United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

SEP 1 7 1979

In Reply Refer To:
Mail Stop 905

Mr. Harold Denton
Director of the Office of
Nuclear Regulations
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Denton:

Transmitted herewith, in response to the request by your staff, is a supplement to our review (February 23, 1978) of the geologic and seismologic data relevant to the Skagit Nuclear Power Project, Units 1 and 2 (NRC Docket Nos. 50-522 and 50-523).

This supplement was prepared prior to the completion of a review of certain proprietary seismic profiles which have not yet been received by the U.S. Geological Survey. Any impact of the review of these profiles will be transmitted at a later date.

This supplement was prepared by William H. Hays and Stanley R. Brockman. Assistance was provided by Richard J. Blakely, Robert H. Morris and James F. Devine.

Sincerely yours,

H. William Menard
Director

Enclosure

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Status Review
September 13, 1979

Puget Sound Power & Light Company
Skagit Nuclear Power Project, Units 1 and 2
Project No. 514
Skagit County, Washington
NRC Docket Nos. STN 50-522 and 50-523

Since submitting its last Status Review on the proposed Skagit Nuclear Power Project on February 23, 1978, the U.S. Geological Survey (USGS) has received and reviewed a major submittal from the Puget Sound Power & Light Company (PSPL) entitled "Report of Geologic Investigations in 1978-1979" and dated May 27, 1979. This submittal and a few new questions that have arisen from ongoing studies in the site region are discussed in this review.

Geology

The extensive investigations represented by the submittal of May 27, 1979, were stimulated by new ideas regarding the geology of the site vicinity that developed in the coarse of the long-term program of the USGS for mapping the geology of northwestern Washington. The new ideas concern a tectonic mixture of meta-igneous and metasedimetary rocks that is widely exposed south of the plant site in the Table Mountain-Haystack Mountain-Bald Mountain region. (These rocks are hereafter termed "CH/Ju rocks", a term coined from symbols for these rocks on the maps of the applicant and of J. T. Whetten.) In the Preliminary Safety Analysis Report (PSAR) of early 1978, the applicant identified these rocks as part of the Church Mountain thrust plate, dragged or pushed into this region from the east by the overriding Shuksan thrust, and as being generally correlative to the Chilliwack Group of largely Paleozoic age, which composes that thrust plate in the Cascade Range farther east (Misch, 1966, 1977, 1979). In identifying the CH/Ju rocks with the Church Mountain plate and the Chilliwack Group, the applicant was probably influenced by the fieldwork of G. M. Miller (1979, in press), who has sought to extend Misch's mapping westward into the Cascade foothills. At NRC-USGS meetings with the applicant in May 1978, and at the Atomic Safety and Licensing Board (ASLB) hearing in June of that year, J. T. Whetten of the USGS, who has been mapping in the San Juan Islands (Whetten and others, 1978) and was extending his work eastward into the mainland, proposed some markedly different relationships. He correlated the CH/Ju rocks south of the plant site with the Mesozoic Decatur Terrane (including the Fidalgo Ophiolite of Brown [1977] and Brown and others [1979]) that he had mapped as a thrust sheet in the eastern part of the islands--a correlation that is

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supported by petrologic and radiometric data. Whetten presented evidence that these rocks are not part of the Church Mountain thrust plate, structurally underlying the Shuksan thrust, but, rather, part of a higher plate that has been thrust over the Shuksan plate. These new ideas, later expanded in publications (Whetten and Zartman, 1979; Whetten and others, 1979; Whetten and others, in press) have produced uncertainty and division in the thinking of the geologic community regarding the basic structural framework of parts of the Cascade foothills. Such uncertainty is of significance to review of the site proposal in that it could limit identification and understanding of younger, post-thrust deformation of the rocks of the region.

In hope of resolving quickly the question of the basic structural relationship of the Shuksan thrust plate to the CH/Ju rocks and also more specific concerns regarding possible high-angle faults of post-thrust age, the NRC and USGS requested, on June 9, 1978, that the applicant make additional studies, including (1) core boring, to determine the orientation of the fault contact between the Shuksan and Ch/Ju rocks near Little Haystack Mountain; (2) aeromagnetic surveys, to help define the location and the attitude of the same contact regionally and to investigate an anomaly southeast of Butler Hill that had been revealed on an earlier, less detailed survey; and (3) further studies, including examination of Quaternary deposits, relative to the possible presence and significance of faulting in the vicinity of and parallel to Gilligan and Day Creeks.

The applicant responded vigorously to the NRC-USGS requests and extended the scope of its studies slightly beyond the requests in order to address more fully concerns regarding the hypothesized "B and B Fault." The applicant was unable to carry out completely the requested drilling near Little Haystack Mountain, but drilled 11 core holes there and elsewhere; carried out an extensive detailed aeromagnetic survey and analysis thereof; markedly increased the density of data on its regional geologic map, including data near Gilligan and Day Creeks; carried out on-ground gravity and magnetic surveys across the lower parts of the two creeks; reexamined photographic and radar imagery; and studied Nanaimo-Chuckanut stratigraphy in the northern San Juan Islands.

In May and June 1979, the applicant distributed its report, "Report of Geologic Investigations in 1978-1979" (hereafter termed "RGI"), on the studies outlined above. The principal topics addressed by the applicant in this report and other aspects of regional and local geology that have seemed important in recent considerations of the proposed plant site are discussed briefly below:

1. <u>The basic tectonic framework of the region</u>--In its 1979 RGI, the applicant concludes that the controversial CH/Ju rocks south of the plant site and other exposures of similar rocks in the region are indeed parts of the Church Mountain thrust plate and structurally lower than the Shuksan thrust plate--a conclusion consistent with

that in the earlier PSAR and in conflict with Whetten's model of the region. The applicant does modify its earlier position somewhat (p. 3.1-5) in stating that the CH/Ju rocks probably include some Mesozoic rocks similar to rocks in the eastern San Juan Islands, and the RGI includes (p. 3.1-4, 3.1-5) a brief description of a third structural model, that of Joseph Vance, which incorporates some features of the other two.

It seems clear, regrettably, that the issue raised by Whetten regarding the place of the CH/Ju rocks in the basic tectonic framework of the foothill region around the proposed plant site has not been resolved by the considerable new data acquired in the past 18 months and that no consensus on this problem can be expected until some future time when much more of the region has been mapped geologically in detail and more geophysical data have been acquired. The present situation of uncertainty in the geologic community is exemplified by recent studies in the vicinity of Little Haystack and Talc Mountains, where the aeromagnetic and core-hole data recently supplied by the applicant can apparently be accommodated both by the applicant's mapping and interpretation of the thrust and by Whetten, Dethier, and Carrol's (1979) very different mapping and interpretation. The most logical and responsible present course in the evaluation of the Skagit site seems to be acceptance of the existence of some major uncertainty among geologists regarding the geologic framework of the site region and recogition of this uncertainty in conservative evaluation of the bearing of specific geologic features on site safety.

2. High-angle north-trending faults near the plant site--The applicant has fairly conclusively demonstrated, by detailed observation and mapping supported by geophysical surveys, that no significant north-trending faults follow the valley floors of Gilligan and lower Day Creeks. The applicant has found little or no evidence for faults within the Shuksan metamorphic rocks on the slopes above the creeks, but it is prudent to bear in mind that such faulting might be difficult to detect.

   In two localities in the vicinity of the plant site, on the south side of the Skagit valley, the strong possibility or likelihood of high-angle faulting younger than any regional thrusting is a present concern east of Gilligan Creek, along the contact between the Shuksan and CH/Ju rocks, and in the valley of Loretta Creek, at and near the Chuckanut-Shuksan contact.

   The applicant's mapping (RGI, fig. 3.2-2 and Appendix H, sheet 1) of the fault between the Shuksan and the CH/Ju rocks in sections 12, 13, and 24 or T. 34 N., R. 5 E. accords closely with Whetten's mapping (1979), and all agree that the dip of the fault is steep there. In section 1 of the same township, bedrock exposure is

commonly poor, and the contact can be less accurately located. Available outcrops and probable outcrops suggest that it continues, with a northerly trend, through about the center of the section. In the northern quarter of the section, the few outcrops may permit an inference that the contact turns abruptly east, so as to join the thrust contact between the same rock units in the northeast quarter of section 6, T. 34 N., R. 6 E. Even if the Shuksan-CH/Ju contact follows such a course, it seems likely that the semilinear high-angle fault that forms the contact for miles south of section 1 continues on across the section to the north. Rather than a steeply folded segment of a thrust, the fault east of Gilligan Creek (hereafter termed the "Gilligan Fault") is probably a younger fault that cuts across the thrust.

The extent of the Gilligan Fault to the north and south is unknown and perhaps almost indeterminable. If it extends northward beneath and beyond the Skagit valley, it enters a large mountainous mass of rather poorly exposed Shuksan metamorphic rocks; to the south, beyond upper Gilligan Creek, it is within the tectonically mixed CH/Ju rocks. In both the Shuksan and CH/Ju terranes, the identification and mapping of faults can be very difficult. South of upper Gilligan Creek, the fault is conceivably related to a discontinuous lineament, apparent on side-looking radar (RGI, p. 3.2-8 to 3.2-11), that extends south to a point near the west end of Lake Cavanaugh, but there is little or no evidence that this lineament is related to the Gilligan Fault or to any geologic structure. The offsets in glacial lake deposits about where this lineament crosses the Lake Cavanaugh Road (Bechtel, Inc., 1978) are probably nontectonic.

A second locality where there is concern regarding high-angle faulting, the valley of Loretta Creek (RGI, Appendix H, sheet 1; Whetten and others, 1979), was called to the attention of USGS reviewers by J. T. Whetten and P. R. Carrol. In the course of mapping geologically the lower part of the valley, Whetten and Carrol encountered an exceptionally good exposure of the Chuckanut-Shuksan contact in a small waterfall, at an elevation of about 1,250 feet. Here the contact consists of a near-vertical shear zone, at least about 6 feet wide, that appears to strike north-northwest. The zone very probably represents a significant high-angle fault of post-Chuckanut (post-Eocene?) in age. In the absence of strongly supportive data, the acceptance of any other interpretation here would be highly imprudent. The length of this fault (hereafter termed the "Loretta Fault") and the amount and exact sense of displacement on it are unknown. If it is present north of the Skagit valley, the difficulties in mapping it there would be similar to those described in the case of the Gilligan Fault. To the south, the fault may follow the Chuckanut contact or may take another course.

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3. The "Loveseth" Fault--The "Loveseth" Fault, mapped as a fault by T. P. Loveseth (1975) and H. D. Gower (1978) is interpreted by the applicant (RGI, Section 3.4.2) and by G. M. Miller (RGI, fig. 3.1-3, sheet 2, and in press), a consultant to Bechtel, Inc., as the basal sedimentary contact of the Chuckanut Formation, disturbed only by local shearing associated with Tertiary folding. The applicant does not mention the existence of any clear exposures of the contact, and apparently its dip cannot be accurately measured anywhere. The geologic constraints on its location, though fairly tight in the northeast quarter of section 10 and perhaps in section 3, T. 33 N., R. 5 E., are commonly loose farther south. On the basis of evidence of strong shearing and of probable discordance of beds to the Chuckanut-CH/Ju contact, it seems most likely that the contact mapped in sections 3, 10, and 11 is a fault. The applicant's interpretation cannot, perhaps, be ruled out here, but it is surely not unique. Farther south, the most likely course of such a fault lies probably along the southwest side of the large volcanic body in section 14 and through the Chuckanut beyond, but other courses may be possible. The applicant's mapping, which established the presence of Chuckanut east of the large volcanic body in section 14, as well as west of it, suggests that the "Loveseth" Fault is not a major structure. The discordant dips in the Chuckanut in the northwest quarter of section 13 suggest that the contact there may be similarly faulted.

4. The "B and B Fault"--The possibility of a "B and B Fault" was discussed at the ASLB hearing in March 1978, largely as a result of USGS concerns regarding a letter received from Peter Ward, a stratigrapher who had been carrying on research in the northern San Juan Islands. Ward suggested that the Nanaimo and Chuckanut sedimentary rocks had been deposited in separate sedimentary basins and that their present juxtaposition across the strait between Barnes and Clark Islands and Lummi Island might be best explained by large-scale strike-slip faulting. The USGS had not fully evaluated Ward's suggestion at the time of the hearing and could only speculate regarding the proposed fault. In informal consideration of possibly permissible courses for the proposed fault south of Lummi and especially of such courses that were closest to the proposed plant site, it was thought that such a fault might possibly bend eastward and pass through the Table Mountain vicinity south of Cultus Mountain. It was this highly speculative, "worst-case" fault trace, between the vicinity of Samish Bay on the north and the vicinity of Lake Cavanaugh on the south, that W. H. Hays sketched on a map at the March 1978 hearing and that was there somehow christened the "B and B Fault."

Since that ASLB hearing, studies by the applicant and others have led to doubt regarding the possibility of large post-Chuckanut faulting west of Lummi Island, but seem to have established the presence of faulting near Table Mountain. In the northern San Juan

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Islands, a major fault between Lummi Island and Orcas Island was first suggested by Misch (1966), and considerable evidence points to faulting there that has affected rocks as young as the Upper Cretaceous Nanaimo Group. The possibility of faulting younger than the Chuckanut Formaion on Lummi Island is, however, more difficult to evaluate. Stratigraphic studies by the applicant (RGI, section 3.4.1) suggest correlation of the Chuckanut formation on Lummi Island with strata on part of Sucia Island and on some other islands west of Lummi and thus support some of the earlier similar conclusions of Vance (1975, 1977). This correlation seems to lack the support of conclusive evidence for the various deposits being of the same age but, if valid, it would seem to preclude inference of large-scale faulting west of Lummi Island since Chuckanut (Eocene and older) time.

Another development since the March 1978 hearing has been increasing realization that the Chuckanut is probably younger than almost all, if not all, of the marine Nanaimo Formation on Barnes and Clark Islands and elsewhere west of Lummi and that the Chuckanut probably need not have been deposited in a basin distinctly separate from the Nanaimo basin, as Ward suggested.

Thus, while large-scale post-Chuckanut faulting west of Lummi Island cannot at present be ruled out, strong evidence for such faulting appears to be lacking. If there is no such faulting, there is, of course, no necessity of accommodating similar movement to the south, along some such structure as the "B and B Fault."

In the Table Mountain vicinity far to the south, which Hays speculated to be on one possible southerly course of the major fault suggested by Ward, continued geologic mapping has indicated the presence of a northwest-trending fault or fault zone (Whetten and others, 1979), an interpretation that is not necessarily inconsistent with the applicant's field studies (RGI, p. 3.4.1-4). Whetten (oral comm., 1979) believes that this fault or fault zone has near-vertical dip and has considerably disrupted the CH/Ju and Shuksan plate rocks in the Table Mountain-upper Nookachamps Creek vicinity. The age of this structure (hereafter termed the "Table Mountain Fault") and its extent to the northwest and southeast are unknown.

5. The age of high-angle faulting in the site vicinty--It seems clear that a conservative geologic analysis of the site vicinity must take into account the probable presence of fairly numerous high-angle Tertiary faults, one or two of which may pass within a few miles of the plant site. These faults include the Gilligan, Loretta, "Loveseth," and Table Mountain Faults discussed above; probably some of the faults mapped by Whetten, Dethier, and Carrol (1979) and the applicant west of middle and upper Day Creek; and perhaps the Shuksan-CH/Ju contact at "No Name Creek." All of these

faults should probably be presumed to be younger than latest Chuckanut deposition (Middle Eocene), though some may be older. Some probably formed during the ealy Tertiary (Eocene?) deformation that folded the Chuckanut, but the near-vertical dips of at least many of the fault surfaces and the linearity of the surface traces of the Gilligan Fault and probably other faults suggest that some of these structures formed after that deformation.

In discussing the possible age of this faulting, it may be instructive to consider the nearest faults that have, tentatively at least, been considered capable. The Devil's Mountain Fault, which passes 21 km southwest of the plant site, is considered capable by the USGS, largely on the basis of a lack of evidence that it could not be capable and of probable displacements as depicted in marine profiles located west of Whidbey Island. The Straight Creek Fault, 48 km east of the site, has probably moved a little since mid-Tertiary time and is "tentatively classified as capable" (McCleary and others, 1978, p. ii) in a study carried out by a consultant to the Washington Public Power Supply System. While it seems legitimate, in a conservative site analysis, to consider both of these faults capable, it should be remembered that both are very long, very large regional structures, which have doubtless moved many times; that displacement along the Straight Creek Fault was very largely, if not almost entirely, accomplished by Miocene time; and that there is no evidence that movement along the Devil's Mountain Fault was not also largely completed by that time. The capability of two master faults of the region does not logically establish capability for the many smaller faults. It seems likely that most, if not all, of the high-angle faults of the site vicinity have not moved in Quaternary time. There is no strong evidence of such movement on any of them. On the other hand, displacements, especially minor displacements, that might conceivably have occurred on these faults between 500,000 years ago and the end of the last glaciation (about 13,000 years ago) could have been covered or obscured by that glaciation; and the applicant has presented no strong evidence against such conceivable movement. In summary, it appears that the high-angle faults of the site vicinity are very probably but uncertainly incapable.

6. The 1946 earthquake near the northeast coast of central Vancouver Island--Several papers dealing directly or indirectly with the 1946 earthquake have been published since submittal of the last USGS Status Review in February 1978. Rogers and Hasegawa (1978) recompute the epicenter of the earthquake and place it on Vancouver Island near its northeast coast, rather than under the Strait of Georgia. They favor a fault-plane solution calling for a northwest-striking fault surface, possibly in close proximity to the similarly striking Beaufort Range Fault, but they do not rule out a northeast-striking surface. Riddihough (1978) relates the 1946 event to a northeast-trending fault in the subducting plate

beneath the crust of Vancouver Island. Slawson and Savage's (1978) resurvey of an old triangulation network revealed distortions consistent with movement on the Beaufort Range Fault, but association of the earthquake with surface geology appears to remain doubtful.

Aeromagnetic Data

The USGS has reviewed the analysis of aeromagnetic data by Exploration Data Consultants, Inc. (Edcon) and found it to be generally satisfactory. Alternative interpretations are possible in some cases, however, and the data do not unambiguously establish the correctness of the applicant's mapping and tectonic model. The following are several general conclusions arising from our review of these data and the Edcon report:

(a) Aeromangetic anomalies help to define the shape and location of highly magnetic rock types, which are probably serpentinites in this area. In particular, aeromagnetic data were used to deduce the nature of the contact between Shuksan metamorphic rocks and the CH/Ju rocks. However, the dips of the surfaces of the serpentinite bodies may be unrelated to the attitudes of the thrust because (1) the serpentinite may not be originally associated with thrusting; (2) serpentinite is a highly mobile rock when subjected to stress; and (3) serpentinites possess highly variable magnetic properties.

(b) Concern regarding an abrupt change in trend of the aeromagnetic contours southeast of Butler Hill, on small-scale USGS aeromagnetic maps (see RGI, fig. 3.3-2), was expressed in the NRC-USGS request to the applicant of June 1978. The additional more detailed aeromagnetic survey data provided by the applicant indicate that there is no magnetic basis for a fault with an east-west trend along Skagit Valley south of Butler Hill.

(c) Anomalies along the thrust contact in the vicinity of Talc Mountain are caused by rock bodies (probably serpentinite) which appear to have northeast-dipping northeast faces. However, these bodies extend to only about 2,000 feet below ground surface and could, therefore, be confined within a thin thrust sheet.

(d) The absence of fault-related aeromagnetic anomalies near the mouth of Gilligan Creek, south of Butler Hill, and elsewhere does not necessarily preclude the existence of faults in these areas.

(e) Aeromagnetic maps show that anomalies characteristic of CH/Ju rocks usually terminate at the thrust contact between Shuksan and CH/Ju rocks. This suggests that if CH/Ju rocks underlie Shuksan, as the applicant has suggested, they lie at depths in excess of 10,000 feet. As CH/Ju frequently crops out in small areas surrounded by Shuksan and away from the thrust (e.g., at Butler Hill), this lack of anomalies over Shuksan terrane forces a rather complicated geologic model.

Seismology

A detailed discussion in the Geology and aeromagnetic data sections of this review is presented concerning the existance and age of numerous high-angle faults in the site vicinity. The conclusion offered there is that these faults are "very probably, but uncertainly, incapable."

On the other hand, there have been numerous small earthquakes in the area containing the site. Their magnitudes range from 1.2 to 3.3 and several have been felt locally. An alignment of epicenters has been noted in the Skagit River Valley but there are doubts about the absolute accuracy of their locations. The stated accuracy of events located by the University of Washington-operated seismic network is 1 to 2 km (Crossen, 1974). However, the seismograph stations in the Skagit Valley vicinity are fewer and more widely spaced than those further to the south and because the locale is near the northern limit of the network coverage, the accuracy is not likely to be that precise. The remaining epicenters appear to be essentially random in the site vicinity. None of the small earthquakes have been associated with identified faults. It is possible that these earthquakes are associated with structures that are sufficiently small that no surface expression has been recognized by the geologic investigations.

Consequently, it is our judgment that for purposes of nuclear reactor design it should be assumed that earthquakes as large as magnitude 4.0 could originate on any of the identified faults or an unmapped fault in the region of the plant site. However, it is our judgment that even if an earthquake of this size were to occur on one of these structures, its consequences at the plant site would be less than that already postulated to result from the two much larger earthquakes discussed in our previous reviews (Jan. 30, 1978 and Feb. 23, 1978).

Since our last review, other articles relating to the tectonics of the Pacific Northwest, in general, and the Vancouver Island vicinity, in particular, have been published. They reinforce the concept that the 1946 earthquake was related to the present-day subduction regime of the region rather than regional north-south compression (Rogers and Hasegawa, 1978). Rogers (1979) suggests that the occurrence of earthquakes having a northeast alignment across Vancouver Island are related to differential movements of the Explorer and Juan de Fuca

plates. Two interpretations of the tectonic settings are presented; his preferred setting suggests that the subducted Nootka fault zone (named by Hyndman, et al, 1978) would represent, in effect, a tectonic boundary, north of which earthquakes would occur because of intense local north-south compression resulting from the Explorer-America plate interaction. To the south of the Nootka fault zone, subduction of the Juan de Fuca plate beneath the America plate would proceed in a normal but aseismic fashion. In view of these considerations, we believe that the constraints on the locus of an event similar to the 1946 earthquake would make its significance less than the two postulated controlling earthquakes (USGS Jan. 30, 1978,and Feb. 23, 1978).

In summary, there is a recognition that there has been a large amount of new geological and geophysical data provided by the applicant and others since the preparation of our last review. However, there remains a major uncertainty as to the completeness, significance, and proper interpretation of both the new and previously discussed data. Consequently, it is still our jugment that for purposes of nuclear reactor design the following two earthquakes should be considered as controlling:

1. an earthquake similar to the one that occurred December 15, 1872 but having its epicenter sufficiently close to the site that no attenuation effects be considered, and

2. a shallow magnitude 7.0 to 7 1/4 earthquake on the Devils Mountain Fault 21 km. from the site.

The USGS reactor site review team agrees with the applicant's proposed use of a bedrock acceleration value of 0.35 g as the Safe Shutdown Earthquake for use with the Safety Guide 1.60 design spectrum for nuclear power plant design.

References

Bechtel Incorporated, 1978, Subsurface investigation of disturbed glacial deposits on Lake Cavanaugh Road: Report to Puget Sound Power & Light Co.

Brown, E. H., 1977, The Fidalgo Ophiolite, in Brown, E. H.. and Ellis, R. C. (eds.), Geological excursions in the Pacific Northwest: Western Washington Univ., p. 309-320.

Brown, E. H., Bradshaw, J. Y., and Mustoe, G. E., 1979, Plagiogranite and keratophyre in ophiolite on Fidalgo Island, Washington: Geol. Soc. of America Bull., Part I, v. 90, p. 493-507.

Crosson, R. S., 1974, Compilation of earthquake hypocenters in western Washington 1970-1972: Division of Geology and Earth Resources Information Circular 53, 25 p.

Crosson, R. S., 1975, Compilation of earthquake hopocenters in western Washington-1973: Division of Geology and Earth Resources Information Circular 55, 14 p.

Crosson, R. S. and Millard, R. C., 1975, Compilation of earthquake hypocenters in western Washington-1974: Division of Geology and Earth Resources Information Circular 56, 14 p.

Crosson, R. S. and Noson, L. J., 1978a, Compilation of earthquake hypocenters in western Washington-1975: Division of Geology and Earth Resources Information Circular 64, 12 p.

Crosson, R. S. and Noson, L. J., 1978b, Compilation of earthquake hypocenters in western Washington-1976: Division of Geology and Earth Resources Information Circular 65, 13 p.

Hyndman, R. D., Rogers, G. C., Bone, M. N., Lister, C. R. B., Wade, U. S., Barrett, D. L., Davis, E. E., Lewis, T., Lynch, S., and Seemann, D., 1978, Geophysical measurements in the region of the Explorer ridge off western Canada: Canadian Journal of Earth Sciences, v. 15, pp. 1508-1525.

Miller, G. M., 1969, Western extent of Mid-Cretaceous thrusting in Whatcom and Skagit Counties, Washington: Geol. Soc. of America Abstracts with Programs, part 3, p. 42.

Miller, G. M., in press, Western extent of the Shuksan and Church Mountain Plates in Whatcom, Skagit, and Snohomish Counties, Washington: Northwest Science.

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Misch, Peter, 1966, Tectonic evolution of the Northern Cascades of Washington State, in Tectonic history and mineral deposits of the Western Cordillera in British Columbia and neighboring parts of the United States: Canadian Inst. of Mining and Metal., 1964 Ann. Western Mtg., Vancouver, B.C., p. 101-148.

Misch, Peter, 1977, Bedrock geology of the North Cascades, in Geological excursions in the Pacific Northwest: Geol. Soc. of America, 1977 Ann. Mtg, Seattle, Washington; publ. by Dept. of Geol., Western Washington State Univ.

Misch, Peter, 1979, Geologic map of the Marblemount Quadrangle, Washington: Washington Dept. of Nat. Res., Div. of Geol. and Earth Resources, Geol. Map GM-23.

Riddihough, R. P., 1978, The Juan de Fuca Plate: American Geophys. Union, EROS, v.59, no. 9, p. 836-842.

Rogers, G. C., 1979, Earthquake fault plane solutions near Vancouver Island: Canadian Journal of Earth Sciences, v. 16, pp. 523-531.

Rogers, G. C., and Hasegawa, H. S., 1978, A second look at the British Columbia earthquake of June 23, 1946: Seismol. Soc. of America Bull., v. 68, no. 3, p. 653-675.

Slawson, W. F., and Savage, J. C., 1978, Geodetic deformation associated with the 1946 Vancouver Island, Canada, earthquake (abst.): American Geophys. Union, EROS, v. 59, no. 12, p. 1210.

Vance, J. A., 1975, Bedrock geology of San Juan County, in Geology and water resources of the San Juan Islands: Washington Dept. of Ecology, Water Supply Bull. 46.

Vance, J. A., 1977, The stratigraphy and structure of Orcas Island, San Juan Islands, in Geologic excursions in the Pacific Northwest, Geol. Soc. of America Ann. Mtg., Seattle Washington; publ. by Dept. of Geol., Western Washington State Uiv., p. 170-203.

Whetten, J. T., Jones, D. L., Cowan, D. S., and Zartman, R. E., 1978, Ages of Mesozoic terranes in the San Juan Islands, Washington, in Mesozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium 2: Pacific Sec., Soc. of Econ. Paleon. and Mineral., p. 117-132.

Whetten, J. T., Zartman, R. E., Blakeley, R. J., and Jones, D. L., in press, Allochthonous Jurassic ophiolite in northwest Washington: Geol. Soc. of America Bull.

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