Puget Sound Power & Light Company Puget Power Building Bellevue, Washington 98009 (206) 454-6363

January 4, 1979
PLN-208

Director of Nuclear Reactor Regulation
Attention: Mr. William H. Regan, Jr., Chief
Environmental Projects Branch 2
Division of Site Safety and
Environmental Analysis
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Subject: Puget Sound Power & Light Company
Skagit Nuclear Power Project, Units 1 & 2
Docket Numbers 50-522 and 50-523
NRC Letter to Mr. J. E. Mecca, Puget Power,
from Mr. W. H. Regan Jr., of the NRC, on
the Geological Aspects of Alternative Sites,
dated July 7, 1978

References: (a) PLN-197 dated August 2, 1978
(b) PLN-198 dated August 9, 1978
(c) PLN-199 dated September 25, 1978
(d) PLN-203 dated October 27, 1978

Dear Mr. Regan:

This letter completes the response to the above subject request.

Enclosed are twenty (20) copies of the document entitled "A Comparative Analysis of Geologic and Seismologic Conditions of the Alternative Sites to the Skagit Nuclear Power Project", dated December, 1978.

If you have any questions regarding this document, please contact me.

Very truly yours,

William J. [signature] (for)

J. E. Mecca, Manager
Nuclear Licensing & Safety

Enc.
cc: H. Lefevre
P. Leech
Correspondence List
ASLB Correspondence List

7901090 201

C002 ES 1/20 ADD

January 4, 1979
PLN-208

CORRESPONDENCE LIST

Mr. Richard L. Black
NRC Legal Staff
U. S. Nuclear Regulatory Commission
Office of the Executive Legal Director
Washington, D. C. 20555

Mr. Roger M. Leed, Esq.
Suite 610
1411 Fourth Avenue Building
Seattle, Washington 98101

Mr. Nicholas D. Lewis, Chairman
Washington State Energy Facility
Site Evaluation Council
820 East Fifth Avenue
Olympia, Washington 98504

Mr. Robert C. Schofield, Director
Skagit County Planning Department
Room 218
County Administration Building
Mount Vernon, Washington 98273

Mr. Robert Lowenstein
Lowenstein, Newman, Reis & Axelrad
1025 Connecticut Avenue N. W.
Suite 1214
Washington, D. C. 20036

Mr. F. T. Thomsen
Perkins, Coie, Stone, Olsen & Williams
1900 Washington Building
Seattle, Washington 98101

CFSP and FOB
c/o E. Stachon & L. Marbet
19142 South Bakers Ferry Road
Boring, Oregon 97099

Mr. Richard M. Sandvik, Esq.
Assistant Attorney General
State of Oregon
Department of Justice
500 Pacific Building
520 S. W. Yamhill
Portland, Oregon 97204

Mr. Richard D. Bach, Esq.
Rives, Bonyhadi & Drummond
1400 Public Service Building
920 S. W. 6th Avenue
Portland, Oregon 97204

Mr. H. H. Phillips, Esq.
Vice President and Corporate Counsel
Portland General Electric Company
121 S. W. Salmon
Portland, Oregon 97204

Russell W. Busch
Evergreen Legal Services
5308 Ballard Ave. N. W.
Seattle, Washington 98107

Donald S. Means
Swinomish Tribal Community
Box 277
LaConner, Washington 98257

ASLB CORRESPONDENCE LIST

Mr. Valentine B. Deale, Esq., Chairman
Atomic Safety and Licensing Board
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dr. Frank F. Hooper, Member
Atomic Safety and Licensing Board
School of Natural Resources
University of Michigan
Ann Arbor, Michigan 48104

Mr. Gustave A. Linenberger, Member
Atomic Safety and Licensing Board
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Mr. Alan S. Rosenthal, Chairman
Atomic Safety and Licensing Appeal Panel
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

A COMPARATIVE ANALYSIS
OF GEOLOGIC AND SEISMOLOGIC CONDITIONS
OF THE
ALTERNATIVE SITES
TO THE
SKAGIT NUCLEAR POWER PROJECT

BECHTEL, INC.

DECEMBER, 1978

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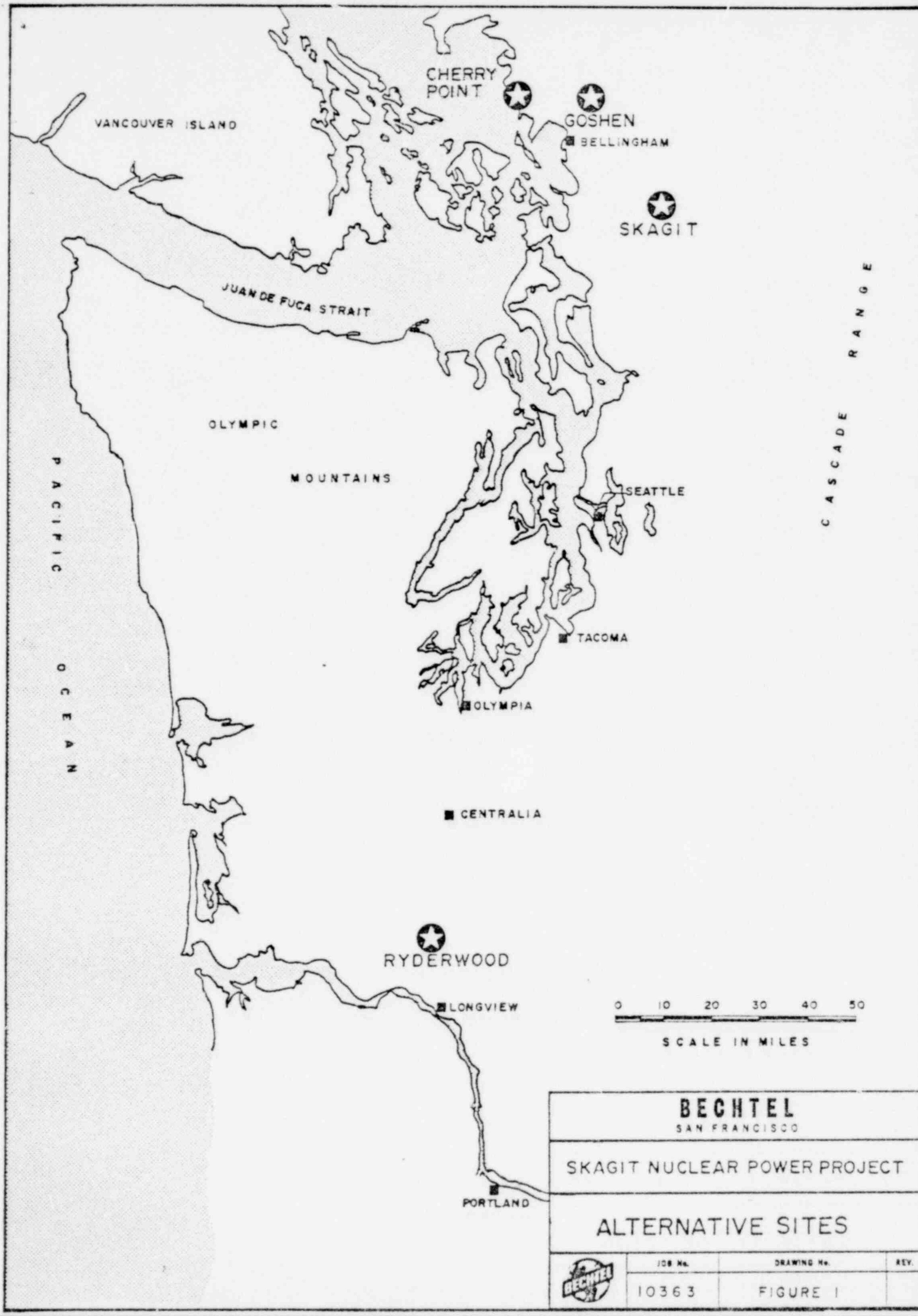
December,1978

INTRODUCTION

This report has been prepared in response to a request by the Nuclear Regulatory Staff to provide an up-dated comparative analysis of the Cherry Point, Skagit, Goshen and Ryderwood sites based on geologic, seismic and geotechnical data now available. The scope of this review is restricted to the specific conditions which are normally investigated during early site review. It should be noted that the selection of the Skagit site pre-dates this report by several years; however, a systematic process of site evaluations and comparisons was used prior to that selection. Although the selection procedure was not a regulatory requirement at that time, it appears to sati·ˆ‹ current siting policy. Earlier siting studies in this general area include a 1967 report on geologic conditions at the Cherry Point site, the Thermal Power Plant Siting Study of 1970 which evaluated 117 sites, and an evaluation of six selected sites in 1973. This assessment does not materially alter the conclusions reached during the original site selection process.

The sites were compared on the basis of similar criteria. The criteria include historic seismicity, distance from known or assumed capable structures, foundation conditions, ground water conditions, slope stability, volcanic hazards, and potential development of mineral resources at or near a site. This report briefly describes the regional geology and seismicity followed by a discussion of the criteria catagories for each site. A comparative summary of the sites is provided at the end of the report.

The Goshen and Cherry Point sites are located in Whatcom County. The Goshen site is located in Section 23, T. 39 N., R. 3 E. The Cherry Point site is located in Sections 18 and 19, T. 39 N., R. 1 E. The Skagit site is located in Skagit County within Section 11 and 12, T. 35 N., R. 5 E. The Ryderwood site is located in Lewis County within Sections 26, 27, 34, and 35, T. 11 N., R. 3 W. (See Figure 1)



BECHTEL
SAN FRANCISCO

SKAGIT NUCLEAR POWER PROJECT

ALTERNATIVE SITES

JOB No.	DRAWING No.	REV.
10363	FIGURE 1	

REGIONAL PHYSIOGRAPHY AND TECTONIC PROVINCES

Physiography

Northwestern Washington and adjacent British Columbia have been divided into several geomorphic provinces. These provinces include the Coast Ranges, the Outer Mountains, the Coastal Trough, the Puget Lowlands, Coastal Mountains, and the Cascade Mountains. The Goshen and Cherry Point sites are within the Whatcom Lowland subprovince of the Coastal Trough or Georgia Depression physiographic province. The Skagit site is located just inside the western boundary of the Cascade Mountains physiographic province.

Tectonic Provinces

The boundaries of tectonic provinces in this region are not uniformly accepted, and are not significant to setting the SSE for the Skagit Site. The same situation would apply to the Cherry Point and Goshen Sites.

The Satsop PSAR delineates tectonic provinces in the area around the Ryderwood Site.

REGIONAL SEISMICITY

The sites under review are located in a moderately active seismic zone which extends from Portland, Oregon northward into British Columbia. The most active area within this zone is the Puget Sound depression which represents a N-S trending topographic and structural trough found between the Olympic Mountains to the west and the Cascade Range to the east. The sites under consideration all lie within the felt areas of deep-seated, epicentral Intensity VIII earthquakes which have occurred in Puget Sound. The depression also has a much higher concentration of shallow, low intensity earthquakes than has been experienced elsewhere in the region. Algermisson et al. (1969) depict an isoseismal map of Oregon and Washington showing maximum intensities between 1841 and 1966. This map shows the Skagit, Cherry Point, and Goshen sites in an intensity VI zone, while the Ryderwood site is located in proximity to a boundary between intensity VII and VIII zones. The 1949 Olympia earthquake, which registered a magnitude 7.1 on the Richter scale is a controlling event on this map. This event and the 1965 magnitude 6.5 Olympia earthquake are associated spatially with large geophysical anomalies in the southern Puget Sound. Hypocenters of these earthquakes were both deeper than 50 km and are most likely related to interactions between the Juan de Fuca and North America plates. Other areas within the zone under consideration, such as the Olympia Mountains to the west and the Cascade Range to the east, are relatively aseismic

compared to the Puget Sound basin. Characteristically, the shallow, low intensity earthquakes which occur within the Puget Sound depression are not associated with known faults (Hawkins and Crosson, 1975).

The Chelan-Wenatchee earthquake of 1872 either did not result in surface disruptions or that surface disruption has not been located; however, newspaper accounts cite repeated, local seismic activity in the epicentral area. The U.S. Geological Survey conservatively assumes that the 1872 disturbance is a "random" event and a similar event, maximum Intensity IX, could occur near the Skagit site, and presumably near the Goshen, and Cherry Point sites.

The 1946 earthquake on Vancouver Island was a magnitude 7.3 event. It was located approximately 140 miles north of the U.S. Canadian border. It caused Intensity VI near the Skagit Site. This earthquake has been related to structure; it is not considered to be a "random" event.

These are the largest earthquakes which have occurred in historic time within at least 200 miles of any of the four sites considered here. Details of regional seismicity and tectonics are discussed in numerous publications. The bibliography in the PSAR for the Skagit Site lists many such publications.

REGIONAL GEOLOGY - (SKAGIT, CHERRY POINT AND GOSHEN SITES)

The geological history of northwestern Washington and southwestern British Columbia is a record of several long periods of sedimentary and volcanic deposition separated by episodes of strong deformation.

The oldest rocks in the area are pre-Devonian igneous and metamorphic "crystalline basement". The geologic record represented by the basement rocks is not completely clear, but it is evident that these rocks have experienced several episodes of deformation and metamorphism followed by large scale igneous intrusion. The basement rocks commonly occur as tectonic slices at the surface as a result of the extensive deformation subsequent to the mid-Palezoic. There is a significant break in the geologic record between the basement rocks and the overlying units.

A thick sequence of metamorphosed Paleozoic to Cretaceous sedimentary and volcanic rocks overlie the crystalline basement, and have been repeatedly metamorphosed and deformed. Post-metamorphic, westward-directed thrust faulting separates these units; this thrusting occurred during the mid-Cretaceous orogeny (Misch, 1966).

Continental sedimentary rocks were deposited from late Cretaceous to Eocene. These rocks were strongly folded and locally faulted during Eocene time. Late Eocene and Oligocene sedimentary and volcanic rocks in foothill and basin areas have been mildly deformed. The Cascade Range resulted from Late Pliocene to Early Pleistocene uparching along a north-south axis with subsequent eruptions of the Cascade volcanoes.

At least four major glacial advances in the Pl .-Pliestocene deposited extensive glacial drift in the region. These glaciers covered the Goshen, Cherry Point and Skagit Sites, but did not extend as far south as the Ryderwood site.

The major geologic structures in the region are the Straight Creek fault and the Shuksan and Church Mountains thrust faults. The Straight Creek fault underwent large lateral displacement during the mid-Cenozoic, and dip-slip displacement in the Eocene and perhaps early Oligocene, but it does not offset late Cenzoic igneous intrusive bodies. The thrust faults are major westward-directed structures which were active in the mid-Cretaceous; they have not been active since deposition of the Chuckanut formation in Late Cretaceous-Eocene. These thrusts were folded and deeply eroded during the Cenozoic.

The regional geology is discussed in detail in the Skagit Project PSAR Section 2.5.1.1. Several publications by Misch and Miller discuss the geology of northwestern Washington at length. Danner, (1968) and Richards and McTaggart (1976) have published details of the geologic history and tectonics of adjacent British Columbia. The glacial geology and history are discussed in several publications by Easterbrook (1963, 1969, 1973, 1974). There are of course many other publications on regional geology (See Bibliography in Skagit PSAR).

GEOLOGY OF THE SKAGIT SITE AREA

The Skagit site is near the Skagit River Valley within the margin of the North Cascade foothills physiographic section. The North Cascade foothills is a section of the Cascade Mountains physiographic province (Skagit, PSAR).

The site is located on a glaciated bedrock bench underlain by sedimentary rocks belonging to the Chuckanut Formation and Darrington phyllite. A thin veneer of glacial till and some glacial outwash deposits mantle the bedrock. The glacial till is composed of dense, unsorted, unstratified pebbly silt and clay. The glacial outwash consists of poorly sorted, stratified sands and gravels.

The Chuckanut Formation is Upper Cretaceous to Eocene in age and consists of sandstones and siltstones, with occasional conglomerates and coal seams. In the site area the Chuckanut beds form the northeast limb of a northwesterly trending syncline. The bedding at the site strikes approximately N55°W and dips southwest at 50° to 75°. Drilling and trenching across the contact have shown these sediments to be in depositional contact with the Darrington phyllite. Careful examination of the contact reveals that shearing has occurred locally in response to Eocene folding (Skagit PSAR).

The Darrington phyllite is the lower unit of the Shuksan Metamorphic Suite. These pre-Jurassic rocks are highly contorted, tightly folded,

and exhibit sheared and crushed zones in the weaker graphitic phyllite. These features indicate the unit has undergone several stages of deformation most of which occurred during the mid-Cretaceous orogeny (Misch, 1966). The phyllite has well developed foliation with a variable northwest strike and high angle dip (Skagit PSAR).

Faults

There are no capable faults within 5 miles of the Skagit Site. The Devils Mountain Fault Zone is the only fault within 15 miles of the site which has been assumed to be capable. This fault has been extensively studied and investigated. Examination and mapping of the fault by graduate students, the USGS, Bechtel, and others has not shown any evidence of Quaternary deposits being displaced by the fault (Loveseth, 1975; Skagit PSAR, NRC, 1978). Trenching and drilling did not find evidence of offset in overlying glacial materials. Historical seismicity does not suggest that the fault zone is active (Skagit PSAR); however, the NRC and USGS have conservatively assumed that Devils Mountain fault to be capable because it cannot be proven that it has not moved in the past 500,000 years (NRC, 1978).

Historical Seismicity

Intensity VI has been experienced in the Skagit site vicinity from large, distant earthquakes and a smaller local event. The 1949 and 1965 Puget Sound earthquakes, plus a small, magnitude 3 earthquake located 4-1/2 miles from the site resulted in intensity VI in the local area. The

small earthquake was not felt at the site although it resulted in the aforementioned intensity VI at some structures underlain by alluvium in the Skagit Valley. In most cases, intensities experienced in adjacent towns which are founded on alluvium would be greater than those experienced on bedrock at the site (Skagit PSAR).

Lineations and Geophysical Anomalies

Geophysical

Geophysical surveys within 15 miles of the Skagit site consist of USGS aeromagnetic surveys, the Washington State Bouguer gravity map, the Schriener thesis gravity study, and gravity data included in the Skagit PSAR. The aeromagnetic studies have helped to define the configuration of the mid-Cretaceous thrust sheets. The geophysical data does not indicate the existance of faults which have not been identified by other methods. The Devils Mountain fault zone has a strong linear magnetic anomaly associated with it; the fault has been assumed to be capable. No other linear anomalies of similar character are found within 15 miles of Skagit site.

Imagery Lineations

For the Skagit site, several types of imagery were used to define lineations. The lineations which were identified were examined in the field, geologically mapped and discussed in the Skagit PSAR. It was found that major faults with the exception of the Shuksan thrust appear as lineations on the imagery. No other lineations that had not been previously identified as faults were found to be faults.

An independent study of ERTS imagery was conducted by Amuedo (1975) for the area within 100 miles of the site. That study did not identify any previously unknown structures.

Volcanic Hazards

Mt. Baker, 22 miles to the northeast, and Glacier Peak, 56 miles to the east are the closest sources of possible volcanic hazards to the Skagit site. Volcanic activity which could affect the site include lava flows, hot ash flows, mudflows, and ashfall. The threat to the site from lava flows and hot ash flows is very low because these materials usually do not extend for substantial distances beyond the base of volcanoes (Hyde, 1975). A mudflow with the volume and characteristics of the Osceola mudflow was postulated on Mt. Baker to evaluate the effect of such an event on the Skagit Site. The Osceola mudflow occurred about 5,000 years ago at Mt. Rainier and is one of the largest mudflows known to have occurred in Washington. The total volume of the mudflow plus the water in the Baker River reservoirs was postulated to be deposited within the Skagit Valley between the Skagit site and the town of Concrete. This mudflow would be more than 200 feet thick in the valley but it would not reach the Skagit site which is 300 feet above the valley floor. The greater distance of Glacier Peak from the Skagit site would make the same postulated mudflow on Glacier Peak even less of a hazard than is Mt. Baker (Skagit PSAR).

Mt. Baker is not considered to be explosive in nature and, therefore, is not a likely source of significant ash fall (tephra) at the Skagit

site. An assessment of the tephra hazard of Mt. Baker by the USGS (Hyde, 1975) indicates that the Skagit site is on the boundary of the low risk zone. Glacier Peak is more of a potential source of tephra than is Mt. Baker, because of its explosive history and chemical composition. If the Katmai eruption of 1912 had occurred on Glacier Peak, ash from it would not have fallen on the Skagit Site due to the predominant wind direction. During the projected 40 year life of the facility, no ash is expected to fall at the Site. However, a highly conservative estimate for a hypothetical maximum ash fall at the site is 6 inches within a 24-hour period. The facility could accomodate this event satisfactorily for safety related functions (Skagit PSAR).

Foundation Conditions

General

The Skagit site has very good foundation conditions. The foundation material is well indurated, competent sedimentary rock below a thin, discontinuous layer of glacial drift. The depth of weathering in the bedrock is shallow, therefore the amount and depth of excavation needed to reach competent rock is minimal. Minor concrete dental work will be required in coal beds and soft or crushed zones. There is no potential for liquifaction during an earthquake. There are no known in situ stresses or soluble minerals in the bedrock at the site. Due to the hard, dense nature of the foundation bedrock, settlement under plant structures will be very low. There has been no withdrawal of oil or gas in the vicinity of the site (Skagit PSAR).

Two short, exploratory coal adits near the site were worked for a short period of time. These adits were both under 100 feet in length and are over 3200 feet from proposed structures; therefore, potential collapse or subsidence of these workings would not create a problem.

Slope Stability

A study of the slope stability of the Skagit site involved examination of remote sensing data for old landslides and geologic mapping of the slope surrounding the site. Lyman Ridge, north of the site, slopes toward the site but does not create a potential threat of large slides. The slope is underlain by foliated phyllite with bedding attitudes favorable to slope stability. In addition, no evidence of former large slides was found along the slope or along the foot of the slope. The reactor sites are over 3000 feet from the toe of the slope. In a slope stability study of the area by Heller (1978), no unstable slopes were identified which would affect the site safety.

Minor slides and mudflows occur in the glacial outwash deposits south of the Skagit site. These slides have moved south, away from the plant site, therefore, the instability does not threaten the safety of the site structures (Skagit PSAR).

Potential Mineral Resources in the Site Area

There is no known potential for the extraction of oil or gas from the rocks in the vicinity of the Skagit site. The coal deposits in the site area are of low grade and occur in thin seams within the steeply dipping host rock. Combustion tests show a high proportion of ash, therefore, there is a very low potential for commercial extraction (Skagit PSAR).

GEOLOGY OF THE GOSHEN SITE AREA

The Goshen site is located within the Nooksack Lowland section of the Whatcom Lowland physiographic province. The geologic units exposed in the site area are late Quaternary glacial drift and outwash deposits overlying the Eocene Huntingdon Formation. Continental sandstones and shales with occasional coal beds are the rock types found in the Huntingdon Formation.

A recently published USGS map (Easterbrook, 1973) shows three Quaternary units exposed in the site area. The youngest unit consists of peat and organic silts which have formed in the former channels of the Sumas meltwater outwash from the last glacial advance. A radiocarbon date from a peat sample at Lake Fazon near the site gave an age of 9,300 ± 250 years before present. A second mapped unit in the site area is the Sumas outwash sands and gravels. These well sorted glaciofluvial deposits have been estimated to possibly exceed 50 feet. The oldest Quaternary unit exposed in the site area is the Bellingham drift of the Everson Interstade. This unit has been described by Easterbrook as a blue-gray, unsorted, unstratified pebbly sand, silt and pebbly clay which was derived from rock debris melted out of floating ice and deposited on the sea floor. He states that the unit locally contains marine mollusks and wood which have been dated between 11,000 and 12,000 years before present. The unit has an estimated maximum thickness of 20 feet. Following the maximum advance of the Sumas glacier, large volumes of meltwater eroded the Bellingham drift deposits in the site area.

As a result Bellingham drift deposits form a terrace approximately 100 feet above the outwash channels and peat bogs.

Several small exposures of the Huntingdon Formation crop out near the site and underlie the area around the site. This formation has been mistaken for the Chuckanut Formation because of it similar lithology however, it has been shown to be of Middle to Late Eocene age and to be only mildly deformed (Miller, 1963). The Goshen site is on the axis of an arcuate, northeasterly trending anticline (Vonheeder, 1977, Jenkins, 1923). Bedding to the west of the site dips 3° to 10° to the west and to the east of the site dips at about 5° southeast (Bechtel, 1973). The Huntingdon unit is over 1,100 feet thick, in the Jennie Russler No. 1 exploratory oil well, which was drilled within a mile of the Goshen site. On the basis of spore and pollen determinations the Huntingdon was identified at a depth of 1,160 ft. and Chuckanut Formation at 2,600 ft. (Vonheeder, 1975). The units are separated by an angular unconformity. The Chuckanut Formation is not exposed in the site area but it extends to a depth of over 4,000 feet in the Russler well. The formation consists of Upper Cretaceous to Eocene sandstone, conglomerate, shale, and bituminous to sub-bituminous coal. The Chuckanut was strongly folded and eroded prior to deposition of the younger Huntingdon Formation (Miller and Misch, 1963).

Faults

There are no known capable faults within 15 miles of the Goshen site. The Boulder Creek fault is the only known fault within 5 miles of the

site. This fault is overlain by undisturbed sediments of the Huntingdon Formation, thus, last movement is dated at a minimum age of 40 million years before present (Miller and Misch, 1963). Further south it cuts, and therefore antedates, the northeastward trending Smith Creek fault.

Offshore geophysical data in the Straits of Georgia have shown a structure at the south edge of the Bellingham Basin (Skagit PSAR). This structure is last mapped as a fault 17 miles west of the site. Eastward the structure is a sharp flexure with possible faulting. No bedrock faults have been mapped in the Goshen site vicinity which could to be the extension of this structure.

Several northeasterly trending faults have been mapped between Vedder Mountain and the Boulder Creek fault. These include both normal and thrusts faults within the Chilliwack Group. They have not been shown to disturb the overlying Huntingdon Formation. Exposures of Cretaceous thrusts faults also occur within 15 miles to the east of the site.

Several short faults have been mapped by Miller and Misch (1963) within the Chuckanut Formation on Chuckanut Mountain, Lookout Mountain and east of Lake Whatcom. These structures have small displacements and are related to folding which occurred in the Eocene (Miller and Misch, 1963).

There are no known capable faults within 15 miles of the Goshen site. The extent of the fault in the Straits of Georgia which forms the south edge of the Bellingham Basin would need further investigation. Recent studies of Quaternary tectonic deformation in Whatcom and Skagit Counties (Palmer, 1978) conclude, "Where tentative correlations have been made, no evidence of differential relative vertical movement has been observed in the course of this investigation".

Historical Seismicity

The maximum historical intensity experienced near the Goshen site in historical times is Intensity VI. This intensity was experienced from the 1949 Olympia, 1965 Seattle, and the 1872 Chelan-Wenatchee earthquakes as well as the 1909 and 1920 Intensity VII earthquakes. Newspaper accounts of both the 1909 and 1920 earthquakes indicate that they caused an Intensity VI in Bellingham. The town of Everson, 5 miles from the site, experienced an Intensity V in 1909. In the 1920 earthquake an Intensity V was felt at Lynden, 7 miles from the site. Based on this intensity data, the epicenters of both events are believed to have been located in the San Juan Islands or the Straits of Georgia. Earthquakes have not been associated with any know surface faulting within 15 miles of the Goshen site.

Lineations and Geophysical Anomalies

Geophysical Anomalies

Bouguer gravity maps and recent aeromagnetic maps were reviewed for geophysical anomalies occurring near the site. The gravity data

indicates a weak east-northeast trending anomaly of limited length coinciding with the density contrast between the granitic rocks north of the Frazer River and the metamorphic rocks to the south. This anomaly does not continue westward toward the site.

The aeromagnetic data does not indicate any anomalies of significance to the Goshen site. East of the site, in the Sumas Mountain area, several strong magnetic highs are indicated. These highs coincide with Cretaceous thrust structures which have emplaced serpentinites at or near the ground surface. These serpentinites have been mapped by Moen (1962). The anomalies are small, ellipsoid shaped contour patterns rather than linear anomalies.

Imagery Lineations

Studies of ERTS and other imagery have been made of the area surrouding the Goshen site (Skagit PSAR and Amuedo and Ivey, 1975). The few lineations within the Whatcom basin reflect cultural features. Lineations were found to the north and east of the site in bedrock areas. The Ivey report (1975) identifies several northwest trending lineations in the Sumas Mountains area east of the site. One of these coincides with a mapped fault, the Smith Creek fault. This fault is dated as being pre-Boulder Creek faulting, which has a minimum age of 40 million years. The southeast trending lineation along the Nooksack River is described as being the result of logging patterns. Other lineations result from glacial processes, bedding or jointing. None of the lineations has a pattern of earthquake epicenters along it.

Volcanic Hazards

The closest source of potential volcanic hazard to the Goshen site is from Mt. Baker which is 26 miles to the east-southeast. Volcanic events that could affect the site include lava flows, pyroclastic flows, mud flows and ashfall. The hazard from lava flows and pyroclastic flows is extremely low due to the distance from the volcano. The risk of mud-flows along the Nooksack River is considered to be low, therefore they are of even lower risk to the site, which is not within the river's flood plain. The wind direction is predominantly to the east in this area; the wind blows in a direction from the volcano to the site only about 1% of the time. Therefore, the potential for a tephra eruption from Mt. Baker affecting the site is very low (Hyde, 1975).

Foundation Conditions

An estimated 10 to 50 feet of glacial deposits overlie bedrock of the Goshen site. The bedrock consists of sandstone, conglomerate, shale, and some coal beds of the Huntingdon Formation (Bechtel, 1973). This formation generally provides good foundation stability and is not subject to liquifaction. The depth of excavation required in the site area is estimated to be from 10 to 50 feet in order to found the plant structures on rock; however, one mile south of the site, top of rock is over 200 ft. below ground surface.

There are no known materials with unrelieved in situ stresses and no soluble minerals in the site foundation materials. The ground water

table is estimated to be at a shallow depth. The Huntingdon Formation is described as having very low permeability. The overlying glacial drift and outwash deposit permeabilities may vary over a wide range. Outwash deposits have high permeabilities as compared to Bellingham glacial drift which has a low permeability (Easterbrook, 1976).

Coal beds are known to occur at depths between 50 and 1200 feet in drill holes surrounding the site and a shallow mining operation, which terminated in 1951, located 1 mile east of the site. No subsidence hazard currently exists from coal mining activities.

Slope Stability

The Goshen site has low topographic relief with the exception of banks along Tenmile Creek in the southwestern corner of the site. The soils near the site area have been classified by Easterbrook (1976) as "stable under most natural conditions, for slopes less than 15 percent". The steep slopes along Tenmile Creek Valley are classified by Easterbrook as being marginally stable. This area does not pose a threat to the remainder of the site.

The foundation material at the site is expected to be well indurated sandstones of the Huntingdon Formation which should provide stable excavation cuts. Depth and thickness of coal beds would have to be determined to assess their significance to the site.

Potential Mineral Resources in the Site Area

The petroleum exploration which has been conducted in the site area has been unsuccessful and no wells have gone into production.

Coal appears to be the only potential resource within the site area. The Goshen coal mine, one mile east of the site produced a small amount of coal from a near surface bed. Exploration holes located four miles to the southwest encountered up to seven coal beds at depths between 470 and 1200 feet (Bechtel, 1973). Based on the lack of coal mining activity, the minor amounts of coal and depths of it's occurrence, the potential loss of a mineral resource in the area is minor.

GEOLOGY OF THE CHERRY POINT SITE AREA

The Cherry Point site is located along the Strait of Georgia coast on the Mountain View Upland. This area is within the Whatcom Lowland basin and surface topography is characterized by dissected late Quaternary glacial deposits which form low upland terraces and broad flat river valleys. (Molenaar, 1960, Bechtel, 1967)

Thick glacial deposits overlie sedimentary rock at the site. The glacial sequence is over 250 ft. thick where measured in a drill hole in the site area. The four exploratory auger drill holes penetrated glacial clays, silts and sand and gravel materials, in a total of 637 linear feet of drilling (Bechtel, 1967). The youngest glacial deposit exposed in the site area is a terrace deposit of well-sorted, well-stratified sand and gravel from the Sumas stade. The majority of the site area is underlain by Bellingham drift, described by Easterbrook (1976) as blue-gray, unsorted, unstratified, pebbly, sandy silt and pebbly clay. These materials are derived from rock debris melted out of floating ice and deposited on the sea floor between 11,000 and 12,000 years before present, during the Everson Interstade. Stratigraphic units below the Bellingham drift, as exposed in the sea cliffs in the site area, are Klushan glaciomarine drift, the Vashon till, the Mountain View sand and gravel, and the Cherry Point silt.

A gentle anticlinal feature has been identified in the stratified silts of the Cherry Point unit. Exposures in sea cliffs 2 miles north of

Neptune Beach consist of stratified clay and silts dipping approximately 7 degrees southward. To the north of this locality the dips range from horizontal to 7 degrees northward. Undisturbed Vashon drift (minimum age approximately 12,000 years) overlies this fold (Gower, 1978).

The sedimentary bedrock encountered in the drill hole southeast of the site has been described as Chuckanut Formation by Molenaar (1960), however, it most likely is part of the Huntingdon Formation of middle to late Eocene age which unconformably overlies the Chuckanut sediments. Rock types in the two formations are very similar and were not originally recognized as belonging to separate units.

Faulting

There have been no capable faults mapped within 15 miles of the Cherry Point site. Recent studies of tectonic deformation (Palmer, 1977, 1978), offshore shallow reflection surveys (Skagit, PSAR) and detailed mapping of glacial deposits within 15 miles of the site have not found conclusive evidence of capable faulting. A broad anticlinal fold in stratified glacial sediments is exposed in the sea cliffs near the site. These sediments are believed to be 32,000 years in age and this folding may indicate minor tectonic deformation (Bechtel, 1967). The glacial sediments are overlain by undisturbed Vashon stade glacial till and drift.

In the Strait of Georgia, deep seismic reflection profiles by Mobil Oil have indicated a northwest to east-west trending, steep, monoclinal

fold and fault 3 miles north of Sucia Island (Skagit PSAR). This structure is on-line with the southern edge of the Bellingham Basin which has been mapped on land (Miller and Misch, 1966). This structure deforms Lower Miocene sediments; it is not clear if it deforms upper Miocene as well. It passes within 5 miles to the south of the site. To date, the structure, "has not been demonstrated to be noncapable", (NRC, 1978).

Southeast-dipping, late Mesozoic thrust faults have been mapped on the San Juan Islands to the southwest of the Cherry Point site. These faults are not considered to be significant to the site.

Historical seismicity

The maximum intensity experienced at the site in historic time appears to be Intensity VI. Both the 1909 and 1920 earthquakes (both listed as epicentral Intensity VII) produced Intensity VI in Bellingham and Blaine, based on a recent survey of newspaper articles. The epicenters are believed to be centered either in the San Juan Islands or the Straits of Georgia. The largest historical earthquakes in Puget Sound (1949, 1965) also caused intensities of VI in the Bellingham area.

Lineations and Geophysical Anomalies

Geophysical

No anomalies are observed on the gravity map within 15 miles of the Cherry Point Site. A weak northeasterly linear pattern is observed

between the granitic rocks north of the Fraser River and the metamorphic rocks to the south. This anomaly does not extend into the site region.

Aeromagnetic surveys by the USGS (1978) in the area do not indicate any strong linear gradients within a 15 mile radius of the site. A high intensity oval anomaly is centered over the north end of Lummi Island, 9 miles south of the site. Juassic-Cretaceous metavolcanic rocks have been mapped in the area but have not been conclusively associated with the anomaly. Several low magnitude, kidney shaped anomalies of unknown origin are found within five miles of the site.

Imagery Lineations

ERTS imagery of the area encompassing the Cherry Point site does not indicate any structures of significance. The lineations within the Whatcom lowland and the Fraser Delta area are related to cultural features (Amuedo, Ivey, 1975). The linear features north of the Fraser River and east of the site are interpreted as resulting from glacial processes and jointing. One lineation is the Smith Creek fault, dated as Early to Middle Eocene. The few lineations present in the San Juan Islands are not associated with mapped faults.

Volcanic Hazards

Mt. Baker is 43 miles to the east of the Cherry Point site and constitutes the nearest source of volcanic hazard. The types of hazardous material which could result from an eruption include lava flows, pyroclastic flows, mud flows and tephra. Due to the long distance from the volcano,

there is a very low hazard to the site from any type of ejecta; there are no documented ash falls extending this far from Mt. Baker. Wind direction from the volcano toward the site occurs only 1% of the time, based on weather measurements from Quilleute, Washington (Hyde, 1975).

The only known ash deposits found within 15 miles of the site are from the Mt. Mazama eruption which occurred 6600 year ago. These deposits, which have been found in peat bogs, are less than 6 inches thick. (Easterbrook, 1973).

Site Foundation Conditions

Plant structures would be founded on glacial deposits as the depth to bedrock is over 250 feet in the plant vicinity. Borings and exposures at the site have shown the glacial materials to consist of clays, silts, sands and gravels. These materials are compact but not indurated (Bechtel, 1967). The silts and sands would have to be evaluated for liquefaction potential during seismic shaking. The silts and clays are known to be unstable and subject to sliding when saturated (Easterbrook, 1976). Several of the borings at the site encountered peat, and sand and gravel with organic material from the surface to a depth of 23 feet. This may be a minimum depth for foundation excavation. There are no known in situ stresses, soluble materials, or former areas of mineral extraction which could cause subsidence.

Ground water conditions at the site are not well known. The highly impermeable silts and clays in the area would impede migration of

radionuclides in the event of an accidental spill. Some of the materials underlying the site are permeable sands and gravels through which rapid migration would be expected.

Slope Stability

The site area has generally low relief. Steep slopes occur only along the sea cliffs and several small streams in the area. These areas are designated as marginally stable due to the unconsolidated clayey materials (Easterbrook, 1976) but are not located such as to present stability hazards to primary plant structures.

Potential Mineral Resources in the site area

There are no known mineral resources in the area at present. Coal mining is apparently infeasible due to the depth of potential coal bearing strata. Oil and gas exploration has been conducted in the area over a period of years, however, there has been no production except for minor amounts of gas used for domestic purposes.

RYDERWOOD SITE

Location

The Ryderwood site is located in southwestern Lewis County on Cougar Flat along Washington Highway 506 between Ryderwood and Vadar (Figure 1). The site is approximately 90 miles southwest of Seattle.

REGIONAL PHYSIOGRAPHY AND TECTONIC PROVINCES

Physiography

The Ryderwoc. site is within the Pacific Border physiographic province which lies east of the Continental Margin province and west of the Cascade Range province. The Pacific Border province is subdivided into six sections, three of which, the Vancouver Ranges, the Olympic Mountains and the Oregon Coast Ranges, are mountainous. The remaining three, the Chehalis Lowlands, the Puget Lowlands and the Willamette Valley are lowland regions. In general, the mountainous sections range from 2000 ft. to 8000 ft. in elevation and form a discontinuous chain along the Pacific Coast. The Puget Lowland and Willamette Valley sections for a discontinuous trough to the east of, and roughly parallel to, the mountain ranges.

The Chehalis Lowlands lie between the Puget Lowlands and the Pacific Ocean and separate the Olympic Mountains to the north from the Oregon Coast Ranges to the south. According to Henrikson (1956), the area of the Ryderwood site is within the Willapa Hills area of the Oregon Coast Range physiographic section.

The Oregon Coast Range varies in elevation from 0' to 4000 ft. and average 2000 ft. The Range extends for 250 miles along the Pacific Coast in a belt 50 miles wide. The present topography resulted from uplift and subsequent disection of an old erosion surface. The Ryderwood site is situated on the east side of the Oregon Coast Range physiographic section (WPPSS-Satsop PSAR).

Tectonic Provinces

The Ryderwood site is within the eastern edge of the Willapa Hills subprovince of the Coast Range tectonic province as delineated by King (1969). The Willapa Hills subprovince is characterized by periodic basement uplifts which have exposed basalts of the Cresent (Metchosin) Formation. Northwest and northeast trending fault patterns have been recognized cutting these basalts and overlying sedimentary rocks. Sedimentary units tend to thicken away from the basement uplifts, indicating recurrent movement throughout the Tertiary until the mid-Miocene. The basaltic basement complexes exhibit the highest degree of faulting, with younger rocks having progressively lesser amounts. Fold axis are orierted northwest and are parallel to the reverse faulting, indicating northeast crustal compression and shortening.

Tectonism in the Pliocene and Pleistocene, consisting of moderate uplift and minor faulting, is indicated by elevated marine and river terraces. This uplift was apparently uniform and without significant arching or tilting during the later Pleistocene (WPPSS-Satsop PSAR).

Several miles east of the site is the Cowlitz-Willamette subprovince of the Puget-Willamette Trough tectonic province. (WPPSS-Satsop PSAR). This subprovince consists of alluvial basins and low rolling hills, underlain by faulted Eocene through Pliocene rocks. Faults are commonly northwest trending, high angle, and of a reverse nature. Tectonism occurred during mid-Miocene to late Pliocene.

REGIONAL GEOLOGY

The oldest rocks exposed in the area are extrusive volcanics and interbedded marine sediments of Tertiary age. These rocks were deposited in a eugeosynclinal basin environment which extended from Vancouver Island southward to the Klamath Mountains and eastward beneath the present Cascade Range.

A thick sequence of Eocene volcanics underlie the Coast Ranges. These volcanics include Umpqua, Siletz River, and Tillamook volcanics in Oregon, and the Cresent and Metchosin volcanics in western Washington. They interfinger with fossiliferous, tuffaceous siltstones, sandstones, wackes, and conglomerates. Deposition continued in the basin through the Oligocene, Miocene, and into the Pliocene, alternating in varying proportions between volcanics, marine, and nonmarine sediments. Periodic uplifts served to restrict the area of marine sedimentation in favor of nonmarine deposition. The Olympic Mountains and Coast Ranges probably attained their present elevations during the Late Pliocene (Snavely and Wagner, 1963).

Quaternary deposits, consisting primarily of glaciofluvial gravels and sand, are common on valley floors and terraces; they mantle some of the foothill areas. Deposits of till occur locally within the Pleistocene Logan Hill Formation, a unit composed primarily of outwash sand and gravel, exposed to the north and east of the site. Outwash

from the Vashon glaciation occurs to the north of the site area while material from the Alpine drift (Roberts, 1958) occurs to the east. Recent materials consist predominantly of alluvial deposits of clay, sand, silt, and minor amounts of gravel; they are generally confined to valley bottoms and streams.

GEOLOGY OF THE RYDERWOOD SITE AREA

Stratigraphy

The lowermost unit exposed in the vicinity of the Ryderwood site is the lower (?) and middle Eocene Metchosin volcanic series. It consists of basaltic lavas (primarily submarine), volcanic breccias, and pyroclastic rocks together with tuffaceous shallow marine sedimentary interbeds. The Eocene volcanics in the Coast Ranges are estimated to be over 10,000 feet thick in many localities. Conformable deposition of the Cowlitz Formation began in late Eocene. This formation has been divided by Henriksen (1956) into four members. They are the Stillwater Creek member, the Pe Ell volcanics member, the Olequa Creek member, and the Goble volcanics member. The members interfinger and locally grade into one another, representing different lithologic facies of the Cowlitz Formation.

The Stillwater Creek member, which forms the uppermost bedrock at the Ryderwood Site, is composed of at least 5,400 ft. of predominantly marine siltstones, sandstone, and shales. The sediments are often tuffaceous, micaceous, carbonaceous, limy or clayey, and contain abundant foraminifera. Feldspathic sandstones, sandy siltstones, and locally cross-bedded arkoses are encountered, indicating deposition in a marine or brackish water environment. Thin basalt flows, sills, and dikes occur near the base of the member.

The lower part of the Stillwater Creek member is intercalated on the west with the Pe Ell volcanics member, which consists of 1,200-1,500 feet of "massive to thickly bedded, water-laid basaltic lapilli tuff with subordinate basaltic agglomerate and breccia, and thin, hard tuffaceous siltstone interbeds" (Henriksen, 1956).

The Stillwater Creek member grades upward into the Olequa Creek member, representing a change from predominantly marine deposition to brackish-water, shallow marine and nonmarine deposition. The Olequa Creek includes arkoses, feldspathic sandstones, siltstones with intercalated coal beds, and fossiliferous siltstones and mudstones. Thickness of this unit is between 4,000 and 5,000 feet.

The Goble volcanic member is a series of basalt flows, flow breccias, and minor pyroclastics interbedded with tuffaceous sediments. The unit is probably less than 1,000 ft. thick and is overlain and underlain by sediments of the Olequa Creek member.

Northeast of the site area the Cowlitz Formation is unconformably overlain by the late Eocene and Oligocene Lincoln Creek Formation which consists of over 1,500 feet of light gray, partly tuffaceous, fine-grained sandstones, and sandy siltstones. This unit is unconformably overlain by the Miocene Astoria Formation, consisting of approximately 2,000 feet of interbedded basalt flows and thickly bedded to cross-bedded, predominately marine sandstones. These units are locally intruded by

basalt and diabase dikes, sills, and other irregularly shaped intrusives. Pliocene age rocks do not occur near the site area. Pleistocene glaciation apparently caused no direct effects in the vicinity of the site. Erosion and alluviation are the processes responsible for the present topography.

Structure

Structural development reflected in the rocks exposed in the vicinity of the site began in late Eocene with the first of three Tertiary tectonic events. Gentle folding and uplift restricted the area of marine deposition and erosion, and resulted in the unconformable relationship of the overlying Oligocene strata. A similar event during the late Miocene caused complete withdrawal of the seas and development of the major features of the present structural framework. "The Willapa Hills anticline, the North River-Dryad syncline and the other broad northwestward-trending folds reached most of their present structural relief....Most of the faulting in the lower Cowlitz River-eastern Willapa Hills area occurred at this time" (Henriksen, 1956).

The third Tertiary deformation took place at the end of the Pliocene completing structural development of the area in the form of renewed uplift and folding of pre-existing structures.

The major structural feature in the vicinity of the site is the Willapa Hills Anticline. It is a large bifurcated anticline which trends S35°-60°E and plunges southeastward. It bifurcates southwest of Pe Ell, with the northern branch trending S70°E and dying out a short distance

southeast, its closest approach would be about 5 miles from the site. A small branch fault, trending north-south is also indicated by Henriksen; the southernmost limit of this fault, now indicated as 8 miles north of the site, should be verified.

Other fault locations mapped by Henriksen (1956) were examined in the field where access permitted. Those examined were found to be minor features with small offsets and could not be traced over any distance. They are individually described in the 1973, Bechtel report of "Geological Reconnaissance for Six Potential Power Plant Site in Western Washington".

Henriksen (1956), Roberts (1958), and Armentrout (1973, 1977) all map and describe faults approximately 2-1/2 miles southwest of Toledo, 8 miles northeast of the site. These faults are reported to displace coal beds in the Leavell and Huntington-Ely mines. These are high angle, both normal and reverse faults, trending northwestward. Displacement is said to be probably less than 200 feet.

Henriksen (1956) further describes his mapped faults as follows:

> A well-exposed fault crosses the channel of the South Fork of the Chehalis River 1-1/2 miles southeast of Wildwood. It cuts well-bedded marine siltstones of the Stillwater Creek member and trends N70°W, transverse to the strike of the beds. The plane of the fault is indicated by a layer of light-gray pyritized limy gouge 3 inches in thickness; it dips 45° in a northeasterly direction. There is a marked difference in the attitudes of the strata on opposite sides of the fault, which is apparently a reverse fault along which part of the movement was rotational. The total displacement is not large. Alluvium and soil cover the Eocene rocks on both sides of the river; hence the continuation of the fault beyond the banks of the river is not exposed.

Faulting accounts for the presence of a narrow wedge of marine mudstones and siltstones in the upper part of the Pe Ell volcanics member along the Chehalis River and Sand Creek in Pe Ell. The marine sediments constitute a small block which has been faulted into the pyroclastic rock unit. The anomalous southeasterly dip of the sedimentary strata is also thought to be due to faulting. The faults which bound the wedge of sediments were not observed in the field because of the lack of exposures.

In the northeast corner of the area the Cowlitz formation and the lower Oligocene Gries Ranch beds are separated by a well-exposed fault in the southeast bank of the Cowlitz River at the abrupt bend 2-1/2 miles southwest of Toledo. The fault trends N40°W and dips southwestward at an angle of 80°. It is a reverse fault, along which the total displacement is not large. The highly fossiliferous Oligocene conglomerates and grits on the upstream side of the fault dip northwestward at a low angle. The well-bedded Eocene sandstones downstream from the fault dip southwestward at angles ranging from 5° to 10°.

Other minor faults were mapped along Stillman Creek, Stillwater Creek, Olequa Creek, and the Cowlitz River; then cannot be traced beyond their exposures in the stream valleys. Movement along these faults apparently was slight. Small faults in this area are generally marked by an abrupt steepening of dip in the beds adjacent to the faults.

Henriksen (1956) indicates that most of the faulting in the lower Cowlitz River-eastern Willapa Hills area occurred during the second Tertiary tectonism which took place in late Miocene time. Weigle and Foxworthy (1962) state that folding and local faulting also occurred during the late Pliocene and "minor folding and faulting may have continued into the Pleistocene epoch, but no definite evidence of such deformation was found...." They further state "... the slight angular unconformity seen at a few exposures of the contact between the Logan Hill formation and the underlying nonmarine sedimentary rocks suggests that most of the deformation, at least, has occurred before the deposition of the (early Pleistocene) Logan Hill formation."

None of the mapped faults within 15 miles of the Ryderwood site is believed to be active.

Historical Seismicity

The 1949 magnitude 7.1 Olympia earthquake about 50 miles from the site caused the highest intensity the Ryderwood site area has experienced in historic time; it is not clear whether that Intensity was VII or VIII. The town of Vader, 5 miles east of Ryderwood, experienced intensity VIII from this shock, but Winlock experienced Intensity VII and it is closer to the epicenter than is Vader. It is quite likely that Ryderwood was in the Intensity VII zone, close to the border of Intensity VIII.

The closest historical earthquake to the site occurred in 1895 about 15 miles to the east-northeast; its intensity was V. The site is quite favorably located in regard to distance from historical earthquakes, but the relatively strong historical intensity which has occurred near the site must be considered in the selection of the SSE for the site.

Capable Structures

According to the WPPSS PSAR for the Satsop site there are no capable faults within the Willapa Hills tectonic subprovince or the Cowlitz-Willamette tectonic subprovince. Thus, according to that report, there are no capable faults within at least 15 miles of the Ryderwood site.

south of Vader. The south branch trends S45°-60°E and "appears to continue to the vicinity of Mount St. Helens in eastern Cowlitz County" (Weaver, 1937B). The northern branch of this anticline is mapped by Henriksen (1956) as passing directly through the Ryderwood site, dying out to the east. Mapped dips in this area generally do not indicate the presence of this structure. North of this structure is the south limb of the North River-Dryad syncline (Henriksen, 1956) which is apparently equivalent to Robert's (1958) Napavine syncline. Eocene beds of the Cowlitz Formation typically dip northeastward between 10° and 20° on this limb of the syncline. Numerous small folds are superimposed on these major structures but cannot be traced for any distance.

Faulting has played a minor role in the structural development of the area. Mapped faults generally show small displacement and cannot be traced over significant distances. They have little or no relation to major structural features.

The largest mapped fault zone in the area is the post-Oligocene Crego Hill fault zone, northwest of Winlock. It is described by Henriksen (1956) as a series of small, en echelon faults, with a total displacement of probably less than 100 feet. This zone was examined in the field, and shear surfaces with slickensides were observed, but actual displacements could not be determined. Henricksen's report does not give amount of displacement, but only refers to "small parallel or en echelon faults, along each of which there has been some displacement." The Crego Hill fault zone trends generally northwest southeast. Its closest approach to the Ryderwood site is approximately 8 miles; if it extends to the

The 1949 Olympia earthquake has been related to the Olympia lineament in the WPPSS-Satsop PSAR. The SSE for the Satsop site is based on the assumption that this lineament is capable of generating a large earthquake. At present, this lineament is the closest assumed capable structure to the Ryderwood site (approximately 40 miles).

Also to be considered is the activity associated with the subducted Juan de Fuca plate. The four largest earthquakes in the Puget Sound region have been linked to readjustment within this fossil subduction zone (USGS Open-File Report 75-375, 1975). However these earthquakes were all more than 50 miles northeast of the Ryderwood site.

Lineations and Geophysical Anomalies

Geophysical Anomalies

A Bouguer gravity map by Stuart (1965) indicates a strong gravity lineation in the vicinity of the Ryderwood site. It trends north-northwest extends for approximately 35 miles. This lineation is apparently produced by the gravity difference between the volcanics in the Cresent Formation (Metchosin Formation equivalent) and adjacent sedimentary rocks. The nature of the contact is, at present, not known. Its closest approach to the site could be less than a mile.

Although no magnetic data is available for the Ryderwood area, there is data available for the areas immediately to the north. The gravity lineation described in the previous section extends partly into this area

of magnetic coverage. There is a distinct change in the magnetic character of the rocks from one side of the gravity lineament to the other. On the northeast side, the magnetic map exhibits a low relief, even gradient, while on the southwest in the volcanic rocks, the gradients are steep and highly irregular. (Henderson, 1958)

Imagery Lineations

The ERTS imagery used for the WPPSS PSAR study of the Satsop site has cloud cover in the immediate Ryderwood site area. However, that PSAR shows a group of lineations 5 to 10 miles in length, trending west-northwest approximately 8 to 10 miles northwest of the Ryderwood site. Approximately 20 miles south-southwest of the site, a 12 mile long, northwest-trending lineament is indicated. None of these lineaments are shown to be coincident with known faulting.

Several tentative lineations in the Ryderwood area were noted on ERTS imagery which did not have cloud cover. One such faint lineation passes close to the Ryderwood site, trending northwest and corresponding in approximate location to the gravity lineament previously indicated.

Other tentative lineations which have been noted include a 30-mile-long lineation trending east-northeast, the center of which passes approximately 5 miles south of the site. A 25-mile-long lineament, with its southwest end 20 miles east of the site, trends northeast and extends through Davisson Lake (Riffe Lake), east of the Mossyrock Dam. Several other

very faint traces have been noted, however, they are so indistinct they would require better photography to evaluate.

SLAR imagery evaluated for the Satsop PSAR indicates a north-northwest trending, 20-mile-long, discontinuous lineation approximately 10 miles east of the site. The southwest end of a northeast trending, 15 mile long lineament is located 15 miles northwest of the site. Finally, a northwest trending, 8 to 10-mile-long lineament occurs approximately 12 miles southwest of the site. The cause and signficance of these lineaments has not been determined.

The coinciding gravity, magnetic, and ERTS lineations trending north-northwest through the Ryderwood site area appear to be potentially the most significant. They are slightly southwest of, and parallel to, the Crego Hill Fault zone. These and the other lineations noted would have to be studied further in order to determine if they are significant to the Ryderwood Site.

Volcanic Hazards

Mount St. Helens is the nearest (40 miles) and potentially most hazardous volcano to the Ryderwood Site, however, hazard from it is considered to be minimal. According to Crandell and Mullineaux (1976) a debris flow approximately 2,000 years ago extended down the North and South Forks of the Toutle River, entered the Cowlitz River, and flowed to the Castle Rock area. They use this as the maximum probable extent to which the

area could be affected by mudflows and floods. Since the Ryderwood site is well upstream and 5 miles west of the Cowlitz River, it would not be directly affected by such an event.

Crandell (1973) shows a low risk area along the upper Cowlitz River extending to the upper end of Riffe (Davisson) Lake as a result of debris flows from Mt. Rainer. Due to Mossyrock Dam and Mayfield Dam, turbid water conditions from such a flow should be minimal.

Crandell and Mullineaux (1976) indicate that wind directions at Mount St. Helens are in the northeast and southeast quadrants 80% of the time. They further indicate that winds blow from Mount St. Helens toward the Ryderwood site only 1% of the time. They indicate essentially no hazard from tephra deposits in the Ryderwood area. Mount Rainer exhibits a similar low hazard level with regard to the Ryderwood area.

Foundation Conditions

The site area is underlain by sedimentary rocks of the Stillwater Creek member of the Cowlitz Formation of Upper Eocene age (Henriksen, 1956). The rocks of this member consist primarily of soft, poorly cemented siltstone, and silty fine-grained sandstone, with some soft shale. Based on numerous outcrops observed along Brim, Owens, and Stillwater Creeks in the site vicinity, rock is expected to be within 10 to 20 feet of ground surface. South and east of Ryderwood, siltstone and poorly cemented sandstone are exposed at several locations along Campbell

Creek and in the hillside adjacent to Cougar Flat. Rock is weakly cemented at this site but foundation conditions are expected to be very uniform. The rock is dense enough and sufficiently cemented that liquefaction should not be a problem.

Ground Water

Information was obtained on three wells in the site vicinity. Two are apparently in overburden and extend to depths of approximately 12 feet. One of these is listed as having hard water of unspecified quantity; conditions of the other are not noted. The third well is 80 feet deep and produced soft water but was pumped dry.

Slope Stability

Landsliding is quite common in Cowlitz and Lewis Counties. The Ryderwood site is located in a flat area not subject to sliding but there are slopes east and west of the site. The slopes to the east are not steep but they would have to be evaluated for landslide potential. Slopes to the west are farther from the site than those to the east.

Stability of cut slopes would depend upon the amount of cementation of the rock at that particular location. Since the rock at the site has been classified as poorly cemented it would seem that cut slope angles should be low or otherwise laterally supported. Overburden areas would also require low angle cuts or support.

Mineral Resources

Mineral resources of interest in this area include coal, oil and natural gas. Coal is said to be absent from the Stillwater Creek member of the Cowlitz Formation. Oil and gas exploration in this area has been limited; however, the region is considered to have oil and gas potential and future exploration cannot be ruled out.

Comparisons Between Sites

The following summary gives a relative comparison of the sites, based on presently available information for each of the factors identified below. Ratings are given from most to least suitable. It should be recognized that some of the relative rankings between sites would likely be revised after detailed studies of a site and the region around it. Also, each of the factors considered is not equal in importance to each of the other factors.

Sites were ranked for each of the following factors:

- Historical Seismicity
- Distance from faults which may be capable
- Foundation Conditions
  - Competence of foundation materials
  - Liquefaction potential
  - Subsidence potential
- Slope Stability
- Ground Water Conditions
- Volcanic Hazards
- Possible Mineral Resources

Historical Seismicity

The Skagit, Goshen and Cherry Point site areas have experienced a maximum historical intensity of VI. The Ryderwood site apparently experienced an Intensity of at least VII and possibly VIII as a result of the 1949

Olympia earthquake. The Ryderwood site is given a lower rating than the other sites because of the higher historical intensity felt near it and its closer proximity to the largest historical earthquakes in Puget Sound. Cherry Point and Goshen are rated lower than Skagit because they are closer to the Intensity VII earthquake of 1909.

Relative ratings are Skagit, Goshen, Cherry Point and Ryderwood.

Distance from faults which may be Capable

There are no structures known or assumed to be capable within 15 miles of the Ryderwood site; the coincidence of lineations within about 5 miles of the site must be studied. The subducting or subducted slab under Puget Sound dips eastward, consequently the Ryderwood site is closest to the top of this slab, followed by Cherry Point, Goshen and the Skagit site. The Cherry Point site is within 5 miles of the fault and fold which form the southern boundary of the Bellingham Basin. The Goshen site is approximately 17 miles from the eastern end of this fault. That structure would have to be investigated to determine if it may be capable and if it may be significant to Cherry Point and Goshen. The Devils Mountain fault zone, which has been assumed to be capable, is within 13 miles of the Skagit site.

Relative ratings of the sites are Ryderwood, Skagit, Goshen and Cherry Point.

Foundation Conditions

The Skagit site has very good foundation conditions. The Goshen site is expected to be underlain by well cemented rock at a depth of 10 to 50 feet. The significance, if any, of the nearly horizontal coal beds under the Goshen site would have to be determined. At the Ryderwood site bedrock is estimated to be at a shallow depth probably less than 10 feet, but the rock is poorly cemented. The Cherry Point site has relatively poorer foundation conditions as structures would be founded on soils. Liquefaction potential would have to be investigated. There is no problem with liquefaction of foundation materials at Skagit or Goshen and probably not at Ryderwood.

Relative ratings are Skagit, Goshen, Ryderwood and Cherry Point.

Slope Stability

Relative ratings for the sites are Goshen, Skagit, Ryderwood, and Cherry Point. If the gentle slope east of and close to the Ryderwood site is stable (as is probably the case), it should be rated as high as the Skagit site. Cherry Point is given a relatively lower rating because of the deep soils and the steep slopes adjacent to Puget Sound.

Ground Water Conditions

The Cherry Point site would be expected to require considerable dewatering to handle ground water inflow to excavations. Skagit will require very

little dewatering, and Ryderwood is not expected to require much more because of the apparent low permeability of the foundation rock. If the Goshen site does not require a deep excavation to found structures on rock, dewatering should not be difficult.

Little information is available on the direction and velocity of movement of ground water at any of the sites except Skagit.

The relative ratings are Skagit (because conditions are known) Ryderwood, Goshen and Cherry Point.

Volcanic Hazards

Relative ratings for the sites are Cherry Point, then Ryderwood, with Skagit and Goshen judged to be about equal. Since volcanic hazards at Skagit have been determined to be minimal, this factor is of minor significance in making comparisons between sites.

Potential Development of Mineral Resources

Relative ratings of the sites are Cherry Point, Skagit, Goshen and Ryderwood. Ryderwood is given the lowest rating because it has some slight potential for oil and gas development. Goshen is given a relatively lower rating because of the coal which occurs near the site; however, it is considered to be unlikely that the coal will ever be mined.

OVERALL RANKINGS OF SITES

Based on the available data using the criteria discussed previously, the sites are ranked from most to least suitable, in terms of geologic and seismologic conditions, as:

1. Skagit
2. Ryderwood
3. Goshen
4. Cherry Point

The Cherry Point site is clearly the least desirable of the four sites. The difference in suitability of the Skagit and Ryderwood Sites is considered to be small.

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