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SEE DRAWINGS

SUBJECT: Forwards responses to Questions 361.20 through 361.25 in NRC 820426 ltr re USGS draft status review.Thirteen oversize figures encl.Aperture cards are available in PDR.

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G02-82-509
June 11, 1982

Docket No. 50-397

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

Dear Mr. Schwencer:

Subject: NUCLEAR PROJECT NO. 2
RESPONSES TO NRC QUESTIONS CONTAINED
IN THE USGS DRAFT STATUS REVIEW

Reference: Letter, A. Schwencer (NRC) to R.L. Ferguson (SS), "WNP-2 Request for Additional Information," dated April 26, 1982

Enclosed are seven (7) copies of the responses to NRC Questions 361.20 through 361.25 which were transmitted to the Supply System via the reference letter. These responses address the questions from the U. S. Geological Survey in their Draft Status Review. In order to expedite review of these responses, a copy has been provided under separate cover to M. T. Hait of the U.S.G.S.

The questions and responses will be incorporated into an FSAR amendment in the near future.

Very truly yours,

G D Bouchey

G. D. Bouchey
Deputy Director, Safety and Security

CDT/jca
Enclosures

cc: R Auluck - NRC
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Q. 361.20

To-scale cross-section(s) of the geology through the site to a depth sufficient to include the elements critical to evaluation of the model.

RESPONSE:

The locations of cross-sections referred to in the responses to questions 361.20 to 361.25 are shown on Figure 361.20-1. A crustal geological cross-section through the site area extending from the south flank of the Frenchman Hills to the southwestern flank of Rattlesnake Mountain is shown as Figure 361.20-2a. This section, prepared at a scale of 1:62,500, incorporates: (1) surface geologic data; (2) two subsurface horizons based on magnetotelluric surveys (the base of resistive plateau basalts and possible pre-Columbia River basalt group volcanic rocks; the top of highly resistive crystalline basement (?) rocks; Myers and Price, 1979); and (3) the probable depth to basement rock based on Eaton's (1976) analysis of crustal structure using data from regional quarry blasts. Figure 361.20-2a extends to a depth of 20 km, 5 km above the seismically-inferred depth to the Moho beneath the Pasco Basin (Eaton, 1976; Hill, 1972, 1978)

Figure 361.20-2b also shows the location of earthquake hypocenters projected from zones 10 km wide on each side of the section (ie. 20 km total width). The seismicity shown includes all earthquakes above magnitude M_c 1.0, regardless of depth; all events having poor quality location (type D) and those events arbitrarily assigned a fixed 3.0 km hypocentral depth are excluded (WNP-2 FSAR Appendix 2.5J). The relationship between shallow crustal seismicity in the Plateau and individual geologic structure is discussed in WNP-2 FSAR, Appendix 2.5J.

REFERENCES

Eaton, J.P., 1976, Notes on the Distribution of Earthquakes within and near the Hanford Seismic Network, 1969-1974, and Preliminary Results on Crustal Structure of the Region Obtained from an Analysis (by the Time-Term Method) of Industrial Explosions Recorded by the Network, Informal Notes: United States Geological Survey, Menlo Park, California, 22 p.

Hill, D. P., 1972, Crustal and upper mantle structure of the Columbia Plateau from long range seismic refraction measurements: Geological Society of America Bulletin, v. 83, p. 1639-1648.

Hill, D. P., 1978, Seismic evidence for the structure and Cenozoic tectonics of the Pacific Coast States: Geologic Society of America, Memoir 152, p. 145-174.

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

Reidel, S.P., Long, P.E., Myers, C.W., and Mase, J., 1981, New evidence for greater than 3.2 km of Columbia River basalt beneath the central Columbia Plateau: Abstract American Geophysical Union Pacific Northwest Section 1981 Meeting, central Washington University, Ellensburg, Washington.

Q. 361.21

To-scale illustration of the geometry and origin of the folds and faults common to the tectonic end-members of the "structural spectrum" referred to in Items 6 and 7 of "Conclusions": (a) primary folding, secondary faulting, and (b) primary faulting, secondary folding.

Q. 361.22

Maps and cross sections of actual examples within the "structural spectrum;" and explanation of how these examples bear on structural interpretations extended into the WNP-2 site area.

Q. 361.25

Provide comparison, with suitable cross sections, of the structural geology of the Umtanum-Gable Mountain-southeast anticline with Toppenish Ridge. Explain more fully what leads you to postulate a fault origin for Toppenish (WCC, 1981a) and a fold origin for Umtanum-Gable Ridge (Item 7, "Conclusions").

RESPONSE:

Introduction

Questions 361.21, 361.22, and 361.25 all refer directly or indirectly to the concept of a "structural spectrum" presented by the Supply System to the NRC in an NRC/USGS/WNP-2 meeting held in Bethesda, MD, November 17, 1981. After consultation with USGS Staff (5-18-82), it was decided to combine the answers to these questions in order to present our response as clearly and con-

cisely as possible. The questions are concerned with the geometry of Columbia Plateau folds and faults and request maps and cross-sections that bear on the possible existence of a "structural spectrum" ranging from (a) primary folding with secondary faulting to (b) primary faulting with secondary folding.

This combined response to the three questions emphasizes the geometry and kinematics of plateau fold/fault elements of the "Yakima" type. Possible regional tectonic models for the formation of the Yakima structures and those of the CLEW/RAW structural trend are discussed in response to Question 361.23, which emphases regional tectonics and geometric relationships between the two structural assemblages. The combined response to questions 361.21, 361.22, and 361.25 is based largely on the analysis of geologic maps from the following sources: WNP-2 FSAR, Chapter 2.5 with Appendices; S/HNP PSAR, Chapter 2.5 with Appendices; Rockwell Hanford Operations Publication RHO-BWI-ST4 (Myers and Price, 1979); USGS Open-File Report 80-200 (Bentley and others, 1980); and USGS Open-File Report 79-1364 (Swanson and others, 1979). To-scale cross-sections have been prepared emphasizing the Umtanum Ridge-Gable Butte-Gable Mountain-Southeast Anticline, Saddle Mountains, and Toppenish folds (see Figures 361.20-1 and 361.21-4 for locations of cross-sections discussed in this response).

Geometric Characteristics of the Yakima Folds and Associated Faults

The distribution and geometry of the major Yakima-type plateau folds north of the Columbia River are displayed in Figure 361.21-1, a structure contour map drawn on the top of the Miocene Wanapum Basalt. This map clearly illustrates the characteristic 20 to 30 km north-south spacing of the Yakima folds in areas northeast and southwest of CLEW (WNP-2 FSAR, Appendix 2.5-0) as well as the closer spacing, anomalous northwest trend, and less

continuous nature of fold structures in that portion of CLEW between Yakima and Kittitas Valley.

Outside of CLEW, with the exception of the Horse Heaven Hills fold, individual anticlines are typically narrow with respect to the broad synclines that separate them. Although most of the folds are asymmetric and verge northward, most also exhibit box-like profiles along portions of their length. Examples among the latter are: Columbia Hills, west of 121° W. (Figure 361.21-2); Horse Heaven Hills at Greyback Mountain (Anderson, 1982); Toppenish and Ahtanum (Figure 361.21-1); Umtanum Ridge north of Wenas Valley (Figure 361.21-3; Bentley, 1977) and to a lesser degree at the Yakima River and Priest Rapids (Price, 1982); Saddle Mountains (Figure 361.21-4); and Gable Mountain (Figure 361.21-5). Several folds (Columbia Hills, Snipes Mountain, and Cleman Mountain) exhibit southward vergence.

Reverse or thrust faults commonly have been recognized or inferred along one or both flanks of the Yakima folds where fold amplitude is high with respect to width, or where fold limbs dip steeply (greater than 50 to 60 degrees). Where exposed, the dips of major faults range between 15 and 50 degrees. Core holes south of Priest Rapids Dam indicate that the Umtanum fault probably dips southward at angles between 30 and 45 degrees (S/HNP PSAR, Appendix 2N, p. 2-39). West of Filey Road, the fault dips subhorizontally to gently northward (perhaps as a consequence of younger arching; Figure 361.21-6). The "north-dipping reverse fault" along the south flank of Gable Mountain dips 19 degrees on the basis of bore hole data (S/HNP PSAR, Appendix 20). These limited observations discount the hypothesis of Bentley (1977), now abandoned by him, that the Yakima folds are primarily "drape" folds related to dip-slip displacements along vertical to steeply dipping faults that extend into crystalline basement.

The net slip along reverse or thrust faults associated with Yakima-type folds has been determined directly for only a few faults on the plateau. No plateau geologic studies have recognized more than 1 km of displacement on any fold-related fault, and data presented below suggest that fault displacements of no more than 2 km can be postulated on the largest structures. Structure contour maps drawn on the top of the Grande Ronde and Wanapum basalts (Swanson and others, 1979; Myers and Price, 1979) provide data for limiting fault displacement associated with the Yakima folds. Figure 361.21-2, modified from Swanson and others, 1979, shows estimates (in feet) of stratigraphic throws of the top of the Grande Ronde basalt along all major faults between the Columbia River and Frenchman Hills. Cross-section AA (Figure 361.21-7) is a north-northeast trending profile along the top of the Grande Ronde basalt using the contours of Swanson and others. This cross-section transects seven major faults with approximate stratigraphic throws from south (Columbia Hills) to north (Frenchman Hills) along the line of section of 1,000, 400, 500, 500-600, 400, 600, and 450 feet. Thus, the cumulative throw across all faults along this one-hundred mile long (160 km) section is only approximately 4,000 feet (1.3 km), a figure representative of cumulative throws ($\pm$ 1000') along parallel sections in this part of the plateau.

The largest stratigraphic throws (1900') occur on faults associated with the Columbia Hills and Saddle Mountains structures. If it is assumed that foot wall and hanging wall flows are horizontal, a throw of 1,900 feet across a fault dipping 20^{o} produces a net dip-slip displacement of only 5,500 feet (1700 m); with the same throw, a fault dipping 45^{o} produces only 2,700 feet (820 m) of dip-slip displacement. Geologic cross-sections drawn across the Umtanum, Hansen Creek, and Saddle Mountain faults (Figures 361.21-8 and 361.21-9), where the Vantage interbed between the Grande Ronde and Wanapum Basalts is present, indicate that displacements of about 1 to 2 km may be present.

This analysis of fault displacement associated with Yakima-type folds and the amount of shortening produced by folding corroborates Bentley's (1980) estimate that north-south shortening across the Columbia plateau west of 120° W. longitude is 10% or less. The total shortening of the plateau at the more easterly longitude of the WNP-2 site is significantly less (ca. 3%; Bentley, 1980). A clear indication of this eastward diminishment in compressive deformation is presented in Figure 361.21-10, a series of profiles drawn on the top of the Wanapum basalt through the Saddle Mountains and Umtamum Ridge-Gable Butte-Gable Mountain-Southeast Anticline folds.

Although much attention has been directed in past studies towards the periodic spacing of plateau anticlinal folds, particularly between the town of Yakima and the Columbia River to the south, not enough attention has been directed to fold amplitude and breadth. The vertically exaggerated (21X and 2X) cross-sectional profiles along the top of the Grande Ronde basalt (Figure 361.21-7) illustrate the striking dissimilarity of the Horse Heaven Hills fold to its flanking anticlinal structures. As shown on Figure 361.21-7, the Horse Heaven Hills anticline in areas west of 120° W. longitude dwarfs the adjacent Columbia Hills and Toppenish folds in amplitude and cross-sectional area. The syncline to syncline width of this fold near Satus Pass (120° 40' W.) is between 55 and 65 km, in contrast to the 5 and 8 km widths of the Toppenish and Columbia Hills structures respectively. The gross symmetry of the Horse Heaven Hills anticline between 120° and 121° W. longitude is seen in both the cross-section and on the structure contour map of the top of the Wanapum basalts (Figure 361.21-1). The anomolous geometry of the broadly uplifted Horse Heaven Hills anticline suggests that diverse mechanisms may play a role in the development of plateau anticlines which appear to be very similar when only their crest to crest separation is emphasized.

Primary Folds vs. Secondary Folds

At an NRC/USGS/WNP-2 meeting held in Bethesda, MD, on November 17, 1981, G. Davis, on behalf of the Supply System, presented a list of tentative conclusions regarding plateau structural geology and regional tectonics (letter dated 26 April 1982, from A. Schwencer, NRC, to R. Ferguson, Washington Public Power Supply System). One conclusion presented at that time was that plateau folds "appear to represent a structural spectrum between (1) primary folds with secondary reverse (or thrust) faulting, and (2) secondary folds related to intra-crustal thrust-type detachments or less through-going zones of interconnected fault and kink-bands."

The case for primary folding with secondary faulting was anchored on a detailed structural analysis of the Umtanum anticline near Priest Rapids by E. Price (1980, 1982). Price concluded that formation of the Umtanum fault near Priest Rapids occurred late in the development of Umtanum anticline, a fold formed by buckling mechanisms of flexural flow and limited flexural slip. He interpreted the Umtanum fault as a secondary, accomodational structure in the formation of this major concentric fold, not the direct result of regional plateau shortening.

Davis (WNP-2 FSAR, Appendix 2.5N) suggested that changes in vergence of major fold structures along their axial traces (e.g. Umtanum Ridge, Gable Mountain, and Saddle Mountain anticlines) could best be explained by a buckling origin for the folds. His reasoning was that pre-existing structural and/or stratigraphic anisotropies in the layered sequence being folded could produce differential directions of limb steepening. Such differential steepening could, if deformation continued, lead to the development of accommodating secondary tear faults between segments of opposite vergence and, ultimately, to still-younger reverse or thrust faults on the steep flanks of the fold (WNP-2 FSAR, Figure 2.5N-8).

The case for the other end of the structural spectrum, (ie. that the Yakima folds are the consequences of displacement along primary thrusts or reverse faults) was based on general geometric arguments by Laubscher (WNP-2 FSAR, Appendix 2.5O) and Bruhn (1981). Both authors postulated the existence of south-dipping thrust ramps beneath the major Yakima folds, but differed markedly in their conclusions as to the depth of detachment that the existence of such ramps would imply.

Toppenish Ridge was considered by Woodward-Clyde Consultants (1981) as a likely candidate for a fold structure related to primary compressional faulting. Their conclusion was based on the existence of Quaternary scarps along the north flank of the Toppenish anticline for a distance of between 24 (Woodward-Clyde Consultants, 1981) and 32 km (Campbell and Bentley, 1981). According to the Woodward-Clyde report (1981, page 29): "A comparison of the characteristics of the scarp features observed at Toppenish Ridge with the characteristics of scarps and surface deformation developed during historic surface-faulting events suggest that the basal set of scarps represent a primary thrust or reverse fault and the mid-slope and crestal set of scarps represent high-angle secondary faults on the upper plate." Ground access to the Toppenish scarp has been denied the Supply System, therefore, we have been unable to investigate these scarps in detail.

In response to the NRC/USGS questions the Supply System has reevaluated the concept of a structural spectrum for the development of Yakima fold/fault structures. Geometric analyses of possible end members for the spectrum (e.g. the Umtanum Ridge and Toppenish anticlines) has led us to conclude that the concentric and locally box-like geometries of both fold/fault structures are similar. Therefore, an unequivocal choice between origin by primary faulting vs. primary folding for these folds and other folds in the province cannot be made on the basis of our present understanding of subsurface structure and crustal stratigraphy.

Cross-sections through the high amplitude portions of plateau concentric fold structures require varying combinations of folding and reverse faulting at depth, a relationship first emphasized by Laubscher (WNP-2 FSAR, Appendix 2.50). Since the amplitude of concentric anticlinal folds such as the Umtanum anticline near Priest Rapids Dam must diminish downward (Price, 1980, 1982; Figure 361.20-11), the greater shortening of higher structural levels by folding must be compensated by fault detachment at depth - detachments that are most likely stratigraphically controlled. As shortening represented by folding diminishes, the geometric need for discrete detachment surfaces at depth is diminished on lower amplitude folds in the Yakima system (such as Southeast Anticline; Figure 361.21-10). In other words, small amounts of shallow compressive strains accomplished by flexuring can be compensated at depth by diffuse compressive strains (e.g. by distributed slip on bedding planes or other surfaces such as joints), by layer-parallel shortening through mechanisms of penetrative flow, and by the upward movement of less competent stratigraphic units into the cores of folds.

The Umtanum Ridge-Gable Butte-Gable Mountain-Southeast Anticline Structural Trend

Umtanum Ridge Anticline

The Umtanum Ridge anticline near Priest Rapids Dam is well-exposed due to deep erosion across its core by the Columbia River. Studies by Price (1980, 1982), and by Golder Associates (S/HNP PSAR, Appendix 2N) in the Filey Road area directly west of the area mapped by Price, concluded that the anticline formed in response to the buckling of a multi-layered basaltic sequence. Price proposed that as the northern limb of the asymmetric "kink-like" fold reached a subvertical orientation its continued rotation was impeded. As a consequence, shortening of the structure under continuing compression occurred by disruption and transport of the limb along the Umtanum fault, which developed upward from the hinge-zone of the fold.

Several relationships in the area cast doubt on, but do not disprove, the secondary nature of the Umtanum fault. Much of Price's analysis of the late, secondary role for the Umtanum fault relies on his estimate (1982) of only a limited horizontal component of displacement along the fault (less than 175 meters) where it intersects the earth's surface. This estimate was based on the assumption that the stratigraphic sequence of the lower plate is intact beneath the horizontal Priest Rapids flow exposed in the footwall. However, to the west in the Filey Road area Bentley (1977) and Golder Associates (S/HNP PSAR, Appendix 2N; WNP-2 FSAR, response to NRC Question 360.17, 1982) have mapped a complex structural zone here interpreted as a zone of imbricate thrust slices (Figure 361.21-6). One or more of the thrust bounded panels may lie in the footwall of the Umtanum fault in Price's area (Figure 361.21-6 and 361.21-11), thus negating stratigraphically-based reasons for Price's estimate of limited displacement along the Umtanum fault there. An estimate by Golder Associates of approximately 2,000 feet of displacement along the shallow-dipping Umtanum fault in the area west of Filey Road appears reasonable (Figures 361.21-6 and 361.21-12A). It is our interpretation that the geometries of the anticline and Umtanum fault in this area are suggestive that faulting was not the result of folding.

The lower plate of the Umtanum fault zone in the Filey Road area is in the upper plate of the Hansen Creek fault to the north (Figure 361.21-11). This south-dipping reverse or thrust fault probably merges with the Umtanum fault beneath Quaternary deposits east of Priest Rapids Dam, as originally suggested by Laubscher (WNP-2 FSAR, Appendix 2.5O). Although the junction of the two faults is not exposed, a prominent southeast-trending aeromagnetic anomoly coincident with the Hansen Creek fault in areas west of the Columbia River merges with anomalies coincident with Umtanum Ridge in an area about five miles east of Priest Rapids Dam (WNP-2 FSAR, Figure 2.5-8). It can be conjectured that the westward development of the Hansen Creek fault compen-

sates for the westward diminishment in shortening by folding and faulting across the more southerly Umtanum Ridge structure.

West of the Columbia River, the Umtanum Ridge and Hansen Creek faults, plus the Saddle Mountains and Frenchman Hills faults farther north (Figures 361.21-2 and 361.21-8; Figure 2.5-13) have the spacing and geometry of an imbricate, south-dipping thrust zone of primary origin. Structure contours drawn at the top of the Vantage interbed (Swanson and others, 1979, Sheet 1) indicate that the Saddle Mountains fault crosscuts discordantly the south-plunging hinge of the Hog Ranch anticline in its lower plate. Structure contours at the top of the Vantage interbed in the Saddle Mountains plate trend easterly and indicate that a north-vergent fold of limited amplitude (200 to 800 feet) is present at the leading edge of the plate, possibly as the consequence of northward rotation (drag) of hanging wall strata along the underlying thrust. There is no evidence in the structural contours of the lower plate, however, for east-west folding prior to development of the discordantly overriding Saddle Mountains plate. Maximum stratigraphic throw of the Vantage interbed along the four thrust faults described here (Umtanum, 1,600 feet; Hansen Creek, 700 feet; Saddle Mountains, 1,400 feet; Frenchman Hills, 400 feet) suggests maximum displacement along each of 1.5 km or less, assuming fault dips as low as 20°. Steeper faults would, of course, diminish the displacement on each structure. It is important to note that geologic evidence in the Filey Road area (Bentley, 1977; S/HNP PSAR, Appendix 2N; Figure 361.21-6) indicates that most of the growth of the Umtanum anticline and displacement along the Umtanum fault occurred prior to deposition of the Pomona Member of the Saddle Mountains Basalt approximately 12 million years ago. The ages of the more northerly fault structures described in this section are not known, although synchronous development of the Hansen Creek and Umtanum faults has been suggested for the above kinematic reasons.

As is true of other major Yakima folds, the Umtanum structure exhibits a general eastward decrease in amplitude and amount of shortening. Figure 361.21-10, a stacked sequence of 21 cross-sections through the Saddle Mountains and the Umtanum to Southeast Anticline structural trend, shows this relationship clearly. The section, drawn on the top of the Wanapum Basalts, indicates the eastward plunging-out of the Umtanum anticline south of Vernita Bridge and west of Gable Butte (Section HH', Figure 361.21-10; Figure 361.21-13).

Gable Butte, Gable Mountain, Southeast Anticline

Gable Butte, Gable Mountain and Southeast Anticline are en echelon fold structures of low amplitude that lie in the northern part of the Hanford Reservation. Although part of an east-west structural trend that includes Umtanum Ridge to the west, they clearly constitute a structural assemblage that is physically distinct from the Umtanum anticline (S/HNP PSAR, Appendix 2O). In the area south of Vernita Bridge, geologic data, including structure contour maps drawn on the top of basalt (Myers and Price, 1979) and the top of the Wanapum Basalt (Figures 361.21-1, 361.21-10 HH', and 361.21-13), and gravity data (S/HNP PSAR, Appendix 2O and Appendix 2K, Figure 2K-13) indicate that the area coincides with a structural saddle between the east-plunging Umtanum anticline and the west plunging Gable Butte fold. Cross-sections constructed on the top of the Wanapum Basalt (Figure 361.21-4) display, eastward from south of Vernita Bridge, the progressive development of the low amplitude Gable Butte structure (II', JJ'), a structural low between it and Gable Mountain (KK'), and the Gable Mountain - Southeast Anticline (LL' -UU'). A series of more detailed sections through Gable Butte, Gable Mountain, and Southeast Anticline (Figure 361.21-5) illustrate the en echelon and separate character of Gable Butte and Gable Mountain, as does the "Top of Basalt Map" (Myers and Price,

1979). The more detailed sections of Figure 361.21-5 have been drawn on the basis of surface mapping, borehole data, and two seismic reflection profiles across the western and eastern portions of Gable Mountain; data sources for the cross-sections are referenced on the figure. The three cross-sections through Gable Mountain (Figure 361.21-5 sections DD', EE', and FF') were prepared in response to question 361.25. Section DD' through the western half of Gable Mountain is of particular interest for several reasons: (1) it crosses the Gable Mountain anticline in its area of maximum structural relief (ca. 1250 feet on the top of Wanapum Basalt); (2) it crosses the structure where it exhibits its maximum horizontal components of shortening, approximately 925 feet (ca. 500 feet by flexuring between the axis of Wahluke syncline and borehole DC 1/2 and ca. 425 feet of heave on the "north-dipping reverse fault" projected into the line of section from the east); and (3) it crosses Gable Mountain where it most closely resembles the box-like geometry of Toppenish Ridge (Figure 361.23-2), although it verges southwards in contrast to the northward vergence of Toppenish.

All existing data indicate that the "north-dipping reverse fault" (S/HNP PSAR, Appendix 20) is the main fault associated with of Gable Mountain. A "blind" south-dipping reverse fault with small displacement is inferred on the northern flank of the mountain in Section DD' to account for the monoclinal flexure there, but its existence is not a geometric necessity. No additional faults are drawn between the monocline and the axis of Wahluke syncline because of the well-defined continuity of the top of basalt (Elephant Mountain member) within the same geographic interval on Rockwell's reflection seismic line 4, one and one-half miles (2.3 km) to the west of the section.

Section DD' crosses the Central fault, which separates the western and eastern anticlines on Gable Mountain. Minor "blind" reverse faults at depth beneath the subdued box-like fold limbs seen on that section could be postulated, but any such faults

would have smaller displacements than the "north-dipping reverse fault".

The eastern Gable Mountain anticline has a lower amplitude and, generally, a higher degree of symmetry than is seen on Section DD' (Figure 361.21-5). However, the westernmost part of the eastern anticline (near the Central fault) does have a steeply-dipping northern flank ($\leq 50^{o}$) that is possibly associated with a south-dipping reverse fault comparable to the "north-dipping reverse fault" to the west. If so, the pronounced symmetry of the eastern fold as seen on Section FF' would constrain the length of such a fault to less than a few kilometers.

The amplitude to breadth ratio of the eastern Gable Mountain anticline from the vicinity of Section FF' eastward is so low that any inference of major flanking faults appears unwarranted. The same conclusion applies to Southeast anticline which has an even smaller amplitude (Figure 361.21-5, Sections HH' and GG').

The south-vergent western Gable Mountain anticline resembles more a fold produced by buckling, than a fold that has formed in response to displacement along the "north-dipping reverse fault". The Central fault, extensively studied by Golder Associates (S/HNP PSAR, Appendix 20), is a tear or accommodating structure between oppositely verging western and eastern anticlines on Gable Mountain. The existence of the Central fault and the change in fold vergence across it also support a buckling origin for the Gable Mountain anticline (cf. WNP-2 FSAR, Appendix 2.5-N, Figure 2.5N-8).

Several differences exist between the geometries of Toppenish Ridge anticline and the Gable Mountain anticline, but they are primarily differences in scale and setting. Toppenish Ridge anticline has a greater maximum amplitude (50% higher than that of Gable Mountain as determined on the top of the Wanapum Basalt), and a considerably greater length, 80 to 85 km compared

with 15 to 20 km. Toppenish Ridge anticline, which has a consistently steeper north flank, is markedly more asymmetric than Gable Mountain. The gentle south flank of Toppenish Ridge represents a minor reversal in dip of the very broad, gently north-dipping flank of the Horse Heaven Hills anticline (Figure 361.21-7). In contrast, the Gable Mountain anticline is a generally more symmetrical fold between the broad and shallow amplitude Wahluke and Cold Creek synclines.

As discussed elsewhere in this response we do not believe that the Toppenish and Gable Mountain anticlines represent ends of a "structural spectrum" between folds of primary and secondary origin with respect to faulting. The "north-dipping reverse fault" on Gable Mountain could be a geometric counterpart to the south-dipping Mill Creek thrust fault on Toppenish Ridge. The maximum earthquake magnitude for the "north-dipping reverse fault", assuming that it is capable, has previously been determined (WNP-2 FSAR, response to question 360.20). The resulting ground motions at the site are well below the design ground motion level. It is our conclusion that no other faults exist in association with Gable Mountain that would have dimensions greater than those of the Central fault and the "north-dipping reverse fault".

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Q. 361.23

Well-illustrated explanations of the structural relationship between the RAW trend and the large folds (Gable Mountain, Saddle Mountains, and Frenchmen Hills) that extend far to the north and east of RAW. This explanation should include but not be limited to, adequate analysis of Price's (1981) model, Item 10 (2) of "Conclusions," which suggests many miles of northward translation of an originally east-west trending fold. How does this translation take place? What is the evidence for translation and what bearing does the translation represented by this and other folds have on structural interpretations below the WNP-2 site?

RESPONSE:

Introduction

This response addresses regional tectonic models for plateau deformation and possible relationships between Yakima-type fold/fault structures and those of CLEW, a somewhat diffuse zone that extends northwestward across the Columbia Plateau. This zone was recognized by Raisz (1945) as part of his Olympic-Wallula Lineament (OWL) and was later termed CLEW by Laubscher (WNP-2 FSAR, Appendix 2.5O) for his inferred Cle Elum-Wallula Lineament. RAW is the acronym given this zone for its length between the Rattlesnake Hills and the vicinity of Milton-Freewater.

Two regional tectonic models are presented here, both of which have in common the premise that the structures of the Columbia Plateau, for at least the past 15 million years are primarily a response to north-south shortening and a probable north-south orientation of sigma 1, the maximum compressive stress (WNP-2 FSAR, Appendices 2.5N, 2.5O). Miocene and younger compression in the Columbia Plateau and Blue Mountains provinces has occurred

synchronously with east-west, and then northwest-southeast extension in the Great Basin province to the south. Compressional deformation in the former areas probably represents an incompletely linked response to extension in the latter areas (WNP-2 FSAR, Appendices 2.5N, 2.5O). Geologic studies on the Plateau suggest that most of its deformation occurred prior to Pliocene time (WNP-2 FSAR, Appendix 2.5N).

The two models discussed here are regional counterparts to the "structural spectrum" of fold/fault development originally applied to specific plateau folds. These models are: (I) the development of both Yakima-type structures and those of RAW as a consequence of intracrustal detachment with analogy to the incipient formation of a thrust and fold belt of foreland type (Figure 361.23-1A); (II) the development of Yakima-type structures in response to crustal buckling dynamics, treating the plateau as a layered medium and including geometrically-required detachments that develop as a consequence of buckling (Figure 361.23-1B). In model II the structures of RAW represent interference effects between a buckled and locally detached upper crustal level and a deeper zone of diffuse and limited dextral strain.

In both models, the existence of a single, continuous detachment or decollement beneath the entire folded portion of the Columbia Plateau is unlikely, although both models are compatible with the existence of a zone or zones of limited or partial detachment within the plateau crust. In both models, the structures of RAW are considered to have components of both compressional (fold and reverse dip slip-down to the northeast) and transcurrent (dextral) strains. As amplified below, the models (as applied to RAW) differ in the downward extent of the dextral strains. Neither model proposes a pure strike-slip origin for the structure of RAW.

Model I: Deformation Related to Intracrustal Detachment in a Compressive Regime

Summary

Model I is a variant of the original synthesis presented by Laubscher, initially in draft form (1977) and now as Appendix 2.50 of WNP-2 FSAR. The model differs from Laubscher in that it does not postulate a master decollement at the base of the crust, nor does it consider CLEW as a zone of wrench-faulting extending through the entire crust.

Yakima-type structures north of the Horse Heaven Hills anticline represent the upward branching of south-dipping thrust faults with limited displacement (less than 2 km) from a subhorizontal zone (perhaps stratigraphically controlled) within the upper plateau crust. The anomalously wide Horse Heaven Hills anticline may lie above a southward-dipping segment of the detachment zone, thus placing the zone of detachment at deeper levels south of that structure. The Columbia Hills anticline may represent back-thrusting above the south-dipping ramp.

In this model the structures of the plateau may represent an incipient foreland fold and thrust belt now apparently aborted, or at least waning in its development. Therefore, we postulate sub-regional detachment in southern plateau areas towards the Basin and Range province, and more localized detachment beneath northern regions along one or multiple zones of stratigraphic anisotropy.

Although data on the dip of thrust faults beneath the Yakima folds are limited, sections through the Toppenish Ridge and Saddle Mountains structures (Figures 361.23-2 and 361.23-3) suggest detachment horizons at depths of approximately 5 to 6 and 3 km respectively, and southwest dips of fold-associated faults of 40° to 50°. Total shortening across all of the plateau

structures shown in Figure 361.21-2 is estimated at 15 km or less, an estimate compatible with 10% or less compressive strain for this part of the plateau (cf. Bentley, 1980).

The direction of tectonic transport in this model is north-northwest, more or less at right angles to the trend of the Columbia Hills, Horse Heaven, and Toppenish structures west of 119° 30' W. longitude. The northwest-trending structures of RAW, especially the Rattlesnake and Horse Heaven Hills anticlines, are formed above an oblique tear structure in the detached terrane. This hypothesized tear allows the upper crust west of RAW to translate more to the north-northwest than the crust to the northeast. Because RAW trends more westerly than the direction of regional translation, it is a zone with components of both compressive and dextral transcurrent strains between the more imbricated western terrane and the less shortened, more stable block of the Pasco Basin and Palouse Slope. Total dextral strains are diffuse and limited to a few km (less than 3), and are increasingly difficult to recognize to the northwest. The regionally higher elevation of CLEW north of Red Mountain (cf. Laubscher, WNP-2 FSAR, Appendix 2.5O, Figure 2.50-24) may be a consequence of the crowding of the imbricated western terrane along this zone of compressive tearing in the plateau.

Some aspects of Model I closely resemble aspects of Price's (1982) buttress tectonic model, particularly in that the Rattlesnake Mountain and eastern Horse Heaven Hills structures are folds of Yakima-type formed along a northwest-trending crustal boundary. Unlike Price's model (1982, Figure 91), large compressive strains (several tens of percent) and clockwise rotational strain of the Yakima fold province are not required. Indeed, recent paleomagnetic studies of the Pomona Basalts from 15 plateau localities on both sides of RAW and CLEW (Magill and others, 1982) indicate no clockwise rotation of these basalts since their extrusion 12 million years ago, either with respect to RAW or to the 12 million year-old Miocene pole position of

North America. In contrast, Pomona Basalts in the southwestern corner of Washington show a large-scale regional clockwise rotation of approximately 16^{o} with respect to the stable Columbia Plateau and North America. Accordingly, rotational aspects of Price's (1982) model "which suggests many miles of northward translation of an originally east-west-trending fold" (quotation from NRC/USGS Question 361.23) are not valid. Instead, the regionally anomalous northwest trend of the Rattlesnake Mountain and Horse Heaven structures represents primary growth along the detachment-related oblique tear known as RAW. Model I predicts that the dextral strains associated with RAW continue to depth along southwest-dipping thrust or reverse faults only to the level of underlying crustal detachment, presumably at depths of 10 km or less (response to question 361.24).

Problems With the Model

At present, too little is known of the deeper stratigraphy and crustal structure of the Columbia Plateau to rigorously test this model. Therefore, we do not know which stratigraphic horizon or horizons could control a regional pattern of detachment, or for that matter, the geometry of primary buckling. For several reasons, however, it is unlikely that a single, throughgoing detachment surface underlies the folded part of the Columbia Plateau:

(1) Compressive strains of 10% (significantly less in areas northeast of CLEW) are probably insufficient to have generated a regionally continuous detachment surface across what is inferred to be a stratigraphically complex volcanic and sedimentary assemblage. Since at least Eocene times, the Columbia Plateau has been characterized by topographic variations and non-marine deposition with their expected lateral and vertical complexities of stratigraphic units (Cowan, S/HNP PSAR, Appendix 2S). As such, the Columbia Plateau differs markedly from the continuously layered sequences of miogeosynclinal strata in which foreland thrust

and fold belts typically develop (e.g. Canadian Rocky Mountains, western Wyoming, and Valley and Ridge province of the Appalachians).

(2) Plateau thrust faults with displacements of generally less than 1 km and with interfault spacings of 10 to 30 km would most likely dissipate into a subhorizontal zone (or zones) of diffuse translation rather than merging into a master decollement. Such merging is the case in the foreland fold and thrust belts of orogens where compressional strains of 40 to 50% are characteristic across belts 150 to 200 km wide. Stratigraphic throws across individual thrust faults of the Cordilleran foreland belt commonly attain 30,000 to 40,000 feet, in marked contrast to the 4,000 ± 1,000 feet of cumulative stratigraphic throws across the entire Yakima fold province in south-central Washington.

(3) If a regional detachment exists, it would have to involve pre-Miocene rocks in areas west of Yakima and north of Kittitas Valley where plateau folds extend into stratigraphic units of the central and northern Cascades. These Cascade areas generally have structural styles that differ from those of the plateau and are unlikely to be linked kinematically with it.

(4) Variabilities in plateau folds of amplitude, breadth symmetry, and vergence - both among folds and along the trend of individual folds (cf. Figure 361.21-10) - argue against the simplistic geometry of a single throughgoing detachment controlling the deformations and for buckling models of folding (cf. Davis, WNP-2 FSAR, Appendix 2.5N).

Some major plateau folds appear to lack accompanying thrust or reverse faults (e.g. Umtanum anticline north of Cleman Mountain, Figure 361.21-3; the anomalously broad Horse Heaven Hills anticline east of 120°W. longitude; and the Yakima anticline

south of Priest Rapids Dam, Figure 361.21-11). However, it could be argued that "blind" thrust faults, i.e. faults that die out upwards before intersecting the surface, may exist. Such hidden faults are equally compatible with the buckling origin for major plateau folds in Model II. However, there is no geometric requirement for accommodating faults of any type beneath fold structures with low amplitude/breadth ratios (e.g. Southeast Anticline, the eastern end of Saddle Mountains, or the Horse Heaven Hills anticline near Satus Pass where flank dips of 3°-5° are present).

Model II: Deformation Related to Buckling and Strike-Slip Crustal Strain in a Compressive Regime

Summary

Model II proposes that plateau deformation is largely a response to concentric buckling of a competent volcanic sequence over less competent units, presumably sedimentary at depth. This model is consistent with small compressive strains in the plateau (less than or equal to 10%) and the likelihood that the upper plateau crust is a multi-layered medium.

Using principles formulated by Biot (1961) for the deformation of layered viscoelastic media, the spacing and concentric geometries of plateau folds can be approximated. For example, J.L. Anderson (personal communication, May, 1982) has successfully modeled the 30 $\pm$ 5 km-wide spacing of the five plateau folds from Gordon Ridge in north-central Oregon to Ahtanum Ridge south of Yakima. To do so, his assumptions included (1) that two equally thick basalt layers each 1.45 km thick, lie above a less competent and physically less uniform sequence of rocks, and (2) that the basalts were subjected to laterally directed compressive stresses equivalent to 62% of their crush strength (approximately 1.6 kbar). Folding of the layers is only possible when decoupling occurs both between the two inferred basaltic layers and beneath

them. Such decoupling indicates one similarity of primary buckling models (Model II) to primary detachment models (Model I) for the formation of the Yakima structures. The concentric geometries of the Yakima folds with high amplitude/breadth ratios require combinations of flexuring and faulting, thus leading to our general inability to discern on a fold-by-fold basis which structural element - fault or concentric fold - developed first. However, buckling models for Yakima folds of high amplitude/breadth ratios require neither a regionally continuous layer above which buckling occurs nor a common depth to local surfaces of detachment.

Using buckling theory, the shorter wavelength of folds between Yakima and Kittitas Valley could be explained by calling upon the presence of a thinner basaltic sequence than is present in areas farther south as reported by Swanson and others (1979). The anomalous breadth and amplitude of the Horse Heaven Hills anticline could be explained by preferential flow of especially thick sub-volcanic units into the core of the fold during layer-parallel shortening. Another possible explanation for the fold's great breadth and height west of 120°15'W. longitude unrelated to either Model I or II, is that plutonism related to surficial Simcoe volcanism may have selectively elevated this portion of the structure after its main pre-Pliocene (?) phase of development.

The structures of RAW, according to Model II, are expressions of north-south crustal shortening related to the presence at depth of a northwest-trending zone of dextral strain. As discussed by Davis (WNP-2 FSAR, Appendix 2.5N) in his modification of Laubscher's concept of CLEW as a zone of dextral wrench faulting (WNP-2 FSAR, Appendix 2.5O), the foldfault structures of RAW north of Wallula Gap are interference structures resulting from the interaction of two levels of deformation: (1) an upper crustal level where folding and local detachment have affected plateau stratigraphic units; and (2) a lower level of dextral

shear strain which becomes either deeper and/or broader toward the northwest. As in Model I, the high level structures of RAW would thus exhibit both compressional and strike-slip strain components. Unlike Model I, however, in which dextral strain is present only as a component of oblique thrusting above a level of detachment, Model II postulates essentially pure dextral strains in a zone beneath the buckled and detached upper crust. The lower extent of such a zone is not known, but might presumably extend through the crust of the plateau. Again, total dextral strain as expressed in the structures of RAW are less than 3 km and are distributed across a zone 10 to 15 km wide.

The case for north-south crustal shortening by strike-slip faulting along the trend of RAW is supported by the wide spread occurrence of strike-slip faults in the adjacent Blue Mountain province of northeastern Oregon and southwestern Washington. Recent studies of faulted Grande Ronde basalt in the La Grande area (Gehrels and others, 1980) and southwest of Milton-Freewater near Tollgate (Kendall and others, 1981) indicate that the structure of the broad Blue Mountain anticline in this region is dominated by late-Tertiary and Quaternary (?) dextral strike-slip faulting along the northwest-striking La Grande fault system and sinistral sense along the northeast-striking and apparently conjugate Hite fault system. These faults undoubtedly extend into the pre-Tertiary crystalline core of the Blue Mountain anticline, giving credence to the postulate of Model II that strike-slip faulting beneath RAW could involve basement rock.

Problems with the Model

Perhaps the stongest arguement against a primary buckling model for the Yakima fold structures is the general spatial association on the plateau of very long anticlines and closely associated flanking thrusts or reverse faults, most of which lie along the north flanks of the folds and dip southward. The geometry of the Umtanum Ridge-Hansen Creek-Saddle Mountains-Frenchman Hills sequence of structures west of the Columbia River is, as discussed above, supportive of an imbricate thrust fault configuration. Folding associated with the northern three faults is not as pronounced as at Umtanum Ridge and the apparent eastward merging of the Hansen Creek and Umtanum fault suggests a kinematic linkage of the two structures.

Although the shorter wavelength or closer spacing of plateau fold/fault structures north of Yakima can be attributed to a thinner sequence of basaltic rock in that area than to the south, the wider spacing of the Umtanum Ridge-Gable Mountain, Saddle Mountains, and Frenchman Hills structures to the east and northeast is not easily attributable to a thicker sequence of basalt in that northern plateau region. Nevertheless, uniform spacing of these three structural alignments is difficult to explain using either model I or II in light of the small cumulative compressive strains represented by them.

Summary Statement of Tectonic Models I and II

For the reasons discussed above, there is no reason to exclude either of the tectonic models, I or II, at this time. However, both models require interrelationships between faulting and folding and, in both, faults with appreciable dimensions can develop along more highly compressed portions of major structures. Similarly, faults associated with minor fold structures of lesser length and amplitude, whether primary or secondary in origin, are unlikely to have significantly large

surface areas. The two cases just mentioned appear to be exemplified by the lengthy and youthful basal scarp system of Toppenish Ridge (the former case) and the areally restricted north-dipping, south, and central thrust faults of Gable Mountain (the latter case).

Finally, in both models, the structures of RAW are considered to be associated with faults exhibiting oblique slip, i.e., with both reverse and dextral strike-slip components. In the response to Question 360.14, the ground motions that would result from the maximum earthquake on RAW were estimated assuming either a strike slip or reverse fault tectonic model. The resulting ground motions for either tectonic model are essentially the same.

Various tectonic models were considered for Gable Mountain-Southeast Anticline in the seismic exposure study (WNP-2 FSAR, Appendix 2.5K). Analysis of detailed geologic cross-sections across Gable Mountain and Southeast Anticline do not affect the relative weights of the tectonic models that were used in the exposure study. Even if a south-dipping thrust or reverse fault is assumed to lie along the entire northern flank of Gable Mountain, the seismic exposure at the site would only be increased by about a factor of two. However, since the completion of the seismic exposure study, additional studies have been conducted that show: 1) the Gable Butte-Southeast Anticline segment is not continous but is, itself, segmented, and 2) the Southeast Anticline fault is not capable (Golder Associates, 1982). Because a large part of the seismic exposure results from the close proximity of Southeast Anticline to the site, the effect of incorporating these findings into the exposure analysis is a substantial reduction (4 to 5 times) in the annual probability of exceeding the design ground motions. This reduction is greater than increases in exposure that could result from changes in the relative weights of the tectonic models.

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Skagit/Hanford Nuclear Projects, Preliminary Safety Analysis Report, prepared by Northwest Energy Services Company, Kirkland, Washington, 1982.

Q. 361.24

Illustrate explanation of the applicant;s concept of "* * * intracrustal thrust-type detachments and less-throughgoing zones of interconnected faults and kink-bands." How do these relate to the "structural spectrum?" Where are they or where would they be expected? Show in schematic cross section(s) the conceptual and spatial relationships between the hypothetical faults and the crustal levels of Appendix 2.5 K (WPPSS, 1981), and the examples within the "structural spectrum" (3) above. Show the vertical zone through which the present-day north-south compression is acting. Show depths of significant earthquakes projected into cross section.

RESPONSE:

The questions and concepts contained in the first three sentences of Question 361.24 are responded to in the combined response to Questions 361.21, 361.22, and 361.25.

Figure 361.24-1 is a schematic cross-section that shows the postulated crustal levels and fault geometries discussed in Appendix 2.5K. These are superimposed on Columbia Plateau seismicity projected into a north-south line along 119^{o} 30'W (Appendix 2.5J). The combined crustal structure and seismicity represent the vertical crustal section through which compression is operating. The line of cross section and an epicenter plot of the seismicity are shown in Figure 361.24-2.

To estimate the fault dimensions and potential earthquake magnitudes for use in the seismic exposure analysis (Appendix 2.5K), a range of fault widths was developed using the postulated crustal levels from available geophysical data and a range of dips reasonable for reverse faults. This analysis resulted in widths of 5, 11, 20 and 23 km. The 5 km width (Fault A) is derived using a fault that dips 60 degrees and extends to a depth

of 4 km. The 4-km depth is the maximum depth to the base of the Columbia River basalts based on gravity data (WNP-2 FSAR, Appendix 2.5L). A width of 11 km is (Fault B) obtained using the average depth to basement of 7.5 km (Eaton, 1976) and a fault dip of 45 degrees. The 20 km width (Fault C) is based on a 30-degree fault dip extending to the maximum depth of the top of the basement at 10 km. The 23 km width (Fault D) is obtained using the average maximum depth of seismicity of 20 km (Appendix 2.5J) and a fault dipping 60 degrees. The choice of depths (crustal levels) reflects the concept that plateau detachments are most likely to originate at mechanical discontinuities.

If the depth to the base of the basalt more generally varies from 2 to 3 km, as it is now considered to do (Fig. 361.24-1), and if this level had been used in Appendix 2.5K, faults widths would be 6 km or less depending on level of detachment and fault dip.

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Hill, D.P., 1972, Crustal and upper mantle structure of the Columbia Plateau from long range seismic refraction measurements: Geological Society of America Bulletin, v. 83, p. 1636-1648.

Q. (No Number Assigned)

The applicant should assess the possibility of having a fissure lava flow at the site.

RESPONSE:

A probabilistic assessment of potential volcanic hazards in the Pasco Basin has been conducted as part of the U.S. Department of Energy efforts to site a nuclear waste repository in Columbia River basalts at the Hanford Site (Ertec, 1981). This study addressed potential volcanic processes and their effects on the Pasco Basin from three potential volcanic source regions: the Cascade Range, the Basin and Range, and the Columbia Plateau itself. The volcanic history was reviewed for each source region to estimate likely events and outcomes that could occur in the Pasco Basin following renewed volcanism, to estimate recurrence intervals for these events and to estimate conditional probabilities for each volcanic event. Event networks were used to illustrate the inferred sequence of events that would follow if volcanism were to recur in any of the source regions.

With regard to the potential of a fissure lava flow affecting the Pasco Basin two outcome events studied by Ertec (1981) may be considered applicable:

- o lava flow and,
- o repository breach by a feeder dike

These events were considered to be associated with renewed basaltic volcanism within the Columbia Plateau. The geologic data suggests that one flood basalt eruption in the Columbia Plateau would occur every 2×10^6 years with an annual rate of 5×10^{-7}/year.

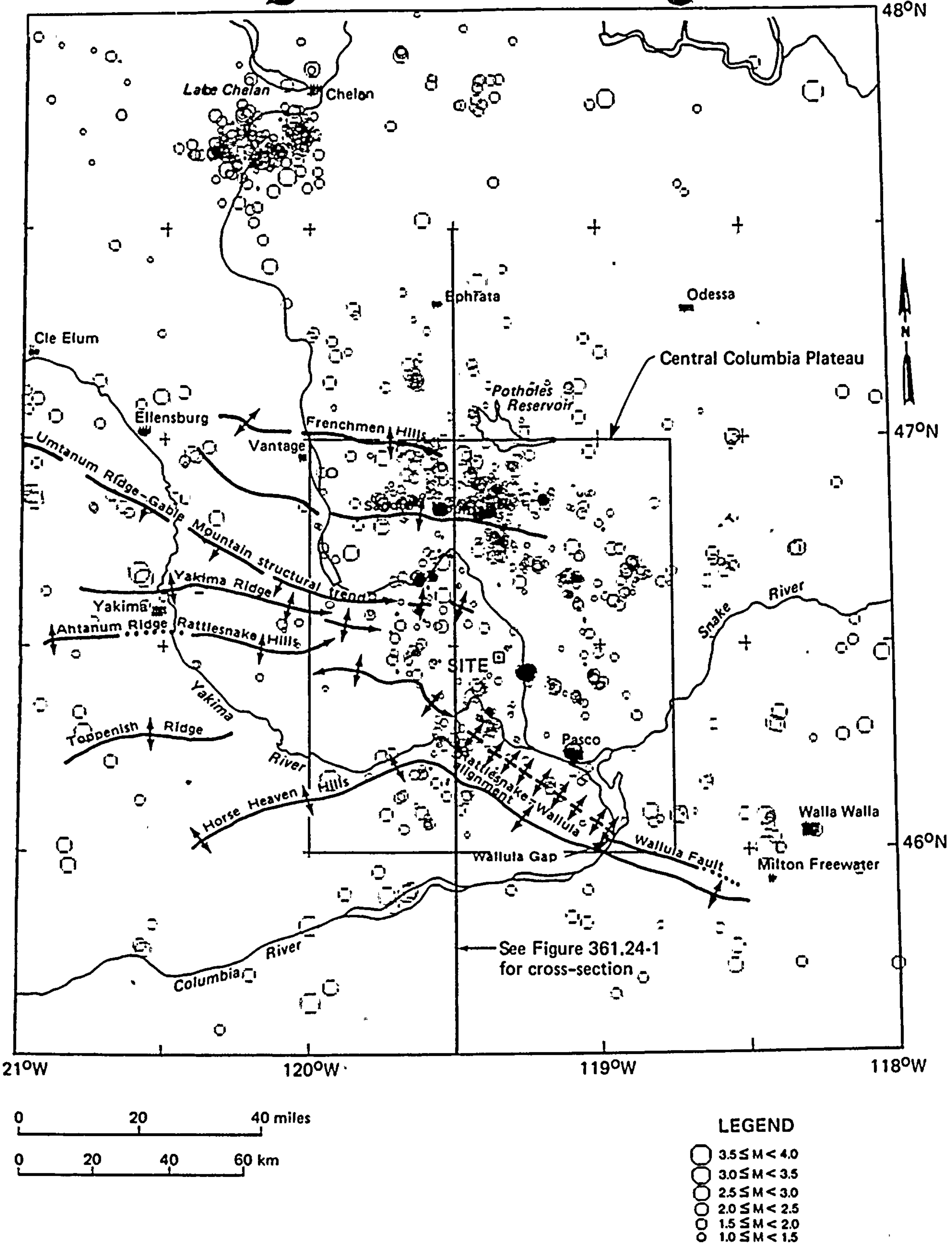
Using the event networks, the relative likelihood and occurrence of the outcome events (lava flow and repository breach) were calculated assuming that the regional volcanism follows a Poisson distribution. The resulting occurrence probabilities for lava flow and repository breach by a feeder dike were:

	Calculated Percent Probability		
	10^2 yrs	10^4 yrs	10^6 yrs
Lava flow	8.1×10^{-4}	0.81	7.8
Repository breach	5.3×10^{-6}	5.3×10^{-4}	0.053

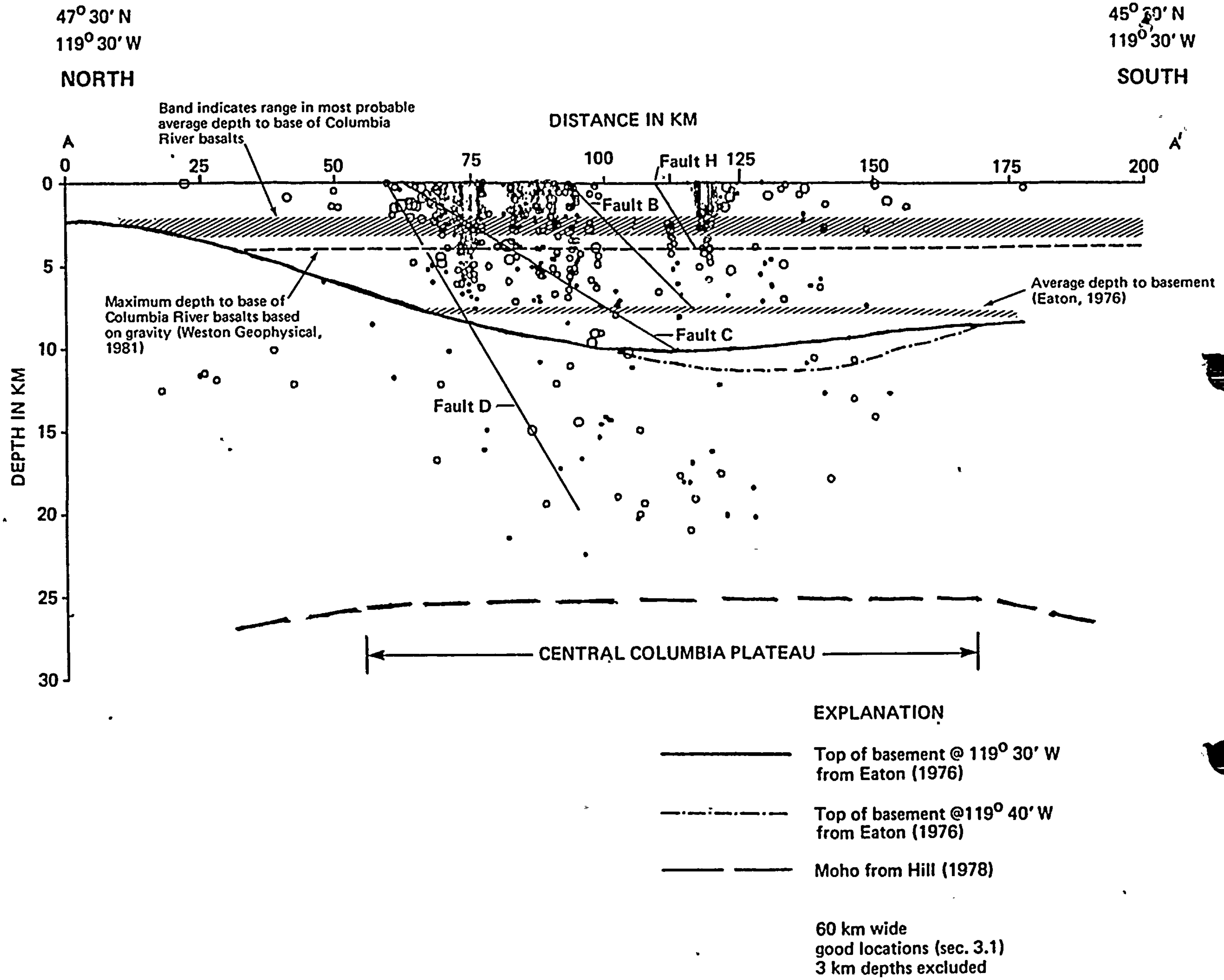
These results indicate that there is indeed a low probability for either lava flows or feeder dikes to affect a repository in the Pasco Basin considering potential repository operational and isolation periods of 100, 10,000, and 1,000,000 years. The results further suggest that annual percent probabilities (applicable to nuclear power plant siting) for lava flows and dikes are extremely low and may be on the order of 8×10^{-6} and 5×10^{-8}, respectively.

Reference

Ertec, 1981, Assessment of potential volcanic hazards, Pasco Basin, Washington: Draft, Rockwell Hanford Operations Report RHO-BW-CR-130P, 34 p.



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EPICENTERS OF NON-SWARM EARTHQUAKES, ALL DEPTHS: MAR. 1969 – DEC. 1980	Figure 361.24-2



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
Nuclear Project No. 2

GEOMETRY OF HYPOTHETICAL FAULTS AND CRUSTAL LEVELS FROM APPENDIX 2.5K

Figure 361.24-1

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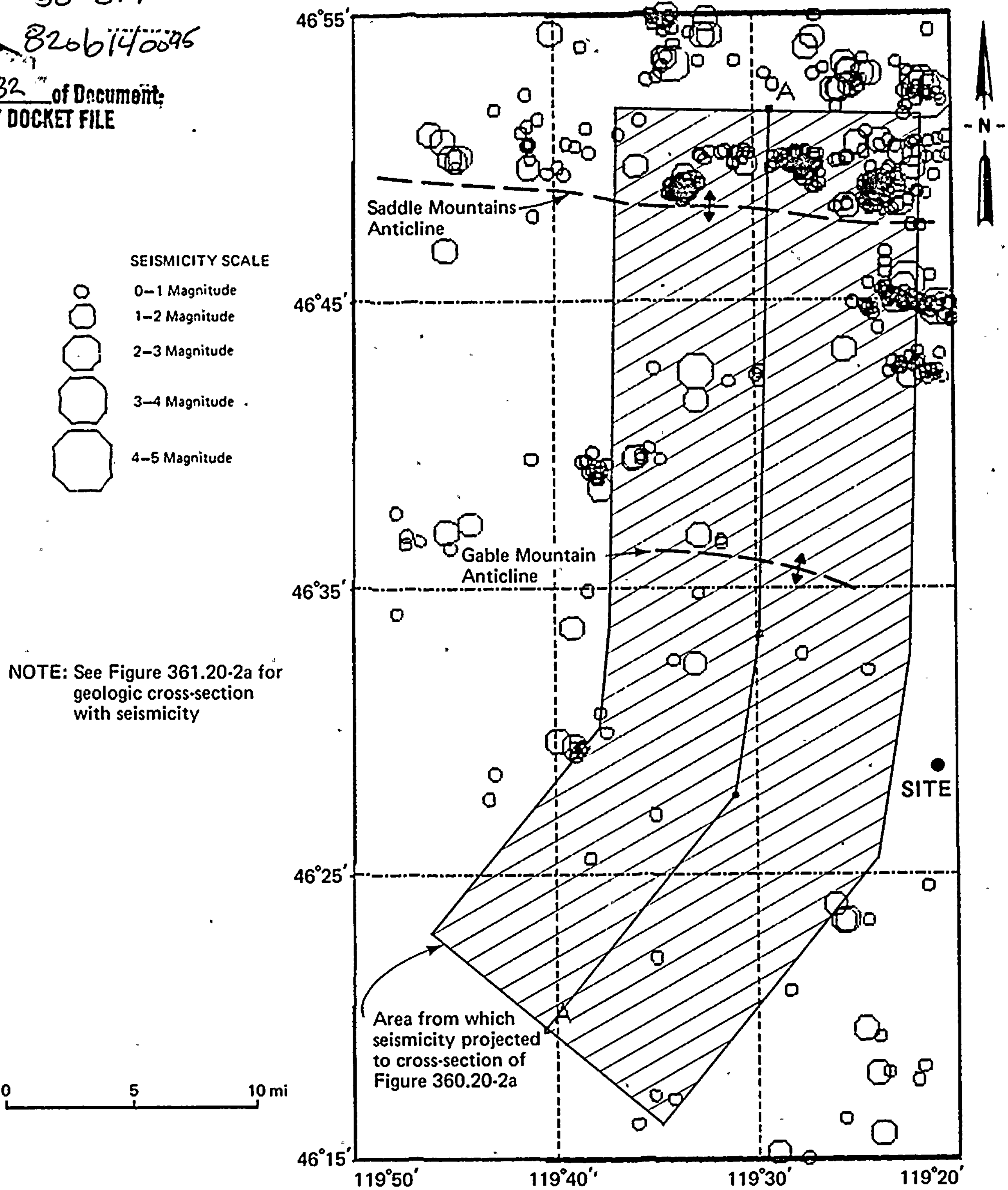
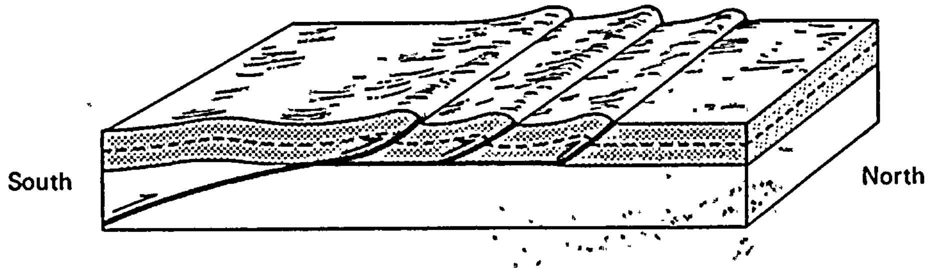
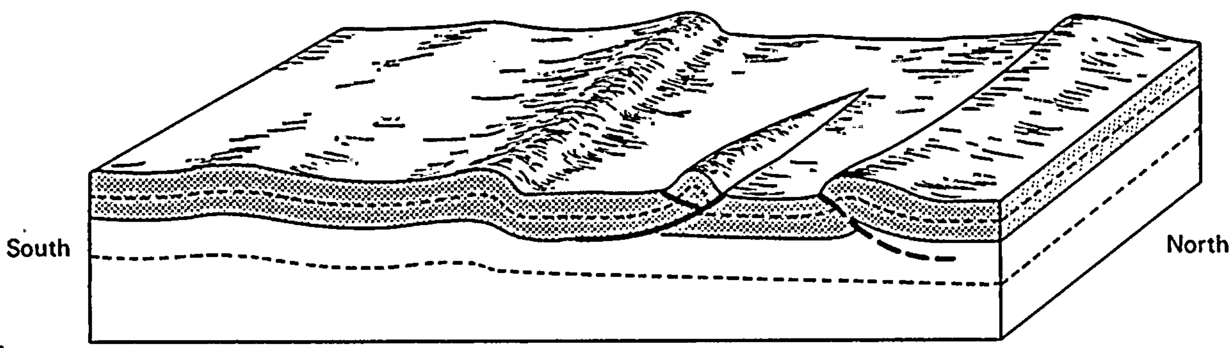


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	EPICENTRAL PLOT, PASCO BASIN	Figure 361.20-2b



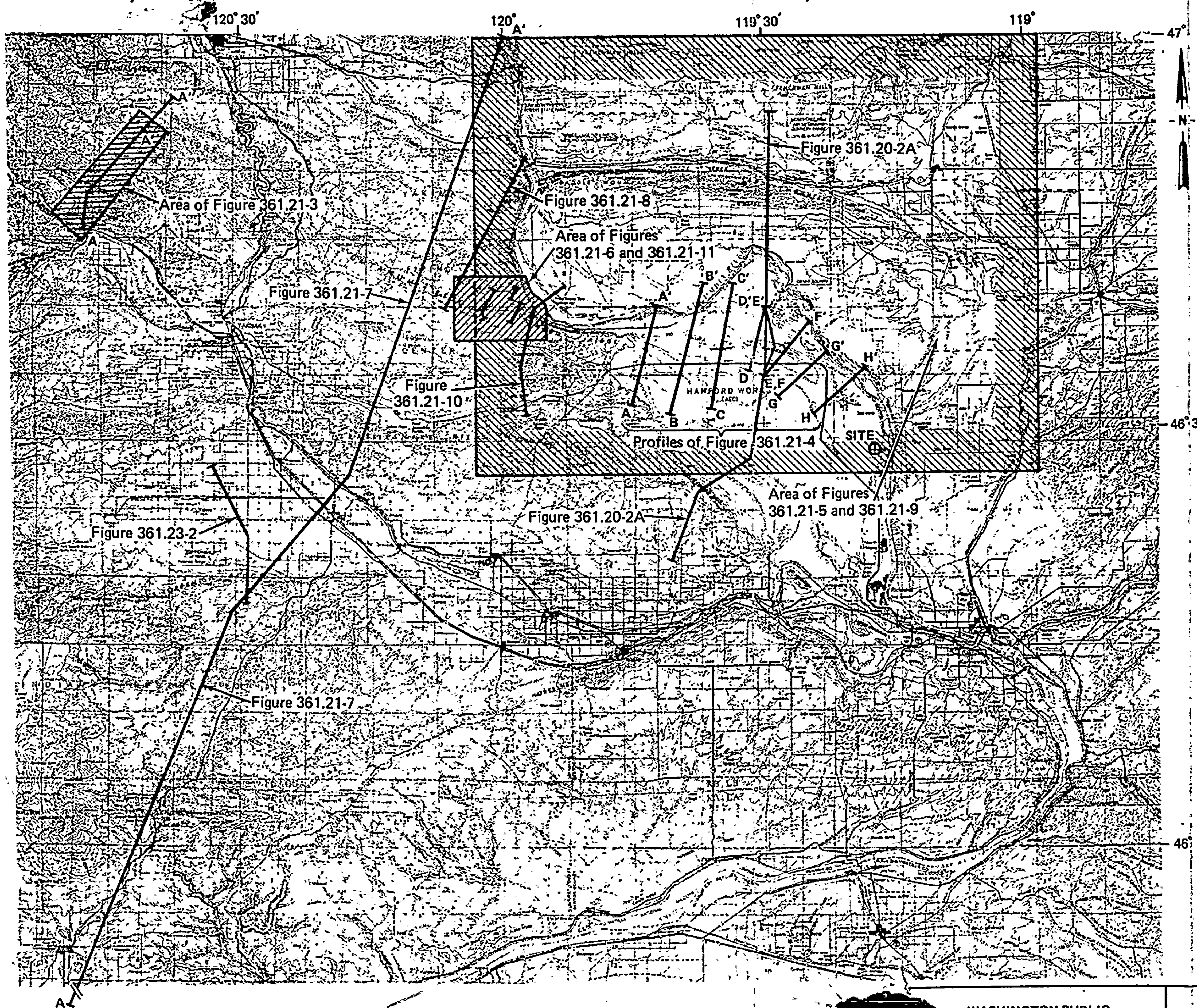
Tectonic Model I

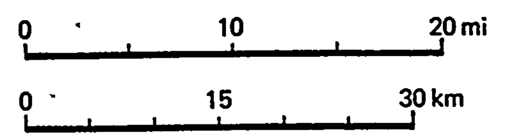


Tectonic Model II

NOTE: Shaded areas approximate the layered basalt sequence (Columbia River basalt)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	SCHEMATIC ILLUSTRATIONS OF REGIONAL TECTONIC MODELS I AND II, COLUMBIA PLATEAU	Figure 361.23-1



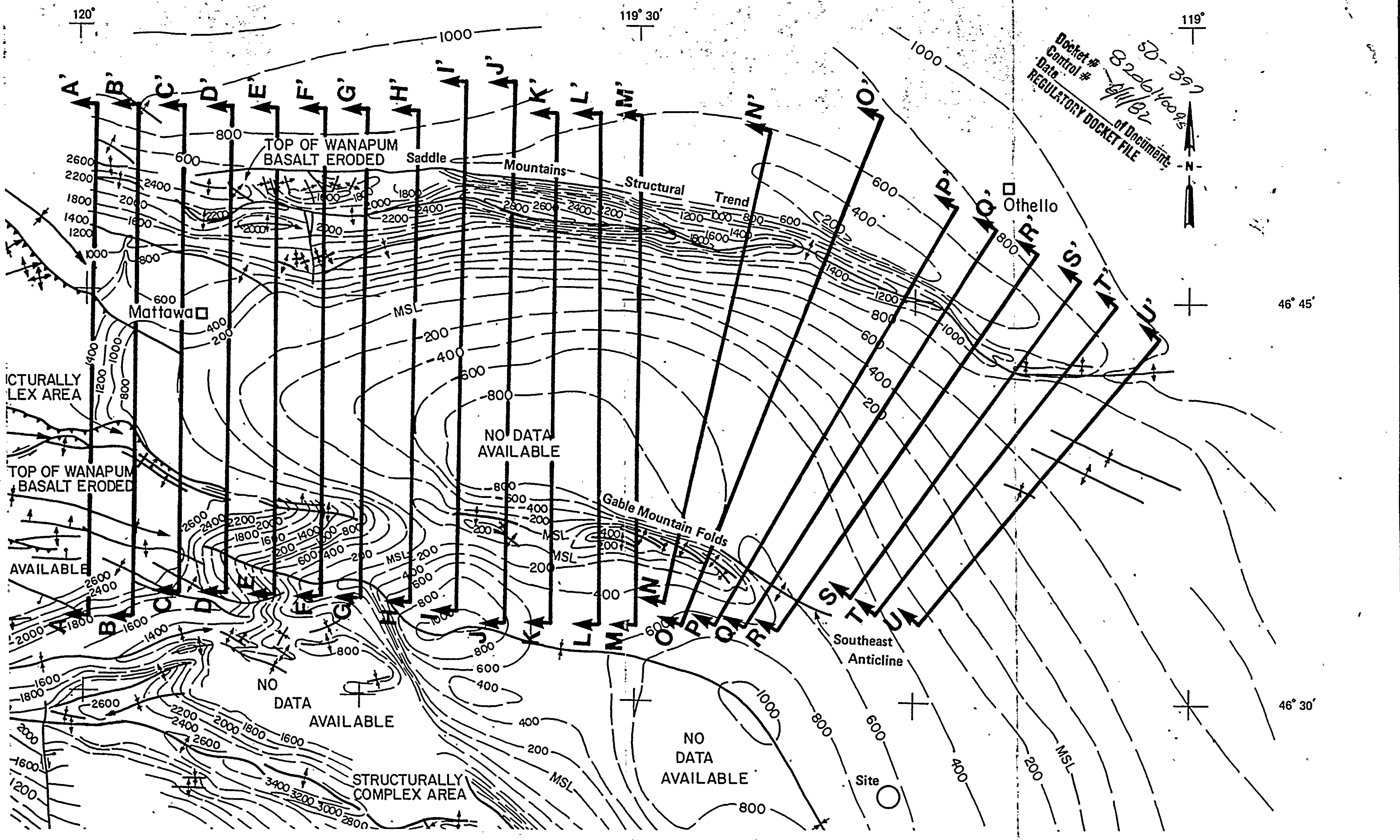


WASHINGTON PUBLIC POWER SUPPLY SYSTEM

clear Project No. 2

INDEX MAP

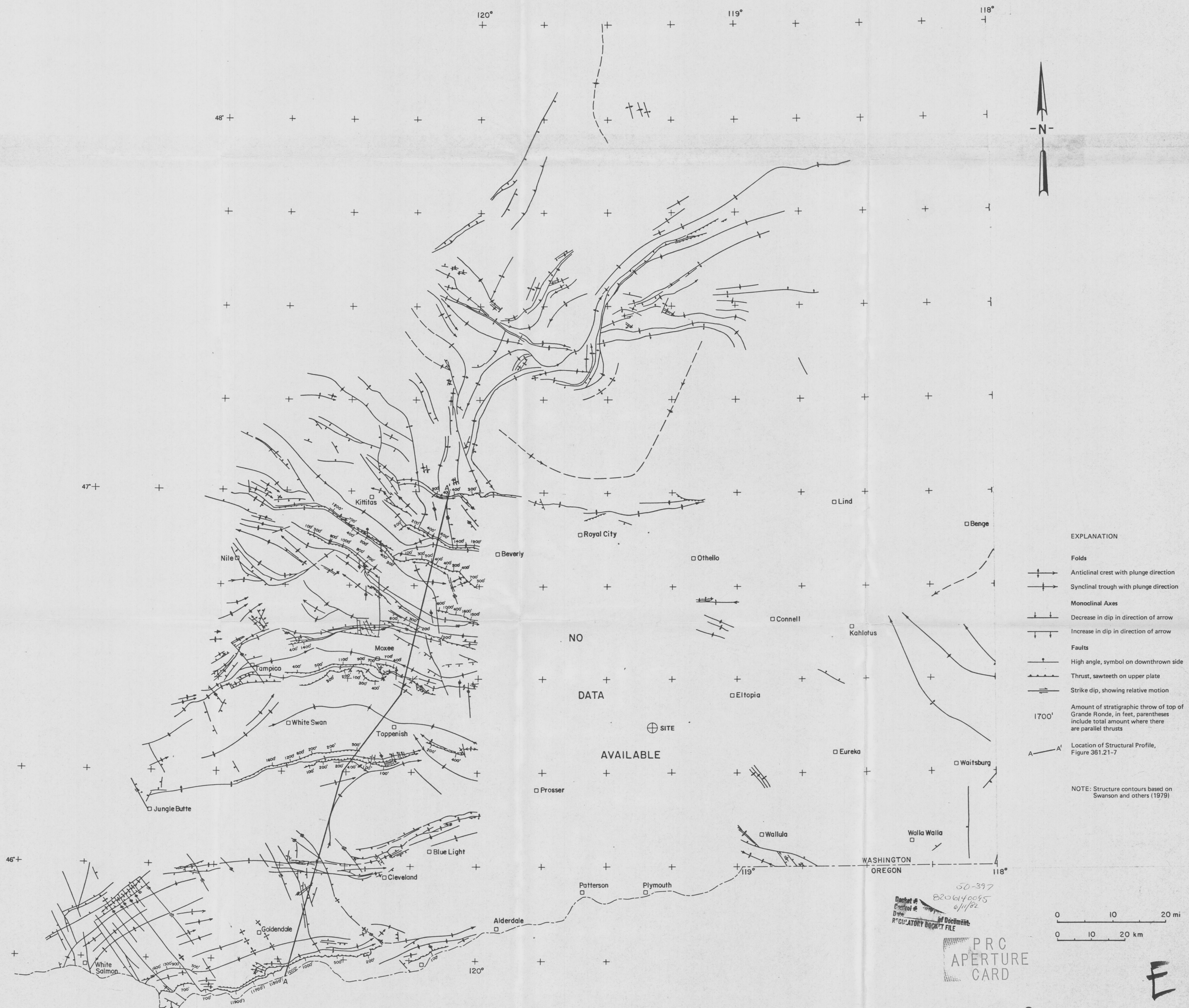
Figure 361.20-1



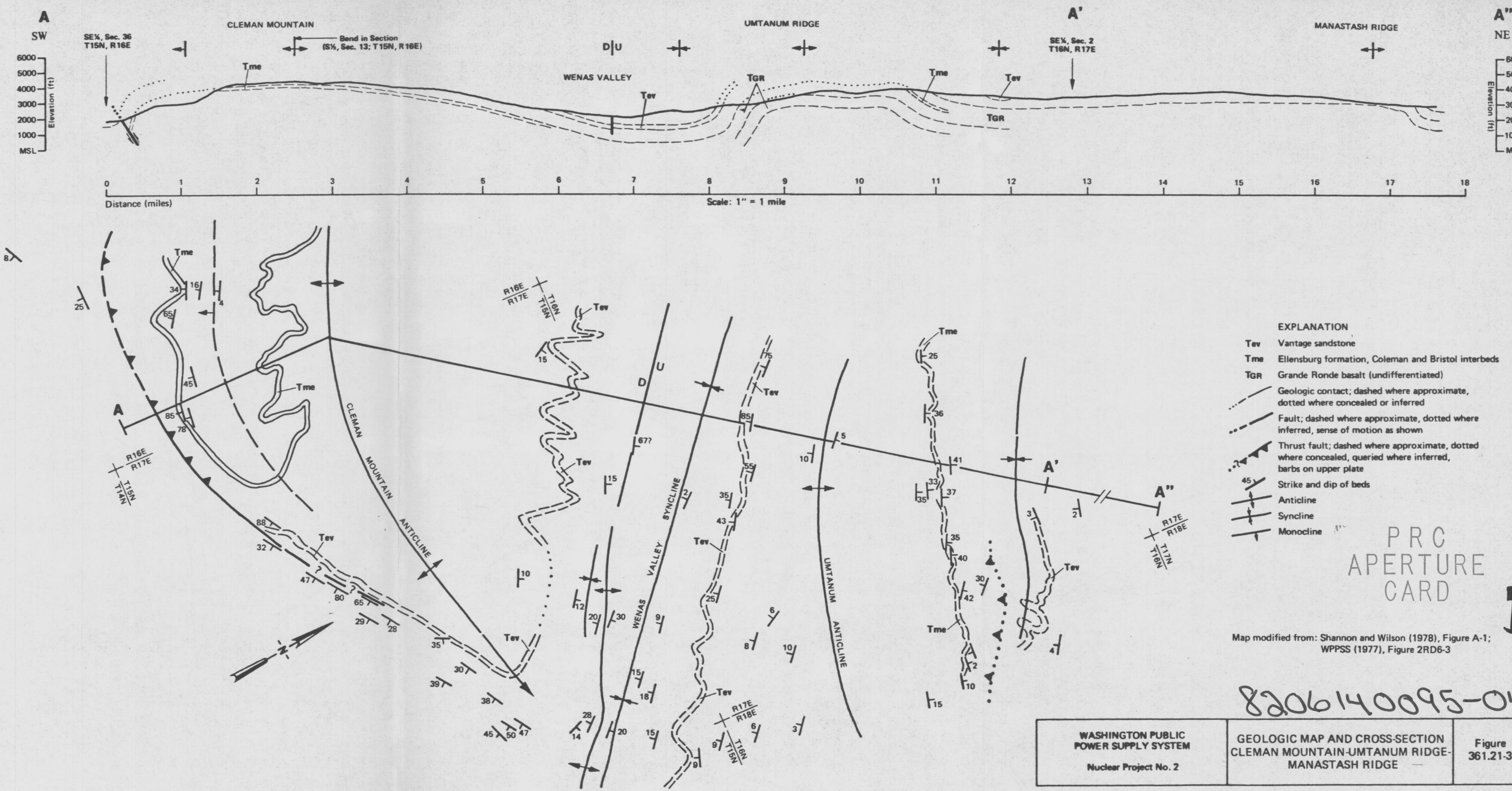
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	LOCATION MAP: STRUCTURAL PROFILES ON TOP OF THE WANAPUM BASALT ACROSS THE UMATANUM RIDGE, GABLE MOUNTAIN, SOUTHEAST ANTICLINE AND SADDLE MOUNTAINS STRUCTURAL TRENDS	Figure 361.21-5

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS-SECTION: RATTLESNAKE MOUNTAIN–SADDLE MOUNTAINS (SITE CROSS-SECTION)	Figure 361.20-2a

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURE CONTOUR MAP ON TOP OF THE WANAPUM BASALT, EASTERN WASHINGTON	Figure 361.21-1

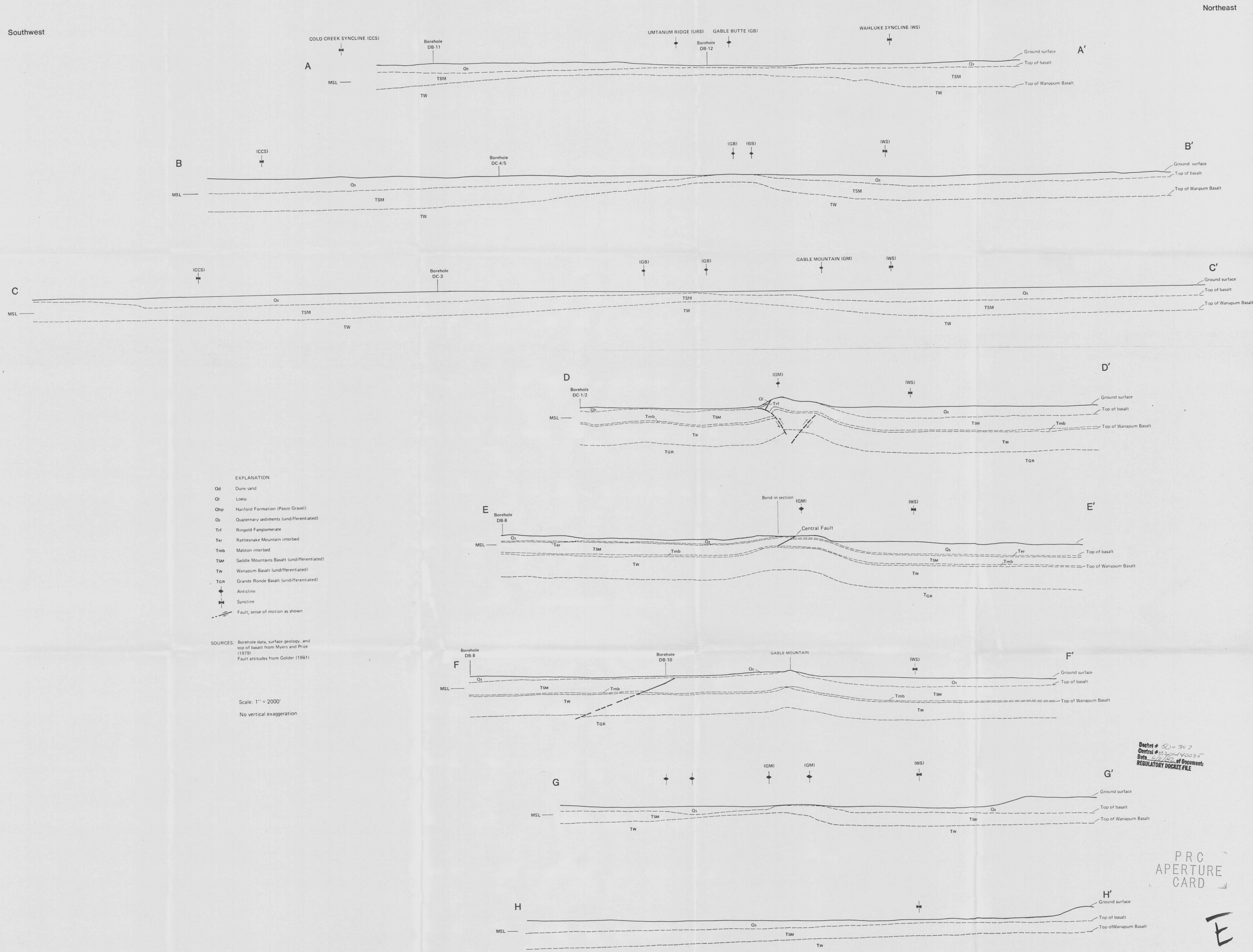


WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURE MAP ON TOP OF THE GRANDE RONDE BASALT, EASTERN WASHINGTON	Figure 361.21-2



Map modified from: Shannon and Wilson (1978), Figure A-1; WPPSS (1977), Figure 2RD6-3

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC MAP AND CROSS-SECTION CLEMAN MOUNTAIN-UMTANUM RIDGE-MANASTASH RIDGE	Figure 361.21-3



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS SECTIONS: GABLE BUTTE, GABLE MOUNTAIN, SOUTHEAST ANTICLINE	Figure 361.21

Modified from: SHNP, PSAR, Appendix 2N, Figure 2N-11.

0 500 1000 2000 3000 4000 feet

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WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC MAP: UMTANUM RIDGE STRUCTURE NEAR PRIEST RAPIDS DAM	Figure 361.21-6

NOTE: See Figure 361.21-2 for location of profile.

Source of structural data: Swanson and others, 1979

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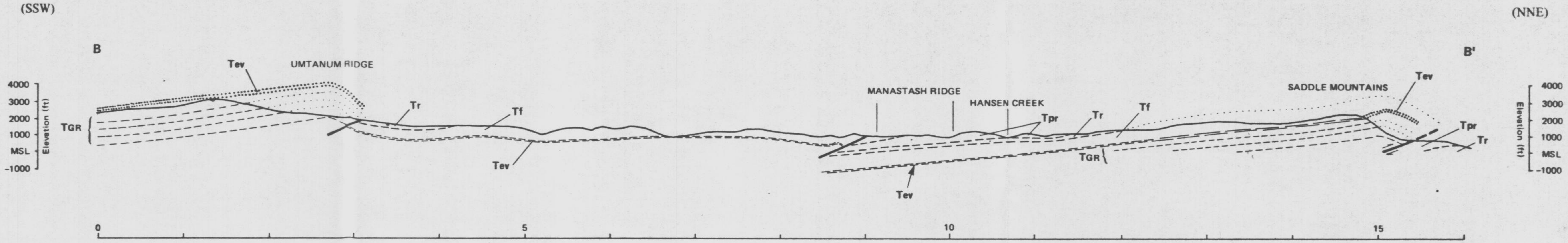
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURAL PROFILE: TOP OF GRANDE RONDE BASALT, COLUMBIA HILLS–FRENCHMAN HILLS	Figure 361.21-7



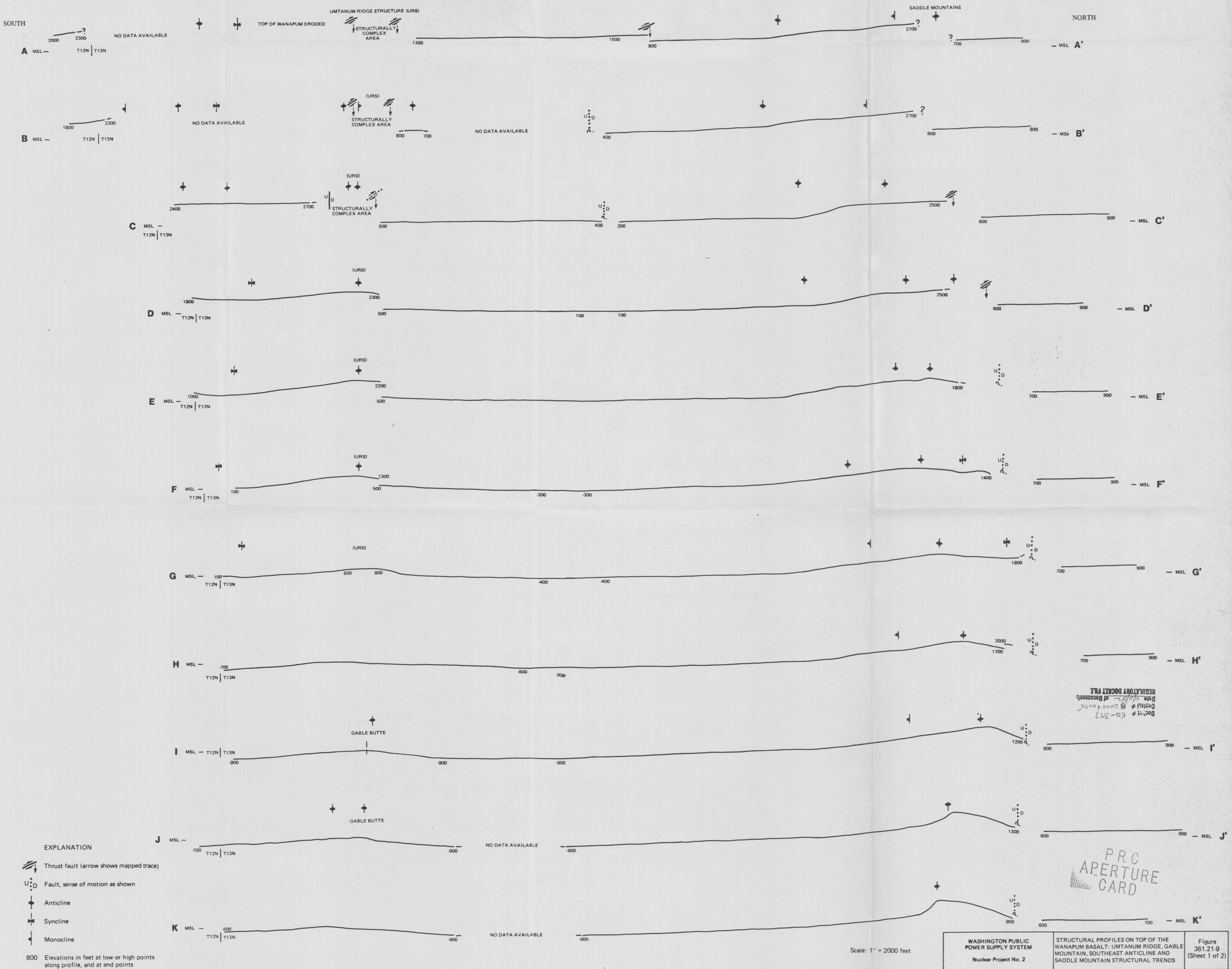
Distance (miles)

Scale: 1" = 1 mile
No vertical exaggeration

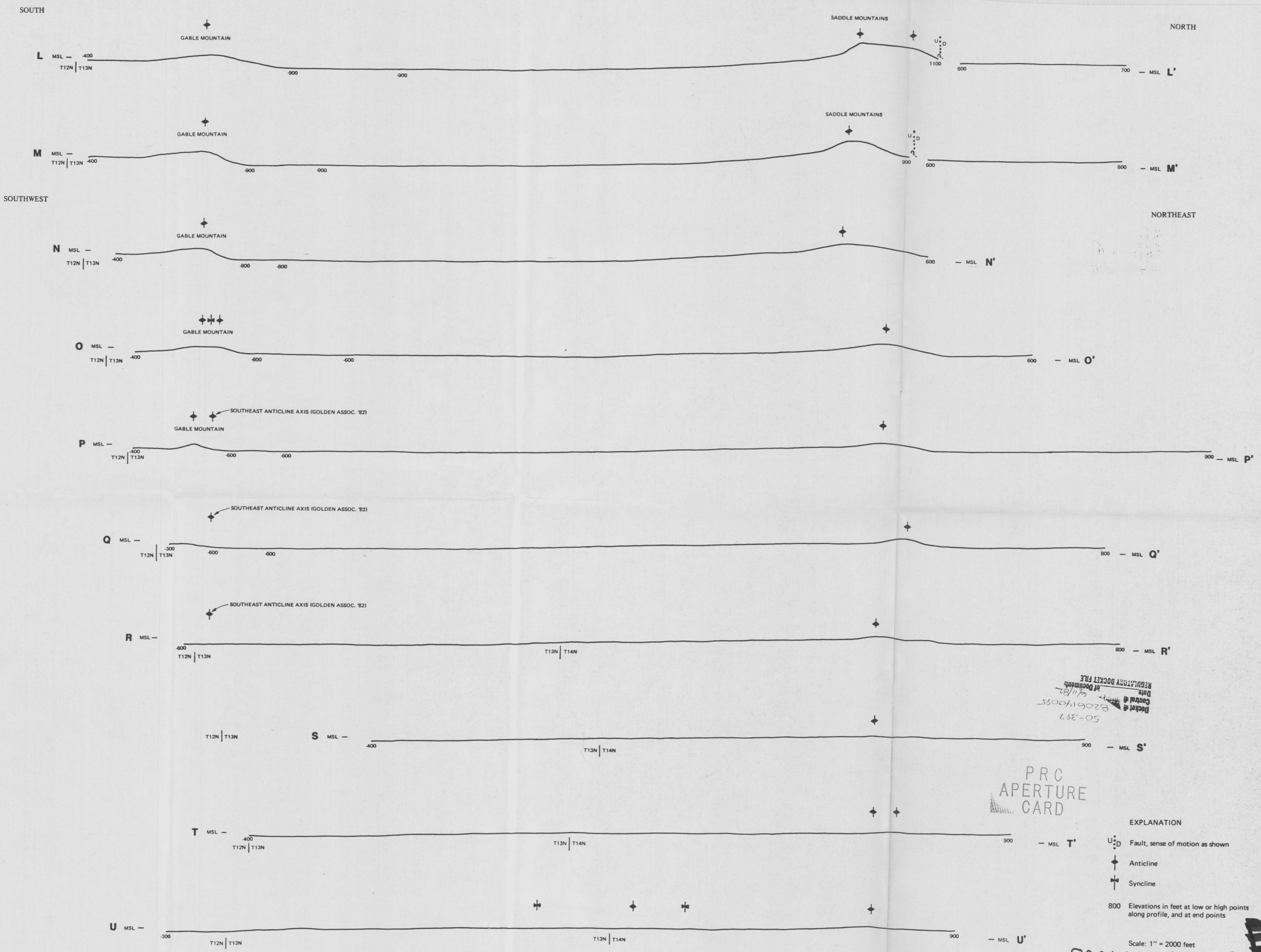
EXPLANATION:

Wanapum Basalt	Tpr	Priest Rapids
	Tr	Roza
	Tf	Frenchman Springs
	Tev	Vantage Sandstone
	TGR	Grande Ronde Basalt (undifferentiated)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS-SECTION: UMTANUM RIDGE–SADDLE MOUNTAINS	Figure 361.21-8



WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURAL PROFILES ON TOP OF THE WANAPUM BASALT: UMTANUM RIDGE, GABLE MOUNTAIN, SOUTHEAST ANTICLINE AND SADDLE MOUNTAIN STRUCTURAL TRENDS	Figure 361.21-9 (Sheet 1 of 2)



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WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	STRUCTURAL PROFILES ON TOP OF THE WANAPUM BASALT: UMTANUM RIDGE, GABLE MOUNTAIN, SOUTHEAST ANTICLINE AND SADDLE MOUNTAIN STRUCTURAL TRENDS	Figure 361.21-9 (Sheet 2 of 2)

D

Modified from geologic mapping by Price (1982)

EXPLANATION

	Qal	Alluvium
	Tel	Ellensburg Formation (undifferentiated)
Saddle Mountains Basalt	Tp	Pomona member
	Ta	Asotin member
Wanapum Basalt	Tpr	Priest Rapids member
	Tr	Roza member
	Tf	Frenchman Springs member
	Tev	Vantage sandstone
Grande Ronde Basalt (TGR)	Tsb	Sentinel Bluffs sequence
	Ts(u)	Schwana sequence (Umtanum flow)

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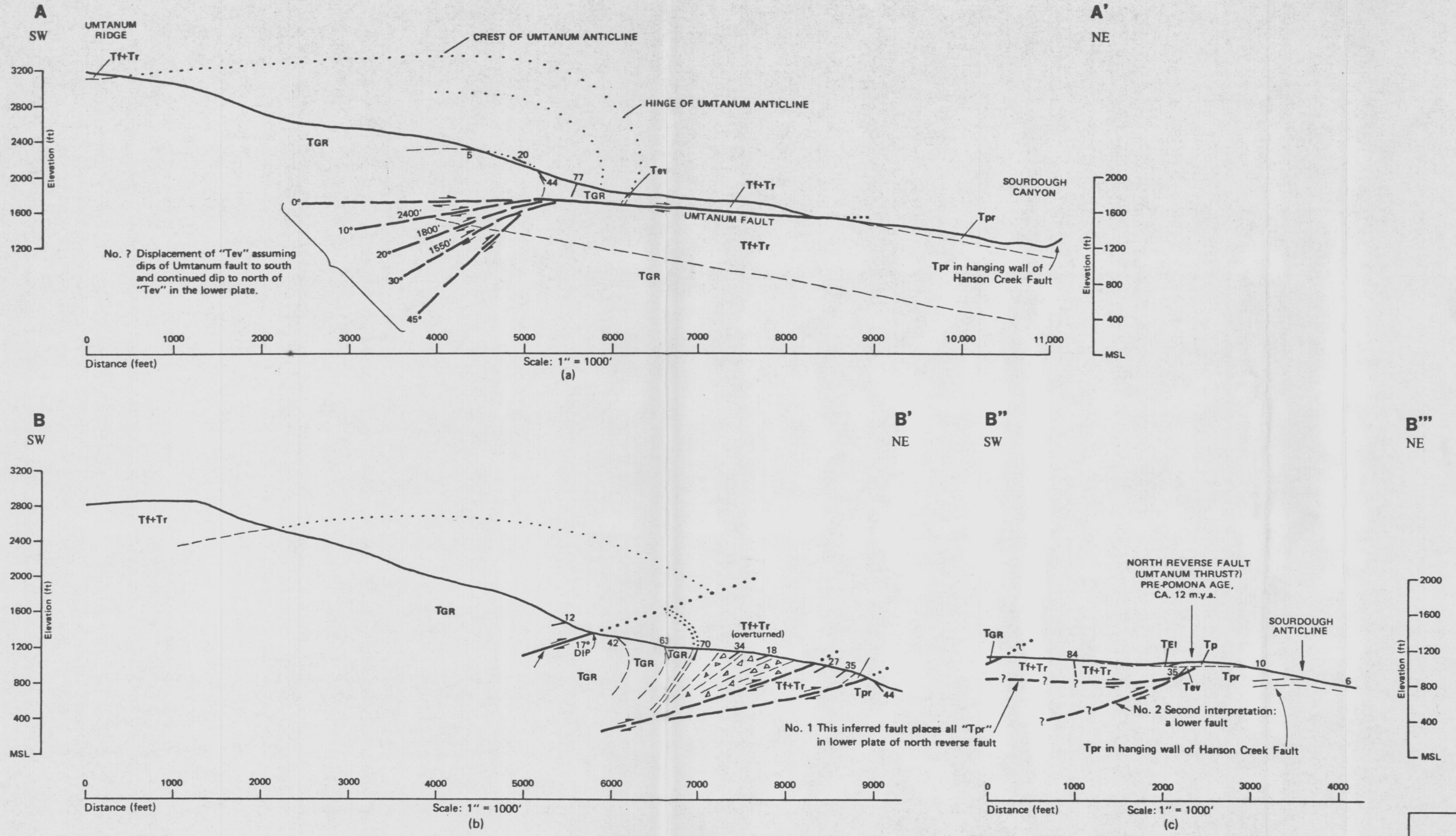
WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS-SECTION: UMTANUM RIDGE STRUCTURE NEAR PRIEST RAPIDS DAM	Figure 361.21-10



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EXPLANATION

Saddle Mountains Basalt	TEl	Ellensburg Formation (undifferentiated)
	Tp	Pomona
Wanapum Basalt	Tpr	Priest Rapids
	Tr	Roza
	Tf	Frenchman Springs
Grande Ronde Basalt	Tev	Vantage Sandstone
	TGR	Grande Ronde basalt (undifferentiated)

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NOTE: For location of cross-sections, see Figure 361.21-6

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WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS-SECTIONS: UMTANUM RIDGE STRUCTURE NEAR SOURDOUGH CANYON	Figure 361.21-11

EXPLANATION

	Qs	Quaternary Sediments
	Qss	Touchet Beds
	Tel	Ellensburg Formation (upper, undifferentiated)
Columbia River Basalt Group	TSM	Saddle Mountains Basalt
	TW	Wanapum Basalt
	TGR	Grande Ronde Basalt
	TOV	Oligocene Volcanics

NOTES:
1. Surficial geology from Bentley and others, 1980
2. Well data from Kinnison and Sceva, 1963
3. Stratigraphic thicknesses and structural data from Bentley and others, 1980
4. Surface dips of Mill Creek thrust and Oak Spring faults from Campbell and Bentley, 1981, and Bentley and others, 1980 respectively
5. Subsurface fault geometry of Mill Creek thrust based upon historic thrust fault events (i.e. San Fernando, CA and El Asnam, Algeria)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM Nuclear Project No. 2	GEOLOGIC CROSS-SECTION: SATUS PEAK ANTICLINE, TOPPENISH RIDGE STRUCTURE	Figure 361.23-2