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SCHWENCER,A. Licensing Branch 2

SUBJECT: Forwards responses to Geosciences Branch 810504 second round questions.Responses will be incorporated into FSAR.Remainder of responses will be transmitted by 810930.

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APP 4

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Washington Public Power Supply System
P.O. Box 968 3000 George Washington Way Richland, Washington 99352 (509) 372-5000

Docket No. 50-397

August 10, 1981
G02-81-229
NS-L-02-CDT-81-029

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

Dear Mr. Schwencer:

Subject: SUPPLY SYSTEM NUCLEAR PROJECT NO. 2
RESPONSES TO ROUND TWO QUESTIONS
GEOSCIENCES BRANCH

Reference: Letter, R. L. Tedesco to R. L. Ferguson, "WNP-2 FSAR - Request for Additional Information", dated May 4, 1981.

Enclosed are sixty (60) copies of responses to the Geosciences Branch questions transmitted to the Supply System by the referenced letter. These responses will be incorporated into the FSAR in an amendment within four months. The remainder of the responses will be transmitted to the Nuclear Regulatory Commission by September 30, 1981.

Very truly yours,

for G. D. BOUCHEY
Director, Nuclear Safety

GDB/CDT/ldm

Enclosure

cc: WS Chin, BPA
AD Toth, NRC
NS Reynolds, Debevoise & Liberman
J Plunkett, NUS Corporation
R Auluck, NRC
OK Earle, B&R
WNP-2 Files

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361.4 Provide a discussion on the effect, if any, of newly acquired data (geological, geophysical and seismological) has on your position with regard to the 1872 earthquake. This should include but not be limited to the magnitude, depth, tectonic province in which a similar event could occur, and any ground motion effects at the site.

Response:

Appendix 2.5-R, Chp. 2.5, WNP-1/4 PSAR (Amendment 23) contains the Supply Systems position and supporting data regarding the December 14, 1872 earthquake. Appendix 2.5-R was included by reference in the WNP-2 FSAR.

The reference list supplied as part of the answer to this question identifies eleven (11) reports relevant to the issue of the December 14, 1872 earthquake that were prepared on behalf of the Supply System after October, 1977 when Appendix 2-R, Chp. 2.5, WNP-1/4 PSAR was filed. These eleven reports document work that was either underway or subsequently initiated at the time Appendix 2-R was prepared in order to clarify the Supply Systems position regarding the location of the December 14, 1872 earthquake and identify other possible regions where future earthquakes of this "type" might be expected to occur. A summary of each of these studies is included as Attachment A. None of newer aquired data or any of the data we are aware of has any adverse effect upon the Supply Systems position regarding the December 14, 1872 earthquake as stated in Appendix 2R, Chapter 2.5, WNP-1/4 PSAR. Some of the data does however serve to further support the Supply Systems position that the December 14, 1872 earthquake did not occur in the Wenatchee to Lake Chelan area. These data are (1) the Shannon and Wilson investigation of the Ribbon Cliff landslide at Entiat, and (2) the Woodward-Clyde Consultants "Microearthquake Studies," that includes the Entiat area. Shannon and Wilson used age determinations of undisturbed trees and stumps occurring on the slide debris to demonstrate that the major portion of the Ribbon Cliff landslide occurred more than 215 years ago and therefore significantly predates the December 14, 1872 earthquake. Consequently, the Ribbon Cliff landslide cannot be used as an indicator either for assigning a maximum intensity to the December 14, 1872 earthquake (USGS/NOAA, 1977) or for establishing the epicenter (Bechtel, 1975,1976,1977).

The Woodward-Clyde Consultants (1978a) study of microearthquakes that included the Entiat area was included in part in Appendix 2-R, Chp. 2.5, WNP-1/4 as subappendix 2-R-L. Most of the data from the seismograph networks that were being operated was still being processed when Appendix 2-R was filed. A subsequent study of this data in the Entiat area indicates that the contemporary seismicity is limited to a zone of approximately 40 km in length, striking about N20°E that appears to dip south, roughly transverse to the Chiwaukum and Methow graben boundary faults. The activity is reasonably well constrained to depths between about 2 km and 10 km,

with most of the activity occurring around 6-7 km. Bor (1978) in a study of the seismicity of this area, concluded that the maximum earthquake expected for this type and size of source area would be around M_L 5.8. In addition, on the basis of attenuation patterns for Pacific Northwest earthquakes and intensity data from the 1872 earthquake, Malone and Bor (1979) concluded that the epicenter of the 1872 earthquake did not occur in the Wenatchee to Lake Chelan area but was located some 150 km to the north-northwest.

The geologic studies of the boundary area between the Columbia Plateau and the North Cascade - Okanogan area reported on previously in Appendix 2-R-D, Chp. 2.5, WNP-1/4 PSAR, found no evidence of any significant deformation along any of the major structures traversing the Wenatchee - Entiat - Lake Chelan area where they pass under the Columbia Plateau basalts. In addition, extensive glacial outwash terrace deposits (dated as 28,000 y.b.p. in the Grand Coulee dam area (Blume, 1972) can be found in esentially an undisturbed state as far south as Entiat.

The closest approach to the WNP-2 site of the Entiat seismicity source area is approximately 130 km. If an 1872 "type" earthquake were to occur in this area, it is estimated that the maximum acceleration in rock at the WNP-2 site would probably not exceed 0.1 g., given any of the currently accepted attenuation relationships.

In regards to establishing a source for the December 14, 1872 earthquake, it was stated earlier that the only evidence for Quaternary displacement that could be found in or near the meizoseismal region, was on the Fraser - Hope - Straight Creek fault system. Woodward-Clyde Consultants (1978b) studied the Straight Creek fault zone near the U.S. and Canadian border. Trenches across "sackung" type features near Marblemount, Washington showed definite Holocene fault displacement. The studies did not resolve the question of whether these displacements were of tectonic origin or were produced by gravity.

Further to the south, in the vicinity of Snoqualmie Pass, Shannon and Wilson (1978d) studied the Evergreen segment of the Straight Creek fault system. This is the area where the hypothetical Olympic-Wallowa Lineament (OWL) would intersect the Straight Creek fault. The latest significant movement on the Straight Creek fault in the Snoqualmie Pass area, was concluded to have occurred prior to 15 m.y.b.p. This conclusion is based primarily on the fact that the Snoqualmie batholith, which was intruded across the southern projection of the Straight Creek fault in late Miocene, shows no evidence of deformation. Weston Geophysical Research (1978c) interpretation of the aeromagnetic data in the Snoqualmie Pass area concludes that the magnetic signature of the Straight Creek fault segment extends for a significant distance to the south of the intersection with the hypothetical "OWL" without any discernable interuption.

In conclusion, it is the Supply Systems position that the December 14, 1872 earthquake occurred in the North Cascades - Okanogan area, a separate and distinct province from the Columbia Plateau where the WNP-2 site is located. The single potential source structure identified for the December 14, 1872 earthquake was the Fraser - Hope - Straight Creek fault system. The geologic data that supports contemporary activity on the Straight Creek fault zone within the United States is <u>not</u> persuasive. The Straight Creek

fault system intersects the hypothetical Olympic-Wallowa Lineament in the Snoqualmie Pass area. The closest approach of the Straight Creek fault system to the WNP-2 site is greater than 130 km. If an 1872 "type" earthquake is postulated to occur along the Straight Creek fault system, the maximum acceleration in rock at the WNP-2 site would probably not exceed 0.1 g. considering any of the accepted attenuation relationships.

References:

Bechtel, 1975,1976, 1977, Appendix 2-J, Chapter 2.5, Puget Sound Power and Light, Skagit Nuclear Power Plant PSAR.

Blume, J.A. Assoc., 1972, "Seismic Safety of Grand Coulee Dam" Report prepared for Washington Public Power Supply System, Richland, WA.

Bor, S., 1977, "Scaling for Seismic Source Spectra and Energy Attenuation in the Chelan Region, Eastern Washington," Attachment A to Malone 1978, Annual Report on Earthquake Monitoring of the Hanford Region, Eastern Washington, Geophysics Program, Univ. of Wash. MS thesis.

Malone, S.D., and Bor, S.S., 1979, Attenuation Patterns in the Pacific Northwest Based on Intensity Data and the Location of the 1872 North Cascades Earthquake, Bulletin of the Seismological Society of America, Vol. 69, No. 2, pp. 531-546, April 1979.

Shannon and Wilson, 1978a, "Studies of the Hope and Yale Faults in Southern British Columbia," Report prepared for the Washington Public Power Supply System, Richland, WA.

Shannon and Wilson, 1978b, "Geologic Investigations of Ross Pass Area, Washington," Report prepared for the Washington Public Power Supply System, Richland, WA.

Shannon and Wilson, 1978c, "Investigations of the Ribbon Cliff Landslide, Entiat, Washington," Report prepared for the Washington Public Power Supply System, Richland, WA.

Shannon and Wilson, 1978d, "Geologic Studies of the Southern Continuation of the Straight Creek Fault, Snoqualmie Area, Washington," Report prepared for the Washington Public Power Supply System, Richland, WA.

Shannon and Wilson, 1978e, "Geologic Reconnaissance of the Cle Elum - Wallula Lineament and Related Structures," Report prepared for the Washington Public Power Supply System, Richland, WA.

Slemmons, D. B., 1979, "Remote Sensing Analysis of Geologic Structures in Relation to the 1872 Pacific Northwest Earthquake," (Included in part in WNP 1/4 PSAR, Appendix 2.5 R-G) Report prepared for the Washington Public Power Supply System, Richland, WA.

U.S.G.S./N.O.A.A. Ad Hoc Working Group on Intensities of Historic Earthquakes, April 1, 1977, " Maximum Intensity of the Washington Earthquake of December 14, 1872," U.S. Geological Survey, Denver, CO.

Weston Geophysical Research, 1978a, "British Columbia Microearthquake Survey, May through October, 1977" (Included in part in WNP 1/4 PSAR, Appendix 2.5 R-E) Report prepared for the Washington Public Power Supply System, Richland, WA.

Weston Geophysical Research, 1978b "Stress, Gravity Anomalies, and the Location of Earthquakes in Washington State," (Included in part in WNP 1/4 PSAR, Appendix 2.5 R-E) Report prepared for the Washington Public Power Supply System, Richland, WA.

Weston Geophysical Research, 1978c "Quantitative Aeromagnetic Evaluation of Structures in the Columbia Plateau and Adjacent Cascade Mountain Area," (Included in part in WNP 1/4 PSAR, Appendix 2.5 R-I) Report prepared for the Washington Public Power Supply System, Richland, WA.

Woodward-Clyde Consultants, 1977, "Microearthquake Survey and Evaluation of Stress Orientation in Central Washington," Appendix 2.5-R-L, WNP-1/4 PSAR

Woodward-Clyde Consultants, 1978a "Microearthquake Studies," (Included in part in WNP 1/4 PSAR, Appendix 2.5 R-L) Report prepared for the Washington Public Power Supply System, Richland, WA.

Woodward-Clyde Consultants, 1978b "Straight Creek Fault Zone Study," Report prepared for the Washington Public Power Supply System, Richland, WA.

Washington Public Power Supply System

Answer to NRC Question 361.4

ATTACHMENT

A

STUDIES OF THE HOPE AND YALE FAULTS IN SOUTHERN BRITISH COLUMBIA

.by
Shannon and Wilson, Inc.
December, 1977

1.0 INTRODUCTION

The north-trending Hope and Yale faults and their extensions northward as the Fraser fault zone in British Columbia and southward as the Straight Creek fault zone in Washington, represent a macrotectonic fracture in the earth's crust in the northern Cascade Mountains and southern British Columbia. Several lines of evidence from investigations reported in subappendix 2.R.D, Amendment 23, WNP 1/4 PSAR, suggested that parts of this macrotectonic structure may have been reactivated in the late Cenozoic. This study was subsequently undertaken to investigate further the possibility that one or both of these faults in southern British Columbia may have been active during the late Cenozoic.

The study area is mountainous and heavily timbered throughout. Bedrock is chiefly metamorphic and plutonic crystalline rock with some Paleozoic and Mesozoic volcanic and sedimentary rocks also present. The area was extensively modified during the Quaternary by glacial erosion and deposition. The investigation involved a detailed study of three Tertiary plutons that appear to truncate one or both of the faults. This part of the study included aerial reconnaissance and oblique photography of inaccessible areas, aerial photo interpretations and detailed investigations of lineaments, fracture patterns, dikes and slickensides in the Chilliwack and Mt. Barr batholiths and the Silver Creek stock. Another part of the study involved additional geologic field reconniassance along the two fault traces and the excavation and detailed mapping of two trenches across the Hope fault and one across the Yale fault. The examination and photographing of offsets in terrace sediments in the Fraser River Canyon north of the town of Lytton, was reported in subappendix 2.R.D, Amendment 23, WNP 1/4 PSAR.

2.0 SUMMARY AND CONCLUSIONS

The study of the three plutons revealed the presence of broad bands of increased density of joints on trend with both the Hope and Yale faults. However, no offsets or other evidence of active faulting could be detected in the plutons along the fault projections. The study also revealed that joints in the plutons apparently were formed in two compressional stages; an earlier east-west phase followed by a later north-south phase.

Stratified sediments representing the youngest glacial deposits in the area were exposed in all three trenches excavated across the faults. No evidence of offset sediments could be found in any of the trenches. A radio-carbon date of 5,238 y.b.p obtained from charcoal associated with the oldest undisturbed ash layer present in one trench across the Hope fault indicates the probable minimun age of most recent movement. Studies of postulated offsets or fractures in late Quaternary outwash deposits near Lytton indicated that the "fractures" are near-vertical, clastic sand dikes without offset and are therefore non tectonic in origin.

In summary, neither the Hope or Yale faults in souther British Columbia appear to have been active in the last several thousand years. No offsets could be identified along the borders or through the three plutons that were intruded during the early Tertiary across the fault zone south of Hope. The presence of broad bands of increased densities of joints on trend with the faults suggests that some late Tertiary and/or early Quaternary movement on the faults may have been propagated through the plutons via a network of en echelon, closely-spaced joints in these broad bands.

GEOLOGIC INVESTIGATION, ROSS PASS AREA, WA.

by
Shannon and Wilson
October, 1977

1.0 INTRODUCTION

During a reconnaissance for faulting in the northern Cascade Mountains, a series of recent appearing scarps and fissures were noted in the Ross Pass area. These features were briefly disscussed in subappendix 2.R.D, Amendment 23, WNP 1/4 PSAR. Subsequently, a more detailed study was undertaken for the purpose of better defining the probable origin and age of these features near the crest of the Cascade Mountains.

2.0 SUMMARY AND CONCLUSIONS

The Ross Pass area is situated in an alpine upland that is characterized by hummocky terrain of low relief formed by glacial erosion. The area is underlain by strongly jointed granitic and gneissic rocks which are intruded locally by andesite dikes. Immediately west of the pass, a series of en echelon, curvilinear fissures and scarps occupy a zone about 1.2 miles long by 0.4 miles wide within a small cirque. Field studies confirmed that these features are incipient gravitational slumps. Based on tephrachronology and lichenometry, this slumping apparently occurred more than 1,000 years before present but postdates Mt. Mazama ash (from Crater Lake, Oregon), deposited about 6,600 years before present. Dendrochronologic studies indicated that no disturbance of these features has occurred for at least the last 200 years. Both the non-tectonic origin and the age of these Holocene features at Ross Pass eliminated the area as a likely source for the December 14, 1872 earthquake.

INVESTIGATION OF RIBBON CLIFF LANDSLIDE, ENTIAT, WASHINGTON

by
Shannon and Wilson, Inc.
February, 1978

1.0 INTRODUCTION

The Ribbon Cliff slide is located on the west bank of the Columbia River about two miles north of Entiat. Here, the Columbia River has entrenched itself several hundred feet into a crystalline bedrock complex of migmatitic gneiss and granodiorite with numerous basaltic dike intrustions. Late Pleistocene and Holocene colluvial and alluvial deposits mantle many of the lower slopes of the valley walls and underlie valley floors in the area. Structurally, the crystalline rocks are complex. Owing to several prominent joint sets in the bedrock, the colluvium and landslide debris from the cliffs consists largely of angular blocks ranging in size from a few inches to several feet in diameter.The presence of this large rock slide on the Columbia River at Ribbon Cliffs near Entiat, Washington, has been used by some investigators as a basis for assigning a relatively high intensity to the December 14, 1872 earthquake and for establishing the epicenter in the Chelan-Entiat area. A preliminary reconnaissance investigation of the Ribbon Cliffs landslide was conducted in 1976 and reported in subappendix 2.R.A, Amendment 23, WNP-1/4 PSAR. Subsequently, a more detailed investigation of the slide was undertaken to evaluate the geologic conditions, physical characteristics and the age of the slide as they might bear on the epicentral location and maximum intensity assigned to the December 14, 1872 earthquake.

The investigation included reconnaissance and detailed geologic mapping of Ribbon Cliff and adjoining area; a subsurface boring; and hydrographic and geophysical profiling to determine the thickness and extent of the slide debris; and dendrochronologic studies to determine the probable and relative age, or ages, of the debris. In addition, the scarp area and slide debris volume were analyzed in order to model pre-landslide conditions.

2.0 SUMMARY AND CONCLUSIONS

Investigations of the slide indicate that an estimated volume of 13.1 million cubic yards of material was involved. This volume is judged to be sufficiently large enough to qualify the Ribbon Cliff slide as a "considerable" landslide; i.e., a major landslide as specified in the Modified Mercalli Intensity Scale of 1931 for an intensity X. Configuration of the slide strongly suggests that it may have partially blocked the Columbia River when it occurred. Presence of some younger talus indicates that minor rock falls occurred subsequent to the major failure of the

cliff. The geologic studies suggest that "prior conditions", including jointing characteristics and the potential for undercutting by the river at the cliff, were such that failure probably could have occurred without the necessity of triggering by an earthquake in the area.

Age determinations made of trees and stumps on the slide debris demonstrate that the major portion of the Ribbon Cliff landslide occurred more than 215 years ago. Thus, it is evident from this study that the major parts of the Ribbon Cliff landslide significantly predate the December 14, 1872 earthquake and consequently cannot be used as an indicator either for assigning a maximum intensity to that earthquake or for establishing the epicenter.

GEOLOGIC STUDIES OF THE SOUTHERN CONTINUATION OF THE STRAIGHT CREEK FAULT, SNOQUALMIE AREA, WASHINGTON

by
Shannon and Wilson, Inc.
December, 1977

1.0 INTRODUCTION

The Straight Creek fault is a major, north-trending structure that extends southward at least 120 kilometers from the Canadian border and another 250 kilometers northward into British Columbia as the Fraser River fault system. This major fault system has been a significant element in the tectonic development of the northern Cascade Mountains and adjoining parts of British Columbia. Parts of the Straight Creek - Fraser River fault system were studied by reconnaissance during the geologic and geophysical investigations related to the December 14, 1872 earthquake and are reported in subappendix 2.R.D, Amendment 23, WNP 1/4 PSAR. This subsequent study was undertaken to supplement the previous studies by evaluating in more detail the possible southern continuation of the fault system south of the Skykomish area and to determine its structural relationship with the Cle Elum - Wallula lineament (CLEW) in the Snoqualmie Pass vicinity.

The study area is underlain by thick sequences of Tertiary volcanic and sedimentary strata, Tertiary intrusive masses and some pre-Tertiary crystalline rocks. Four aspects of the geology along the Straight Creek fault zone trend were investigated; (1) the structural relationship of the known southern extent of the Evergreen fault segment with alternative possible southern continuations; (2) evidence for deformation in the Snoqualmie batholith and associated intrusives emplaced along the fault trend; (3) the character of the fault trend south of the Snoqualmie batholith and its relationship to CLEW; and (4) the timing, magnitude and sense of displacement along the fault trend.

2.0 SUMMARY AND CONCLUSIONS

The Evergreen segment of the Straight Creek fault extends only as far as Tonga Ridge but it is likely that the Straight Creek fault continues farther south along an en echelon system of faults or along a fault that splays off the Evergreen segment.

The Snoqualmie batholith, which was intruded across the southern projection of the Straight Creek fault in late Miocene time, has not been deformed along this projection.

The north-trending Kachess Lake - Goat Peak fault, which strongly resembles the Straight Creek fault to the north, presumably is a southern continuation of the Straight Creek fault system. The Kachess Lake - Goat Peak fault truncates some of the northernmost CLEW structures. Southeastward, the Kachess Lake - Goat Peak fault appears to curve into and merge with the Taneum Lake fault of CLEW. Major north-trending structures are absent south of this junction.

No conclusive evidence exists in the study region for dextral strike-slip movement occurring along the Straight Creek fault trend. Although significant post-early Eocene dip-slip movement occurred along the Kachess Lake - Goat Peak faults, no convincing evidence was found for post-middle Miocene activity along the Straight Creek fault trend.

In summary, the Straight Creek fault system has had a long and complicated history of displacement but it has not been active in the Snoqualmie Pass area for at least 15 million years. The latest movements on the Straight Creek fault in the Snoqualmie Pass area have been largely dip-slip rather than dextral. The northerly trend of the Straight Creek fault system does not continue south of its junction with the west to northwest trending Taneum Lake fault of CLEW.

GEOLOGIC RECONNAISSANCE OF THE CLE ELUM - WALLULA LINEAMENT AND RELATED STRUCTURES

by
Shannon and Wilson, Inc.
December, 1977

1.0 INTRODUCTION

The Cle Elum - Wallula lineament (CLEW) is a structurally complex and topographically conspicuous part of the Columbia Plateau in south central Washington State. Because only parts of this lineament could be studied and reported in time for Amendment 23, WNP 1/4 PSAR, a reconnaissance study was subsequently undertaken to compile and evaluate the geology and tectonics of the entire CLEW lineament. The study was based on existing data supplemented by field mapping of selected areas, particularly those with limited or inadequate data. Special attention was given to (1) the relationships of CLEW structures to those in adjoining parts of the Columbia Plateau; (2) obtaining evidence for any dextral strike-slip faulting along CLEW; and (3) the probable origin of the lineament.

2.0 SUMMARY AND CONCLUSIONS

CLEW is a distinct zone of increased intensity of folding and faulting in the Yakima foldbelt of the Columbia Plateau geologic/tectonic province. CLEW trends southeastward for approximately 200 kilometers, is about 40 kilometers wide where it merges with the Cascade Mountains and narrows to 12 - 17 kilometers wide at its southeastern end near Wallula Gap. CLEW includes a variety of anticlinal, synclinal, monoclinal and faulted structures which individually exhibit a more westerly en echelon trend of N60°W relative to the overall N45°-50°W trend of CLEW.

CLEW is distinct from adjoining areas to the northeast and to the southwest, not only in intensities and complexities of deformation but also in structural styles and trends. The structures within CLEW appear to represent a zone of moderate to extensive compressive folding. Many normal faults and low- to moderate- angle thrust faults occur in the zone, but strike-slip faulting was observed at only one locality. No evidence was observed along CLEW of any significant post-late Miocene movement.

CLEW appears to be a dividing line between adjoining areas with somewhat different structural styles on either side. Although the reasons for differing responses of CLEW and adjoining areas to north-south compressional forces could not be clearly established, field relationships observed suggest that CLEW may reflect a fundamental boundary at depth.

REMOTE SENSING ANALYSIS OF GEOLOGIC STRUCTURES IN RELATION TO THE 1872 PACIFIC NORTHWEST EARTHQUAKE

by
David D. Slemmons
May, 1979

1.0 INTRODUCTION

The epicenter of the December 14, 1872 earthquake has been located within an area extending from Hope, in the southern Coast Mountains of British Columbia, to Lake Chelan, near the boundary between the Northern Cascade, Okanogan, and British Columbia provinces. The earthquake had an estimated magnitude of about 7 and was one of the largest historic earthquakes in the region between Puget Sound and the northern Rock Mountains. The purpose of this study was to determine whether there are U.S. code of Federal Regulations "capable" faults (U.S. Nuclear Regulatory Commission 1975) in or near the epicentral region.

The rationale for conducting remote sensing surveys for active or capable faults has been outlined in previous reports. These previous studies include basic information, methodologies, and results of earlier remote sensing work and are part of Washington Public Power Supply System's Appendix 2.5.R, Amendment 23, WNP 1/4 PSAR, October, 1977. These are as follows:

1. "Imagery and Topographic Interpretation of Geologic Structures in Central Washington," by Charles E. Glass and David B. Slemmons, WNP 1/4, PSAR, Subappendix 2.R.F,

2. "Remote Sensing Analysis of the 1872 Earthquake Epicentral Region," by David B. Slemmons,, Gary Carver, and Dennis Trexler, WNP 1/4, PSAR, Subaplpendix 2.R.G,

3. "Remote Sensing of the Columbia Plateau," by Charles E. Glass, WNP 1/4, PSAR, Subappendix 2.R.K.

These earlier studies identified several segments of the Straight Creek and Fraser River fault zones that appeared to show evidence of late Quaternary surface faulting. There are also fresh appearing scarps on the Hell Creek fault that appear to be part of the Fraser River and Yalakom fault systems in southern British Columbia. These scarps, along with the suggestive, but inconclusive, evidence for activity on parts of the Fraser River fault zone, lead to a classification of "probably active" for the Fraser River fault zone. The earlier study also found evidence of master joints and faults in a batholotic complex along the U.S. Canadian border, connecting the Fraser River and Straight Creek fault zones. The activity of these two fault zones had previously been considered to be older than the batholiths.

2.0 SUMMARY AND CONCLUSIONS

The overall imagery analysis was completed for the Landsat imagery, topography, and special aerial photography obtained for the 1872 earthquake studies. The analysis provided a basis for conducting additional active fault and lineament field studies. The report combines the imagery analysis with the available geologic, tectonic or structure maps, the geophysical maps of macro- and microearthquake activity, and the aeromagnetic and gravity maps.

The topographic analysis presented defines several major lineaments and lineament provinces in Washington. The single most conspicuous zone is a broad belt of NW - SE trending lineaments along the Cle Elum - Wallula zone (CLEW). This zone is up to 50 km in width and divides Washington diagonally into two distinct patterns with primarily conjugate NW and NE lineament sets to the south. Parts of the Okanogan area and the western part of the Northern Cascades have N-S to about N 10 E lineaments: this trend is especially prevalent in and near the Republic graben and near the Straight Creek fault zone.

The Landsat imagery shows the CLEW zone, but also reveals patterns of N-S to N 10 E trend that are parallel to and coincident with the main negative regional Bouger gravity trend along the Cascades. Several Landsat lineaments of this orientation form along alignments not always coinciding with mapped faults and appearing to have different positions in the southern Cascades relative to those of the Northern Cascades. Other lineaments of N-S to N 10 E orientation are in the Lake Chelan to Republic graben zone of the Okanogan province along the northern edge of Washington. These structures do not appear to extend into the Columbia Plateau, with a possible exception in the continuation of the Republic graben trend into the Grand Coulee area. The general absence of lineaments projecting into the Columbia Plateau from the north indicates that the structures controlling the lineament grain of the eastern part of the Northern Cascades and the Okanogan upland region are tectonically inactive or very weakly active.

The analysis of aerial photographs, and study of the area by low-sun angle aerial reconnaissance, revealed many antislope or sidehill trough landforms, especially along and near the Straight Creek fault zone. The distribution of antislope and other back-facing slope features shown by our interpretation of several sets of aerial photographs, including the low-sun angle aerial photographs taken for this project, confirm the conclusions reached by Woodward-Clyde Consultants (1978) for the Straight Creek fault zone study. Their conclusions stated that the origin of the fresh scarps along the Straight Creek fault zone may be of tectonic, gravity, or combined seismic and gravity origin. Their conclusion stated that the fault zone should be tentaively classified as capable. We find that this trend continues southward toward the Cle Elum area, with some of the back-facing topographic features having a NW-SE orientation.

BRITISH COLUMBIA MICROEARTHQUAKE SURVEY
MAY THROUGH OCTOBER 1977

by
Weston Geophysical Research
March, 1978

1.0 INTRODUCTION

The level of microseismicity in certain areas of British Columbia, Canada, was investigated to determine if any active tectonic feature associated with the December 14, 1872 earthquake could be found. This microearthquake survey was conducted in four phases, the previous three of which were initially presented in Appendix 2.R.E, Amendment 23, WNP 1/4 PSAR. Different station configurations designed to monitor various geographic areas suspected to include an active structure were utilized.

2.0 SUMMARY AND CONCLUSIONS

During the six months from May through October, 1977, a microearthquake survey was conducted in south-central British Columbia. Even through the number of operating instruments and the coverage varied during each phase of the survey, a cumulative plot of all epicenters accepted as reliably located shows that the microactivity immediately north of the United States border is much higher than previously known. This area, included in the zone of uncertainty attached to Milne's original epicentral location of the 1872 earthquake, appears to be seismically active.

3.0 SEISMIC ACTIVITY

Table 13 of the report presents the epicenters, depths, magnitudes, and other related data of events for which a hypocentral solution was obtained by computer. Figure 13 of the report shows their geographical distribution. Table 14 of the report lists the origin time and approximate magnitude of other unlocated events clearly recorded at one or two stations. Figure 14 shows the daily temporal distribution of all recorded events listed in Tables 13 and 14 and identified as earthquakes. The fairly smooth distribution suggests that most of the man-made blasts have been successfully removed from the set.

Local seismicity increased during Phase IV with the occurrance of 60 possible earthquakes. The largest event (M_L = 2.4), recorded during Phase IV occurred on October 29, 1977, at 16:20 (UCT), 9:20 (PDST), at a location several kilometers north and west of Chilliwack.

STRESS, GRAVITY ANOMALIES, AND THE LOCATION OF EARTHQUAKES IN WASHINGTON STATE - TWO DIMENSIONAL MODELS

by
Weston Geophysical Research
March, 1978

1.0 INTRODUCTION

Many earthquake epicenters in Washington are located in regions with relatively high gradients of regional Bouguer gravity anomalies. The correlation was discussed in Appendix 2R E, Amendment 23, WNP-1/4 PSAR. Because gravitational anomalies are due to anomalous masses which, in turn, can produce non-homogeneous stress, and earthquakes are a response to stress, this study examines the magnitude of stress in the earth that may be reasonably attributed to mass loading. Non hydrostatic stress of significant size is produced by loading due to (1) topography, (2) anomalous mass and associated with regional gravity anomalies, and (3) combinations of (1) and (2). Answers were sought to the questions regarding the location of earthquakes that might be attributed to the stresses caused by anomalous masses, and the effect of topographic features such as the Cascade range on the location of major earthquakes.

Two models were utilized for the mechanical behavior of the lithosphere: (1) a floating beam model in which the crust is of finite thickness and isostratic restoring forces are provided by a fluid-like upper mantle; and (2) an elastic half-space model in which the crust is infinitely thick and responds elastically to body-force and surface loads. For each of these models, the calculation of the stress field is nonunique, because the mass distribution with depth is not uniquely determined from surface gravity values. Nonetheless, the models allowed for a better understanding of the spatial variation of the stress field and to estimate the magnitudes of the stresses associated with the gravity anomalies.

2.0 SUMMARY AND CONCLUSIONS

A floating beam model was used to model topographic loading combined with the loading due to anomalous mass considered to be located at the surface. An elastic half-space model was used to model buried anomalous mass with topography. For both models, loads consistent with the observed gravity anomalies produced maximum stresses in the range of 100 to 700 bars.

The locations of the largest shear stresses appear to correlate with the regional physiographic and gravity boundaries where seismic activity has been (and is) concentrated. The additional stresses due to topographic loading and anomalous masses appear to be sufficient to localize earthquakes to those regions in which the gradients in the regional Bouguer gravity anomaly field are large.

QUALITATIVE AEROMAGNETIC EVALUATION OF STRUCTURES IN THE COLUMBIA PLATEAU AND ADJACENT CASCADE MOUNTAIN AREA

by
Weston Geophysical Research
March, 1978

1.0 INTRODUCTION

As part of the December 14, 1872 earthquake investigations, an extensive aeromagnetic survey program was initiated over six blocks in eastern Washington designated as the Rattlesnake Hills-Wallula-Saddle Mountains trend (Block A); the Chiwaukum graben area (Block B); the Walla Walla-Blue Mountains area (Block C); the Saddle Mountains-Frenchman Hills-Snake River area (Block D); the Lake Chelan-Moses Coulee area (Block E); and the Kachess Lake-Stevens Pass-Glacier Peak area (Block F). This airborne survey covered 40,000 line miles with 1/2 mile spaced flight lines and 5 mile tie lines. The airborne survey was augmented by a number of ground geophysical traverses with both a gravity meter and a land magnetometer. Initial magnetic models using the aeromagnetic data have been performed along nine selected profiles to examine the relationship between the observed magnetic data and the mapped geology. (These data and models were supplied in response to NRC question 360.4 on WNP 2)

Geologic control and correlations for the interpretations were based on published map information, as well as the data from concurrent geologic investigations of the Washington Public Power Supply System.

2.0 SUMMARY AND CONCLUSIONS

An extensive aeromagnetic survey program was completed in central Washington. Approximately 40,000 line miles of high-resolution magnetic profiling was aquired at a nearly constant height of 1,000 feet above ground surface. The interpreted data have disclosed a number of anomalous trends as well as magnetic linears. These data correlate in most instances with known geology and sometimes with topography.

Block A - The area of the Rattlesnake Hills-Wallula trend, geophysical evidence obtained during both the airborne and land investigation programs leads to the following conclusions: (1) the Rattlesnake Hills-Wallula Gap structure is cut by several magnetic linears which appear to constrain relative horizontal displacements; (2) the gravity anomalies associated with the structure limit relative vertical displacement; and (3) the Juniper Springs linear transects and is younger than the Rattlesnake Hills-Wallula Gap structure and the Yakima and Umtanum Ridges.

Block B - The Chiwaukum graben area, contains two sets of major magnetic linears; one set trends northeast and the other trends northwest. Some of the northwest-trending linears correlate with various fault segments within the Levenworth fault zone and other linears correspond to contacts between various rock types. Most linears in the area of the plateau basalts have no obvious geologic or topographic correlation to basalt structures or to the underlying basement structures.

Block C - The Walla Walla-Blue Mountains area, contains two sets of aeromagnetic linears; one set trends northwest and the other north-northeast. The northwest set of linears correlates, in general, with the Rattlesnake Hills-Wallula Gap structure noted for Block A. Several of the north-northeast linears correlate with the Hite fault system and associated structures. The aeromagnetic linear pattern for the Walla Walla-Blue Mountains area indicates that the Rattlesnake Hills-Wallula Gap structure terminates against the Hite fault system and related structures.

Block D - The Saddle Mountains-Frenchman Hills-Snake River area contains numerous aeromagnetic linears which correlate with known geologic structures or previously unrecognized geologic structures. However, none of these linears cross into the Hanford Reservation. The Juniper Springs and Nancy Linears, recognized in Block A, continue into Block D, crosscutting and slightly deflecting linear aeromagnetic anomalies associated with the Saddle Mountains.

Block E In the Lake Chelan-Moses Coulee area, the geophysical evidence obtained during the airborne survey indicates that northwest-trending structures in the vicinity of Lake Chelan may continue into the Columbia Plateau, but do so only for a relatively short distance and are terminated against north-east-trending structures.

In Block F the primary purpose for acquiring aeromagnetic data was to investigate the Straight Creek fault in the Kachess Lake-Steven Pass-Glacier Peak area . An interpretation of the aeromagnetic data obtained led to the following conclusions: (1) that the Straight Creek fault extends south of its mapped termination for a considerable distance and (2) that the fault terminates and offsets with a right lateral sense of motion, the northwest-trending structures south of Easton, Washington, which are associated with the Columbia Plateau. Therefore, the Straight Creek fault is interpreted as being younger than the structures associated with the Columbia Plateau.

MICROEARTHQUAKE STUDIES

by
Woodward-Clyde Consultants
July, 1978

1.0 INTRODUCTION

Microearthquake studies were conducted from July, 1977 through March, 1978 to supplement the permanent seismographic coverage in central Washington provided by the University of Washington network. The epicentral region of the 1936 Waitsburg earthquake and the suggested epicentral regions of the 1872 North Cascades earthquake were of particular interest for investigation, as well as several prominent structural trends in the northern Cascades that extend towards the Columbia Plateau. Both the spatial location of earthquake activity and the focal mechanisms of the activity were studied.

2.0 SUMMARY AND CONCLUSIONS

No earthquake activity was recorded in the Milton-Freewater, Oregon - Walla Walla, Washington area on the southeast side of the Columbia Plateau. Only negligible activity was recorded in the Methow graben northeast of Lake Chelan or along the Chiwaukum graben southwest of Lake Chelan. A few shallow earthquakes, all less than M_L 1.0, were located southwest of Ross Lake.

Significant activity encountered during this study was in the region between Kachess Lake - Ellensburg - Yakima and included a zone of deeper focus earthquakes. A second zone of significant shallow activity was an east - west zone of hypocenters located east of Entiat and south of Lake Chelan. This activity does not appear to be related to any structural trends in the adjacent Cascades.

CLE ELUM AREA - In the region extending from the vicinity of Kachess Lake southeast towards Ellensburg and Yakima, Washington, about 30 shallow microearthquakes were located. This activity included the aftershocks of a shallow M_L 3.1 earthquake that occurred near Cle Elum, July 13, 1977. The activity was located in proximity to mapped northwest-trending anticlinal structures and faulting. This area also was the location of a distinctive zone of 10 deeper-focused microearthquakes that are located parallel to and immediately north of the Naches River. The focal depths of these earthquakes extended down to about 40 kilometers.

ENTIAT AREA - The highest rate of activity observed during the survey was in an area east of Entiat, Washington, where an average of one microearthquake per day was recorded. This activity occurred in a confined zone that is approximately 40 kilometers long in a general easterly direction and dips approximately 30° south. The thickness of the zone is approximately 7 kilometers.

FOCAL MECHANISMS - The focal mechanisms of previously recorded deep earthquakes in the Hanford region were reviewed along with the focal mechanism data obtained during this investigation. In general, all data indicated a nearly horizontal compressive stress field having an almost due north-south axis of compression. The most consistent data generally indicated reverse faulting on west-northwest striking fault planes. Fault plane solutions commonly exhibited a slight right-lateral (dextral) component. Individual solutions sometimes differed from this generalized motion and showed larger components of strike-slip but in a manner that continued to have a north-south axis of compression. The fault planes having the right-lateral component of motion dipped to the south in the Cle Elum region and to the north near Hanford.

STRAIGHT CREEK FAULT ZONE STUDY

by
Woodward-Clyde Consultants
January, 1978

1.0 SUMMARY AND CONSLUSIONS

Woodward-Clyde Consultants studied the Straight Creek fault zone between Tonga Ridge near Skykomish, Washington and the U.S.-Canada border. These investigations included bedrock mapping, trenching, geophysical surveys, geomorphic studies, aerial recconaissance and air photo interpretation. Most of the ground-based studies were performed in the vicinity of Marblemount, Washington.

The prominant antislope scarps present along the Straight Creek fault zone appear to be sackung or gravitational spreading features. It is probable that the gravitational spreading was seismically triggered and it is possible that some of the scarps located in bedrock terrain along the Straight Creek fault zone may also have a tectonic component of slip. Based on the evidence collected, the Straight Creek fault zone should tentatively be classified as a capable seismographic structure. The Straight Creek fault zone could have been the source of the December 14, 1872 North Cascades earthquake.

2.0 STRAIGHT CREEK FAULT ZONE - BEDROCK EXPRESSION

The Straight Creek fault zone located in the Northern Cascades of western Washington, is a profound structural discontinuity seperating rocks of low temperatrue - high pressure metamorphic conditions west of the fault zone from rocks of high temperature - low pressure metamorphic conditions east of the fault zone. It is apparent that dip-slip displacement cannot account for the juxtaposition of these contrasting metamorphic terraines. Based on a correlation of metamorphic terraines between Harrison Lake, British Columbia (west of the fault zone) and Kachess Lake, Washington (east of the fault zone) , Misch (1977) suggests 120 miles of dextral slip on the Straight Creek fault zone. This interpretation necessitates continuity of the Straight Creek fault zone with the Canadian Fraser River fault system.

Probably in response to a changing stress field, the Straight Creek fault zone changed from a predominantly dextral slip fault to a predominantly dip-slip fault by the Eocene as evidenced by the blocks of Eocene Chuckanut Formation which have been down faulted and preserved along the fault zone (Vance, 1977). Subsequent to the episode of Eocene dip-slip faulting, the Straight Creek - Fraser River fault system was intruded by a

number of plutons ranging in age from 29 to 16 million years before present (Richards and White, 1970). The Chilliwack Batholith now seperates the Fraser River fault system from the Straight Creek fault zone. Since the margins of the Chilliwack and other plutons are not noticeably offset, it is likely that major displacement along the Straight Creek fault zone ended in the Oligocene.

3.0 STRAIGHT CREEK FAULT ZONE - GEOMORPHIC EXPRESSION

At present the Straight Creek fault zone is expressed geomorphically by alignments of prominent fracture traces, notches, linear gully and valley segments, antislope scarps, and landslides. The type and strenth of expression along the fault zone depends somewhat on rock type and elevation.

The geomorphic features most suggestive of young faulting are the antislope scarps. A prominant antislope scarp in the Diobsud Ridge area north of Marblemount, Washington was trenched to investigate these features in detail. In addition to the bedrock, a lodgement till and an overlying wedge of colluvium,were exposed in the trench wall. These units are truncated by a well defined clay coated shear which extends from the bedrock into the overlying deposits. The bedrock east of the well defined shear, including the material underlying the antislope scarp, is highly sheared and deeply weathered. These relationships indicate post glacial displacement along a bedrock fault. The post glacial displacement could be attributed to tectonic or gravitational spreading mechanisms, or a combination of both.

4.0 SACKUNG FEATURE INVESTIGATION

Gravitational spreading, see John (1964), Bech (1968), Tabor (1971), and Radbruch-Hall and others (1976, 1977) produced antislope scarps or sackung features very similar to those seen along the Straight Creek fault zone.

Sackung features are most common in seismically active regions having high mountains, and glaciated terrains where pre-existing bedrock discontinuities are present. These conditions are present in the region traversed by the Straight Creek fault zone.

A detailed photogeologic analysis of geomorphic features within a 2100 square mile area centered on the Straight Creek fault zone was made. The results of this study indicate that scarp-like features are preferentially concentrated along the fault zone. Both the mean and maximum size of these features decrease systematically with increasing distance from the zone. This strong influence on scarp size and distribution suggests that these features are genetically related to the Straight Creek fault zone. They may have been triggered by strong ground shaking with seismic activity along this structure.

5.0 EXPRESSION OF THE FAULT ZONE IN THE CHILLIWACK BATHOLITH

Evidence indicating a lack of significant recent slip along the Straight Creek fault zone is by the apparent lack of displacement of the margins of the Chilliwack Batholith. However, within the batholith, the trend of the Straight Creek fault zone is characterized by parallel alignments of north trending fracture traces, linear gullies and ridge crest notches. In addition, a few antislope scarps are present in the plutonic rocks. Subparallel to and flanking each side of the trend of the fault zone are major lineaments. The eastern lineament includes some sackung like features. Analogous features to those found in the Chilliwack Batholith have been described for the expression of the Kern fault in the Sierra Nevada Batholith (Moore and duBray, 1978).

361.5: Provide a discussion, with supporting bases, of the possibility that the 1872 earthquake could occur in the mantle under the WNP-2 site.

Response:

It is the Supply Systems position, as stated in the answer to NRC question 361.4, that the December 14, 1872 earthquake occurred in the Northern Cascades - Okanogan area. The Columbia Plateau, where the WNP-2 site is located, is a seperate and geologically distinct province southeast of the Northern Cascades - Okanogan area. Using the isoseismal data for the 1872 earthquake established by the Coombs panel (Coombs et.al., 1976) and the relationship of intensity and magnitude to depth proposed by Shebalin (1959), the depths calculated assuming an epicentral intensity VIII range from 60.2 km to 32.2 km (avg. 45.7 ± 9.4 km) with a calculated magnitude 7.2; assuming an epicentral intensity IX range from 23.6 km to 16.9 km (avg. 21.6 ± 2.6 km) with a calculated magnitude 7.1; and assuming an epicentral intensity X range from 11.8 km to 8.9 km (avg. 11.2 ± 1.2 km) with a calculated magnitude 7.1. Using the Coombs panel isoseismals and the relationship of intensity and magnitude proposed by Gutenberg and Richter (1956), the calculation yeilds a depth of 45.7 km and magnitude 6.8 assuming an epicentral intensity VIII; a depth of 21.6 km and magnitude 6.8 assuming an epicentral intensity IX; and a depth of 11.2 km and magnitude 6.9 assuming an epicentral intensity X. Using the Woodward-Clyde Consultants isoseismal map (Appendix 2-R-B, Chp. 2.5, WNP 1/4 PSAR) and the relationship between intenstiy, magnitude and depth proposed by Shebalin (1959), yeilds a depth range of 40.4 km to 30.4 km (avg. 36.3 ± 4.3 km) and a magnitude 7.0, assuming a maximum intensity VIII; a depth range of 21.0 km to 16.0 km (avg. 18.7 ± 2.0 km) and a magnitude 7.0, assuming a maximum intensity IX; and a depth range of 11.0 km to 8.4 km (avg. 9.8 ± 1.1 km) and a magnitude 7.0, assuming a maximum intensity X. Using the Woodward-Clyde Consultant isoseismal and the relationship between intensity, magnitude and depth proposed by Gutenberg and Richter (1956), the calculation yeilds a depth of 36.3 km and magnitude 6.6 for an epicentral intensity VIII; a depth of 18.7 km and magnitude 6.7 for an epicentral intensity IX; and a depth of 9.8 km and magnitude 6.8 for an epicentral intensity X. Given that the depth to the mantle in the North Cascade - Okanagon area is greater than about 30 - 35 km (Smith, 1978) and assuming a maximum epicentral intensity of VIII, the preceeding analysis (albeit based on limited data), would tend to support a focal depth for the 1872 earthquake occuring in the lower crust or upper mantle of the Cascades.

There is a reasonable possibility that the 1872 earthquake was part of the subduction process in the Puget Sound trough that is thought by some to still be going on at a rate of 35 mm/yr (Riddihough and Hyndman, 1977, Riddihough, 1977). Crosson (1980) has analyzed earthquake data for the Puget Sound region (Western Washington network) and concluded that there is evidence for a Benioff zone extending from approximately the east side of the Olympic mountains at a depth of about 40 km to approximately the western edge of the Cascade mountains at a depth of about 60 km. Davis (Appendix 2R-C, Chp. 2.5, WNP-1/4 PSAR; Appendix 2-N, Chp. 2.5, WNP-2 FSAR) concludes that the shallow dipping oceanic slab steepens eastward along the eastern edge of the Puget Sound area. This conclusion is supported by an analysis of geochemical data from Casade mountain Quaternary volcanics (Dickinson, 1975) that indicates the subducting slab has reached a depth of approximately 100 km before it passes under the general axis of the Cascades. Riddihough (1979), using gravity data, models the depth of the downgoing plate at depths of approximately 100 km to 170 km beneath the axis of the Cascades.

To the east of the Cascades in Washington State, the historical earthquake data has shown evidence of earthquakes greater than 25 km in depth (Table 2.5.4, Chp. 2.5, WNP-2 FSAR). This fact is supportive of the conclusion that either the subducting slab is aseismic or has been assimilated in the mantle before the western margin Columbia Plateau margin has been reached.

In conclusion, if the December 14, 1872 earthquake was related to the subduction process, it is unlikely that a similar type of earthquake would occur east of the Cascades beneath the Columbia Plateau.

The Columbia Plateau, where the WNP-2 site is located, is a seperate and geologically distinct province southeast of the Northern Cascades - Okanogan area. The depth to the upper mantle beneath the Columbia Plateau is undefined by long-line seismic measurements but has been extrapolated from the surrounding regions to be about 25 km in the area beneath the Hanford Reservation and the WNP-2 site (Smith, 1978). The occurrence of microearthquakes recorded in the last ten (10) years shows focal depths to approximately 20 km, thus indicating some stress release in the lower crust. The same network showed no seimicity in the upper mantle. In addition, the regionally recorded earthquake data, collected since 1962, have not shown earthquakes greater than about M_L 1.6 at depths greater than 20 km (Table 2.5.4, Chp. 2.5, WNP-2 FSAR). These same data show the preponderance of earthquakes at less than 10 km in focal depth. This suggests that the primary contemporary stress release is principally in the upper 10 km.

Starting in the early 1970's, the U.S. Geological Survey occupied a series of trilateration stations including the Hanford Reservation and covering the major part of the central Columbia Plateau. The results through 1979 (Savage et al., 1981) indicate exceedingly small strain rates for the Hanford area where the WNP-2 site is located (principal strain rates of -0.02 ± 0.01 and -0.04 ± 0.01 microstrains/year). Savage et al. (1981) qualify these measurements by stating "In view of the magnitude of the combined random and

possible systematic errors, the strain rates measured at Hanford are at best only marginally significant and it is quite possible that no measurable strain at all has accumulated there in the 1972-1979 interval.". In contrast, the strain rates for the same time interval in the Puget Sound area (principal strain rates of +0.07 ± 0.03 and -0.13 ± 0.02 microstrains/year) which are more indicative for an area above an actively subducting plate.

The gravity maps (Figures 2.5-9, 9a, 9b Chapter 2.5, WNP-2 FSAR) that cover the Columbia Plateau show several noticable zones of parallel gravity contours to the west and northwest of the Hanford Reservation. If the north-south zone west of the Hanford Reservation reflects a buried structure, it is unlikely that this feature is currently seismogenic for the following reasons:

1) There is no obvious relationships of historic seismic activity to this zone;
2) There is no surface structural or topographic expression of the zone;
3) Miocene and younger (17 m.y.b.p) plateau stratigraphic units show no consistant variation in facies or thickness across the zone; and
4) Structural elements possibly aligned with the zone and with parallel trends in the Northern Cascades (e.g. the Chiwaukum graben) formed during early Tertiary deformation and have not been active since extrusion of Miocene plateau basalts across them.

The contemporary seismic activity of the Lake Chelan area is characterized by focal depths between 2 km and 10 km, with most of the activity around 6 km. (Woodward-Clyde Consultants, 1978). Within this area, the seismic activity occurs in a southeast dipping hypocentral zone that strikes at a high angle to major mapped structural features (e.g. the Chiwaukum and Methow grabens). If the 1872 earthquake occurred in the Wenatchee to Lake Chelan area, and within this focal depth range, surface rupture would be expected on the basis of similar events elsewhere in the western U.S. It has been reasonably demonstrated by geologic field studies (Appendix 2R-D, Chapter 2.5, WNP-1/4, PSAR), that the Wenatchee to Lake Chelan area has not experienced the historic surface rupture that would be expected from a shallow 1872 event. No geologic evidence has been found to indicate any active faulting since at least the late Miocene to Pliocene when the last surface basalts in this area were extruded. In addition, glacial outwash terraces (dated as 28,000 y.b.p. in the Grand Coulee area) lie undisturbed across the projection of the Republic and Methow graben boundary faults. Another line of evidence suggesting that the 1872 earthquake did not occur in the Wenatchee to Lake Chelan area is a study by Bor (1978) that concluded that the maximum earthquake to be expected from this limited source area is about M_L 5.8. In addition, on the basis of attenuation patterns for Pacific Northwest earthquakes and intensity data from the 1872 earthquake, Malone and Bor (1979) concluded that the epicenter of the 1872 earthquake did not occur in the Wenatchee to Lake Chelan area but was located some 150 km to the north-northwest.

If an 1872 "type" earthquake were to occur in the Wenatchee to Lake Chelan area, at a distance of approximately 130 km from the WNP-2 site, it is unlikely that the maximum acceleration would be greater than 0.1 g at the WNP-2 site, given any of the currently accepted attenuation relationships.

In conclusion, it is the Supply System's position that an earthquake similar to the December 14, 1872 North Cascades - Okanogan "type" earthquake reasonably should not be postulated to occur in the upper mantle beneath the Columbia Plateau within a distance of over 100 km from the WNP-2 site.

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Q. 361.9

The FSAR (Vol. 2) lists the epicenter of the July 15, 1936 (local time) Milton-Freewater, Oregon, earthquake at 46.0N., 118.5W., with a magnitude of 5 3/4 (Vol. 2, page 2.5-110). A report by Woodward-Clyde Consultants, "Seismological Review of the July 16, 1936 Milton-Freewater Earthquake Source Region" prepared for The Supply System has relocated the epicenter of this shock at 46 12.5N., 118 14.0W., and computed a magnitude of M_L 6.1. How does this discrepancy affect the ground motion at the site?

RESPONSE:

The differences in locations and magnitudes reported for the 1936 Milton-Freewater earthquake are consistent with the differing kinds of data used and do not indicate discrepancies. The instrumental epicenter computed by Woodward-Clyde Consultants (46°12.5N, 118°14.0'W) is inclose agreement with that originally reported by the International Seismological Centre and the U.S. Coast and Geodetic Survey (46.2°N, 118.2°W) and is discussed in detail by Woodward-Clyde Consultants (1980). The epicenter defined by the area of maximum intensity of MM VI (46.0N, 118.5W) as reported in the WNP-2, FSAR (Chapter 2.5, page 2.5-110) was based on a reanalysis of the intensity data. The difference between the maximum-intensity epicenter and the intrumental epicenter is attributed to local variations in ground response, population distribution, and to rupture propagation effects of the subsurface fault rupture (Woodward-Clyde Consultants, 1980).

The magnitude value of 5 3/4 referred to in the WNP-2 FSAR (Chapter 2.5, page 2.5-110) was published by Gutenberg and Richter (1965, reprinted from the 1954 edition). Geller and Kanamori (1977) concluded that nearly all magnitude values for shallow earthquakes from the 1954 publication could be safely treated as surface wave magnitudes and the 5 3/4 value is considered to be a surface wave magnitude.

The Richter local magnitude (M_L) value of 6.1 determined by Woodward-Clyde Consultants (1980) was based upon data from 17 stations. Eleven Wood-Anderson recordings were examined in the distance range 1000 km to 1500 km: An additional six records from long-period instruments, which were corrected for short-period response, were also used. Although there may be uncertainties in the use of the Wood-Anderson scale

in this distance range (Richter, 1958, p. 345) and the azimuthal coverage is limited, the average value determined from the six closest Wood-Anderson stations (BRK, SFB, MHC, PAC, TIN, FRE listed in Table 8 of Woodward-Clyde Consultants, 1980) at a distance of about 1000 km is the same as the average value of M_L 6.1 for all 17 stations.

The distance from the WNP-2 site to the original 1936 epicenter is 51 miles. The distance from WNP-2 to the relocated 1936 epicenter is 55 miles. An earthquake of approximately magnitude 6 at these distances would not produce peak accelerations greater than 0.10g at the WNP-2 site using accepted attenuation relationships.

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Q. 361.10

With regard to the Woodward-Clyde Consultants' report referred to in question 9, above, the report states that the teleseismic location program, MEVENT (Dewey, 1971) was used to relocate the Milton-Freewater earthquake. The program MEVENT allows for flexibility in assigning weightings to recorded earthquake arrival times. How were the station readings weighted in the relocation, and how do stations with large residuals (for example, 8.5 and 9.9 seconds) affect the relocation?

RESPONSE:

The program MEVENT (Dewey, 1971) was provided by Dr. James W. Dewey (USGS) to Dr. Don Tocher on 4 February 1975. In the use of the program by Woodward-Clyde Consultants (1980), the following weighting scheme was used to reduce the effect of large residuals:

For the first two iterations, the weight W(i) applied to the i^{th} station is given by:

$$W(i) = \frac{1}{1+.02 \exp \left\{ \frac{[RESID(i)-AV]^2}{20} \right\}},$$

where

RESID(I) = adjusted residual (seconds) for i^{th} station

AV = average residual in that quadrant of the earth's surface (with respect to the epicenter) in which the i^{th} station is located.

For subsequent iterations,

$$W(i) = \frac{1}{1+.02 \exp \left\{ \frac{[RESID(I)]^2}{2\ TRUNC} \right\}},$$

TRUNC is the program input parameter that determines the severity of weighting out larger residuals and has the dimensions of variance. TRUNC should be approximately equal to the sample variance of the P-wave observations being processed. The value of 4.0 was selected for TRUNC in locating the 1936 earthquake and is generally greater than the observed variances. This station weighting function is shown in Figure 361.10-1. The solution used in the 1980 report converged after five iterations. Beyond the residual weights for stations SEA and FER (with residuals 8.5 seconds and 9.9 seconds, respectively) were less than 0.02, the influence of the readings for these two stations on the computed location was effectively eliminated.

References

Dewey, J.W., 1971, Seismicity studies with the method of joint hypocenter determination: Ph.D. Dissertation, University of California, Berkeley.

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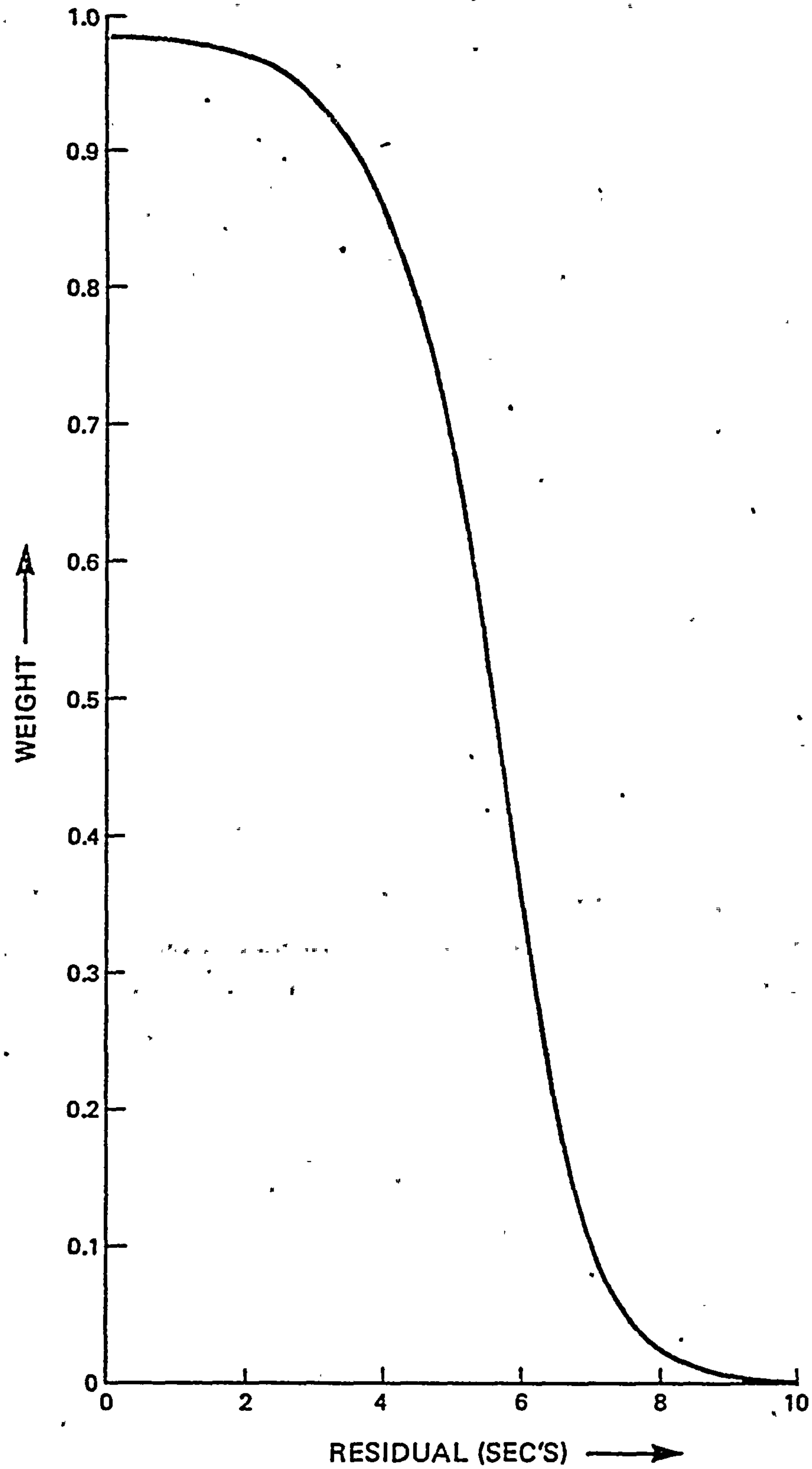

Project No. 14940	Hanford FSAR	PROGRAM "MEVENT" RESIDUAL WEIGHTING USING TRUNC = 4.0	Figure 361.10-1
Woodward-Clyde Consultants			

Q. 361.11

Would relocation of other significant earthquakes in the area affect estimation of the ground motion at the site?

RESPONSE:

Within the area of the Columbia Plateau, the 1893 Umatilla, the 1918 Corfu and the 1936 Milton-Freewater earthquakes are the only historical earthquakes of sufficient size to be of significance in terms of their associated levels of ground motion in the vicinity of the site. The 1893 Umatilla earthquake was not instrumentally recorded. An evaluation of felt reports indicated the highest intensity (MM VI-VII) to be in the Umatilla, Oregon area. This earthquake is discussed in detail in the Pebble Springs PSAR (Docket Nos. 50-514 and 50-515). The 1918 Corfu event has only one instrumental recording available and thus is not relocatable. The location of the 1936 earthquake is discussed by Woodward-Clyde Consultants (1980) and in the response to Question 361.9.

References

Woodward-Clyde Consultants, 1980, Seismological review of the July 16, 1936 Milton-Freewater earthquake source region: report submitted to Washington Public Power Supply System, Richland, Washington by Woodward-Clyde Consultants, San Francisco, California, 44 p.