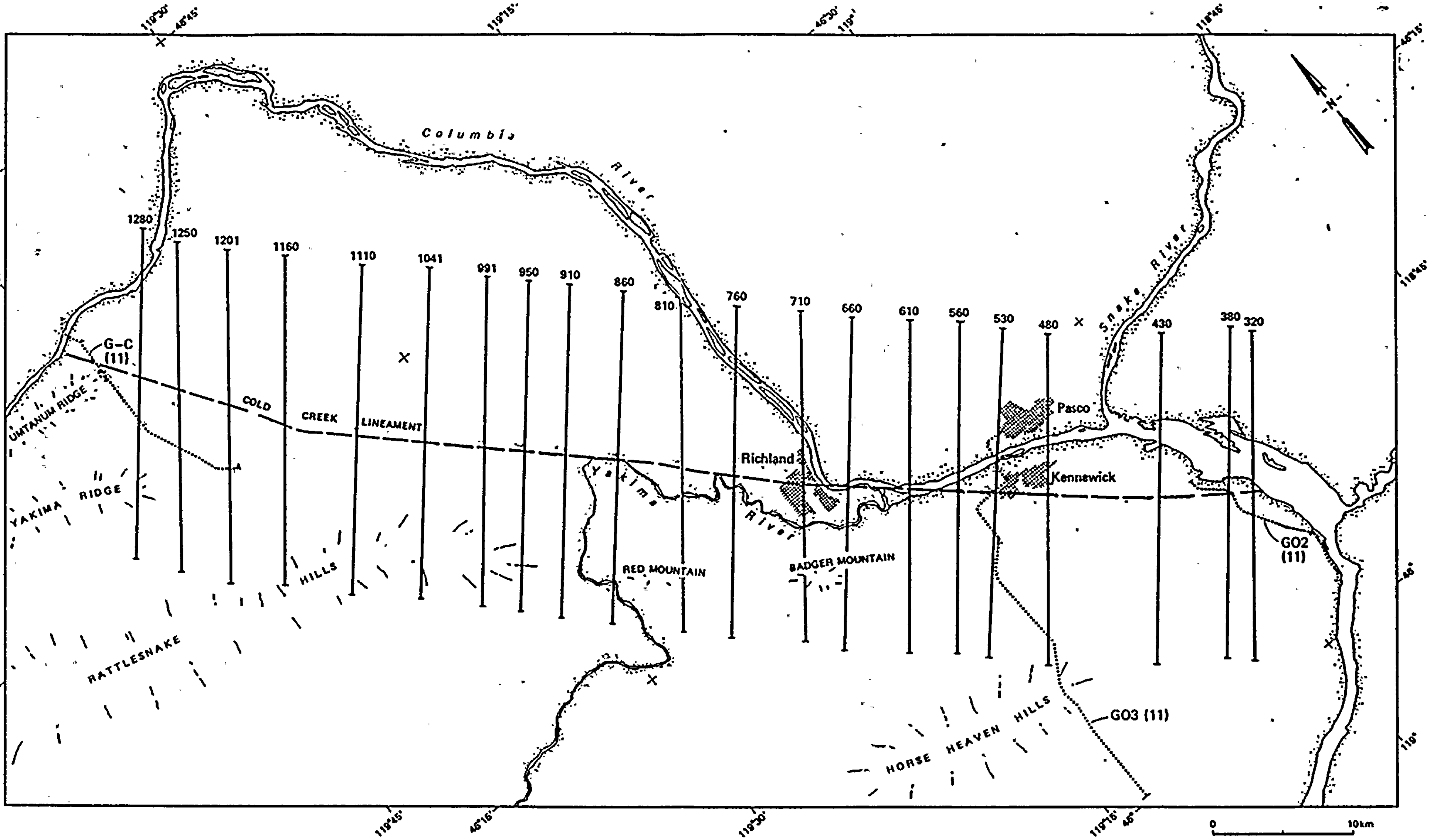
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	HYDRAULIC HEADS REPORTED FROM WANAPUM BASALT DATA	Figure 8



From Myers (Myers and Price 1981)

0 2 4 km

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURES INFERRED BY THE BASALT WASTE ISOLATION PROJECT STAFF	Figure 9



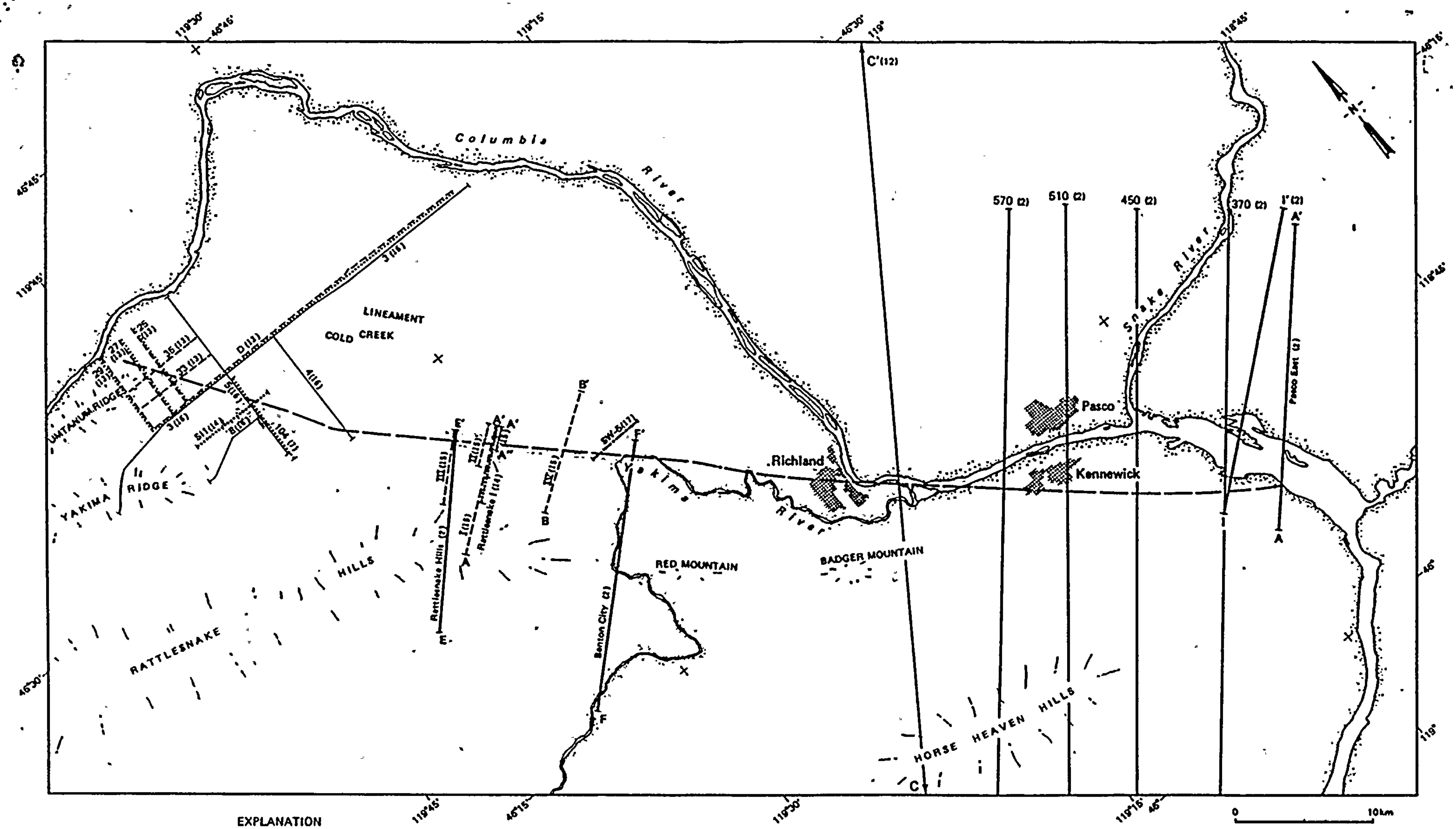
EXPLANATION

Aeromagnetic profile

Ground gravity traverse

NOTE: Profiles 320-1280 from Item (1) Table.
Profiles G-C and GO2 from Item (11) Table.

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOPHYSICAL COVERAGE OF THE COLD CREEK LINEAMENT	Figure 10



EXPLANATION

- Seismic reflection line
- Gravity traverse
- Aeromagnetic model profile
- Ground magnetic traverse
- Seismic refraction
- Gravity model profile

NOTE: Data sources indexed to Table 2. Numbers in parentheses correspond to item numbers in the table.

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOPHYSICAL COVERAGE OF THE COLD CREEK LINEAMENT	Figure 11

REPORT ON THE NATURE AND ORIGIN OF THE
NORTHEAST RATTLESNAKE MOUNTAIN LINEAMENTS

Four rectilinear features that occur at elevations of 800 to 1000 feet on the northeast slope of Rattlesnake Mountain were identified and photographed by Dr. D.B. Slemmons (Figures 1 and 2) during an aerial reconnaissance of the site region conducted by the NRC staff on 9 and 10 December, 1981. It was postulated that these lineaments may be indicative of late Pleistocene or Holocene faulting and the staff requested that the applicant investigate these lineaments to determine if they are due to faulting, and, if they are the result of tectonic faulting, to assess the attitude, length, sense of displacement, age of most recent displacement, and capability of the fault.

The lineaments were located in the field using the oblique aerial photographs taken by Dr. Slemmons (Figures 1 and 2). The lineaments, which are numbered 1 through 4 from southwest to northeast, consist of aligned tributary valleys and topographic breaks in slope. The lineaments trend northwest-southeast and are generally parallel to the topographic contours. Lineament no. 1 is the southeastern extension of the lineament described in response to NRC Question 360.22.

Figure 3 shows the locations of the lineaments reported by Dr. Slemmons and some additional lineaments identified by stereographic evaluation of this and adjacent photographs. The location of the lineaments on Figure 3 relative to the Rattlesnake Mountain fault and to the WNP sites is shown on Figure 4.

Lineaments 1 through 4 and other similar features on the northeast slope of Rattlesnake Mountain (Figure 5) occur in areas that are underlain by Touchet deposits, which consist of silty, and fine-sandy slackwater (lacustrine) sediments that were deposited

in the Pasco Basin during the Pleistocene catastrophic floods. The youngest Touchet deposits are approximately 13000 years old. The Touchet deposits occur up to an elevation of approximately 1260 feet (385 m), and they are mantled by a veneer of loess (eolian sand and silt reworked from the flood and slackwater deposits). Ice-rafted coarse sand and gravel containing numerous pebble-size and occasional boulder-size (maximum size about 1 m) erratics occurs locally in the Touchet deposits. Concentrations of this ice-rafted debris occur intermittently along the northeast sides of the lineaments.

In the vicinity of lineament numbers 1 through 4, the Touchet deposits overlie gravelly to cobbly alluvial fan deposits that have a well-developed caliche (calcic soil horizon) in at least the top 1.5 m (maximum thickness exposed in trenches; see below). The degree of caliche development suggests that the deposits predate the Sangamon interglacial (Oxygen Isotope Stage 5), which lasted from approximately 128,000 years B.P. to about 75,000 years B.P. The fan deposits may be much older.

The lineaments affect the Touchet deposits and on the basis of a geologic reconnaissance of the lineaments, it was concluded that the lineaments are probably erosional in origin. However, the lineaments are subparallel to the Rattlesnake-Wallula structural lineament (RAW) and, if they are tectonic in origin, they would suggest that faults associated with RAW are capable. Three trenches and a test pit were excavated across lineaments 1 through 4 to demonstrate their non-tectonic origin.

Trench RMT-1 was excavated across lineament no. 1. The log of this trench is presented in Figure 6. Trench RMT-4 crosses lineament no. 2 (Figure 7). Test pit RMT-2 was excavated near lineament nos. 3 and 4. Only massive Touchet and loess deposits were encountered in this test pit. No bedding or other stratigraphic markers that could be used to assess the presence or absence of

fault displacement were observed. Therefore, the trench across lineament nos. 3 and 4, trench RMT-3, was excavated along the thalwed of a gully that crosses these lineaments in order to expose deeper stratigraphic units (Figure 8). Descriptions of the lithologic units encountered in the trenches are given on Figure 9.

Topographic profiles were surveyed across the four lineaments (Figures 10, 11, and 12). Lineament no. 1 (Figure 10) is coincident with a topographic break in slope having a maximum depth of 2.9 feet (station 120 in trench RMT-1) and a width of 150 feet. Lineament no. 2 (Figure 11) has a maximum depth of 1.1 feet (station 94 in trench RMT-4) and a width of 70 feet. There is no discernible change in the overall slope of the ground surface in the vicinity of the lineament no. 20. Lineament no. 3 (Figure 11) has a maximum depth of 2.8 feet and a width of 140 feet. Lineament no. 4 (Figure 11) also has a depth of 2.8 feet and a width of 140 feet.

Figure 13 shows the locations of trenches RMT-1, RMT-3 and test pit RMT-2 relative to the lineaments. Trench RMT-4 was not excavated at the time the photograph was taken.

The contact between the Pleistocene alluvial fan deposits and the Touchet deposits was exposed in all three trenches. This contact is undeformed and continuous across all four lineaments indicating that there has been no fault displacement since the deposition of the Touchet deposits. In addition, there is no evidence of fault displacement in the Pleistocene alluvial fan deposits, which are estimated to be more than 100,000 years old and may be much older. Although there could have been some erosion of the alluvial fan surface prior to the deposition of the Touchet deposits, the preservation of the caliche soil indicates that erosion was minimal. In addition, the bedding observed between stations 100 and 112 in trench RMT-3 (Figure 8)

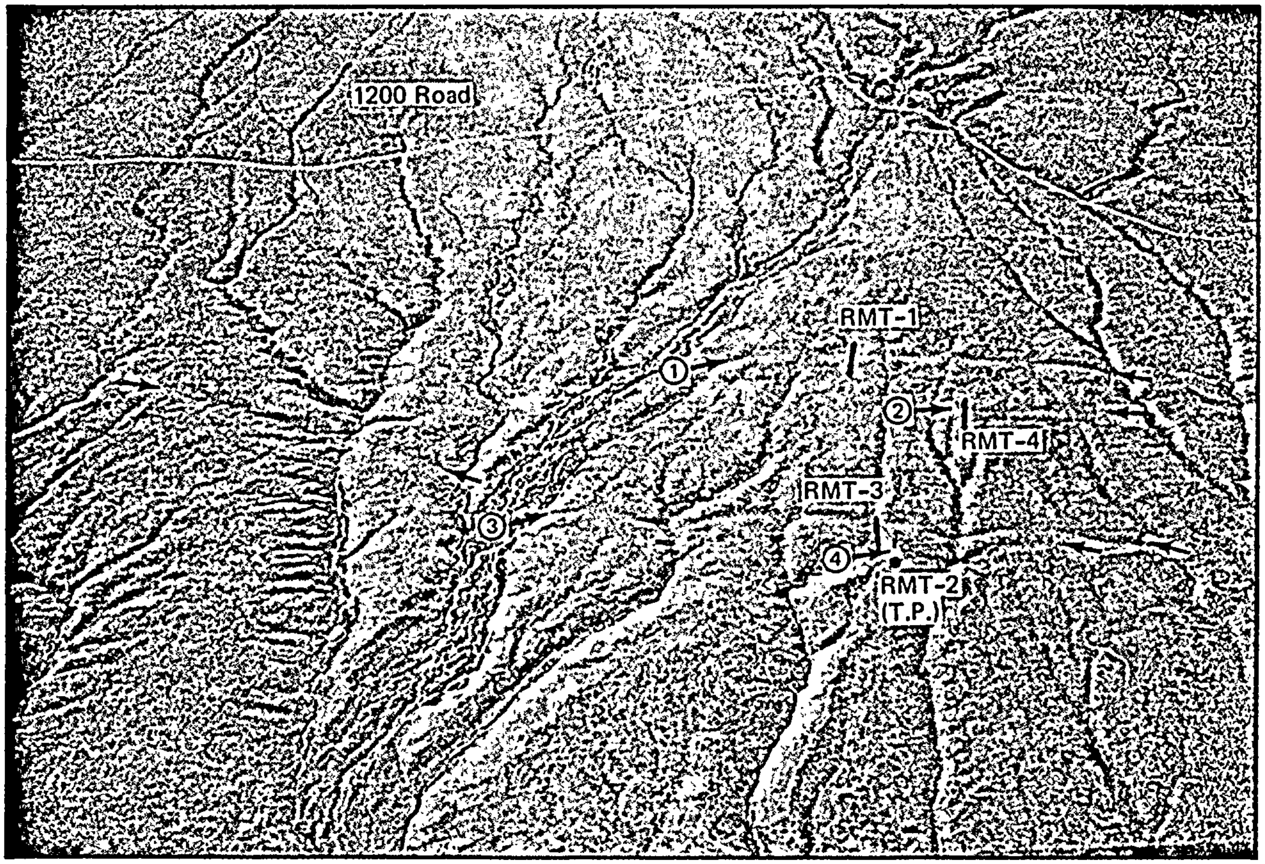
approximately 30 cm below the top of the fan deposits, is parallel to the top of the fan deposits, confirming that there has been little or no modification of the alluvial fan surface by erosion.

The stratigraphic relationships described above and shown on Figures 6, 7, and 8 indicate that the lineaments could not have been produced by tectonic displacement and that they must be the result of erosion that post-dates the deposition of the Touchet deposits.

The fine-grained Touchet and loess deposits are very susceptible to erosion and any perterbation in the surface is enough to divert surface run-off. Some of the tributary drainages that traverse the region may have been initiated along natural or man-made trails (see response to Question 360.22). This may explain the origin of some of the lineaments on the northeast flank of Rattlesnake Mountain. However, the scale (depth and width) of many of the linear depressions suggest it is unlikely that this mechanism can account for all of the lineaments.

The fact that most of the lineaments are generally parallel to the topographic contours and the topographic profiles across the lineaments (Figures 10, 11, and 12) suggests that the lineaments may reflect shoreline erosional features that have subsequently been modified by fluvial processes. The lineaments were probably initiated by shoreline erosion during recession of the lake (or lakes) that deposited the Touchet sediments. The presence of ice-rafted non-basaltic debris along the northeast sides of the lineaments probably represents the positions of ice bergs that ran aground and were stranded by the receding lake. Diversion of surface run-off along these shoreline features, differential erosion of the gravelly ice-rafted debris, and fluvial and eolian erosion during the past 10,000 years would account for the resulting alignment of intermittent tributary valleys and breaks in slope that define the lineaments.

Regardless of the exact mechanism (or mechanisms) for the origin of the northeast Rattlesnake Mountain lineaments, the evidence from the trenches across the lineaments indicates that they are non-tectonic in origin and that they are the result of post-Touchet erosional processes. Therefore, the northeast Rattlesnake Mountain lineaments do not affect the assessment of the potential ground motions for the WNP-2 and 1/4 sites.



Photograph courtesy of D. B. Slemmons

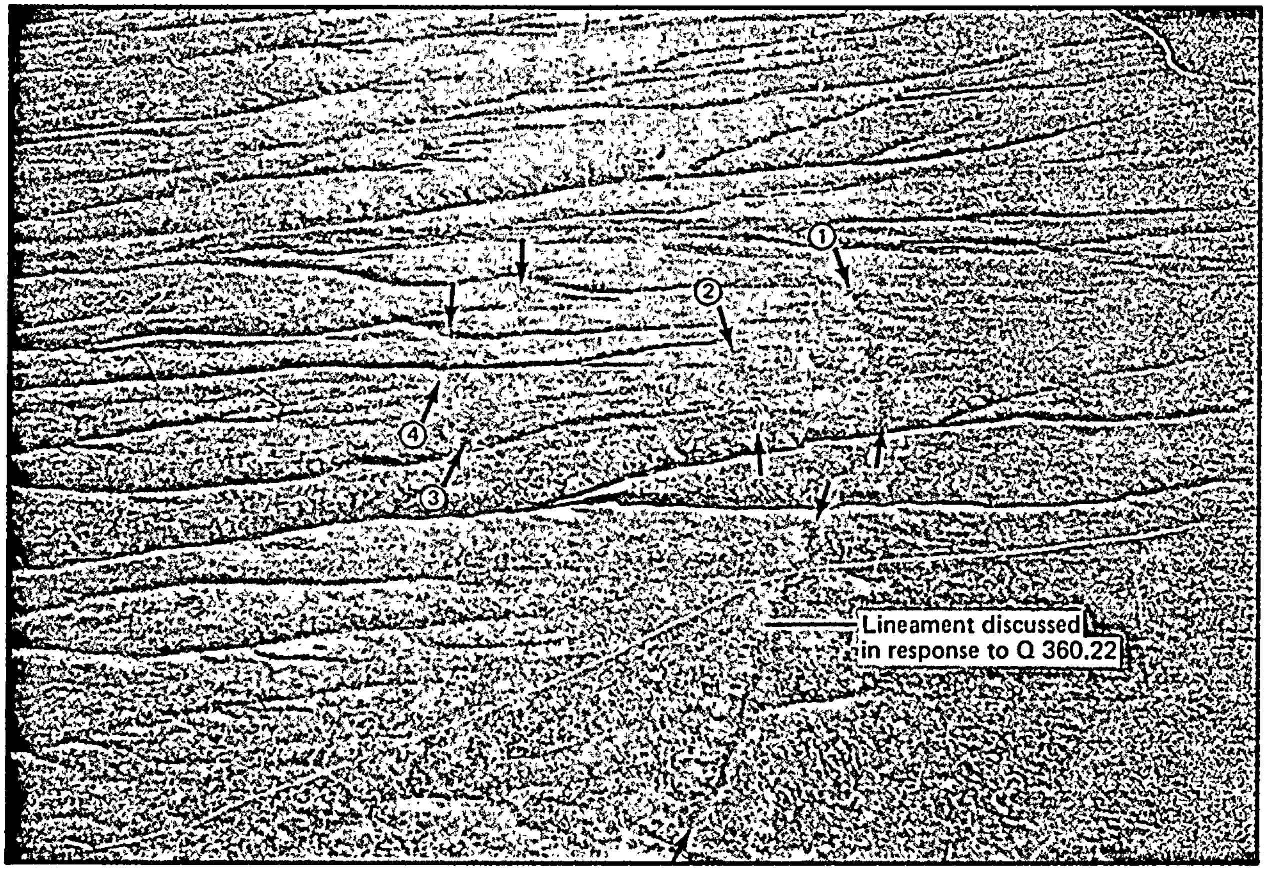
EXPLANATION

→ ← Lineament

/ Location of trench

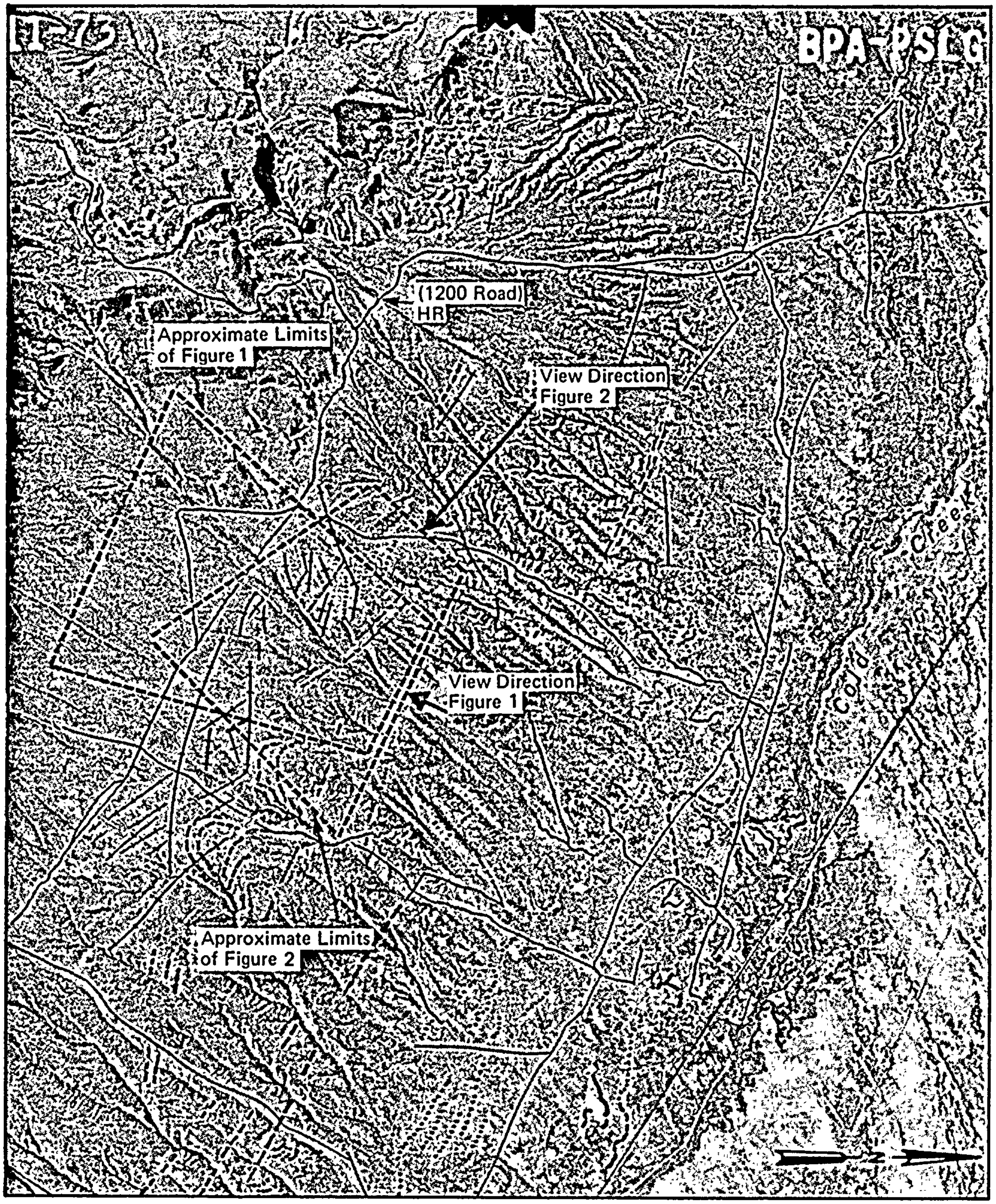
• Location of test pit

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	PHOTOGRAPH SHOWING NORTHEAST RATTLESNAKE MOUNTAIN LINEAMENTS AND LOCATIONS OF EXCAVATIONS	Figure 1



Photograph courtesy of D. B. Slemmons

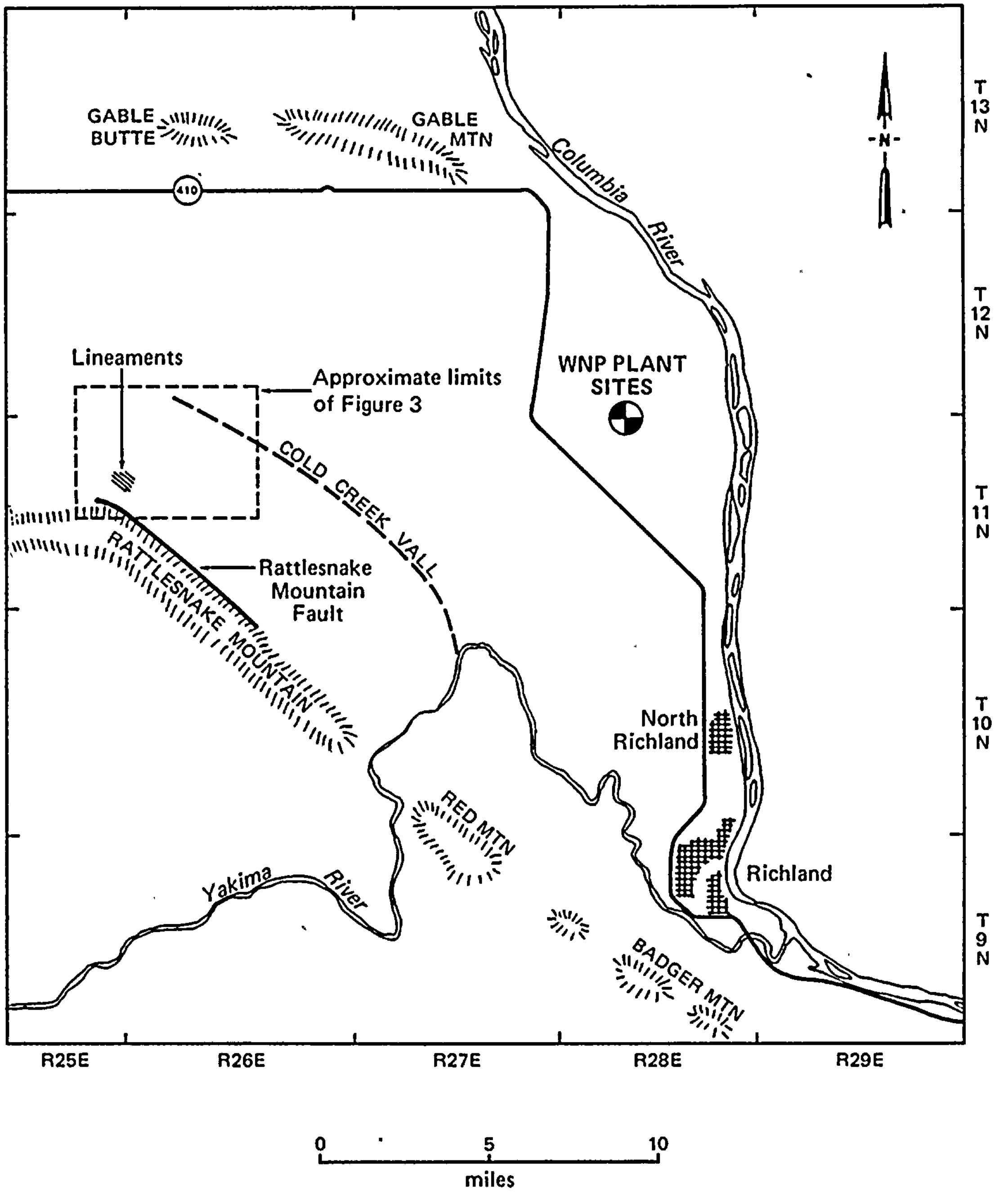
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	PHOTOGRAPH SHOWING NORTHEAST RATTLESNAKE MOUNTAIN LINEAMENTS 1 THROUGH 4	Figure 2



EXPLANATION

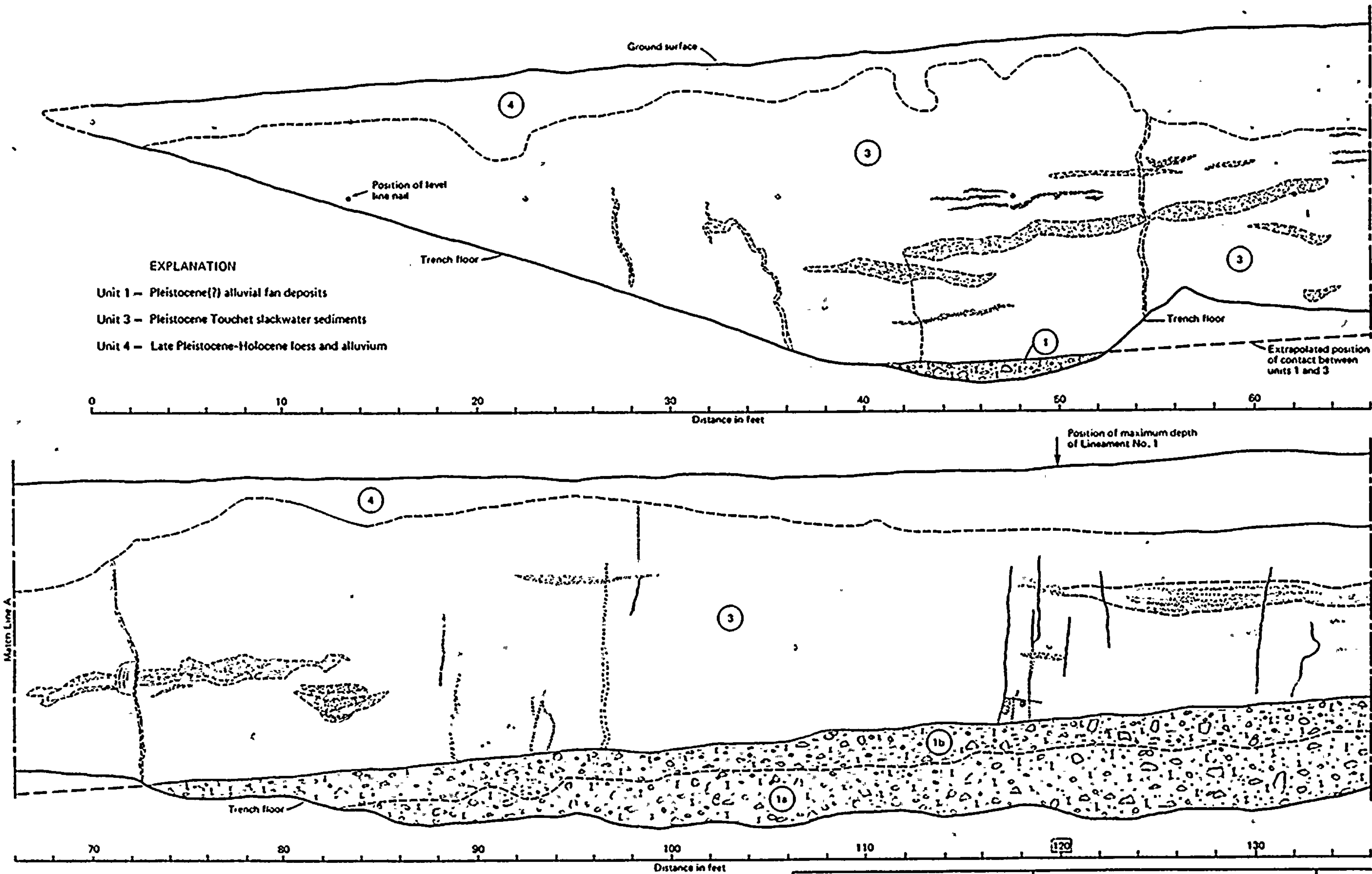
----------	Lineament shown on Figures 1 and 2
———— - -	Man-made tracks/roads
—+—+—+—+—	Vegetational lineaments
oooooooooooooooo	Lineament discussed in response to Q 360.22
———— - -	Probable topographic lineaments

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LINEAMENT ANALYSIS, NORTHEAST SLOPE OF RATTLESNAKE MOUNTAIN	Figure 3

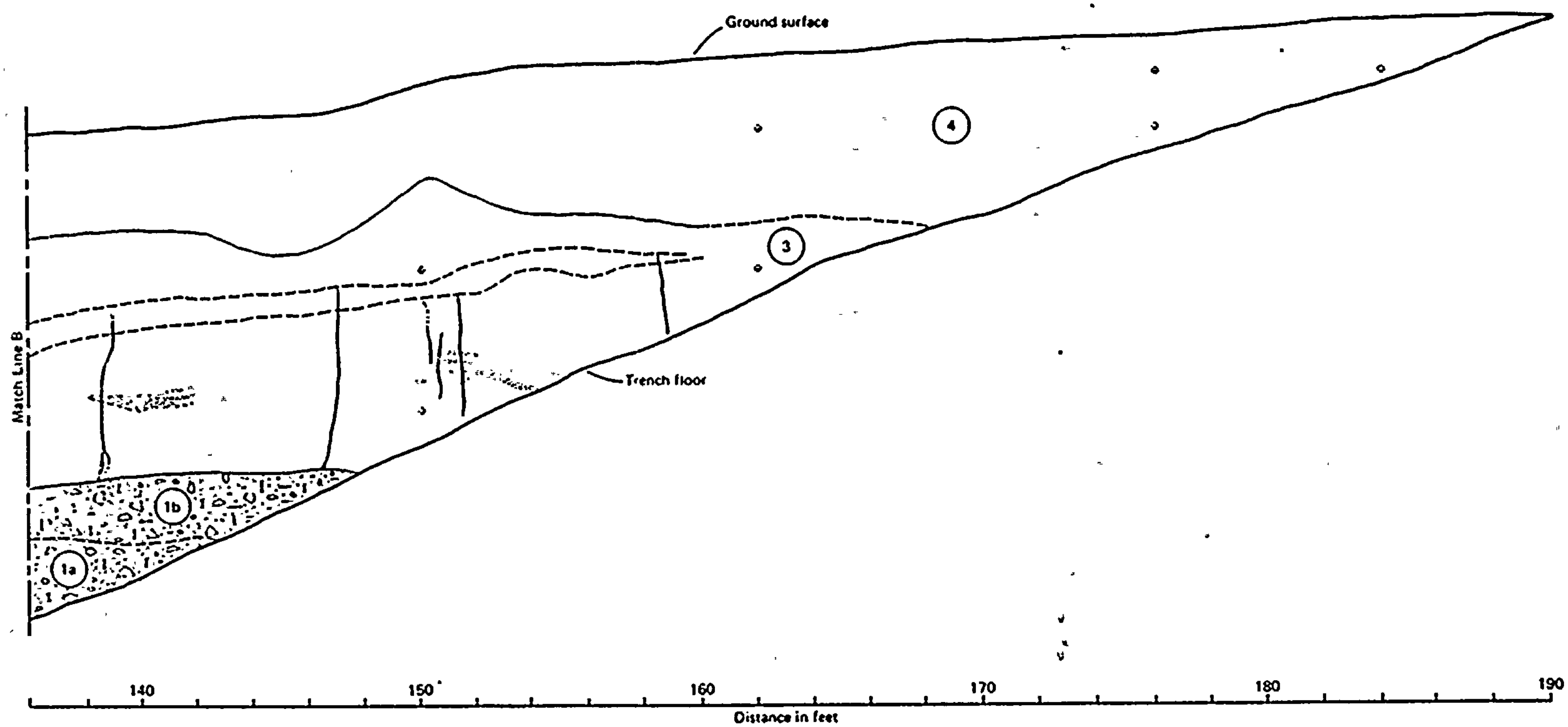


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOCATION MAP	Figure 4

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	PHOTOGRAPH TAKEN FROM TOP OF RATTLESNAKE MOUNTAIN SHOWING ADDITIONAL LINEAMENTS (VIEW IS NE)	Figure 5



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-1	Figure 6a



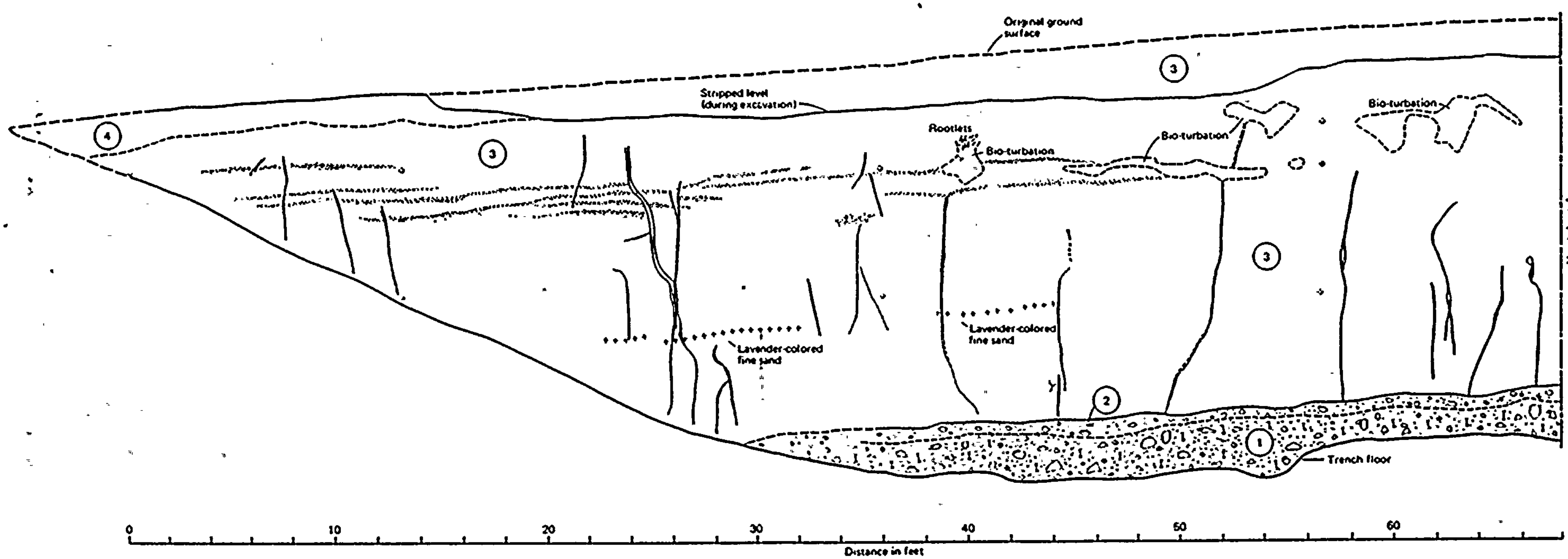
EXPLANATION

Unit 1 – Pleistocene(?) alluvial fan deposits

Unit 3 – Pleistocene Touchet slackwater sediments

Unit 4 – Late Pleistocene-Holocene loess and alluvium

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-1 (continued)	Figure 6b



EXPLANATION

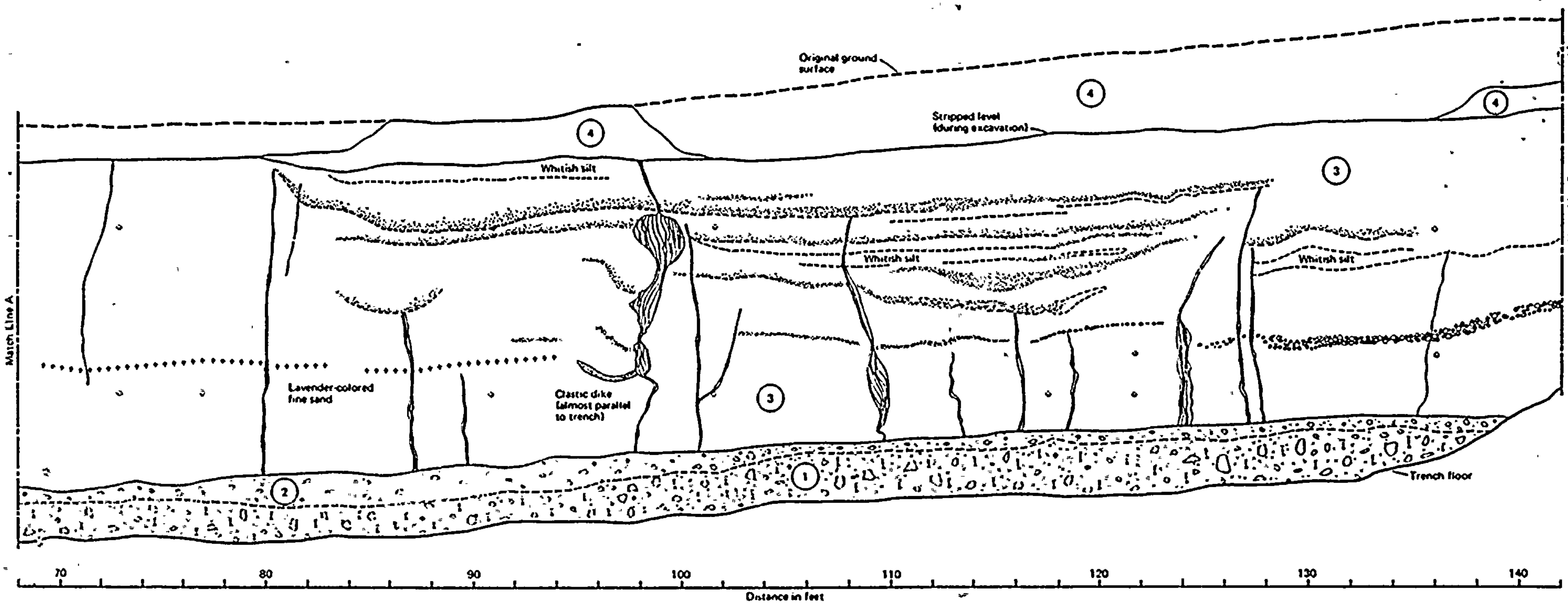
Unit 1 – Pleistocene(?) alluvial fan deposits

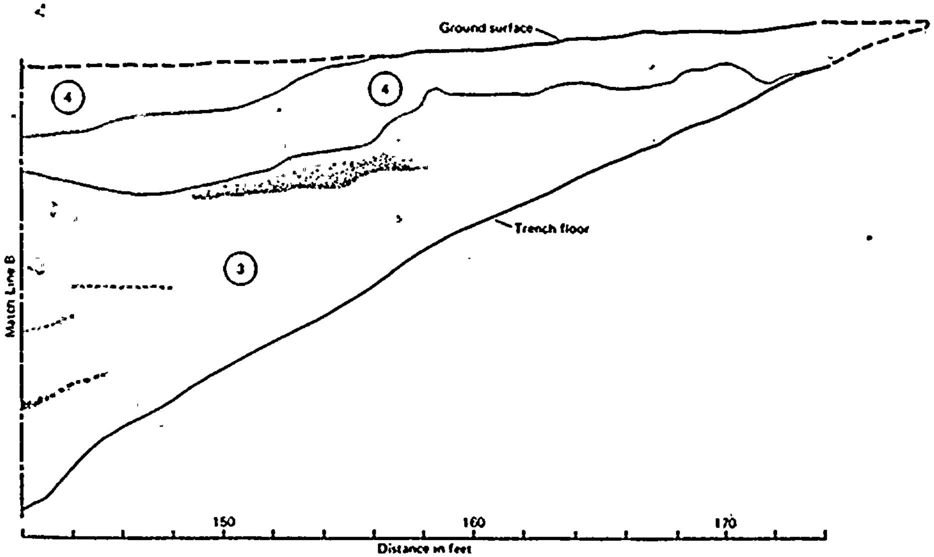
Unit 2 – Pleistocene(?) alluvial gravel

Unit 3 – Pleistocene Touchet slackwater sediments

Unit 4 – Late Pleistocene-Holocene loess and alluvium

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-4	Figure 7a





EXPLANATION

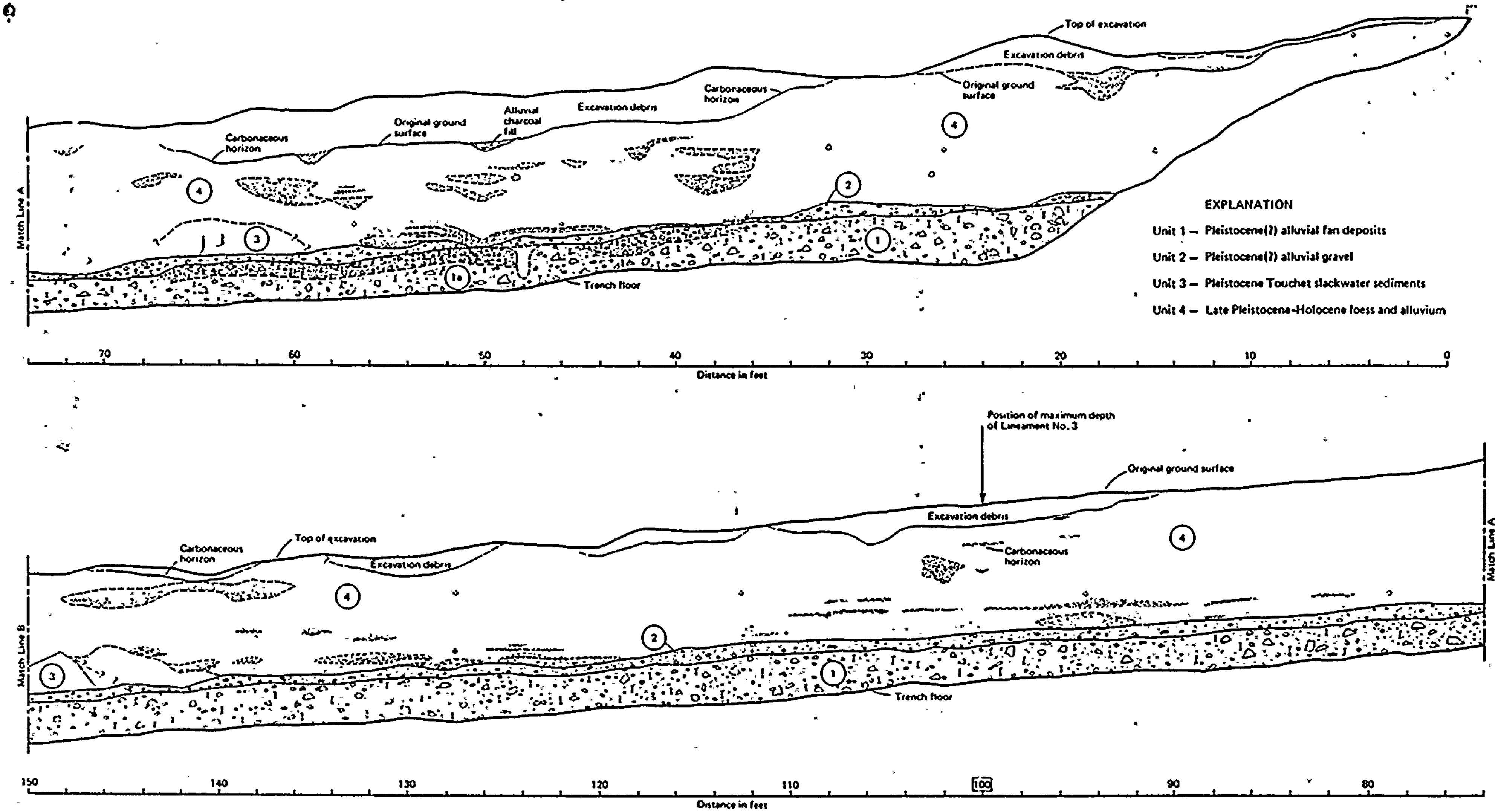
Unit 1 — Pleistocene(?) alluvial fan deposits

Unit 2 — Pleistocene(?) alluvial gravel

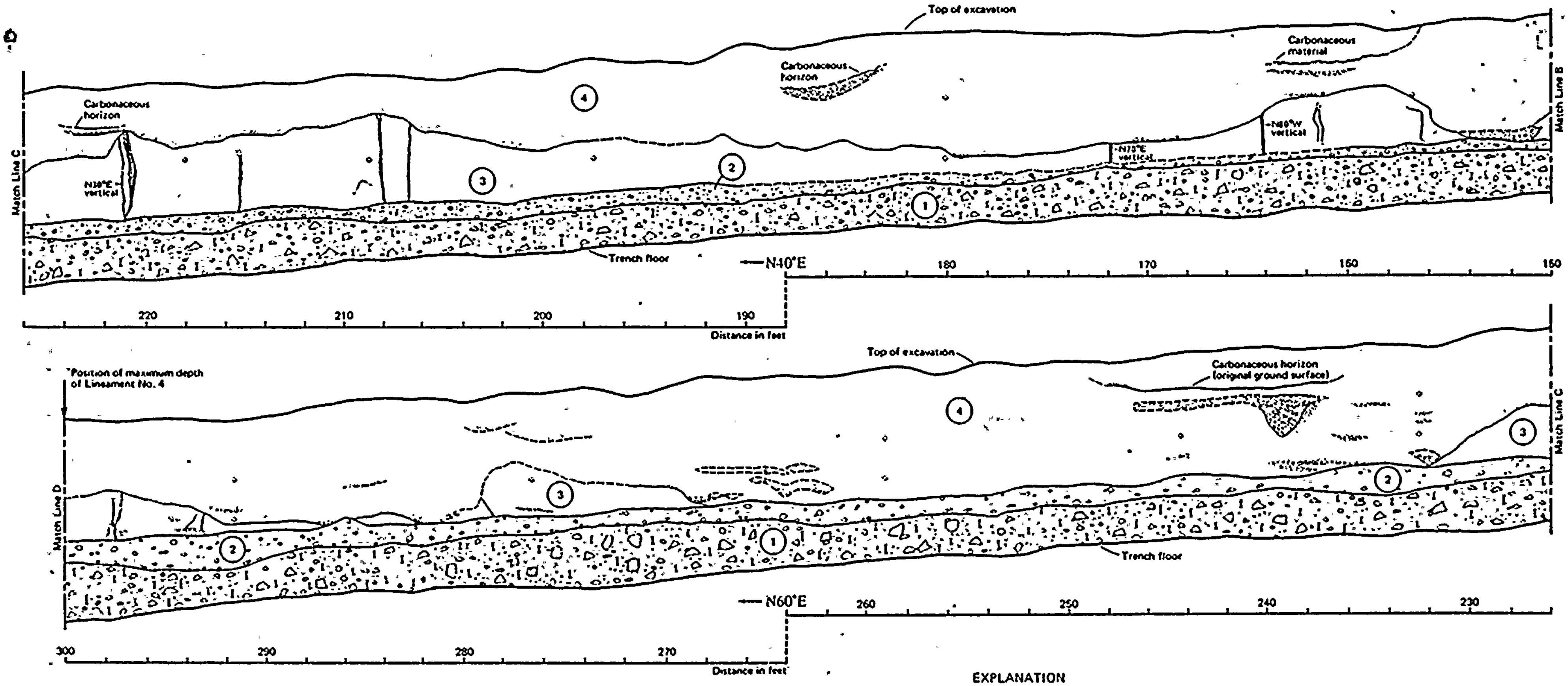
Unit 3 — Pleistocene Touchet slackwater sediments

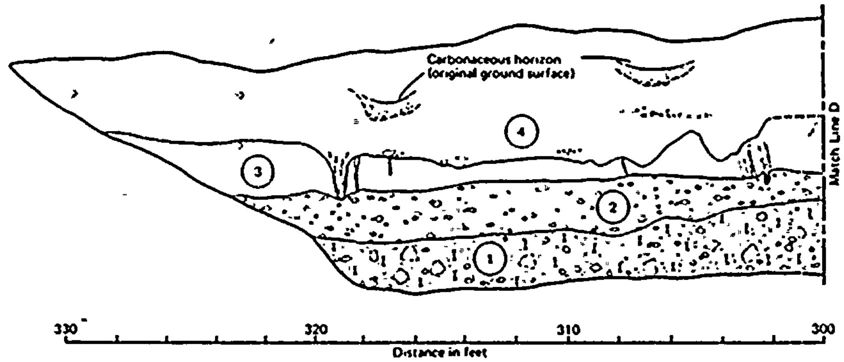
Unit 4 — Late Pleistocene-Holocene loess and alluvium

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-4 (continued)	Figure 7b



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-3	Figure 8a





EXPLANATION

Unit 1 — Pleistocene(?) alluvial fan deposits

Unit 2 — Pleistocene(?) alluvial gravel

Unit 3 — Pleistocene Touchet slackwater sediments

Unit 4 — Late Pleistocene-Holocene loess and alluvium

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOG OF TRENCH RMT-3 (continued)	Figure 8b

UNIT DESCRIPTIONS

oldest

Unit 1 — Pleistocene(?) alluvial fan deposits

Occurs in two generally distinct units: a lower, less well-cemented member (1a) and an upper well-cemented member (1b).

(1a) Similar to Unit 1b but less indurated. No lower contact, joints, or fractures observed.

(1b) Conglomerate, subangular clasts coated with white caliche rinds, clast size varies from sand to cobble size; nearly all clasts observed are basalt. The unit is massive with moderate to slight internal stratification. The unit is highly cemented and well indurated, no joints or fractures observed. Forms a resistant shelf at some locations. The upper contact is sharp and well defined. The lower contact with 1a is irregular and is based on differences in induration (amount of cement).

Unit 2 — Pleistocene(?) alluvial gravel

Consists of reworked Unit 1 deposits. Clast sizes are generally smaller than in Unit 1. No carbonate coatings on clasts.

Unit 3 — Pleistocene Touchet slackwater sediments

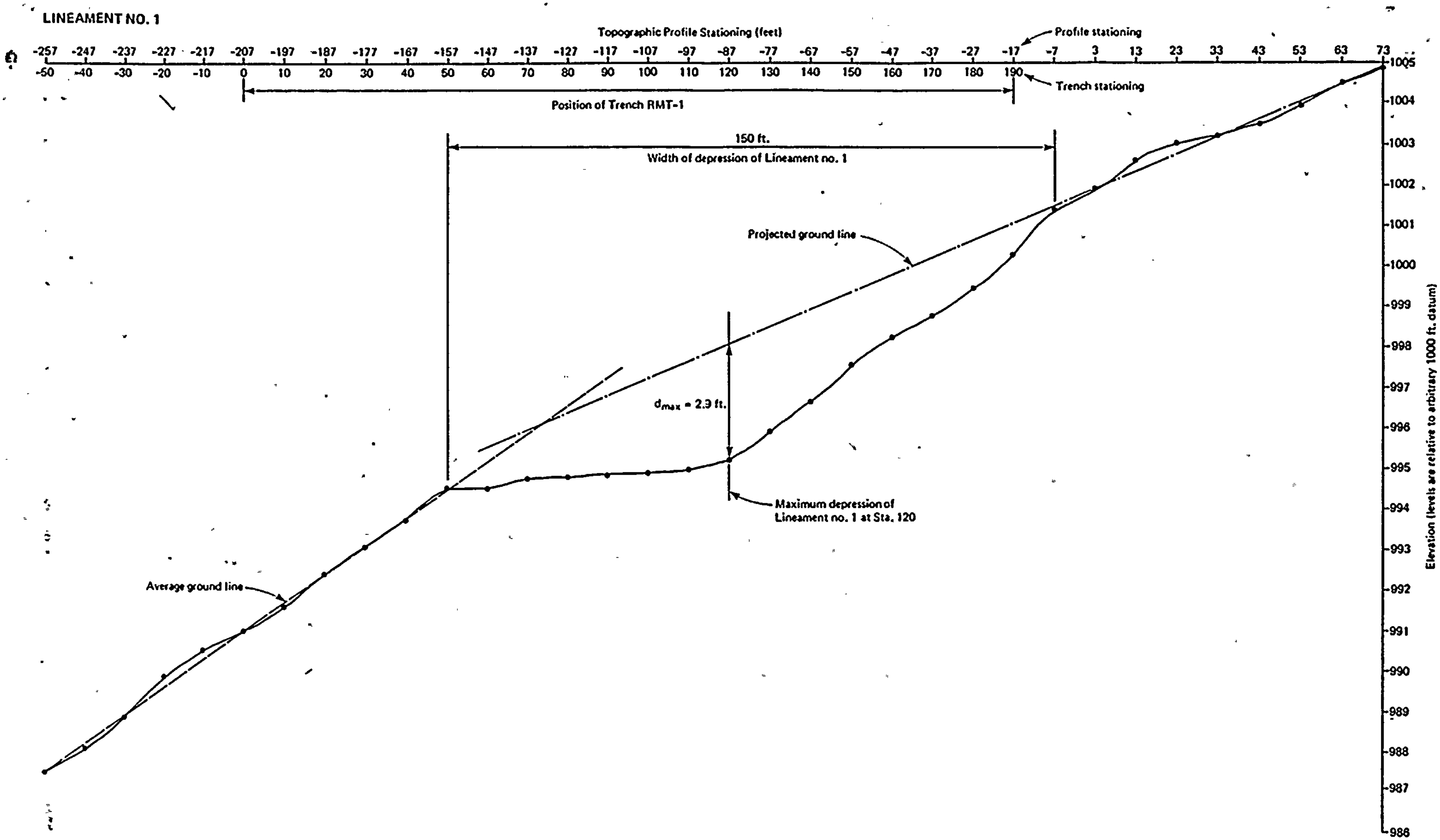
Silt, very fine sand, silty sand, granule sand. The unit is predominantly very fine sand with a variety of sedimentary features and clastic dikes. Very fine sand is light tan, compact, massive to weakly bedded, and has a marked calcified zone at its top. Sedimentary features include numerous sand to granule lenses, some with well-defined stratification. Clastic dikes range from 1/8-in. wide clay seams to 4-in. wide interlayered sand/clay mixtures. Larger clasts, up to gravel size are predominantly non-basaltic in composition. Upper contact is sharp, highly irregular, and marked by a decrease in coherence and color change.

youngest

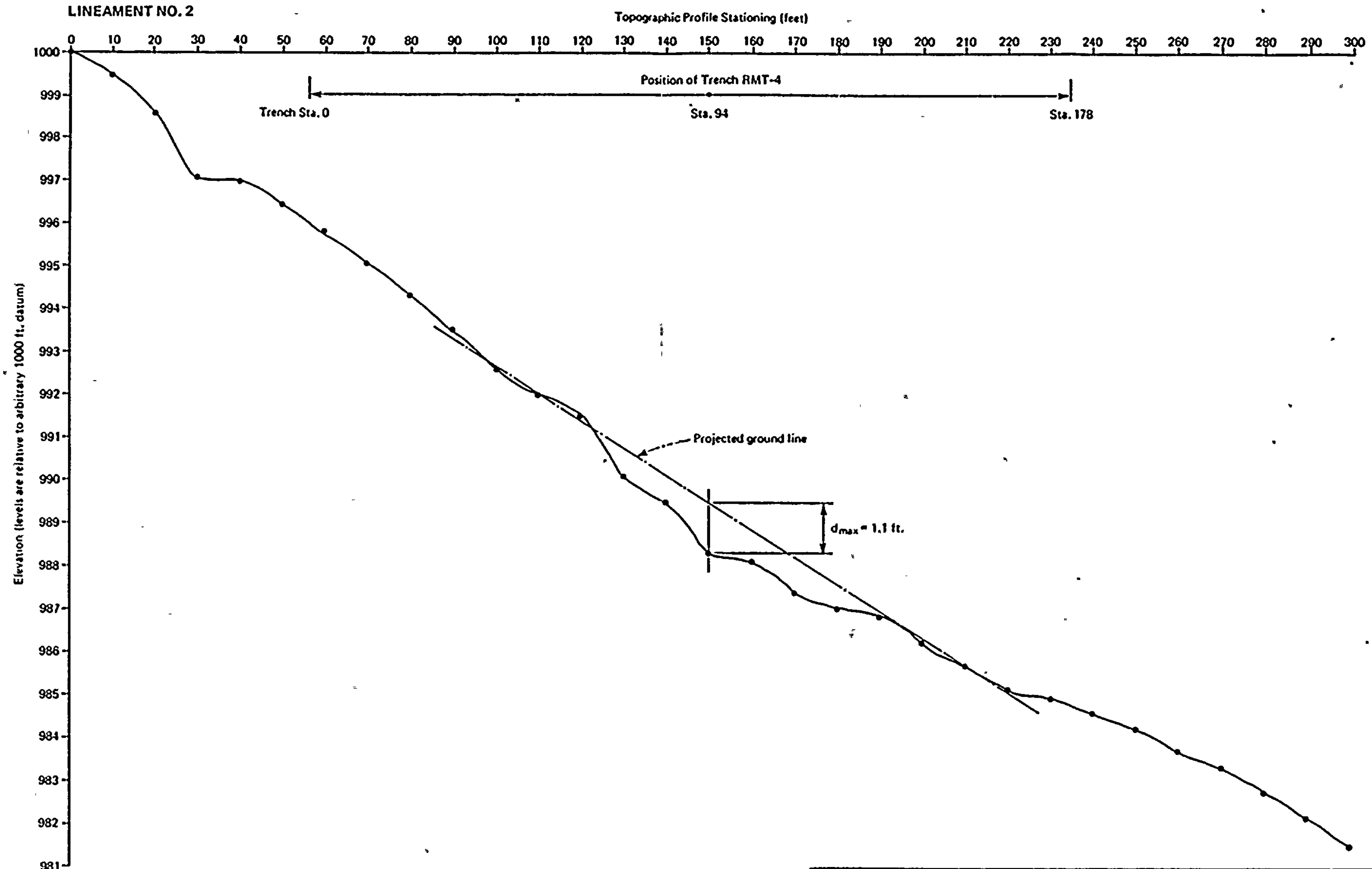
Unit 4 — Late Pleistocene-Holocene loess and alluvium

Silt, medium brown to dark tan; massive; some pebbles. Unit is moderately compact to friable; dessication cracks at surface to 6-in. deep. Unit 4 (loess) is derived from the underlying Unit 3 (Touchet) and may include some bioturbated Touchet deposits. In gullies, Units 3 and 4 have been redeposited as alluvium. No real distinction can be observed between Unit 4 (loess) and Unit 4 (alluvium) except in the degree of compaction and moisture content. Lower contact is marked by increase in calcification and increased compaction.

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	DESCRIPTIONS OF LITHOLOGIC UNITS ENCOUNTERED IN THE TRENCHES	Figure 9

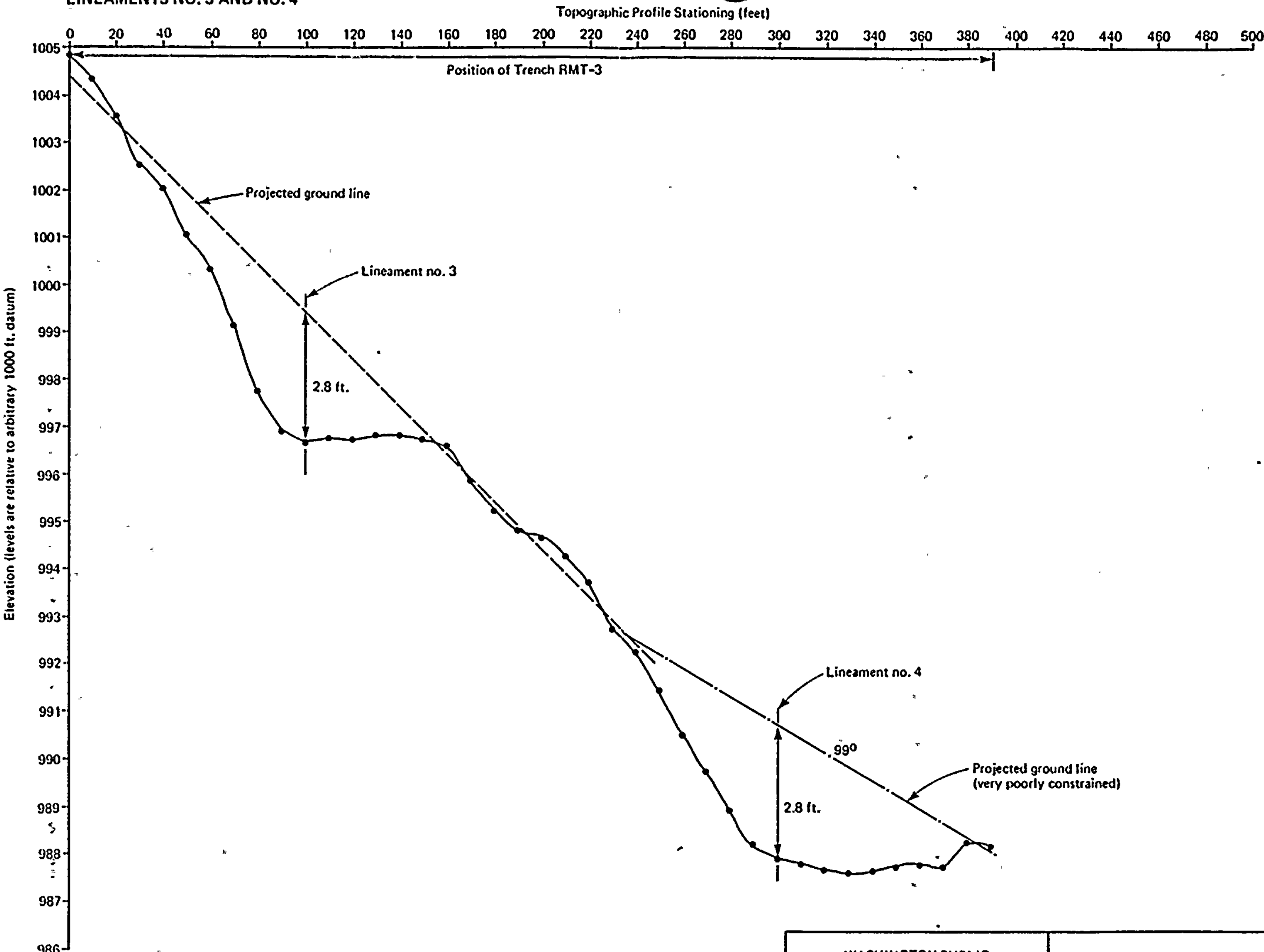


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	TOPOGRAPHIC PROFILE ACROSS LINEAMENT NO. 1 AT TRENCH RMT-1 SITE	Figure 10

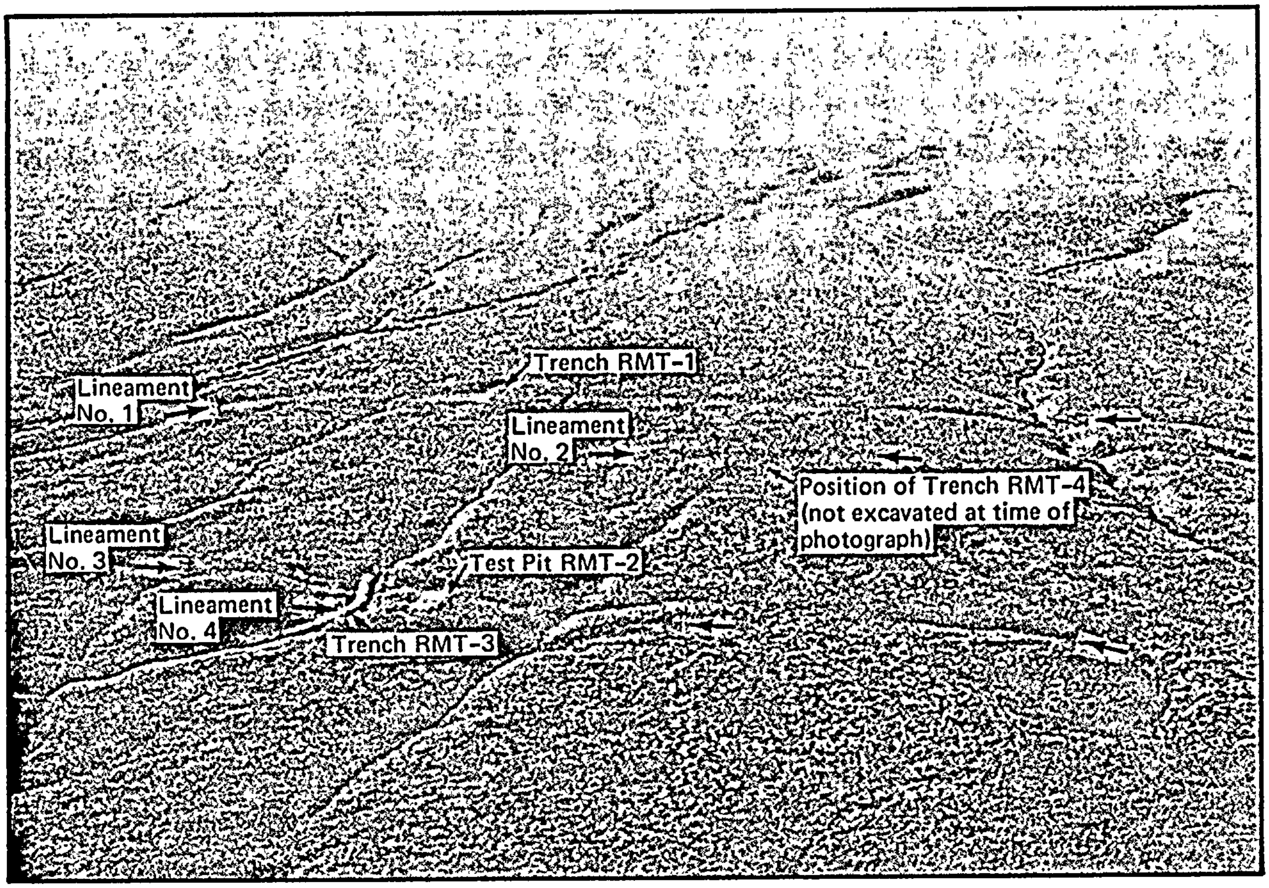


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	TOPOGRAPHIC PROFILE ACROSS LINEAMENT NO. 2 AT TRENCH RMT-4 SITE	Figure 11

LINEAMENTS NO. 3 AND NO. 4



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	TOPOGRAPHIC PROFILE ACROSS LINEAMENTS 3 AND 4 APPROXIMATELY 30 YARDS NORTH OF TRENCH RMT-3	Figure 12



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	PHOTOGRAPH SHOWING TRENCHES ACROSS LINEAMENTS 1 THROUGH 4	Figure 13

EVALUATION OF COCHRAN'S GEOPHYSICAL DATA IN THE VICINITY OF THE BUTTE AND GAME FARM HILL

As discussed previously in the response to Q. 360.14, and in the report on Segmentation (April, 1982) domain II of CLEW (Wallula Gap to Rattlesnake Mountain) is characterized by short, discontinuous folds and faults. The folds are aligned domes and doubly-plunging anticlines. Faults have been mapped along Rattlesnake Mountain, Red Mountain Badger Mountain, Game Farm Hill, The Butte (Finley Quarry), and Molly Hill. The faults occur along portions of individual folds and are present on both the northeast side (Rattlesnake Mountain, Molly Hill, Badger Mountain), southwest side (Game Farm Hill), and near the fold axis (The Butte, Red Mountain). The structural relationship between the faults and the folds along the Rattlesnake-Wallula alignment (domains II and III of CLEW) is uncertain and the applicant has not taken the position that these faults are directly related to the folds. The applicant's position is that geologic mapping along domain II shows that the faults are discontinuous within volcanic rocks that are several millions of years old.

Cochran (1982) has suggested that the Finley Quarry fault may extend 2.5 to 3.5 km (1.6 to 2.2 miles) beyond the northwestern end of The Butte along a trend of N64W. In addition, he postulates the existence of a N83W-striking fault in the basalt bedrock just south of Game Farm Hill. The projections of these two faults intersect between the two anticlines. Both the extension of faulting to the northwest of The Butte and the structure south of Game Farm Hill were inferred from magnetic data obtained along the traverses shown in Figure 1 and from gravity profiles along traverses F4, F7, and F9. The magnetic and gravity profiles are unpublished proprietary data that have been provided by M. Cochran (February, 1982) for this review. Copies of these profiles are being supplied to the NRC staff under separate cover.

Geophysical profiles that cross the mapped faults on The Butte and on Game Farm Hill were carefully examined to characterize the geophysical signatures of the faults for comparison with the magnetic and gravity anomalies on which Cochran based his hypothesis. Alternate explanations for the latter anomalies are also considered, and are discussed below.

Faulting on The Butte has been extensively investigated (Woodward-Clyde Consultants, 1981). A 15-m (50-ft) wide fault zone containing three fault traces is present at the northwestern end of The Butte in Finley Quarry. This zone strikes approximately N65W and the faults dip between vertical and 60 degrees southwest. These faults juxtapose Pomona basalt against Umatilla, Pomona against younger sediments and sediment against sediment. At Finley Quarry the faults show a consistent sense of displacement down to the northeast. However, approximately 1 mile to the southeast, near the summit of The Butte, the same fault shows up to the northeast displacement.

Magnetic profiles F1 and F2 (Figure 1) cross this fault zone. On profile F1 the magnetic anomaly shown at location A on Figure 1 is coincident with the mapped fault near the summit of The Butte. This is a negative, V-shaped anomaly having an amplitude of 700 gammas and an apparent width of about 350 feet. However, the northeastern limb of this anomaly is obscured by two large (2000 gammas), narrow, positive anomalies that correspond to the edges of an outcrop of Umatilla basalt. The anomaly on profile F2 that is coincident with the fault zone at Finley Quarry is also marked A on Figure 1. This is a negative, U-shaped anomaly having an apparent amplitude and width of 1250 gammas and 1250 feet, respectively. Profile F2 does not extend far enough to the southwest to allow this anomaly to be reliably characterized in full. Although two magnetic traverses cross the mapped fault zone and an anomaly on each profile can be associated with the zone, the characters of these anomalies differ from each other

and the data do not allow the exact magnetic signature of the fault zone to be identified with certainty. The width of anomaly A on profile F1 would appear to be more consistent with the characteristics of the mapped faults than the relatively broad anomaly on profile F2. The apparent width of the latter anomaly, however, could be due to the fact that profile F2 crosses a zone containing three mapped fault traces in close proximity; there are three secondary minima within the overall anomaly.

Profile F10 crosses a mapped fault on Game Farm Hill (Figure 1). This fault is not well defined geologically, and it is not obvious which, if any, of the magnetic anomalies on profile F10 correspond to the fault. Immediately over the mapped trace of the fault is a relatively low amplitude (500 gammas) magnetic high that has a width of about 150 feet. This small anomaly is superimposed on a larger magnetic low. Although the width of this negative anomaly is similar to that of anomaly A on profile F2, neither of the F10 anomalies closely resembles either of the anomalies (A) on profiles F1 and F2.

The characteristics of magnetic anomalies within the geological and geomagnetic environment of the Columbia Plateau are influenced to a large degree by the strong natural remanent magnetizations (NRM) exhibited by individual basalt flows. It is conceivable that the characters of the anomalies described above are associated solely with the mapped faults, depending on the exact polarities and orientations of the NRM's in each of the juxtaposed basalt flows. However, the following features may also have a significant influence on the magnetic anomalies, and add to the uncertainty in identifying the magnetic signature of the faults:

1. The geologic investigations at Finley Quarry showed that there is a steep-walled canyon eroded in Umatilla basalt that was subsequently filled with Pomona basalt. Within

Finley Quarry, the buried canyon wall strikes approximately N20W and the projection of this contact crosses the southwestern end of profile F2. This steeply-dipping contact between reverse-polarized Pomona basalt and normally-polarized Umatilla basalt probably has a large influence on the character of the magnetic anomaly on profile F2.

2. On The Butte and at a locality just northwest of Game Farm Hill, the basalt section is observed to have been folded into a northeastward-dipping monocline. In both areas, the monocline strikes N55W to N65W and dips 20 to 25 degrees northeast. Subsequent erosion of the crest of this fold could have exposed Umatilla basalt, resulting in lateral juxtaposing of Umatilla basalt on the southwest against Pomona basalt on the northeast at certain localities. A negative anomaly would be observed on a northeast magnetic profile where it crosses from normally-polarized Umatilla to reverse-polarized Pomona.

A prominent magnetic anomaly is present on profiles F3, F4, and F5, the locations of which are marked B on Figure 1. The shape of this anomaly is very consistent from line to line, and it undoubtedly corresponds to the same bedrock feature at each location. The anomaly is V-shaped, negative, and has an amplitude of 1500 to 2000 gammas and a width of approximately 1500 feet. As can be seen on Figure 1, the positions of anomaly B on profiles F3 through F5 align along a trend of N60W. The northwestern extension of the Finley Quarry fault zone was postulated by Cochran (1982) based on the observation that this trend continues along the strike of the zone. However, as discussed above, the magnetic signature where profiles F1 and F2 are known to cross the fault zone is not well defined. Anomalies A on these profiles show no striking similarity to anomaly B. Therefore, the characters of the anomalies do not immediately suggest that

anomalies A and anomaly B have the same source, and the inference that anomaly B represents an extension of the Finley Quarry fault zone is based solely on the alignment along the projected extension of the zone.

Magnetic anomalies on profiles F6 through F8 are less prominent than on profiles F3 through F5. An anomaly having the same general shape as anomaly B on profiles F3 through F5 can be tentatively identified on each of the profiles F6 through F8. Although the correlation of these anomalies with anomaly B is not certain, their locations are also indicated as B in Figure 1. These anomalies have an amplitude of approximately 1000 gammas. Anomaly B on profiles F6 and F7 is broader and has gentler gradients than on profiles F3 through F5, whereas on profile F8 these characteristics are similar to those on profiles F3 through F5.

There are two separate sets of magnetic anomalies on profiles F9 and F10 (marked C and D on Figure 1). The shape of anomaly D on profile F9 is similar to that of anomaly B on the other lines. However, this anomaly and anomaly D on profile F10 have much larger amplitudes (2000 gammas) than anomaly B on profiles F6 through F8. Cochran (1982) postulated that anomaly D is probably related to a bedrock fault that strikes N83W south of Game Farm Hill. The gravity anomaly that is approximately coincident with magnetic anomaly D on profile F9 (G on Figure 1) could be interpreted as a fault signature, although, as discussed below, an alternative explanation of these anomalies is probable. Anomaly C on profile F10 is approximately 750 feet to the southwest of the anomalies that may be related to the fault mapped on Game Farm Hill. The characteristics of none of these anomalies, nor of anomaly C on profile F9, are similar to anomalies on profiles F3 through F8. Therefore, as implied by Cochran (1982), there is no a priori reason, based on the magnetic data alone, to suppose that the fault mapped on Game Farm Hill extends to the southeast.

Because of the difficulty in characterizing the magnetic signatures of the faults on The Butte and on Game Farm Hill, the possibility that any of the magnetic anomalies discussed above is fault related cannot be ruled out based on these data alone. However, a plausible alternative explanation for these anomalies is suggested by gravity and geological data.

Coincident with magnetic anomaly B on profile F4 is a negative, V-shaped, gravity anomaly (G on Figure 1). The shape of this anomaly, and particularly the fact that it is symmetrical (rising to approximately the same level on both sides of the minimum with equal gradient), strongly suggests that it (and, hence, magnetic anomaly B) is not fault related; the gravity signature of a fault is, in general, distinctly asymmetrical. A more feasible interpretation of this anomaly is that it represents a depression in the bedrock filled with low-density sediments. Combining available geological data with the geophysical data suggests that this hollow is a buried stream channel eroded into the top of basalt.

When all observed basalt outcrops are plotted in the area between The Butte and profile F10, a line can be drawn between an area to the southwest where outcrops are abundant and an area to the southeast where there are no outcrops, as shown in Figure 1. Where this line crosses profiles F3 through F8 it is coincident with either the minimum or the steep southwestern limb of magnetic anomaly B. The line crosses profiles F9 and F10 at the position of anomaly D; this is consistent with anomaly D having the same character as anomaly B, as noted above. These observations suggest that the line marking the northeastern limit of basalt outcrops and magnetic anomalies B and D represent a step in the basalt surface that is the edge of a buried channel. The absence of basalt outcrops to the northeast is a result of erosion of the top of basalt and subsequent burial by sediments. The gravity anomaly on profile F4 indicates that the channel is symmetrical and approximately 1500 to 2000 feet wide at this

location. The minima of gravity lows on profiles F7 and F9 are marked G on Figure 1. The gravity anomaly on F7 is asymmetrical and suggests that the channel is broader at this location, and that its southwestern side is steeper and higher than the northeastern side. The 1000-foot wide central portion of this anomaly, however, is symmetrical. Gravity profile F9 is also asymmetrical, and also suggests that the southwestern side of the channel is steep. This profile does not extend far enough to the northeast to indicate the possible width of the channel south of Game Farm Hill.

Two geological observations add further support to this hypothesis. First, loose gravels are present at two locations along the southern flank of Game Farm Hill. Large-scale cross bedding is present in the gravel outcrop to the west that indicates a southeastern direction of current flow. This is consistent with the trend of the line delineating the limit of basalt outcrops and with the interpretation of the geophysical data. Second, Myers and Price (1979) show the top of basalt immediately to the north of The Butte to be 10 feet deeper than 1/2 mile farther north. Considering the overall northeasternly dip of the basalt surface in this area, this suggests channeling in the top of basalt just north of The Butte.

Conclusions

The northwesterly extension of the Finley Quarry fault zone proposed by Cochran (1982), is equivocal. The magnetic signature of this fault zone on The Butte is not well characterized, and the prominent magnetic anomaly on profiles between The Butte and Game Farm Hill is not closely similar to the anomalies on either of the two profiles that cross the fault zone. Similarly, magnetic anomalies that may be associated with a fault on Game Farm Hill do not resemble the anomalies on profiles immediately to the southeast.

Although the possibility cannot be ruled out that the magnetic anomalies on profiles between The Butte and Game Farm Hill, and to the south of Game Farm Hill, do represent faults, these data do not provide a priori evidence that faulting is continuous between the anticlines. Re-interpretation of Cochran's gravity profiles and the existing geological data suggest that a more plausible explanation of the magnetic anomalies is that they represent the northeastern edge of a buried channel that was eroded into the basalt surface and subsequently filled with low-density sediments.

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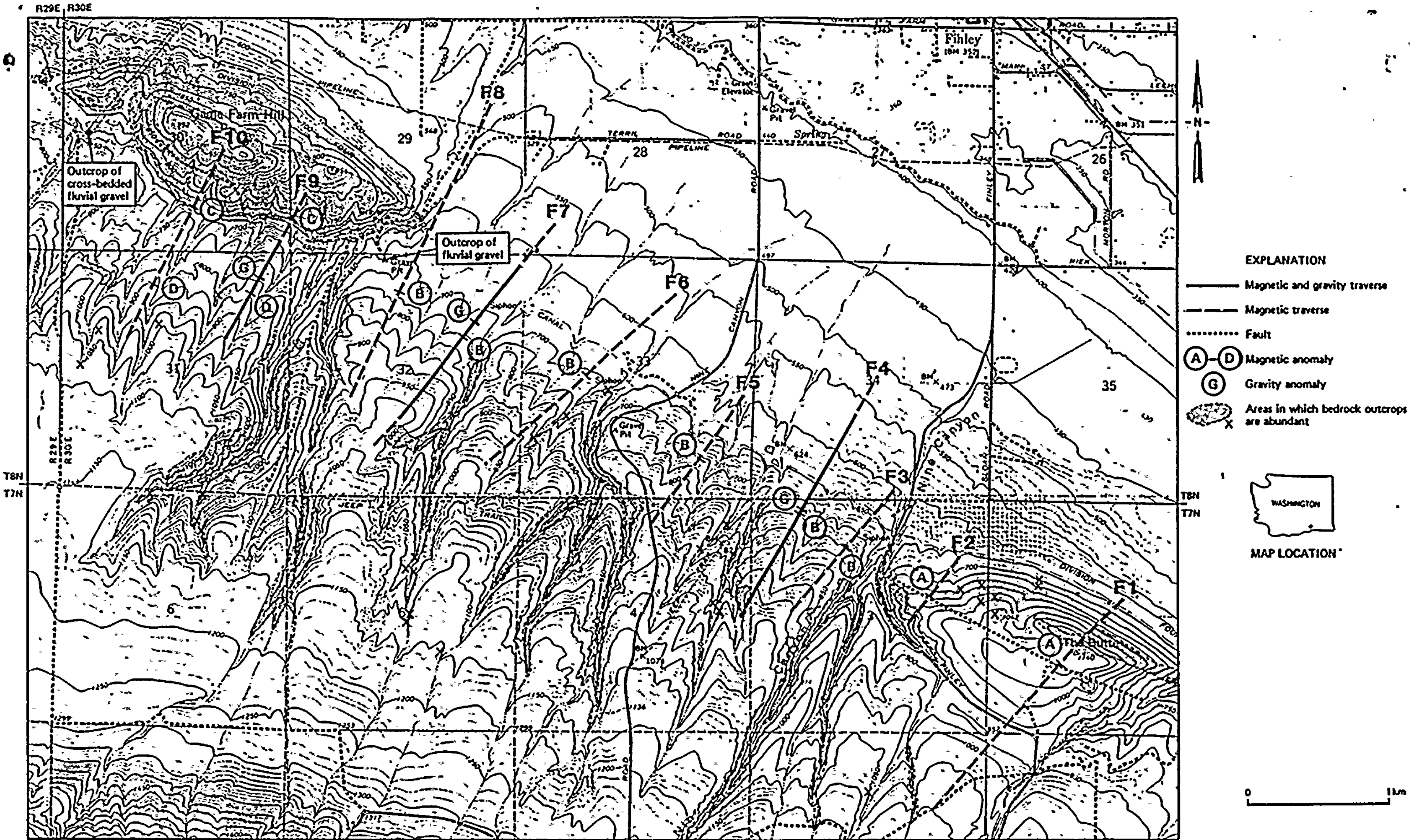

Base map from Pasco and Nine Canyon 7.5' quadrangles, United States Geological Survey

Project No. 14940	Hanford FSAR	GEOPHYSICAL TRAVERSE AND ANOMALY LOCATIONS IN THE VICINITY OF THE BUTTE AND GAME FARM HILL	Figure 1
Woodward-Clyde Consultants			

SUPPLEMENT TO RESPONSE TO QUESTION 361.17:

In the response to NRC Question 361.17, site specific response spectra were developed for the WNP-2 site by averaging a suite of response spectra computed from ground motions recorded during earthquakes of local Richter magnitude M_L 6.1 ± 0.3. The chosen M_L of 6.1 corresponded to the assigned magnitude of the 1936 Milton-Freewater earthquake. For the analysis, an earthquake of similar magnitude was assumed able to occur randomly near the site. As discussed in the response to Question 361.17, the 1936 earthquake is considered to be associated with a north-east trending fault, parallel to, and likely an element of, the Hite fault system. The assumption that an event of similar size could occur randomly in the vicinity of the site is considered not to be a valid hypothesis.

During the meeting of February 10, 1982, the NRC staff requested the following additional information pertaining to the random earthquake analysis:

- Evaluation of the effect of a revised magnitude estimate for the 1936 earthquake on the site specific response spectra.

- Documentation of the site response analyses that were used as an aid in judgement in assessing appropriate recording station site characteristics.

- Computation of statistical response spectra for reduced data sets with mean distances (rupture - epicentral) of 14 km and 12 km.

- Computation of statistical response spectra for the basic data set with one of the two recordings obtained at the San Juan Bautista Overpass during the 1979 Coyote Lake earthquake removed.

- Computation of statistical response spectra for the basic data set weighted by area using rupture - epicentral distance to determine the applied weighting.

This document provides the requested additional information.

Effect of Revised Magnitude Estimate for 1936 Earthquake

Re-evaluation by Woodward-Clyde Consultants (1982) of the magnitude for the 1936 Milton-Freewater earthquake indicates that the magnitude of 6.1 is not a local Richter magnitude. The study concludes that the M_L cannot be determined for the 1936 earthquake and that the surface wave magnitude of M_S 5.7 should be used for estimating ground motions.

The site specific spectra presented in response to Question 361.17 were computed by averaging a suite of recordings obtained on soil sites at distances of 3 to 26 km from earthquakes of local magnitude M_L 5.7 to 6.4. The mean magnitude of the data set is M_L 6.1 and the mean distance to the earthquake rupture is 17 km. The range of surface wave magnitudes for the earthquake in the M_L 6.1 data set is from M_S 5.3 to 6.6. The mean surface wave magnitude for the data set is also 6.1, which is 0.4 magnitude units above the M_S for the 1936 earthquake.

The effect of a change in surface wave magnitude from 6.1 to 5.7 on ground motions at a distance of 17 km can be evaluated using available attenuation relationships. Appendix 2.5K to the WNP-2 FSAR presents attenuation relationships developed for peak horizontal accelerations. In addition, recently published

studies by Campbell (1981) and Joyner and Boore (1981) present attenuation relationships for peak horizontal accelerations.

All three relationships give fairly consistent results in terms of the difference in ground motions from M_S 6.1 and 5.7 events at a distance of 17 km; the relationships indicate that at a distance of 17 km the peak acceleration from a magnitude 5.7 earthquake should be approximately 20 percent lower than the peak acceleration from a magnitude 6.1 earthquake. This reduction also reasonably applies to spectral accelerations in the acceleration amplification portion of the response spectra (at periods equal to, or less than about 0.3 seconds). At longer periods, the reduction in spectral accelerations due to a decrease in magnitude should be even greater.

<u>Relative Response Characteristics of Plant Site</u>

Summarized herein are the results of a limited number of ground response analyses and site period calculations to examine the response characteristics of the plant site shear wave velocity profile relative to the response characteristics of velocity profiles typical of recording stations used in the random earthquake analysis.

Site response analyses were conducted for four profiles generally similar to those included in the random earthquake study, and for the WNP1 and WNP4 profiles. Figure 1 shows the idealized shear wave velocity profiles. Figure 2 shows the strain dependent shear modulus reduction and damping relationships used in the analysis. Table 1 summarizes the analysis profile depths and material properties. The soil properties used in the analyses were obtained from the SSI analysis for WNP 1 and 4 (United Engineers and Constructors, 1975). Site response computations were made for all the profiles using computer program SHAKE. The input accelerogram was the Lake Hughes #12 recording (N21E)

obtained during the Feb., 9, 1971 San Fernando earthquake. The accelerogram was input as a rock outcrop motion. The computed shear strain levels are summarized in Table 1.

Figure 3 shows the ratios of surface response spectra calculated for the four soil profiles to surface response spectra calculated for the WNP-1 profile. Figure 4 shows the same ratios for the WNP-4 profile. As can be seen, for periods less than 1.0 second, the computed reponse of the WNP-1 and WNP-4 profiles is generally lower than the computed response of the four soil profiles. The differences in computed site response are well within the observed scatter in the recorded data used in the random earthquake analysis. As the objective of these analyses was to look at relative site response, it is expected that the results are not too sensitive to the characteristics of the input accelerogram.

The fundamental periods of the profiles were calculated using sucessive application of the two layer solution (Dobry et. al., 1976). The site periods obtained in this manner agreed closely with the period of maximum amplifications computed using SHAKE. The computed site periods are summarized in Table 1. The results indicate that the WNP profiles have the general characteristics of a deep stiff soil profile.

The results of these analyses indicate that the response characteristics of the plant site are not significantly different from the response characteristics of the recording stations used in the random earthquake analysis.

Statistical Response Spectra for Reduced Distance Data Sets

To obtain a mean distance (rupture-epicentral) of 14 km, the six most distant recordings were removed from the basic data set. All six were recordings obtained during the 1971 San Fernando

earthquake. The resulting mean distance is 14.0 km and the mean magnitude is M_L 6.1. The median, mean and 84^{th} percentile peak accelerations increase by approximately 6 percent (see Table 2). The resulting statistical spectra are compared with the spectra obtained for the basic data set in Figure 5. The average increase in spectral acceleration is approximately 4 percent with a maximum increase of approximately 10 percent.

To obtain a mean distance of 12 km, five additional records, all from the 1971 San Fernando earthquake, were removed from the data set. The resulting mean distance is 11.8 km and the mean magnitude is M_L 6.0. The median, mean and 84^{th} percentile peak accelerations increase by approximately 10 percent. The resulting statistical spectra are shown in Figure 6. The average increase in spectral acceleration is approximately 6 percent with a maximum increase of approximately 18 percent.

<u>Effect of Removal of One Coyote Lake Earthquake Recording on Statistical Response Spectra</u>

The highway 156/101 overpass near San Juan Bautista, California is instrumented with 4 strong motion recording instruments. Two of these instruments are located at the base of columns supporting the bridge deck. Recordings CL07 and CL08 from these two instruments were included in the basic data set.

Two analyses were performed, one with recording CL07 removed from the data set and one with recording CL08 removed from the data set. The resulting mean magnitude, mean distances, and median, mean and 84^{th} percentile peak accelerations are tabulated in Table 2. The resulting statistical spectra are compared with the spectra obtained for the basic data set in Figures 7 and 8. Removal of either of the records results in less than a 3 percent change in the results.

Effect of Alternate Area Weighting Scheme on Statistical Response Spectra

A difficulty with the methodology used in developing the site specific response spectra is that the analysis is subject to the chance distribution with distance of available recordings which satisfy the selection criteria. As discussed in the response to Question 361.17, if earthquakes are assumed to occur randomly within a 25 km radius from the site, then the relative frequency of earthquakes occurring within a certain distance band should be proportional to the ratio of the area of the annular ring defined by the distance band to the total area of the circle. A weighting scheme was developed in order to achieve the proper distribution of recordings with distance. The weight applied to each record in a particular distance band, $W(R_1 \text{ to } R_2)$, is computed by the relationship:

$$W(R_1 \text{ to } R_2) = \frac{R_2^{\,2} - R_1^{\,2}}{R_T^{\,2}} \quad \frac{N_T}{N(R_1 \text{ to } R_2)}$$

where R_1 and R_2 are the limits of the distance band, R_T is the radius of the circle (25 km), $N(R_1 \text{ to } R_2)$ is the actual number of records in the distance band and N_T is the total number of records in the data set. In the response to Question 361.17, the number of events falling into each distance band was determined on the basis of rupture-hypocentral distance, which is the more conservative choice.

If the rupture-epicentral distance definition is used, the following weights are obtained:

R_1 (km)	R_2 (km)	N (R_1 to R_2)	W (R_1 to R_2)
0	5	8	0.35
5	10	14	0.60
10	15	8	1.75
15	20	16	1.23
20	25+	24	1.05

Statistical spectra computed using the above weights are compared in Figure 9 with spectra obtained using the previous weighting scheme. The use of the rupture-epicentral distance definition results in a 4 percent reduction in peak acceleration and an average 3 percent reduction in spectral accelerations. The lower statistical ground motions result from a greater percentage of the data set falling within the first two distance bands and thus these higher acceleration records are given lower weight.

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TABLE 1

Material Properties, Effective Shear Strains, and Site Periods for Response Spectral Profiles

Profiles	Total Depth (ft)	Rock Shear Wave Velocity (fps)	Material Properties		Effective Shear Strains (%)	Site Period (sec)
			Depth Range (ft)	Material* Type		
WNP 1	500	10,000	0-96	1	0.005-0.05	1.2
			96-242	2	0.001-0.002	
			242-500	1	0.02-0.03	
WNP-4	500	10,000	0-96	1	0.006-0.11	1.3
			96-242	2	0.0009-0.002	
			242-300	1	0.02	
			300-330	2	0.002	
			330-500	1	0.02-0.03	
Soil Profile 1	500	2,500	0-500	1	0.009-0.05	1.0
Soil Profile 2	500	2,500	0-242	1	0.02-0.10	0.9
			242-500	2	0.006-0.009	
Soil Profile 3	57	2,500	0-57	1	0.02-0.06	0.3
Soil Profile 4	200	2,500	0-200	1	0.02-0.11	0.7

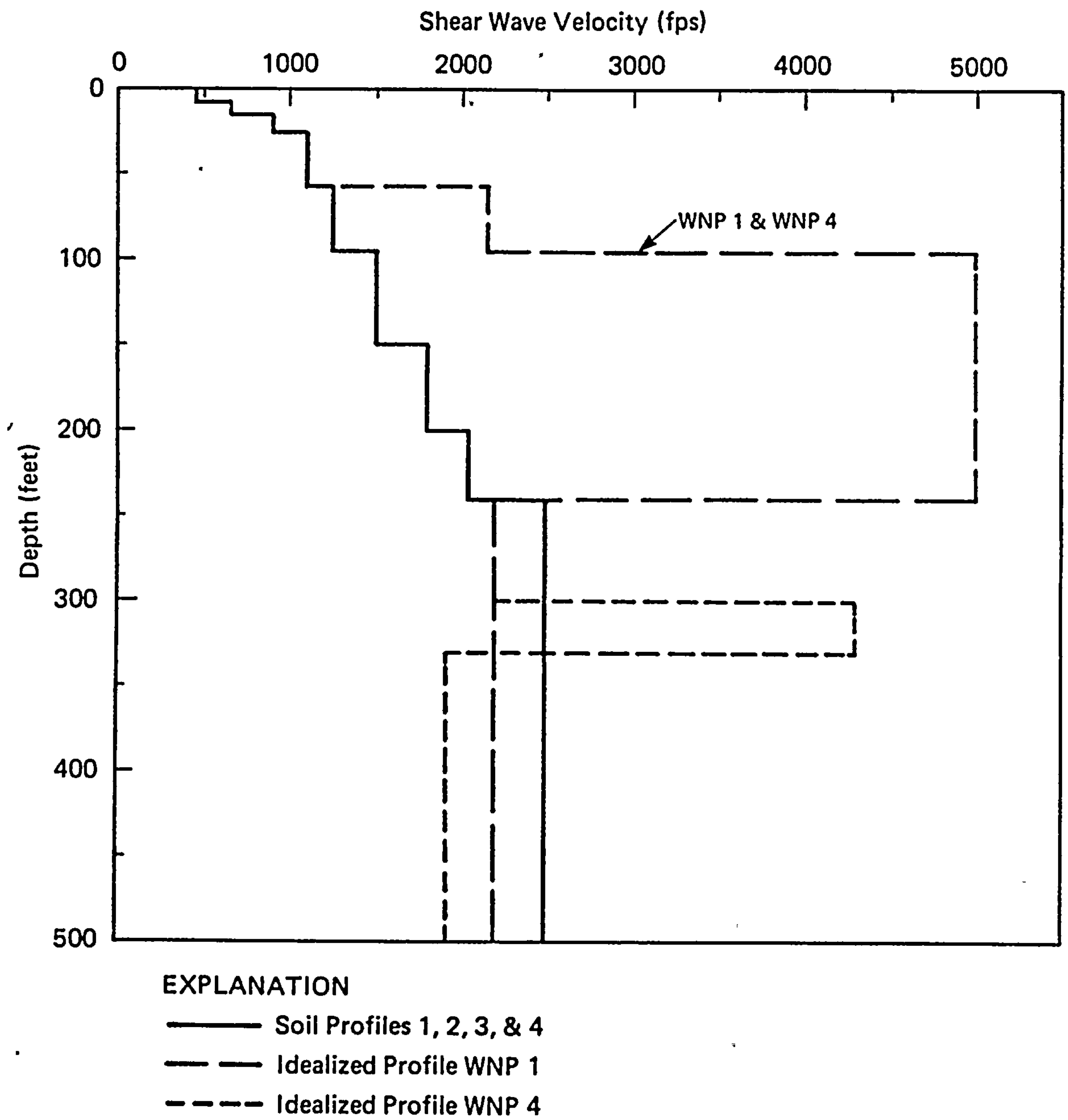
*Strain Dependent Shear Modulus Reduction and Damping Shown in Figure 2.

TABLE 2

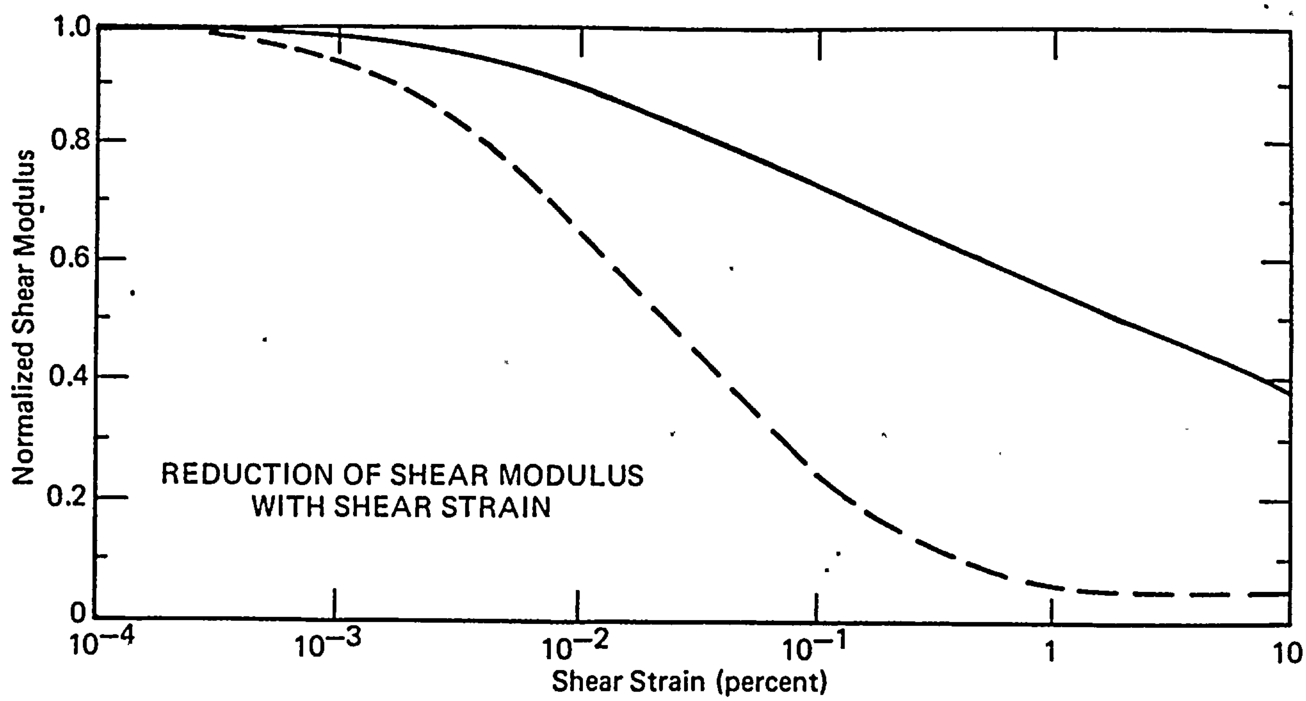
Statistical Magnitude, Distance and Peak Accelerations

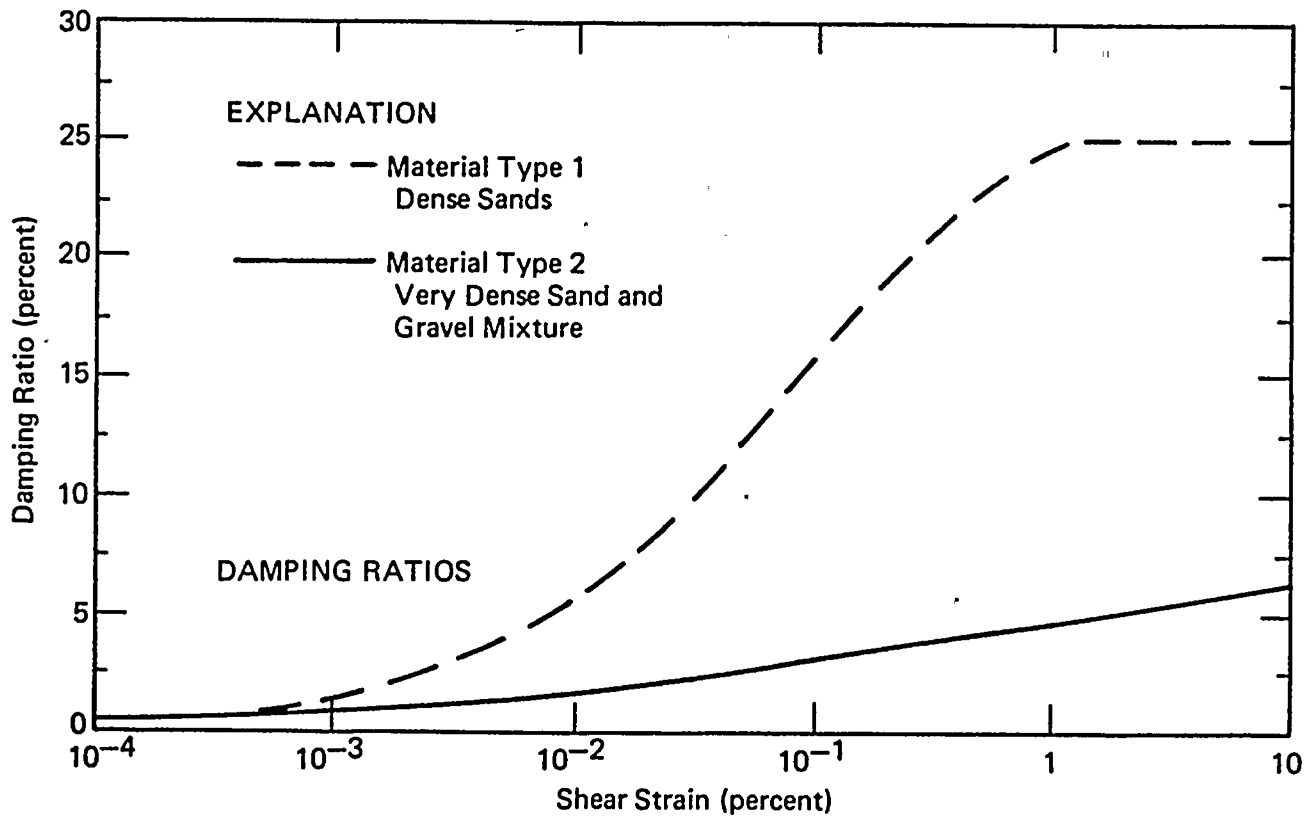
For Analysis Data Sets

Data Set	Number of Records	Mean Magnitude (M_L)	Mean Distance (km)		Peak Acceleration (g)		
			Rupture-Hypocentral	Rupture-Epicentral	Median	mean	84th percentile
Basic Data Set	70	6.12	17.6	16.1	.174	.191	.270
Basic Data Set with CL07 removed	68	6.14	17.6	16.0	.176	.194	.272
Basic Data Set with CL08 removed	68	6.14	17.6	16.0	.177	.194	.273
Reduced Data Set 6 Most Distant Records Removed	58	6.07	15.9	14.0	.183	.203	.288
Reducted Data Set 11 Most Distant Records Removed	48	6.00	14.1	11.8	.186	.209	.300
Basic Data Set Weighted by Area Using Rupture-Hypocentral Distance	70	6.11	17.1	15.3	.170	.186	.260
Basic Data Set Weighted by Area Using Rupture-Epicentral Distance	70	6.13	19.1	17.7	.163	.178	.247

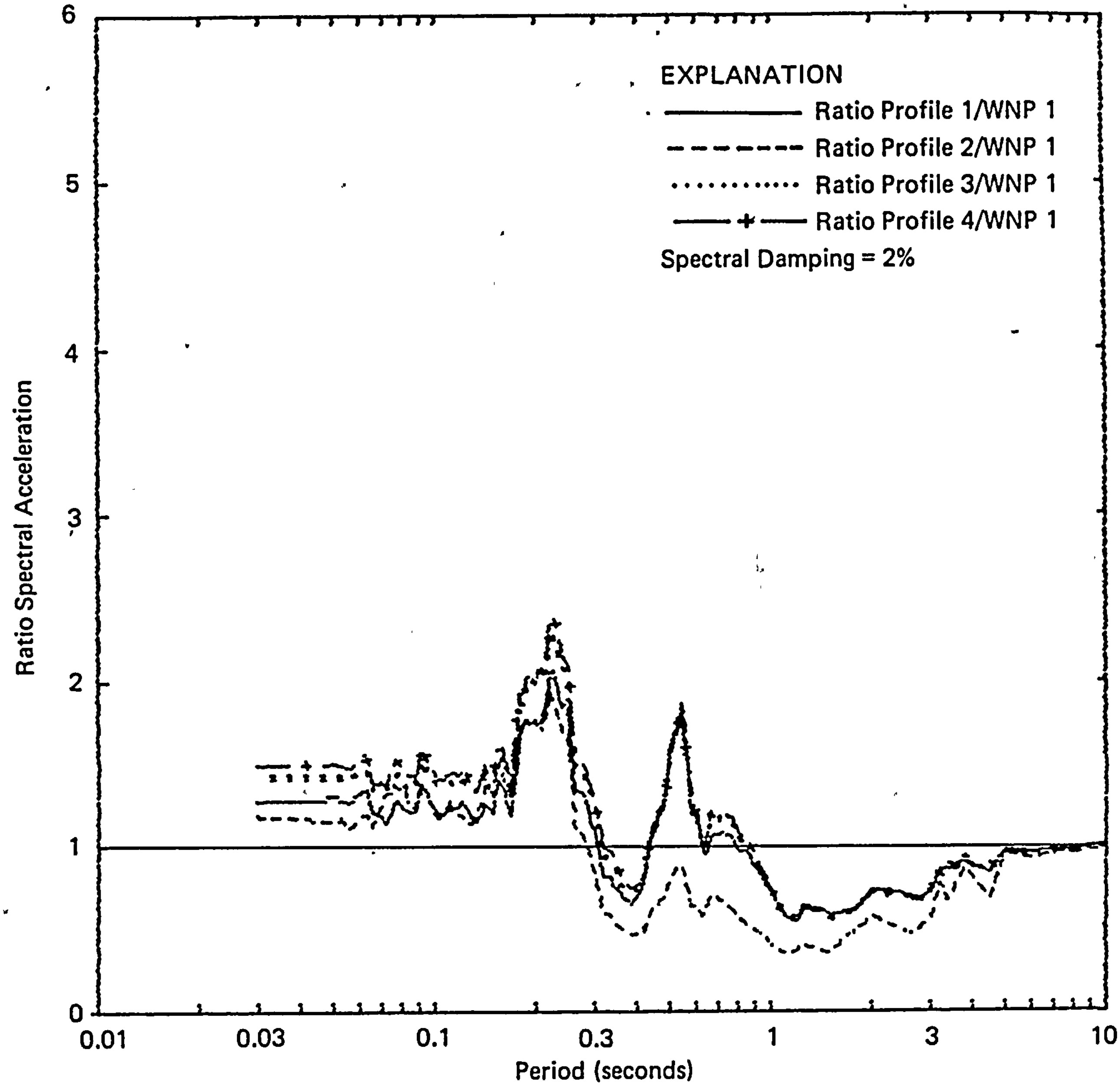


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	SHEAR WAVE VELOCITY PROFILES USED IN ANALYSES	Figure 1

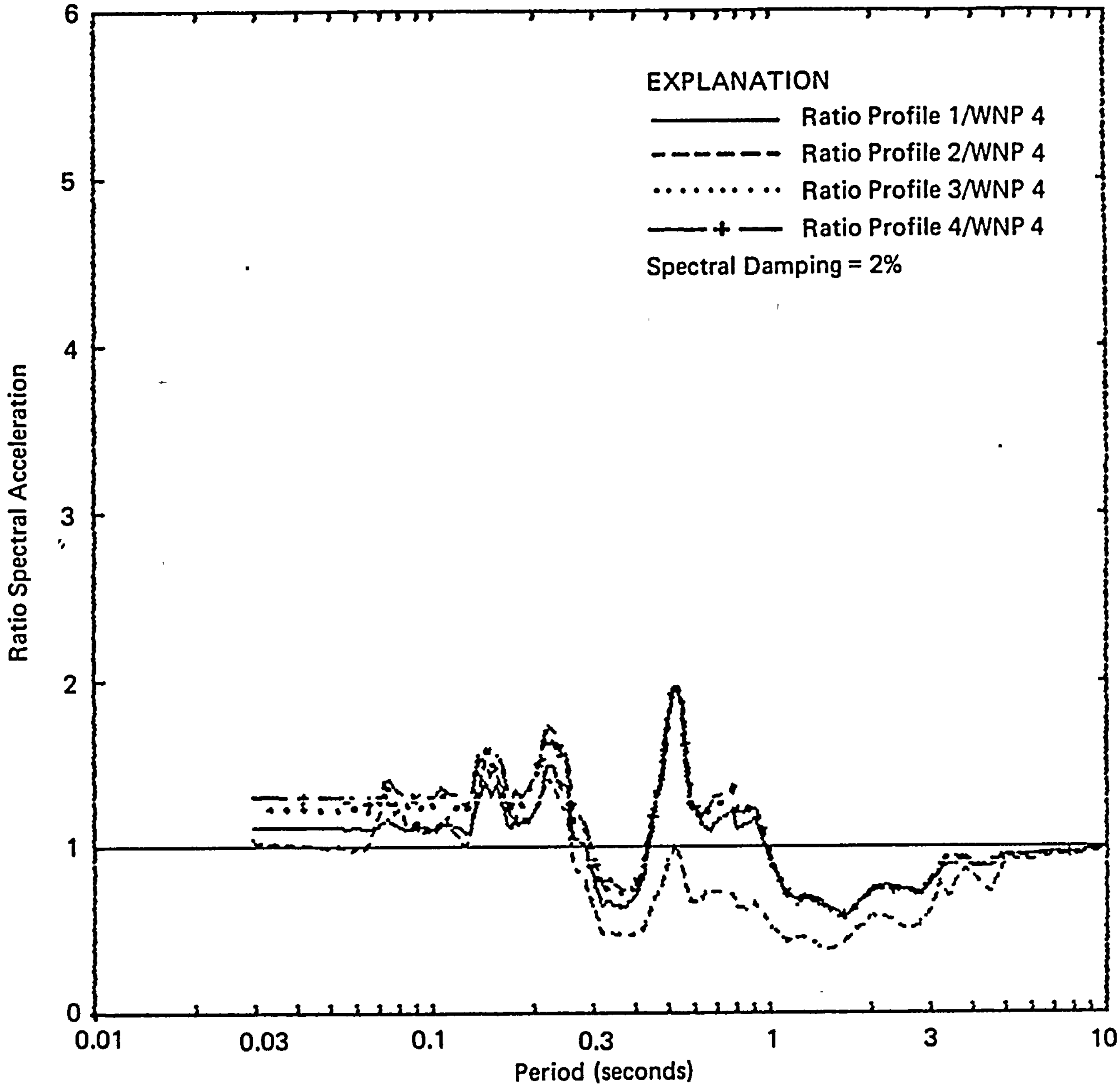




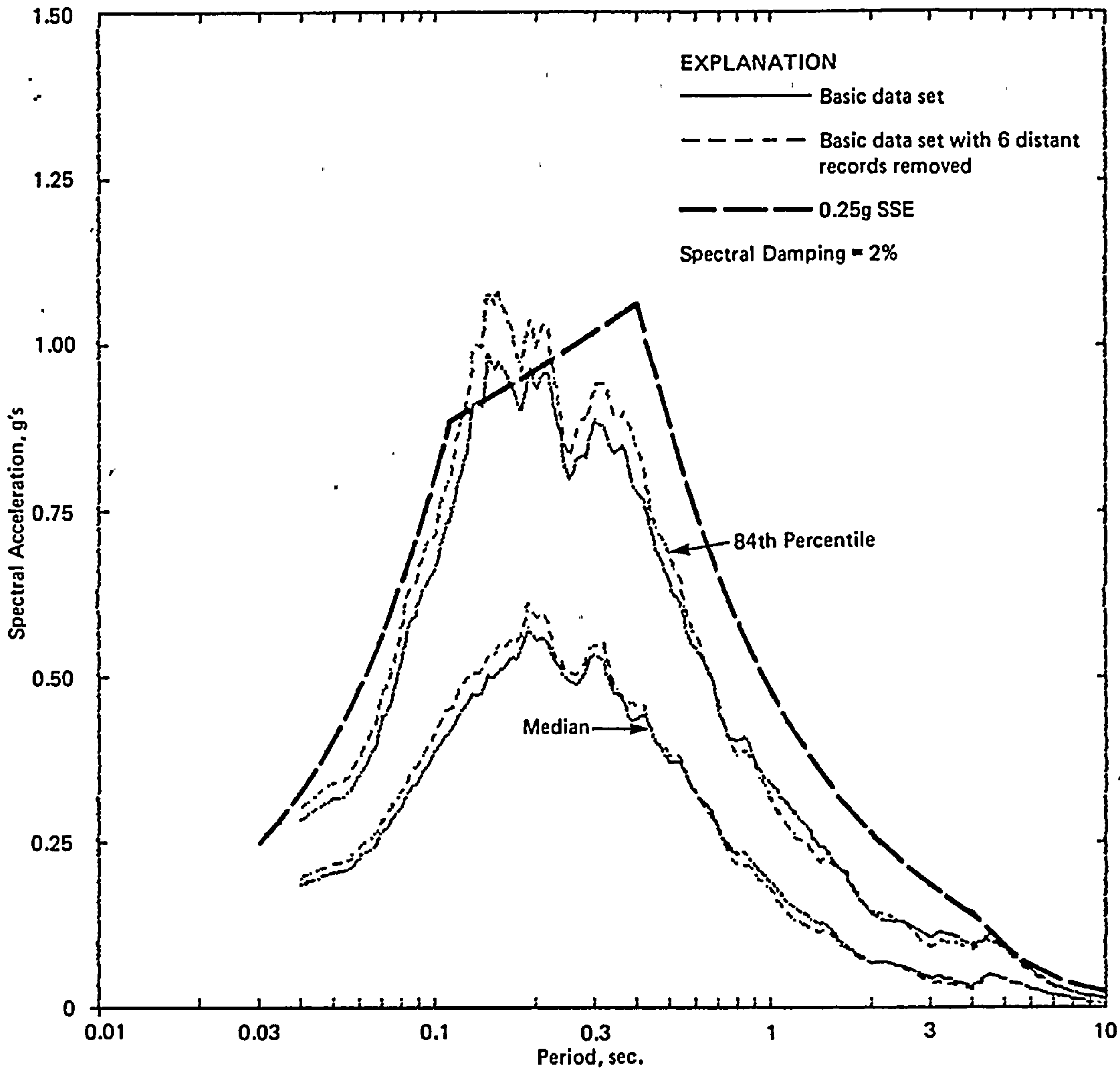
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRAIN DEPENDENT RELATIONSHIPS FOR SHEAR MODULI REDUCTION AND DAMPING USED IN ANALYSES	Figure 2



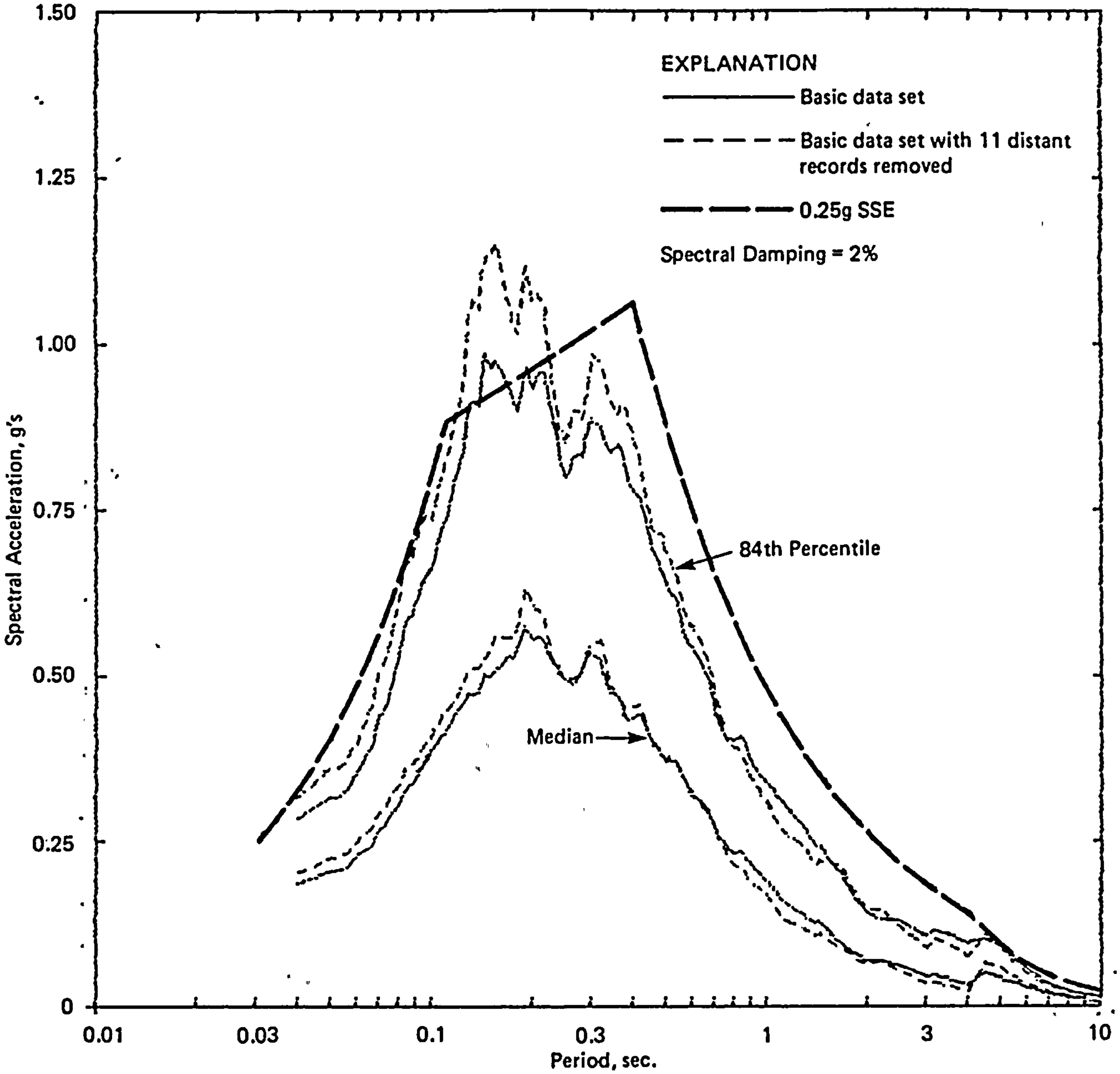
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	RATIO OF COMPUTED SURFACE RESPONSE SPECTRA: ANALYSIS PROFILES 1—4/WNP 1 PROFILE	Figure 3



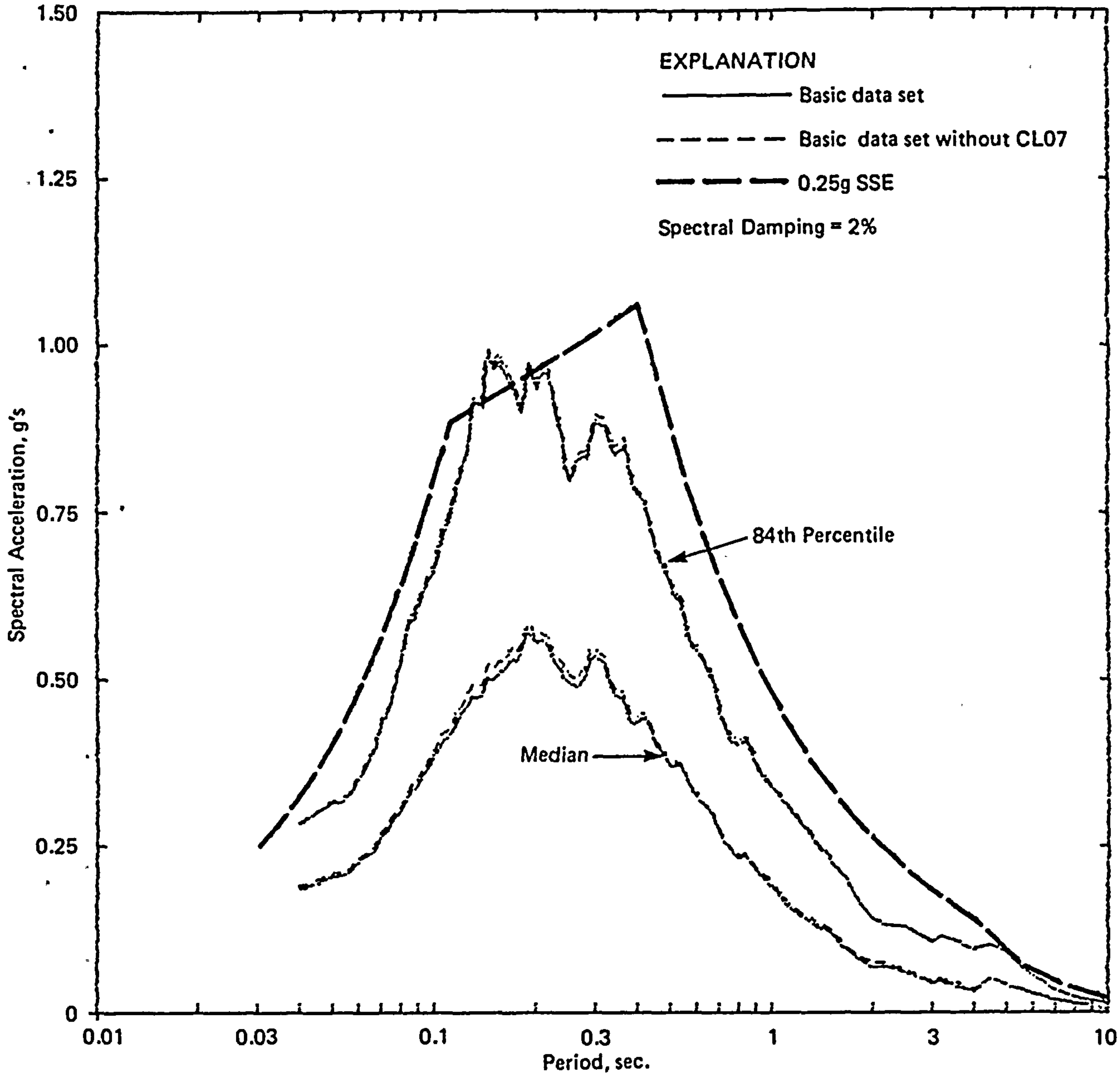
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	RATIO OF COMPUTED SURFACE RESPONSE SPECTRA: ANALYSIS PROFILES 1–4/WNP4 PROFILE	Figure 4



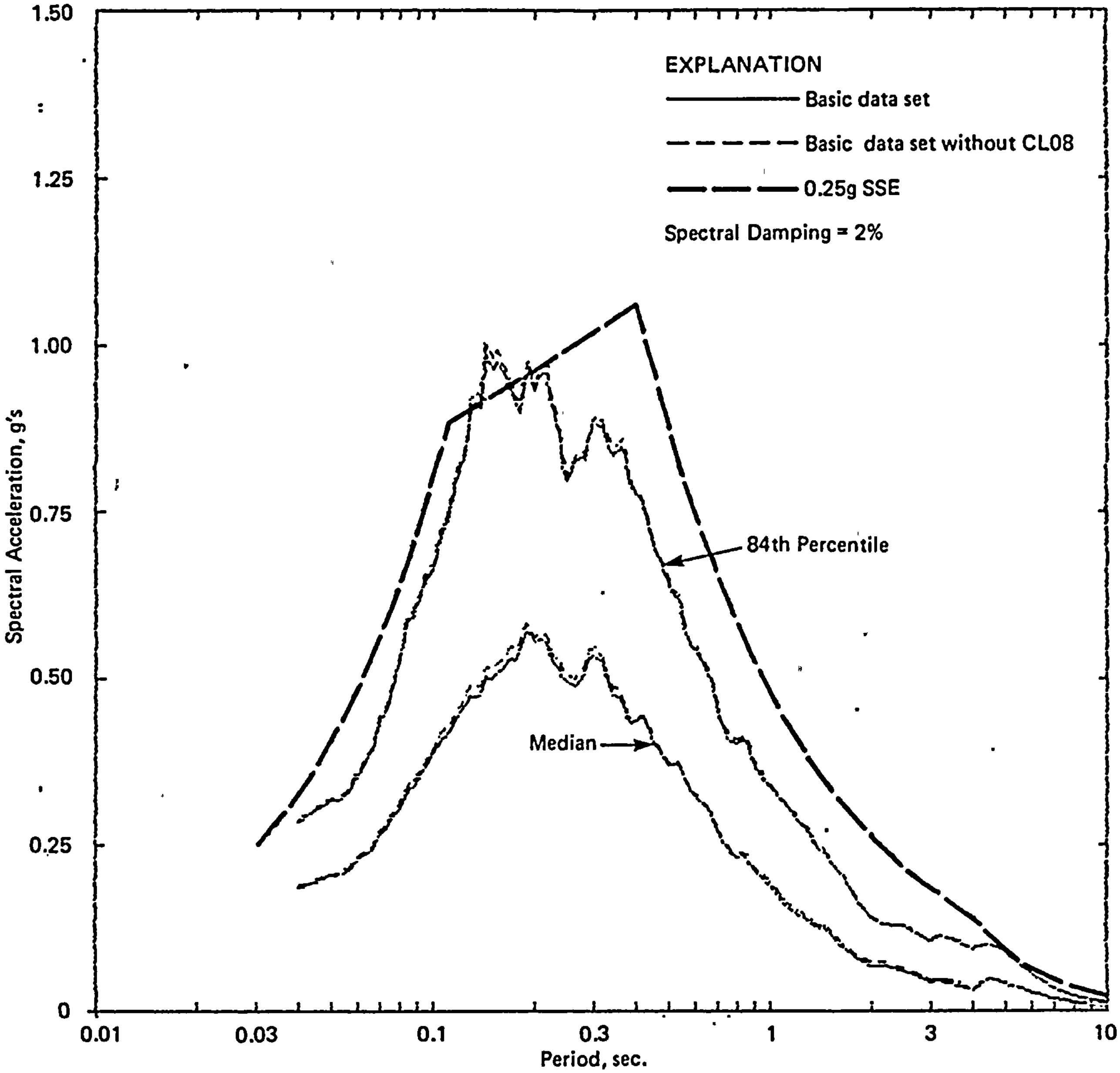
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EFFECT OF REMOVING 6 MOST DISTANCE RECORDS ON SITE SPECIFIC RESPONSE SPECTRA: 2% SPECTRAL DAMPING	Figure 5



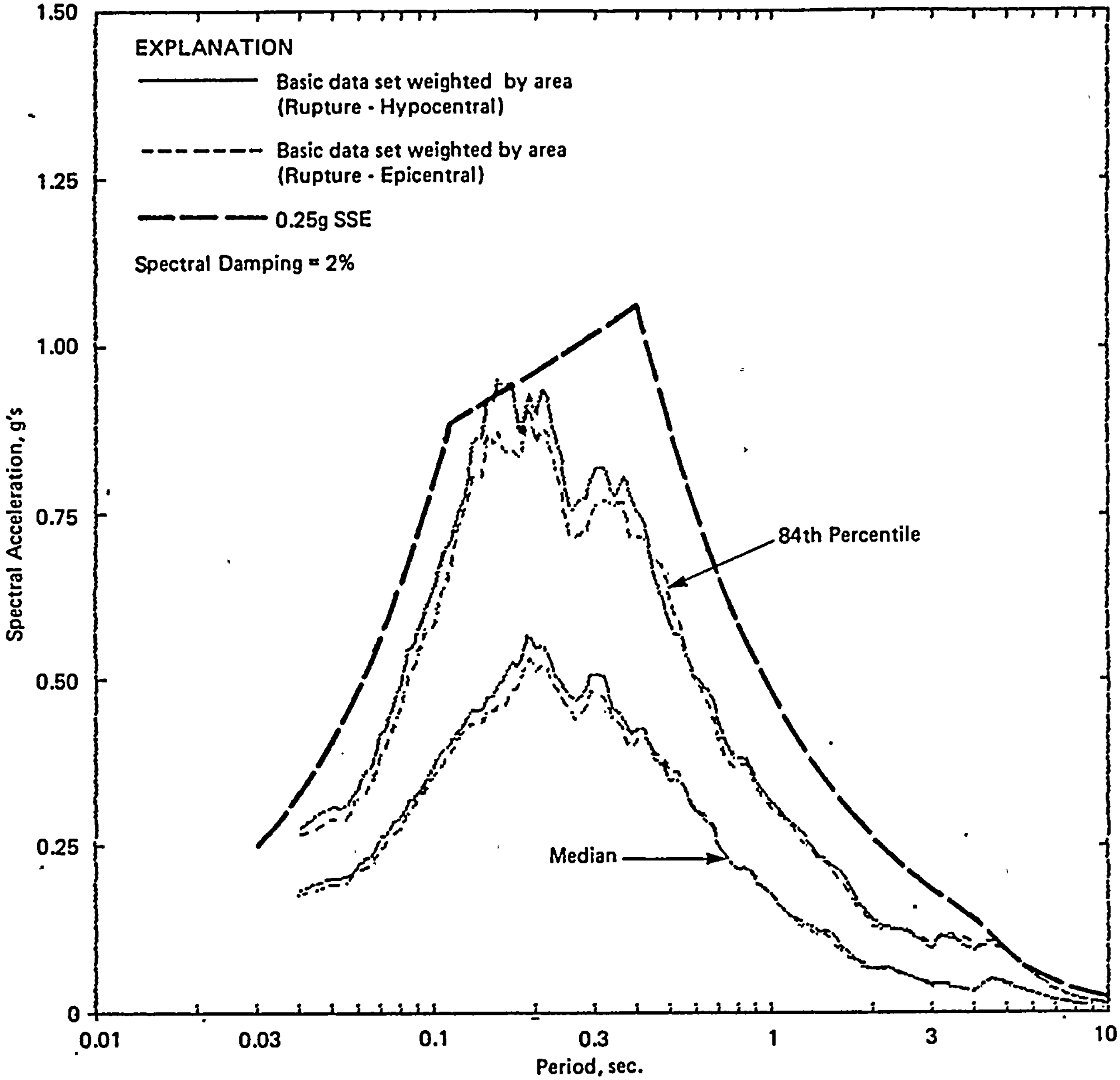
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EFFECT OF REMOVING 11 MOST DISTANCE RECORDS ON SITE SPECIFIC RESPONSE SPECTRA: 2% SPECTRAL DAMPING	Figure 6



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EFFECT OF REMOVING RECORD CL07 ON SITE SPECIFIC RESPONSE SPECTRA: 2% SPECTRAL DAMPING	Figure 7



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EFFECT OF REMOVING RECORD CL08 ON SITE SPECIFIC RESPONSE SPECTRA: 2% SPECTRAL DAMPING	Figure 8



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	COMPARISON OF AREA WEIGHTED SITE SPECIFIC RESPONSE SPECTRA FOR RUPTURE - EPICENTRAL AND RUPTURE - HYPOCENTRAL DISTANCE DEFINITIONS: 2% SPECTRAL DAMPING	Figure 9

SEGMENTATION

This discussion is provided to clarify the concept of structural segmentation by: 1) defining segmentation in terms of the specific usage in the WNP-2 FSAR, appendixes, and response to Q. 360.19; 2) describing the implications of segmentation to fault behavior and the assessment of maximum earthquake magnitude; and 3) summarizing the assessment presented in response to Q 360.14 regarding the segmentation of the Cle Elum-Wallula lineament (CLEW).

DEFINITIONS

The following terms are defined in the context of their usage in the WNP-2 FSAR and supporting documents. Figure 1 is a schematic diagram showing the relationships among the features that are defined below.

Zone of Deformation. A zone of deformation is a general term used to describe an area developed on a regional scale that is characterized by a distinctive amount, style and orientation of folding, faulting, and/or other types of deformation that distinguishes it from surrounding areas. For example, the zone of deformation in Figure 1 is differentiated from surrounding areas by the intensity of folding and faulting and differences in the trend of the folds. Boundaries of a zone of deformation may be sharp or diffuse. Although a zone of deformation may contain faults and fault zones that could be potential seismic sources, a zone of deformation is not a discrete seismic source.

Fault/Fault Zone. A fault is a relatively continuous fracture along which displacement has occurred. A fault zone is comprised of primary and subsidiary faults that together form a relatively continuous zone of faulting, (Bonilla, 1970).

Segmentation. Segmentation is a general term that refers to the identification of parts, or segments, of either a zone of deformation or a fault zone that exhibit geologic and geomorphic evidence of relatively uniform past behavior when compared to adjacent segments.

Structural Domains. Structural domains are segments of a zone of deformation. Structural domains are defined on the basis of similarities in structural style, especially in the relationships between folding and faulting. For example, domain B in Figure 1 is characterized by a relatively continuous fault zone and structural domain A is characterized by a series of anticlines, some of which are associated with faults. The differences in structural style between the structural domains reflect long-term differences in deformational behavior. Structural domains do not necessarily represent discrete seismic sources.

Fault Segments. Fault segments are parts of faults or fault zones and are identified on the basis of geometric and geologic characteristics including: 1) discontinuities in the surface expression of faults, 2) abrupt changes in fault attitude, 3) abrupt changes in fault type, 4) changes in the complexity of faulting in terms of branching and secondary faults, and 5) changes in the displacement history or the age of the most recent displacement. An example of a fault segment is shown in Figure 1.

Fault Rupture Segments. A fault rupture segment is the part of an individual fault or fault zone that ruptures during a single earthquake. A fault rupture segment is defined by its location and length. The bases for recognizing fault rupture segments along a fault are: 1) historical surface faulting, or 2) interpretations of fault segments. For example, the fault rupture segments associated with the 1857 and 1906 earthquakes along the San Andreas fault provide a basis for estimating the location of

future rupture segments. In the absence of historical surface faulting data, fault segments may be interpreted from geologic and geomorphic data to represent fault rupture segments. For example, Wallace (1978) identified fault rupture segments associated with prehistoric earthquakes on faults in the Great Basin province. Another example is the Satus Peak anticline segment of Toppenish Ridge, which is interpreted to be a fault rupture segment on the basis of the age of deformation and the continuity of Holocene scarps (see Response to Q360.19). In addition, Swan and others (1980) have recognized fault segments of the Wasatch fault and work is continuing to identify individual fault rupture segments associated with prehistoric earthquakes (Swan, personal communication, 1982).

Fault Rupture Length. Fault rupture length is the length of a fault or fault zone that ruptures during an earthquake. Methods of estimating fault rupture length include: 1) identification of fault segments, and 2) assuming some fraction of the total fault length will rupture during a single event. If the second method is used, the rupture may occur at any location along the fault. Fault rupture length is an important parameter because it is related to earthquake magnitude.

IMPLICATIONS TO FAULT BEHAVIOR AND MAXIMUM EARTHQUAKE MAGNITUDES

Segmentation has implications to the estimation of the future behavior of faults and zones of deformation. By definition, segments have had relatively uniform behavior through the geologic past. Therefore, if the geologic structures were developed in a stress field having the same orientation as the present stress regime, segmentation can be used to predict future deformation, and the identification of fault segments can be used to constrain potential future fault rupture lengths. This provides a basis for using geologic data to estimate the magnitudes of future earthquakes.

Studies of the historical seismicity of the Columbia Plateau indicate that the region is undergoing north-south compression. This is consistent with the stress orientation that is inferred based on the orientation of the geologic structures in the plateau. Therefore, the nature of the observed deformation can be used to predict future deformation.

The geologic mapping along structural domain II of CLEW shows that the dominant mode of deformation is folding and that the faults are short and discontinuous (Figures 2.5-18 and 2.5-21, WNP-2 FSAR). Within the resolution of the geologic mapping, the ends of most of the faults are marked by the absence of displacement in volcanic rocks that are several millions of years old. From these data, it is reasonable to assume that future deformation will be similar to past deformation and that existing folds and faults will be the locations of future deformation. Domain I is characterized by a broad zone of folding that shows no evidence of throughgoing faulting. The postulation of a throughgoing fault within domain I or domain II during a future faulting event would require the development of new surface faulting within previously unfaulted terrain. A detailed study by Bonilla (1979) of worldwide cases of historical surface rupture has shown that "historic surface faulting that is considered to be new is quite rare." Bonilla found that "...in 108 examples of worldwide historic surface faulting on land, 91 percent occurred or probably occurred on pre-existing faults, 8 percent are indeterminate in this regard based on available data, and 1 percent (1 example) apparently occurred where no fault existed previously." The results of this study confirm that the evidence for the location of past surface faulting provides a sound basis for estimating the location of future surface faulting.

Segmentation has important implications to the assessment of the maximum earthquake magnitude that a fault is capable of gener-

ating. Approaches used to estimate maximum magnitude are presented in Appendix 2.5K and in the Response to Q360.14. The approaches include empirical relationships that relate fault rupture length and rupture area to earthquake magnitude. In applying these approaches, there is uncertainty in the estimation of the appropriate rupture length to be used in the analysis. The assessment of fault rupture length may be based on interpretations of fault rupture segments, which are location-specific; or on assumptions regarding the percentage of the total fault length that may rupture, which are not specific to location of rupture along the fault zone. The fraction of the total fault length that ruptures is usually less than one-half (Albee and Smith, 1966). Slemmons (1982) has shown that for selected major interplate strike-slip faults, the percent rupture decreases with increasing total length of the fault. The longest faults in his data set (1300 km) have ruptured no more than 40 percent of their total length. Slemmons' (1982) relationship may be useful in estimating rupture lengths along major interplate strike-slip faults; however, its applicability to lower activity intraplate tectonic settings and to faults having lengths of less than about 300 km is uncertain.

SUMMARY OF SEGMENTATION MODELS FOR CLEW AND RAW AND ESTIMATED RUPTURE LENGTHS

CLEW is a N50W trending zone of deformation that is defined by changes in the generally east-west trends of some of the folds of the Yakima fold belt to a more northerly trend within CLEW. The boundaries of CLEW as defined by Kienle and others, (1977) are diffuse and are not defined by faults (Figure 2).

CLEW is segmented into three structural domains on the basis of changes in of the style of deformation along its trend (Figure 2). Domain III to the southeast is characterized by down-to-the-north monoclinal folding and by the relatively

continuous Wallula Gap fault. The central domain, domain II, consists of a series of aligned domes and doubly-plunging anticlines. Some of the folds are associated with faults along parts of their length. There is no evidence for a throughgoing fault along domain II. Domains II and III together define the Rattlesnake-Wallula alignment (RAW).

The northwestern domain of CLEW, domain I, consists of a broad zone of folds and associated faults within the Yakima fold belt. Domain I is distinguished from the rest of the Yakima fold belt by the more northerly trend of the fold axes within CLEW compared to the generally east-west trend of the folds outside of CLEW. However, boundaries of CLEW in domain I are very diffuse and many of the fold trends within CLEW are similar to those outside of CLEW. Many of the folds that cross the postulated boundary of CLEW do not show any change in trend (e.g., Umtanum Ridge, Rattlesnake Hills, Yakima Ridge). This confirms that there is no sharp structurally defined boundary to CLEW in domain I and raises questions about its existence in this area. There is no evidence for a throughgoing fault in domain I.

For purposes of estimating maximum earthquake magnitudes, the faults within the structural domains of CLEW were considered. Domain I of CLEW is a diffuse zone of folds and associated faults and there are no throughgoing faults associated with the CLEW zone of deformation. The faults within this domain are too short and too far from the site to be of greater significance to the site than the faults in domains II and III. Therefore, only the faults in domains II and III (RAW) are considered in the deterministic assessment of maximum earthquake magnitudes. Domain II is characterized by folding and discontinuous faulting. The longest and most significant fault in this domain is the Rattlesnake Mountain fault. The Rattlesnake Mountain fault is a south dipping reverse fault. The mapped length and probable total length of the fault is 7 km, and, if the fault is inferred

to be present along the entire Rattlesnake Mountain anticline, its maximum inferred length is 20 km. In domain III, the Wallula Gap fault is the fault of most significance to the site. The maximum length of this fault is 45 km. It is a high angle reverse oblique slip fault that dips to the southwest.

The objective of identifying faults defining fault segments along the CLEW zone of deformation is to assess the location and length of fault that might be expected to rupture during the maximum earthquake on that fault if the fault is capable. Segmentation models depend, in part, on the deformational history and tectonic model of the structure. Although the weight of the available geologic data suggests that faults associated with the Rattlesnake-Wallula alignment are reverse-oblique- and reverse-slip faults, there is still some uncertainty regarding the kinematics of RAW. Therefore, two tectonic models are used to estimate the maximum rupture lengths that might occur on faults associated with RAW (domains II and III of CLEW). Table 1 summarizes the estimated rupture lengths for faults and inferred faults associated with RAW based on the different tectonic models and the various approaches that are used to estimate fault rupture lengths. These estimated rupture lengths are the ones presented in the response to Question 360.14 to estimate maximum earthquake magnitudes using empirical relationships that relate rupture length and rupture area to earthquake magnitude.

If faults associated with RAW are assumed to be predominantly strike-slip, two approaches were used to estimate the rupture length . If future displacements will occur only on faults that exist at the surface, the rupture length is estimated to be 50 percent of the total fault length as proposed by Wentworth and others (1969). The longest fault along RAW is the Wallula Gap fault. Fifty percent of its total length gives a rupture length of 23 km. Using this approach, it is assumed that this rupture can occur at the closest approach of the fault to the site. The

other faults that have been identified along RAW are the Finley Quarry, Badger Mountain and Rattlesnake Mountain faults. Of these, the Finley Quarry and Badger Mountain faults are too short and too far from the site to be of greater significance to the site than the Wallula Gap fault. The strike-slip model is not applicable to the Rattlesnake Mountain fault because it is a reverse-slip fault.

The second approach used to estimate fault rupture lengths along RAW, assuming a strike-slip model, is based on the fractional fault length relationship proposed by Slemmons (1982). However, it is uncertain whether the relationship is applicable because: 1) the data set of Slemmons (1982) is based on major interplate strike-slip faults and it is likely that the faults along RAW have a significant component of reverse slip, and 2) the faults in the data set are continuous fault zones at the surface, and there is no evidence for a throughgoing fault along domain II of RAW. The applicability of this approach to RAW is predicated on the assumption that there might be a wrench fault in the basement beneath RAW that is not expressed as a continuous strike-slip fault in the ten million year old basalts at the surface. This assumption is unlikely unless one postulates a geologically recent change in the orientation of the stress field so that the faults at depth have not had sufficient time to propagate upward and produce a continuous fault at the surface. However, the geologic evidence indicates that the orientation of the maximum compressive stress has been north-south during at least the past 10 million years. The geologic and seismic data suggest that the present maximum compressive stress direction is also north-south. Therefore, there is no evidence to suggest that the stress regime has changed orientation, thereby giving rise to an incipient strike-slip fault at depth beneath RAW.

The total length of RAW is 115 km. The average percent rupture that is associated with this length is 13.5 percent or 16 km, based on Slemmons' (1982) relationship. It is assumed that this rupture can to occur at the closest approach of RAW to the site.

Assuming a predominantly reverse-slip model, fault rupture segments were identified on the basis of the geologic field relationships, and future fault displacements are assumed to occur only where there are faults at the surface. The two faults along RAW that are of potential signficance to the site are the Wallula Gap fault, located 42 km southwest of the site, and the Rattlesnake Mountain fault, located 20 km west of the site. It is assumed that 50 percent of the maximum inferred lengths of these faults might rupture during a single event (Table 1) and that the fault rupture can occur at the closest approach of the fault to the site. Given a tectonic model where the displacement is predominantly dip-slip and has a major vertical component, it is unlikely that there are faults at depth capable of generating significant earthquakes that are not expressed in the basalt stratigraphy at the surface. Therefore, a continuous throughgoing fault is not postulated along RAW for the reverse-oblique-slip tectonic model.

The estimated rupture lengths based on the various tectonic models and approaches described above and in Table 1, are used to estimate maximum earthquake magnitudes that might be associated with RAW if it is assumed to be capable (see response to question 360.14).

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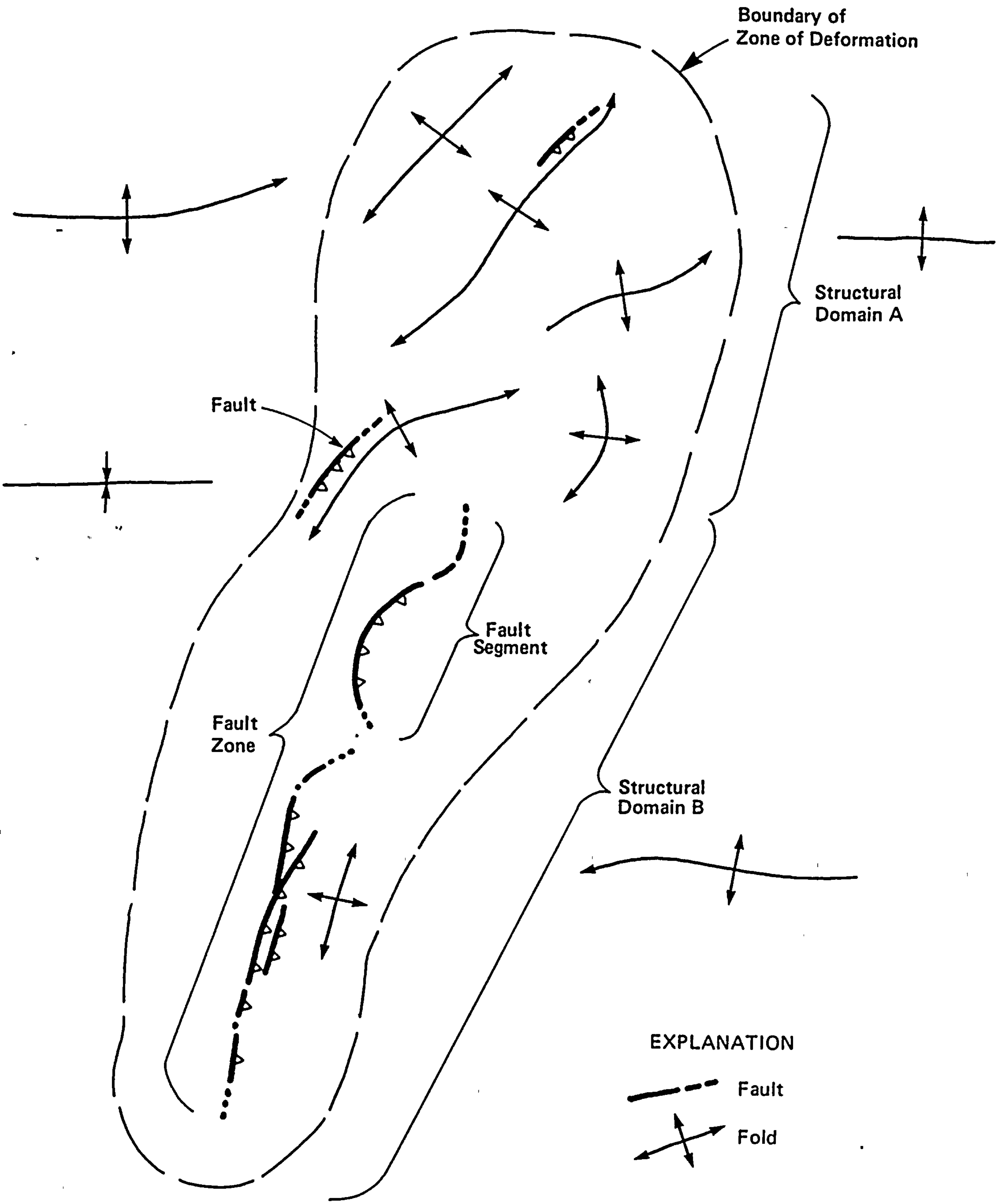
Table 1

ESTIMATED FAULT RUPTURE LENGTHS FOR
KNOWN AND INFERRED FAULTS ASSOCIATED WITH THE
RATTLESNAKE WALLULA ALIGNMENT

	Approach	Basis	Estimated Rupture Length	Closet Distance to Site
STRIKE SLIP MODEL				
	Segmentation	50% of Wallula Gap Fault (46 km)	23 km	20 km
	Slemmons (1982)	13.5% of inferred fault in basement beneath RAW (115 km)	16 km	20 km
REVERSE-SLIP MODEL				
	Segmentation	50% of Wallula Gap Fault (46 km)	23 km	42 km
	Segmentation	50% of maximum inferred length of Rattlesnake Mountain Fault (20 km)	10 km	20 km

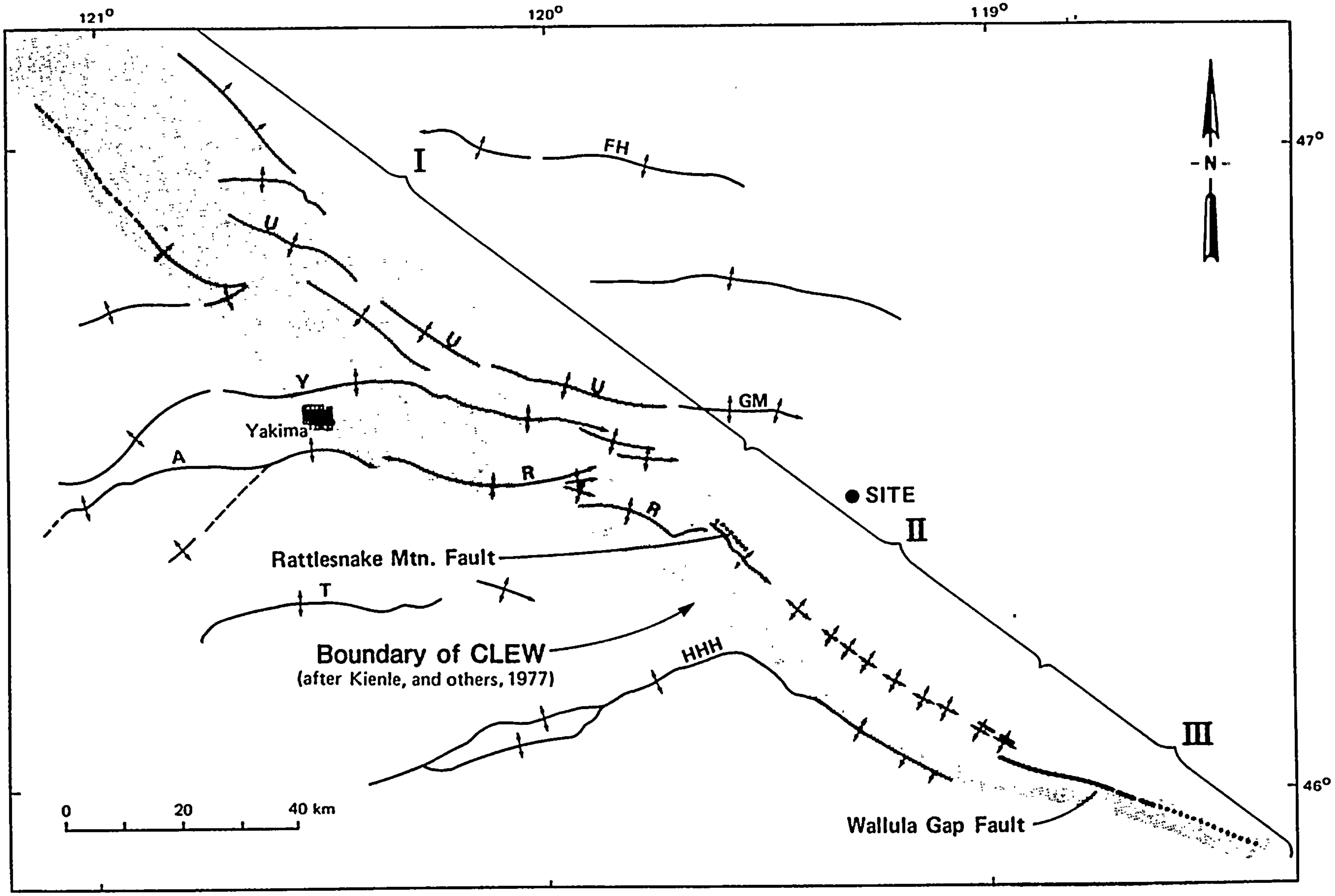


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	SCHEMATIC DIAGRAM SHOWING FEATURES REFERRED TO IN THE TEXT	Figure 1

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
Nuclear Project No. 2

MAP OF THE CLE ELUM-WALLULA LINEAMENT (CLEW)

Figure 2



Map of the Cle Elum-Wallula Lineament (CLEW) showing structural domains I, II, and III. The Rattlesnake-Wallula alignment (RAW) is comprised of domains II and III. Names of anticlinal ridges are: A, Ahtanum Ridge; FH, Frenchman Hills; GM, Gable Mountain; HHH, Horse Heaven Hills; R, Rattlesnake Hills; SM, Saddle Mountains; T, Toppenish Ridge; U, Umtanum Ridge; Y, Yakima Ridge.

REVIEW OF RHO-BWI-ST-14

The applicant has not identified any information in the Rockwell Hanford Operations RHO-BWI-ST-14 report by Myers, Price and others (Myers and Price, 1981) that adversely affects the seismic and geologic assessments of the WNP-2 and 1/4 sites. The purpose of the ST-14 report is to present current knowledge of stratigraphic, lithologic, and structural factors that directly relate to the suitability of the Umtanum flow within the Cold Creek syncline for use as a nuclear waste repository host rock (Myers and Price, 1981).

Chapter 1 presents introductory material including purpose and scope. Chapters 2 through 5 deal with the stratigraphic setting of the Cold Creek syncline. With the exception of chapter 2, which deals with the suprabasalt stratigraphy that is used to assess fault capability, the information in these chapters does not affect the evaluation of the seismic potential of the WNP-2 and 1/4 site region.

Chapters 6 through 8 contain discussions that relate to bedrock structure. Information that has been identified in chapters 2, 6, 7 and 8, and in the supporting appendices, as being relevant to the seismic and geologic evaluation of the WNP sites are described and evaluated as follows.

Chapter 2 - Suprabasalt Sediments of the Cold Creek Syncline Area, by A. M. Tallman, J. T. Lillie, and K. R. Fecht:

The ages and distribution of the suprabasalt units described in this report are in general agreement with those described in the report on Quaternary Sediments Study of the Pasco Basin and Adjacent Areas (Woodward-Clyde Consultants, 1981). No data are presented in chapter 2 that affect the capability assessments that have been made for faults in the site region.

<u>Chapter 6 - Borehole Geologic Studies</u>, and <u>Appendix A - Summary of Borehole Locations and Geologic Activities at Borehole Sites</u>, by D. J. Moak:

Brecciated core was noted in 14 boreholes (Figure 1). Previous studies for Rockwell Hanford Operations by Myers, Price and others (Rockwell, 1979) reported tectonic fractures and breccias only in boreholes DB-10, DC-8, and DC-4. Of all the breccias reported by Rockwell, the only breccias interpreted to be associated with significant displacement are in borehole DB-10, where there is a repeated stratigraphic section indicating the presence of reverse faulting. The two DB-10 faults are described in section 6.5, Appendix 2N, Skagit/Hanford PSAR and the significance of the DB-10 faults to the WNP sites is discussed in the Washington Public Power Supply System's response to Q360.8. All of the other breccias reported by Rockwell are considered by Rockwell to be minor features unrelated to large displacements. The following excerpt from chapter 6 of the ST-14 report (Myers and Price, 1981, p. 6-3) discusses these breccias:

> "In general, tectonic breccias are infrequent in the thousands of feet (meters) of core drilled in the Cold Creek syncline area and elsewhere in the Pasco Basin. The breccia zones that were identified (Table 6-1) are generally intact and <4 in. (<10 cm) in thickness, although some are slightly thicker (Figure 6-2). They appear in all deep boreholes within the Hanford Site and are principally in the Grande Ronde and Wanapum Basalts. As noted in the next chapter, such small tectonic breccia zones and their associated fractures are viewed as typical strain features of folded basalt and should be expected within the limbs of any of the Yakima folds, including the Cold Creek syncline. None of the tectonic breccias examined are judged as being associated with large displacements. This conclusion is based on comparisons

with surface exposures of similar breccias and the lack of anomalously thick basalt flows that would be expected if the section were repeated."

Therefore, these brecciated cores are considered to have no adverse implications regarding the interpreted geologic structure of the site region (see response to Q231.3.b2, S/HNP-PSAR).

<u>Chapter 7 - Distribution of Strain Features within Selected Yakima Fold Structures and Extrapolation of their Nature into the Cold Creek Syncline Area</u>, by E. H. Price:

The structural analyses presented in this chapter show that:

> "relatively little deformation, other than tectonic jointing, has taken place in the anticlinal crests and that little to no deformation has occurred in the synclinal troughs. The gently dipping limbs of the anticlines contain widely disseminated shear along small, conjugate faults; whereas, the steeply inclined flows in hinge areas contain the most extensive faulting and brecciation" (Myers and Price, 1981, p. 7-19).

The structural analysis suggests that the Yakima fold deformation is characterized by a flexural flow buckle model. In this tectonic model, faulting is not required to penetrate below the level of the fold to explain the observed displacements at the surface.

The implications of this tectonic model to the seismic and geologic evaluations of the Columbia Plateau and the WNP sites are discussed in section 2.5K.3.1, Appendix 2.5K, WNP-2 FSAR and in response to Q360.17 and 360.20. The information presented in chapter 7 of ST-14 supports the interpretation that the faulting associated with the Yakima folds is secondary to folding.

Chapter 8 - Bedrock Structure of the Cold Creek Syncline Area, by C. W. Myers

Chapter 8 discusses the bedrock structure of the Cold Creek syncline area (Figure 8-8 of ST-14) based on an integration of the results contained in the preceding chapters 1 through 7 and in appendices A through E of ST-14. The features shown on Figure 8-8 and on maps in the supporting chapters and appendices that relate to the evaluation of the Cold Creek lineament are addressed in the report on the Cold Creek lineament.

The "structures" shown on Figure 8-8 of ST-14 are tentatively interpreted by Rockwell not as structures but as the boundaries of "relatively intact volumes of rock." These boundaries are proposed on the basis of previously interpreted bedrock structure and geometric solutions determined by Werner deconvolutions and aeromagnetic data (Appendix B of ST-14). Those Werner solutions within 5 miles of the WNP sites that have been used to define these boundaries are interpreted by Rockwell and the applicant to be the axes or gently-dipping flanks of low amplitude folds. Consequently, the "structures" shown on Figure 8-8 of the referenced report do not affect the applicant's geologic interpretation of the site vicinity. The "structures" shown on Figure 8-8 of ST-14 extending to within 5 miles of the S/H NP sites ("structures" A, B, C, and D on Figure 2) are discussed in response to Q231.3.b.1, S/HNP-PSAR. Those "structures" tentatively interpreted by Rockwell within 5 miles of the WNP sites (features "A" and "F" on Figure 2) are described in Tables 1, 2 and 3 and are discussed individually below.

Feature "A"

The basis for this feature is Werner solution D-22, which is shown on both Figures B-11 and B-12 of the ST-14 report. Rockwell interpreted this anomaly as a deeply buried, asymmetric

anticline (Myers and Price, 1981, p. 8-53). The gravity and seismic refraction data acquired for the S/HNP site along Line 4A-1 (Figure 2L-16, Appendix 2L, S/HNP PSAR, 1981) confirm the existence of a low amplitude bedrock rise with gently sloping flanks. The central and northern portions of D-22 are also coincident with a northwest-trending, low amplitude gravity high in the vicinity of Station -40+00 on Line 1 and Station -210+00 on Line 2 as illustrated on Figure 2L-8 of Appendix 2L, S/HNP PSAR, 1981).

Feature "A" is interpreted to be coincident with the crest of a low amplitude anticlinal high.

Feature "F"

Feature "F" (Figure 2) is based upon an alignment of Werner solutions D-222, N-240 and D-225 at the 760 meter level and solution N-41 at the 1220 meter level. Rockwell interprets this feature as coincident with the hinge zone of the Umtanum Ridge structure (Myers and Price, 1981, p. 8-22). Werner solutions D-222, N-240 and D-225 are all coincident with the northeast flank of the Southeast Anticline as delineated by gravity, land magnetic and seismic refraction data (Figures 2K-13, 2K-50 and 2K-61, Appendix 2K, S/HNP PSAR, 1981). The northern two-thirds of solution N-41 are coincident with the northeast flank of the Southeast Anticline, solution N-41 is coincident with the crest of the fold at Lines 4B and 4C, and trends perpendicular to the gravity contours in the vicinity of Lines 4D and 4E. The land magnetic data (Figure 2K-50, Appendix 2K, S/HNP PSAR, 1981) indicate a low amplitude anomaly, interpreted as a low amplitude rise in the bedrock, where N-41 intersects Line 4E.

Therefore, the geologic sources of the Werner solutions that provide the basis for Feature "F" are interpreted to be the northeast flank and crest of the Southeast Anticline. It is

probable that the southern 1 mile of Werner solution N-41 is responding to the same source as solution N-265 (see discussion below) and the difference in location between the models for the two levels is the resultant smoothing from the increased separation between the sensor and the source

Evaluation of Remaining Werner Solutions within 5 Mile Radius

The "possible normal faults" identified on Figure B-11 and B-12 of the reference report are, in fact, not identified as possible faults but rather as geometric solutions determined by Werner deconvolution of aeromagnetic data. These solutions are presented graphically in three forms: (1) fault-like solutions, (2) dike-like solutions, and (3) structural disturbances. It is noted on page B-22 of the referenced report that:

> "It should be emphasized that a fault-like solution does not necessarily mean that an actual fault is present. Rather, the fault-like solution indicates that a horizontal magnetic source terminates at a particular location. In the Cold Creek syncline, horizontal termination of magnetic sources (lava flows) can be caused by flow pinchout, possible abrupt changes in the magnetic properties of a flow, steep anticlinal/synclinal flanks, as well as fault displacement."

> "Solutions of thin magnetic layers dipping vertically (±45°) are mapped as "dikes" on the interpretive maps (Fig. B-11 and B-12), although they may not represent true geologic dikes. A similar Werner deconvolution solution is obtained over anomalies caused by recognized anticlinal or synclinal structures. Structural distrubances, as noted on the interpretive maps, are generally solutions that do not meet the criteria for either dike-like or fault-like features. For example, structural distrubances may be mathematically

resolved as a dike-like structure on one survey level, and possibly as two fault-like solutions from another flight level which represents the two edges of a dike-like body."

All of the Werner solutions within a 5-mile radius of the WNP sites (Figures B-11 and B-12 in ST-14) are described along with available geologic and geophysical data in Tables 2 and 3. The following discussion concerns the interpretation of those Werner solutions that were not used in the structural synthesis of Figure 8-8 of ST-14.

Werner Solution N-53

This east-west trending Werner solution is not interpreted by Myers (Myers and Price, 1981). The 760 meter solution for N-53 trends normal to the total Bouguer gravity contours shown on Figure 2K-13 (Appendix 2K, S/HNP PSAR, 1981) and where N-53 intersects Line 1 (Station 80+00) the seismic refraction, gravity and land magnetic data are interpreted as indicative of a smooth bedrock surface (Figure 2K-54, Appendix 2K, S/HNP PSAR, 1981). The 1220-meter solution for N-53 also trends normal to the gravity contours and projects into seismic refraction Line 1 (Station 65+00). The gravity and seismic refraction data indicate a smooth bedrock surface (Figure 2K-54, Appendix 2K, S/HNP PSAR, 1981).

The geologic source for Werner solution N-53 is not manifested in the bedrock surface.

Werner Solution N-54

Werner solution N-54 is not interpreted by Myers (Myers and Price, 1981). The source for solution N-54 is located in an area of gravity and land magnetic coverage and trends perpendicular to the gravity contours shown on Figure 2K-13 (Appendix 2K, S/HNP

PSAR, 1981). The potential field data are interpreted as indicative of a smoothly varying, low gradient bedrock surface. The individual geophysical profiles for Lines M, K and S are compatible with a 3 degree southeastward-dipping bedrock surface.

This low gradient bedrock slope is a possible source for solution N-54.

Werner Solution N-265

Werner solution N-265 is not interpreted by Myers (Myers and Price, 1981). The location of the source for the solution is on the northeast flank of a very low amplitude basalt high evident in the gravity data in the vicinity of Station 30+00 on Line 4B (Figure 2K-13, Appendix 2K, S/HNP PSAR, 1981). This basalt high may be the source for the southern 1 mile of solution N-41 (1220 meter level); the apparent displacement is due to the smoothing resulting from the higher elevation of data acquisition.

The geologic source for solution N-265 is interpreted to be the flank of a very low amplitude bedrock high.

Werner Solutions D-227 and D-228

The geologic sources for solutions D-227 and D-228 are indicated to be at the surface (Figure B-11 in ST-14) and are coincident with the locations for the WNP-1 and 2 structures. It is highly likely that the magnetic anomalies are due to the two structures.

Werner Solution D-23

Rockwell Seismic Reflection Line 2 and WNP Seismic Refraction Line 1 intersect the source for Werner solution D-23. These seismic data have been specifically discussed in the response to

Question 230.1 (S/HNP PSAR Docket). As noted in that response, both the reflection and refraction data show a flat lying basalt surface, no structural feature is indicated.

Other Werner Solutions Within 5 miles

The geologic sources of the above Werner solutions have been interpreted as being either gentle basalt slopes or as not being expressed in the basalt surface and therefore not due to post-Elephant Mountain Basalt deformation. Although there are no other geophysical data with which to interpret Werner Solutions N-42, N-248, N-28, D-16, N-250, N-55, D-230, SD-7, N-267, N-260 and SD-4, their geologic sources are likely to be of similar origin.

REFERENCES CITED

Myers and Price, 1979, Geologic Studies of the Columbia Plateau -- a Status Report: Rockwell Hanford Operations, Richland, WA, RHO-BWI-ST-4.

Myers and Price, 1981, Subsurface geology of the Cold Creek Syncline: Rockwell Hanford Operations, Richland, WA, RHO-BWI-ST-14.

Northwest Energy Services Company (NESCO), 1981, Skagit/Hanford Nuclear Project PSAR, Kirkland, WA.

Woodward-Clyde Consultants (1981), Task D3 -- Quaternary Sediments Study of the Pasco Basin and Adjacent Areas: Report prepared for Washington Public Power Supply System, Richland, WA.

TABLE 1

Bases for the Known and Inferred Structures Presented on Figure 8-8 (ST-14) within 5 Miles of the WNP Sites

Structure	Basis for Delineation
F	Werner Solutions D-222, D-225, N240, and N-41
A	Werner Solution D-22

TA[illegible]2

Werner Solutions from 760-Meter Level Within 5 Miles of WNP Sites

Werner #	Only At This Elevation	Common To Both Elevations	Common Location Different Solution[1]	Ground Geophysical Coverage[2]: WGC Refraction	RHO Reflection	WGC Gravity	WGC Land Magnetics
D-22[3]		X		4A-1	11	2, 1, 4A, 1, 4A-2	2, 1, 4A-1, 4A-2
N-53		X		1	10, 11	1, M, L, K	1, M, L, K
N-54		X		-	-	H, K	H, K
D-227	X			-	-	-	-
N-248	X			-	-	-	-
D-222[4]			X	-	-	1A, 2, 6	1A, 2, 6
N-240[4]			X	1	-	1	1
D-225			X	4A, 4B, 4C	-	4A, 4B, 4C, 4D	4A, 4B, 4C, 4D
N-265	X			-	-	4E, 4F	4E, 4F
N-28	X			-	-	-	-
D-16			X	-	-	-	-
N-250	X			-	-	-	-
N-55		X		-	-	-	-
D-228	X				-	-	-
D-230		X		-	-	-	-
N-267		X		-	-	-	-
N-260	X			-	-	-	-

1 This indicates that what is modeled as a dike on one figure may be modeled as a fault on the other, or it may be a case of a common source type having a different orientation.

2 The geophysical profiles that intersect the inferred structures are indicated.

3 Werner D-22 is greater than 5 miles from the WNP sites but is analyzed because it forms the basis for Feature "A".

4 Werners N-240 and D-222 are greater than 5 miles from the WNP sites but are analyzed because they have a common source with Solution D-225.

TA[illegible] 3

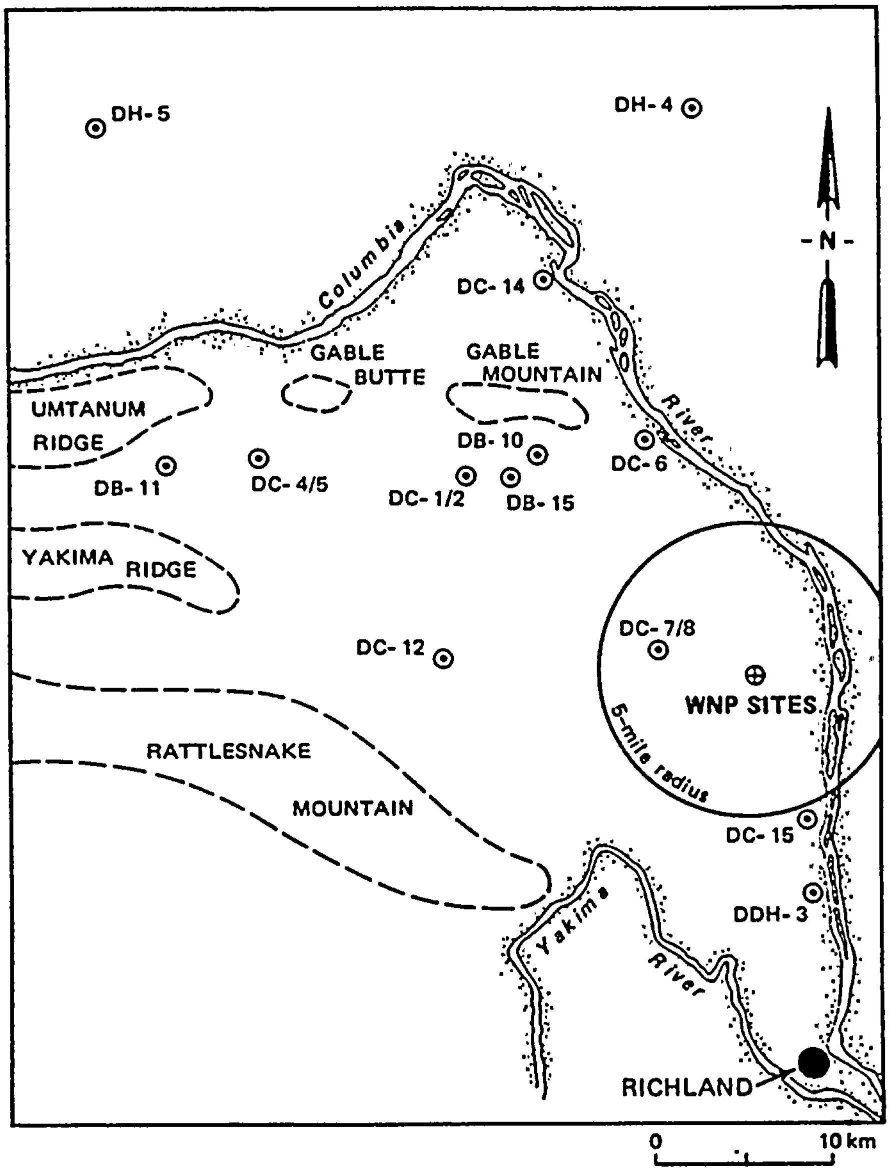
Werner Solutions from 1220-Meter Level Within 5 Miles of WNP Sites

				Ground Geophysical Coverage[2]			
Werner #	Only At This Elevation	Common To Both Elevations	Common Location Different Solution[1]	WGC Refraction	RHO Reflection	WGC Gravity	WGC Land Magnetics
DD-22[3]		X		4A-1	11	1, 2	1, 2, 4A-1, 4
N-53		X		1	-	1, 5A, K	1, 5A, K
N-54		X		-	-	M, K	M, K
D-23	X			WNP Line 1	2	-	-
N-41			X	1, 4A, 4B, 4C	2	-	-
SD-4	X			-	-	-	-
N-42			X		-	-	-
N-55		X		-	-	-	-
SD-7			X	-	-	-	-

1 This indicates that what is modeled as a dike on one figure may be modeled as a fault on the other, or it may be a case of a common source type with a different orientation.

2 The geophysical profiles which intersect the inferred structures are indicated.

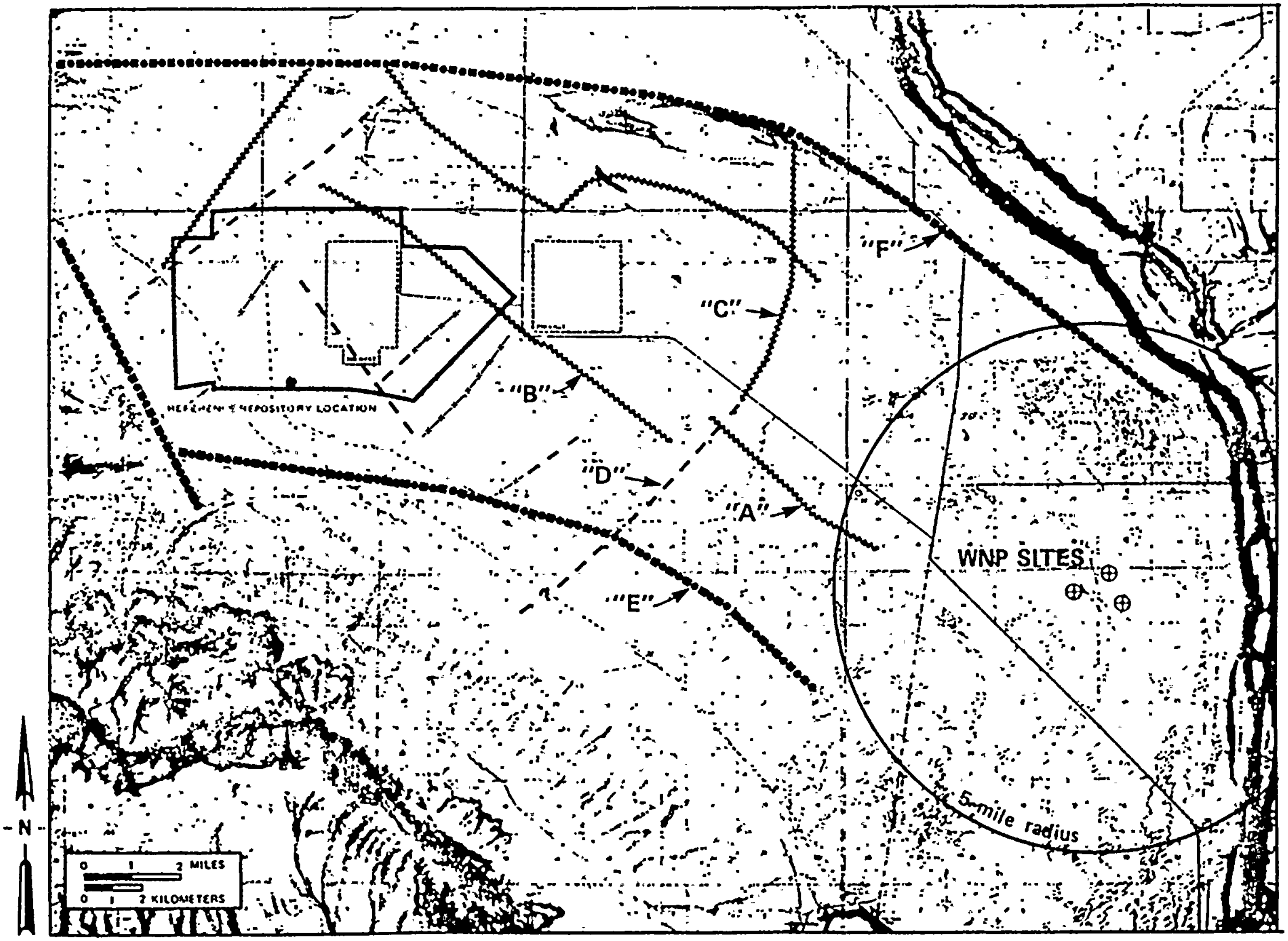
3 Werner D-22 is greater than 5 miles from the WNP sites but is analyzed because it forms the basis for Feature "A".



EXPLANATION

⊙ Borehole location

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOCATION MAP SHOWING BOREHOLES CONTAINING BRECCIA ZONES	Figure 1



(Modified from Figure 8-8, Myers and Price, 1981)

EXPLANATION

Known and Inferred "Structures"

- Major
- Intermediate
- Small
- Deep (may not affect Saddle Mountains groundwater flow)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

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INTERPRETIVE BEDROCK-STRUCTURE MAP SHOWING AREAS OF LARGE, RELATIVELY INTACT VOLUMES OF BEDROCK HAVING BOUNDARIES DEFINED BY KNOWN AND INFERRED "STRUCTURES"

Figure 2