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A GEOLOGIC FEASIBILITY STUDY FOR THE SUPERCONDUCTING SUPER COLLIDER

by

R. Lasmanis and T. Hall

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INTRODUCTION

Purpose of study

The objective of this report is to provide a brief geologic overview of each of the proposed sites for the Superconducting Super Collider (SSC) in the state of Washington. We investigated each of the areas in terms of topography, soil properties, and geology, and we performed literature search and review, reconnaissance studies, and map compilation.

Some accomplishments are:

(1) Identification of the Lewis County and Lincoln County sites as geologically most suitable for building the Superconducting Super Collider.

(2) Due to the presence of thick unconsolidated glacial materials and high water tables, the Pierce-Thurston County site is the least favorable for the SSC.

(3) High water tables and environmental concerns caused the Grant County site to be dropped from further consideration.

ACKNOWLEDGMENTS

The authors are indebted to many individuals and organizations who have aided in completion of this study. Washington State Department of Transportation and the Photos Maps and Reports section of the Washington State Department of Natural Resources were extremely helpful in the preparation of base maps.

This report was made possible through the assistance of Geology and Earth Resources Division staff geologists Josh Logan, Bill Phillips, Hank Schasse, and Tim Walsh. Cartographers Don Hiller, Keith Ikerd, and Nancy Herman prepared the figures and plates. Eric Schuster was responsible for the final editing.

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LEWIS COUNTY SITE

by R. Lasmanis

A twenty mile diameter ring for locating the Superconducting Super Collider was placed between Centralia and Chehalis to the north and Vader to the south, with Interstate 5 transecting the circle. The site is located entirely within Lewis County. See plate 1 for location of area.

The ring was located entirely in bedrock, to take advantage of topographic lows and to minimize depth of access shafts. There is moderate relief in the area with the low point of 50 feet (15 m) above sea level on the Cowlitz River near Vader, and the high point of 700 feet (213 m) above sea level four miles northwest of Vader.

The geology of the area is complex, consisting of faulted and folded Tertiary marine, non-marine, and volcanic rocks. Sedimentary rocks consist predominantly of siltstone, basaltic sandstone, arkosic sandstone, and conglomerate. Coal beds occur in the northern and southern portions. Volcanic rocks found in the area are generally basaltic with some intercalated units of volcanic tuff and pyroclastics. Intrusive gabbro is present in the northeast sector.

The ring is centered over a northwest-southeast trending depositional basin or a shallow plunging syncline that received sediments, volcanic debris, and occasional volcanic flows as a result of Cascade growth. Northwest-southeast and east-west trending faults displace the geologic units and folds.

The surface was modified during the last ice age by glaciation and deep weathering. Landslide deposits are common throughout the area. The valleys are filled with recent sediments.

Due to the topography, the ring would have to be emplaced at approximately 100 feet (30.5 m) below sea level. Geological evidence indicates that tunneling through sedimentary rocks would be relatively easy. However, due to faulting and local tight folding, ground support measures would be necessary at some locations. For cross sections, see plate 2.

Due to complex geology, a program of drilling would be needed to predict ground conditions along the ring right-of-way.

BEDROCK GEOLOGY

Because of topographic constraints, the entire ring would have to be constructed via tunnels at an approximate elevation of 100 feet (30.5 m) below sea level. This would result in the entire facility being located in bedrock.

Structural complexity created by faulting and folding causes the ring to intersect a series of Tertiary age (49 to 3 million years before present) formations. The geology is further complicated by the fact that the Lewis County site area was situated on the edge of the continent during Tertiary time, resulting in deposition of marine and non-marine sediments. This was in response to fluctuating sea levels and structural uplifts or downwarps. Further complications in the geology were introduced by a great variety of sediments being shed into the basin from the youthful Cascades, which continued to build during that time. This mountain building was accompanied by volcanism, resulting in basaltic lavas, pyroclastics, and tuffs being intercalated with sediments. Coal beds are found in several formations. They formed in swamps east of brackish estuarine environments.

As a result of various geologic processes at work during the Tertiary period, it is difficult to predict detailed stratigraphic and lithologic characteristics at any specific location. Fortunately, because of the economic significance of coal deposits and interest in oil and gas, there has been sufficient drilling and mapping in the area to develop a detailed stratigraphic column. For the purpose of this study, we have enough detail to allow a preliminary estimate of rock types that the ring would intersect at an average depth of 500 feet (152 m) below the surface.

The accompanying geologic map explanation (see plate 1) describes the formations one would encounter during the construction of the ring. The oldest rocks are located in the southwest quadrant. They were brought to the surface by the Willapa Hills structural uplift to the west.

McIntosh Formation

Twenty-five percent of the tunnel would be constructed in the McIntosh Formation. In the area of interest, the formation is 4,000 to 4,500 feet (1,219 to 1,372 m) thick. It has been divided into two members by Ray E. Wells (1981) as follows:

> Lower Member - massive to thin bedded and laminated very fine grained to coarse grained basaltic sandstone, arkosic sandstone, and laminated tuffaceous siltstone; interbedded in lower part with pillow basalt flows of the Crescent Formation.
>
> Upper Member - dark gray massive to laminated, thin bedded, tuffaceous siltstone, silty sandstone and arkosic sandstone; basalt cobble conglomerate and slump breccias occur locally. The base of the member is characterized by massive to thick bedded, plane laminated to cross bedded, friable, fine to medium grained arkosic sandstone. The upper 250 feet (76 m) of

> this member consists of massive arkosic sandstone which has been quarried for building stone at Tenino and may provide an excellent host for underground facilities.

Northcraft Formation

While upper member McIntosh sediments were being deposited in the western portion of the area of plate 1, andesitic and basaltic lavas of the Northcraft Formation entered the Centralia-Chehalis basin from the east where they were subsequently buried by sediments of the Skookumchuck (Cowlitz) Formation. Due to Northcraft Formation's depth in the eastern part of the basin, the ring does not penetrate any rocks of this unit.

Skookumchuck Formation

Approximately 20 percent of the ring will be cut through the Skookumchuck Formation in the north or through its southern equivalent, the Cowlitz Formation. The Skookumchuck Formation is 3,500 feet (1,066 m) thick and has been dated at 40 to 44 million years before present. It has great economic significance and contains substantial coal deposits. During 1984, the Washington Irrigation and Development Company (WIDCO) operation produced 3,863,000 tons of subbituminous coal from several open pits situated eight miles northwest of Centralia. In the southern part of the area, in the vicinity of Vader, a number of abandoned coal prospects and mines are documented in the literature. The Skookumchuck-Cowlitz Formation serves as the host of a large new lignite coal field being developed by Royal Land Co. -- a subsidiary of Old Ben Coal Co. -- whose parent is SOHIO. This new coal field lies within the ring on a line between Vader to the south and Curtis to the northwest. In the northern part of the ring, the following coal beds can be expected in the subsurface: Mendota, Upper Thompson, and the Tono No. 1. Mining experience and drilling indicate that the Skookumchuck Formation generally acts as an aquatard. However, due to the variability of the rock types, there is great diversity in porosity and permeability. Measurements on cores of sandstone gave porosity ranges of 5.3 to 35.2 percent and permeability from 1.42 to 3,506 millidarcies. In some of the underground mines ground water inflow was a problem. Extensive timbering was necessary in many of the mines. Lithologies to be expected in the Skookumchuck-Cowlitz Formation, as described by Snavely, and others (1958) are:

> Massive to thin bedded arkosic sandstone and siltstone containing interbedded carbonaceous material; coal beds near top and base of formation; locally rock is plane laminated or cross bedded and can be micaceous; very coarse grained basaltic, andesitic, and tuffaceous sandstones are also known. Locally the formation contains fossiliferous units of marine origin.

Hatchet Mountain Formation

The Hatchet Mountain Formation is confined to the southern part of the area east of Vader. About 10 percent of the ring would be in this formation. The formation is exposed due to the upturned western flank of the gently dipping Napavine Syncline or sedimentary basin. It consists of volcanic rocks and near-source sedimentary equivalents. It is up to 2,750 feet (838 m) thick. The unit lies directly on the Cowlitz Formation and laterally and vertically grades into the Lincoln Creek/Toutle Formation. The following lithologies can be expected in the Hatchet Mountain Formation as described by A. E. Roberts (1958):

> Massive to platy units of porphyritic basalt, calcic andesite, flow breccia, and porphyritic olivine basalt; tuff, tuff breccia, water laid tuff, basal conglomerates, pyroclastic flows and sandstone are also known from this formation; columnar joints are common in the more massive units.

Lincoln Creek Formation

Approximately 35 percent of the ring will be cut through the Lincoln Creek Formation in the north or through its southern equivalent, the Toutle Formation. The Lincoln Creek Formation is up to 2,000 feet (609 m) thick, and the Toutle is up to 1,200 feet (366 m) thick. The rocks have been dated at 40 to 25 million years before present. The Lincoln Creek (Toutle) Formation contains lignite coal beds in the southern part of the area indicating the position of the upper Eocene and Oligocene shore line. Toward the northwest, the formation becomes predominantly marine in origin. The Cedar Creek No. 1 coal seam in the southeast quadrant has had the most development. High alumina clay beds are known in the southeastern part of the area. Locally clay beds could cause difficult ground conditions for underground facilities. This potential adverse condition only exists in the southern portion and at shallow depths. See U.S.G.S. bulletins by Snavely and others as well as A. E. Roberts (1958) for details. The following rock types can be expected:

> Tuffaceous siltstone and very fine grained sandstone; massive to thick bedded, concretionary, bioturbated, with interbeds of glauconitic sandstone and tuff; units at the base of the formation are moderately well sorted and indurated, dark-gray, fossiliferous, arkosic and basaltic sandstone; two 40 foot (12 m maximum) thick clay beds separated by 100 feet (30.5 m) of tuffaceous siltstone are known from east of Toledo; aluminous laterite and ferruginous bauxite have been described from the weathering zone of the Toutle Formation.

Astoria Formation

The Astoria Formation lies on top of the Lincoln Creek Formation and will be cut by 5 percent of the ring. It has a maximum thickness of 700

feet (213 m) in the northwest quadrant and thins down to zero to the southeast. According to Snavely and others (1958) the formation contains the following rock types:

> Massive and cross bedded carbonaceous, arkosic sandstone with thin interbeds of siltstone; locally thick basaltic and andesitic conglomerate beds and pebbly sandstone; fossil wood and leaves are commonly present; a few fossiliferous marine beds are present.

Grande Ronde Basalt

The youngest bedrock formation to be encountered in the tunnel is the Grande Ronde Basalt of the Columbia River Basalt Group. It is confined to valley infillings and is especially prominent in the northwest quadrant two miles north of Curtis. It is estimated that 3 percent of the ring would be located in the Grande Ronde Basalt which consists of one or more flows of dark gray aphanitic, aphyric basalt with a well developed entablature. Upper flows show well developed colonnades with local pillow lavas at the base.

Intrusive igneous rocks

In the northeast sector there is a possibility of encountering intrusive gabbro porphyry and porphyritic basalt. It is estimated that 2 percent of the tunnel would cut such rocks. Without detailed drilling, it would be difficult to predict the occurrence of these rocks at depth.

SURFICIAL GEOLOGY

Extensive units of Quaternary (Pleistocene to Recent) unconsolidated clays, sands and gravels cover a large part of the area. It is only in the southwestern sector that outcrops of bedrock predominate. The surficial units were formed as a result of deep weathering, several periods of glaciation, extensive landsliding, and infilling of valleys with recent stream deposits. Individual units can be up to 300 feet (91 m) thick although 200 feet (61 m) is more common.

Surficial geology is important since a majority of the access shafts to the tunnels would have to be collared in unconsolidated materials. The Quaternary units yield moderate to large quantities of ground water that is utilized for farming and domestic use throughout the region.

For details of the surficial geology, one should consult the excellent paper by J.M. Weigle and B.C. Foxworthy (1962).

Logan Hill Formation

The oldest unconsolidated unit is the Logan Hill Formation. It is up to 250 feet (76 m) thick and forms a blanket over the uplands of the Centralia-Chehalis basin. It is absent at elevations above 400 feet (122 m) above sea level. The Logan Hill Formation consists of glaciofluvial deposits of poorly sorted gravel and sand with minor amounts of silt, clay, and till. The pebbles are decomposed and the upper 30 to 60 feet (9 to 18 m) of the formation is iron stained. Weathering extends to a depth of 20 to 50 feet (6 to 15 m). A bucket wheel excavator is used to strip the Logan Hill Formation at the WIDCO coal operation.

Terrace deposits

Terrace deposits are next in importance in the map area. A major unit, called the Lacamas Creek, extends from Vader to Onalaska. It is of glacial origin and consists of clay, indurated sand, and gravel. The upper portions are extensively weathered. Average thickness is 40 to 60 feet (12 to 18 m) but locally the Lacamas Creek may exceed 250 feet (76 m) in thickness. The Newaukum terrace unit exists along the trace of the South Fork of the Newaukum River from Onalaska to Centralia. Its thickness ranges from 10 to 50 feet (3 to 15 m). Pebbles and cobbles are less rounded and less weathered than in older, higher terraces. Along the Cowlitz River, the Layton Prairie unit (not differentiated on plate 1) consists of sand and gravel up to 100 feet (30.5 m) thick. The interstices are completely filled with rock flour.

Vashon Drift

Outwash sands and gravels from the Vashon glacial stage are present in the valley north of Centralia. They do not affect the construction of the facility but are mentioned here as a good source of construction materials.

Landslide debris

Landslides and other forms of mass wasting that have occurred in Holocene and possibly late Pleistocene time are found throughout the Lewis County site area, but are most common in locations underlain by fine-grained sedimentary rocks and along the principal stream courses. High seasonal rainfall combined with rapid runoff results in accelerated erosion of the generally poorly consolidated Tertiary and Quaternary rocks, frequently producing oversteepened and undercut slopes. Subsequent failures along these slopes by landsliding and soil creep modifies the topography and contributes large volumes of debris to the drainage systems. Landslides commonly cover the valley areas with debris and mask and distort the true structure of the bedrock. The landslide scarps vary in shape from elliptical or arcuate to irregular. Recent landslide areas are characterized by hummocky topography, irregular drainage systems, and ponds; in many places they are bordered on the upslope contact with bedrock by a distinct, and nearly continuous, break-away scarp. Landslides are

Landslide debris - continued

particuarly common along the axial parts of the Lincoln Creek uplift, where siltstone of the Skookumchuck Formation is the predominant rock type. In this area most of the valleys are filled with landslide debris and undisturbed rock is found only along the ridge tops and along those creeks that have cut below the landslide material. Access shafts should be positioned to avoid landslide hazards.

Alluvium

Alluvium, as flood plain deposits of gravel, sand, and silt, fills the valleys adjacent to major streams and rivers. Alluvium generally yields large amounts of ground water.

STRUCTURAL GEOLOGY

The area is dominated by regional structures that determine the distribution of bedrock units. These broad structures are modified by tightly folded anticlines and synclines that generally trend northwest-southeast. Further structural complexity is introduced by east-west and northwest-southeast trending faults that displace all bedrock units. The detailed structures have been documented by underground coal mine workings and extensive drilling programs for coal, oil, and gas.

The basin is dominated by the northwest-southeast trending Napavine Syncline. Dips on the limbs of the basin are so shallow that the structure may represent primary gradients associated with a depositional basin.

The regional Willapa Hills structural uplift to the west of the area has had a marked effect in bringing older rocks to the surface in the west and southwest portions of the area. Northwest-southeast trending faults, spaced every two to five miles cut through the area. Formations dip away from the uplift toward the northeast with 10° to 14° dips.

In the northwest quadrant the predominant regional structure is the east-west Lincoln Creek uplift characterized by the outcrop area of the Skookumchuck Formation. The Salzer Creek and Doty Faults roughly parallel the south side of the uplift, and the Scammon Creek Fault parallels the north limb. Two transverse faults have broken across the east plunging nose of the uplift. The eastern extension of the uplift is known as the Chehalis Anticline, whose axis would be cut by the superconducting super collider ring. The dip of the strata along faulted limbs of the uplift ranges from 20° to 70°. Small anticlinal flexures cut across the uplift.

The northeast sector is dominated by the axis of the Centralia Syncline. It is a broad, shallow downwarp that extends southeasterly to the Salzer Creek Fault. Along the northeast limb of the syncline there is an abrupt steepening of dips due to movement along the Kopiah Fault. Dips vary from 20° to 70° in a southwesterly direction on the northeast limb and 8° to 13° on the southwest limb of the Centralia Syncline.

Structural geology - continued

Quaternary cover and deep weathering have obscured details of structure in the southern and southwestern quadrants. However, due to interest in coal prospects, it is known that at Vader the Cowlitz Formation is folded into a tight northwest-southeast trending anticline with dips of 45° on both limbs. Faulting and a small syncline are mapped in a small area 3½ miles northeast of Vader.

The Jackson Prairie natural gas storage site is situated in sections 8 and 17, T. 12 N., R. 1 W. At a depth of 1,250 feet (381 m) below sea level an anticline in the subsurface is being utilized to store natural gas. The sandstone beds are part of the Skookumchuck Formation. A northeast-southwest trending fault transects the anticline. The gas facility is far enough from the eastern portion of the ring not to be affected by it.

SEISMICITY

Both the Pierce-Thurston and Lewis County sites are located within a seismic risk zone that is centered over the Puget Sound region. Earthquakes up to magnitude 7.5 on the Richter scale have been observed. Two of the most recent major earthquakes were a 7.1 in Olympia (1949) and a 6.5 between Seattle and Tacoma (1965). Seismic risk zones have been plotted based on geology and historical events for the Pacific Northwest. The results were published in U.S.G.S. Open-File Report 80-471. For details, see attached figure 1 by David M. Perkins and others, taken from the above-named report.

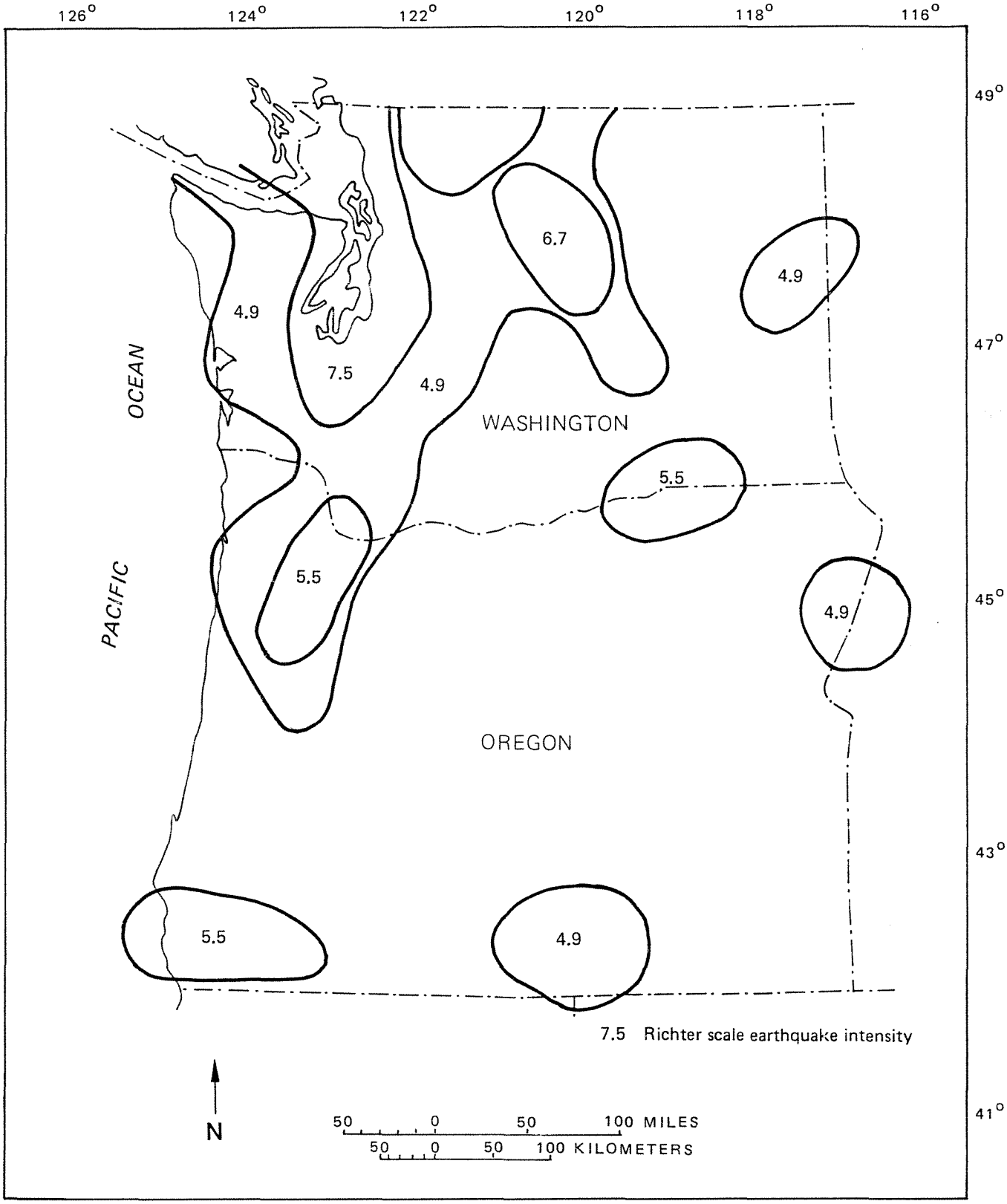


Figure 1. - Map showing a zoning scheme incorporating geological information and historic seismicity.

LINCOLN COUNTY SITE

by T. Hall

The Lincoln County site is located in the east-central part of Washington. The community of Wilbur lies six miles south of the rings' northern limit. The entire facility would be in bedrock.

TOPOGRAPHY AND SOILS

The Lincoln County site lies within the Channeled Scablands of eastern Washington. This area is dissected by a network of coulees, or eroded stream channels, and basalt islands. The dominant features are channels, plateaus, and buttes. Along the channels are outwash terraces, bars, loess islands, cataracts, and basins. On the plateaus the relief is broken by circular mounds of loess surrounded by cobble-size fragments of basalt. In most of the site area, a thin layer of loess overlies the basalt and glacial outwash.

Soils for the site area are typically moderately deep to very deep, and well drained. One-half of the area consists of deep soils, the remainder is composed of shallow soils with rock outcrop. The generalized soils map (see fig. 2) for the area divides soils into three units on the basis of depth and location.

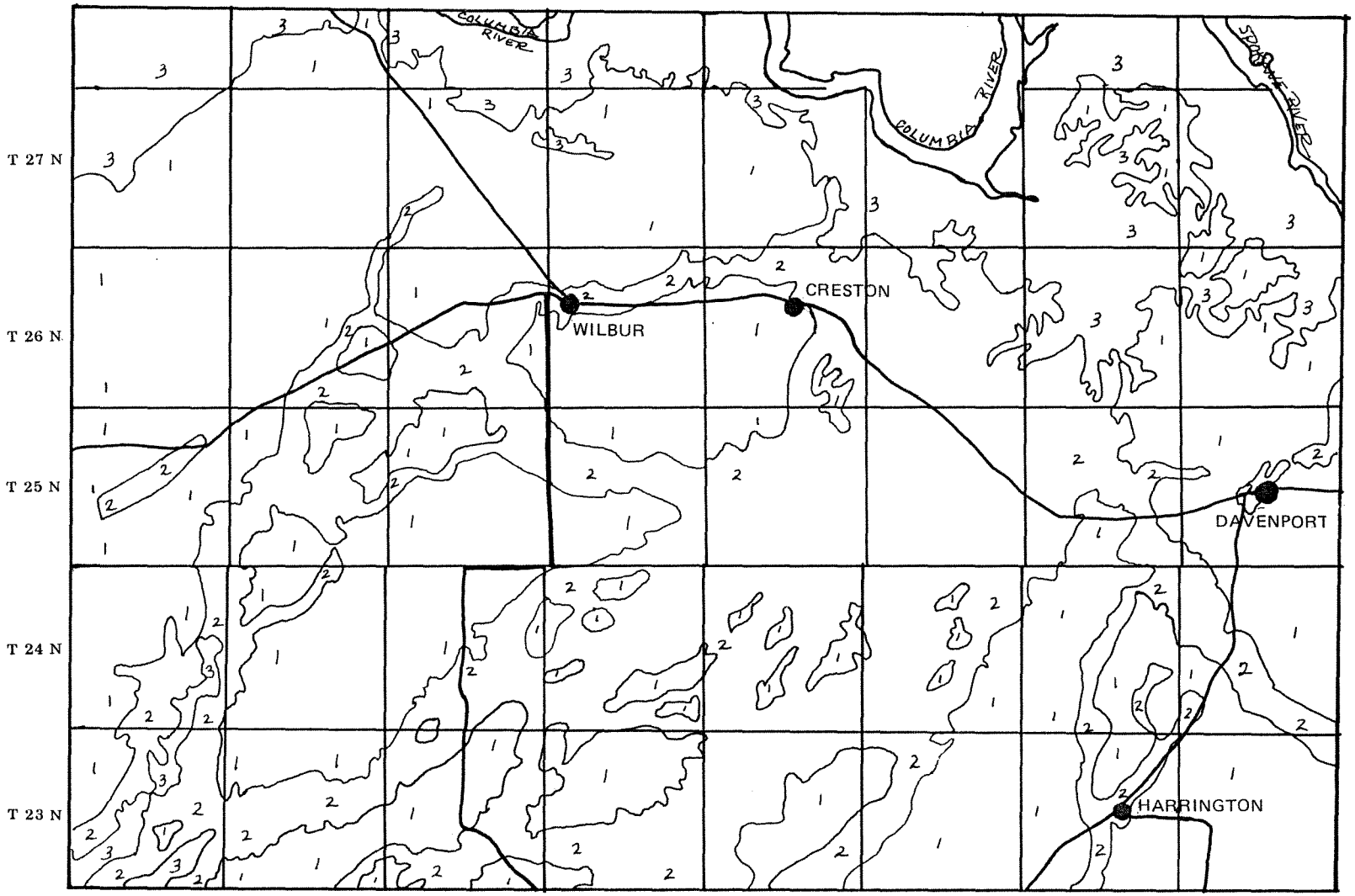
Unit #1: This unit is located on the uplands or basalt islands between coulees. These soils are nearly level to steep and are typically well drained. Soil depth ranges from moderate to deep. Elevation is 1,200 to 1,300 feet above sea level. Unit 1 soils formed in loess.

Unit #2: Unit 2 soils are well drained and have a nearly level to steep topography. They are commonly found on basalt plateaus at elevations of 1,300 to 2,500 feet above sea level. Unit 2 soils formed in loess over basalt. Soils range from rock outcrop, to shallow, to moderate in depth.

Unit #3: This unit is found principally on canyon slopes, plateaus, river terraces, and rock outcrops. Unit 3 soils are very shallow to very deep and can be well drained to excessively drained. Slopes range from nearly level (terraces) to steep (rock outcrop). Elevations are 1,300 to 3,000 feet above sea level. These soils formed in glacial outwash and loess over basalt.

GEOLOGIC HISTORY

The geomorphology of the site area is largely the result of three main events: (1) eruption of flood basalts during Miocene time, (2) lacustrine, fluvial, and eolian deposition during the early Pleistocene, and (3) glacio-fluvial erosion and deposition during the late Pleistocene.



DESCRIPTION OF UNITS

1 Well drained soils forming in loess: on uplands.

2 Well drained soils forming in loess over basalt and rock outcrop; on basalt plateaus.

3 Soils on canyon slopes, plateaus, and river terraces, and rock outcrop.

SCALE 1: 380,160

0 1 2 3 4 5 MILES

From Soil Survey of Lincoln County, 1981

FIGURE 2. GENERALIZED SOILS MAP OF LINCOLN COUNTY SITE

The Columbia Plateau is recognized as the earth's youngest flood basalt province. The basalt erupted from fissures principally located in eastern Washington and Oregon, along the Idaho border. This extrusion took place during an 11 million year period, beginning approximately 17 million years ago and ending an estimated 6 million years ago. During that time, 200,000 square kilometers of land were buried beneath layers of basalt to an average of one kilometer in depth. More than 95 percent of this volume accumulated in the first 3½ million years (17 to 13.5 million years ago).

Between eruptive phases there were times of little volcanic activity. Erosion occurred and sedimentary deposits were laid down on top of basalt surfaces. These sediments were then covered by subsequent flows. Interbeds, such as these, are found principally in the upper 1,200 feet of the Yakima Basalt. Examples of interbeds in the site area are the Vantage and Beverly Members of the Ellensburg Formation, Quincy diatomite, and Latah Formation.

As the basalts increased in thickness, subsidence began. The off-lap relationship of the flows shows that, away from the plateau margin, each successive flow did not extend beyond the limits of previous ones. Stratigraphically higher basalts occur south of Frenchman Hills (Grant County site) and outcrop patterns show a centrally directed dip toward the Pasco Basin. Flow thickness also decreases away from the central plateau region (Pasco Basin). These two criteria suggest that subsidence of the basin occurred during the accumulation of the basalts.

Volcanism had ceased by Pleistocene time. Climatic changes which favored ice development in areas that were normally ice-free resulted in the formation of huge continental glaciers. The Cordilleran Glacial Complex, centered between the Rocky Mountains and the Canadian Coast Range, had its southern boundary in eastern Washington along the Columbia River (see fig. 3). Periodically, lobes of this glacial complex blocked the Columbia River, resulting in the ponding of water in the form of lakes. As these lakes overflowed their divides and spilled southward, they carved coulees, or stream channels, and deposited gravel bars. The greatest quantity of water was released when glacial Lake Missoula in western Montana broke its ice dam releasing some 500 cubic miles of water. This event, which took place an estimated 22,000 years ago, is mainly responsible for the development of the Channeled Scablands of eastern Washington. The Lincoln County site is situated among coulees and basalt islands resulting from this catastrophic event.

STRATIGRAPHY

The units exposed in the site area consist of Pleistocene deposits of glacio-fluvial origin and Columbia River Basalts of the Yakima Basalt Subgroup. These basalts are Miocene in age and range from 17 to 6 million years before present.

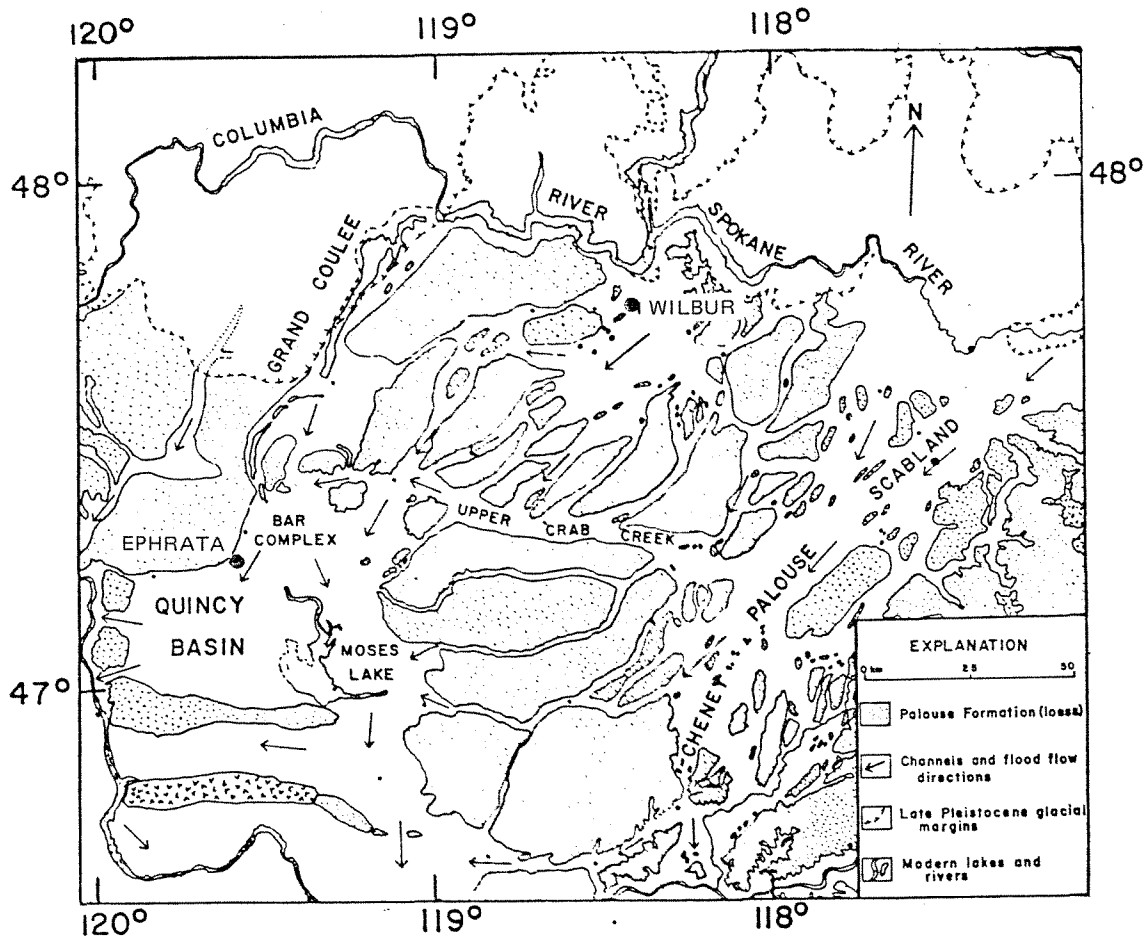


Figure 3. - Map of the Channeled Scabland in eastern Washington showing the distribution of channels and the general extent of loess that was not stripped away by the last major episode of flooding. The Quincy Basin (Grant County site) lies in the southwest corner of the map. Westward arrows show the direction of flow of the ponded water out of the basin. The town of Wilbur is located in the north-central region of the map. The Lincoln County site lies in between eroded coulees and basalt islands left by the catastrophic flooding. (After Baker, V. R. and Numendal, D., 1978).

YAKIMA BASALTS

Terminology

The Columbia River Basalt Group is divided into subgroups (that is, Yakima Basalt Subgroup); subgroups are divided further into formations (see fig. 4). The Yakima Basalt Subgroup consists of three formations: Grande Ronde Basalt (oldest), Wanapum Basalt, and the Saddle Mountains Basalt (youngest).

Formations are further divided into members. Each formation consists of several members. In turn, members are divided into depositional events, or flows and sedimentary interbeds. Flows can be recognized by vesicular flow tops, rubbly bottoms, and the presence of palagonite. Each formation, (that is, Grande Ronde, Saddle Mountains) consists of a number of flows or eruptive events which span millions of years.

Typical basalt flow characteristics

The basalts occurred as a succession of flows or outpourings of highly fluid lava from feeder dikes. Each flow followed a depression in earlier flows or at least flowed downhill. An average flow (or flow unit) consists of dense basalt with a vesicular zone at the top 5 to 10 feet in thickness. At the base the basalt is usually glassy.

Each flow unit has an overall vertical columnar jointing system which varies from one flow to another. Figure 5 shows a typical profile of a basalt flow. Characteristically, basalt flows have three sets of joints that result from shrinkage as the basalt cools. Two joint sets are vertical and one set is horizontal. One vertical set separates the basalt into polygonal, usually hexagonal, columns that are normal to the cooling surface. The other vertical set separates the basalt into straight-sided, irregularly shaped blocks. The third set embraces the horizontal platy cracks. The three types of cooling joints may occur in the same flow.

Description of Units

According to information from various water wells drilled by the Department of Ecology, and downhole geophyscial surveys, the occurrence of the Vantage Member of the Ellensburg Formation is much closer to the surface than implied by the geologic map by Hanson and others (1979). Exposures of the Vantage have been located near the bottom of a number of coulees in the site area. One reason for the failure to recognize this sedimentary interbed could be that the Vantage Member rarely crops out. Because it is usually concealed by talus and debris from flows above it, natural exposures are few.

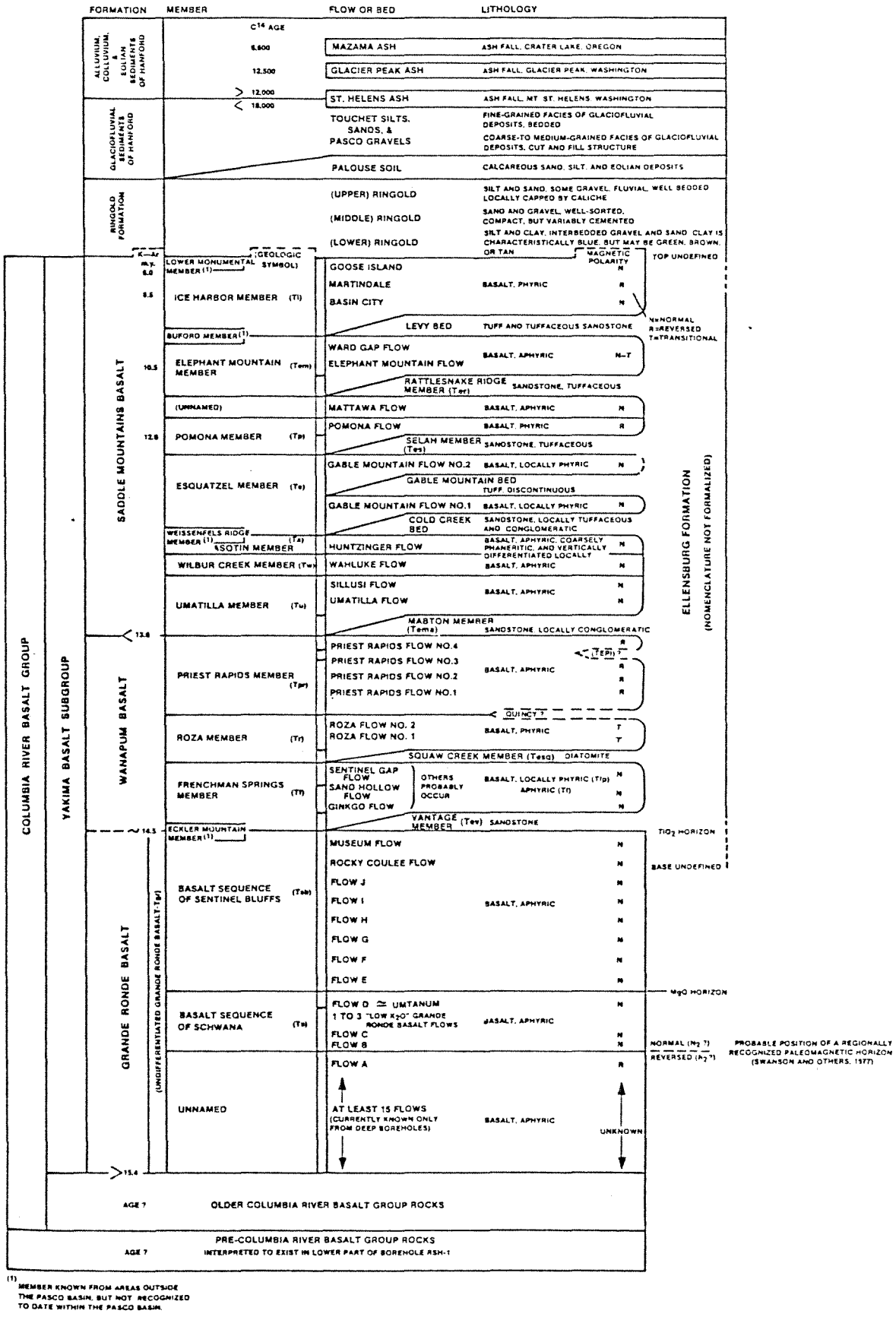


Figure 4. - Columbia River Plateau stratigraphic nomenclature (after Ledgerwood, et. al., 1978).

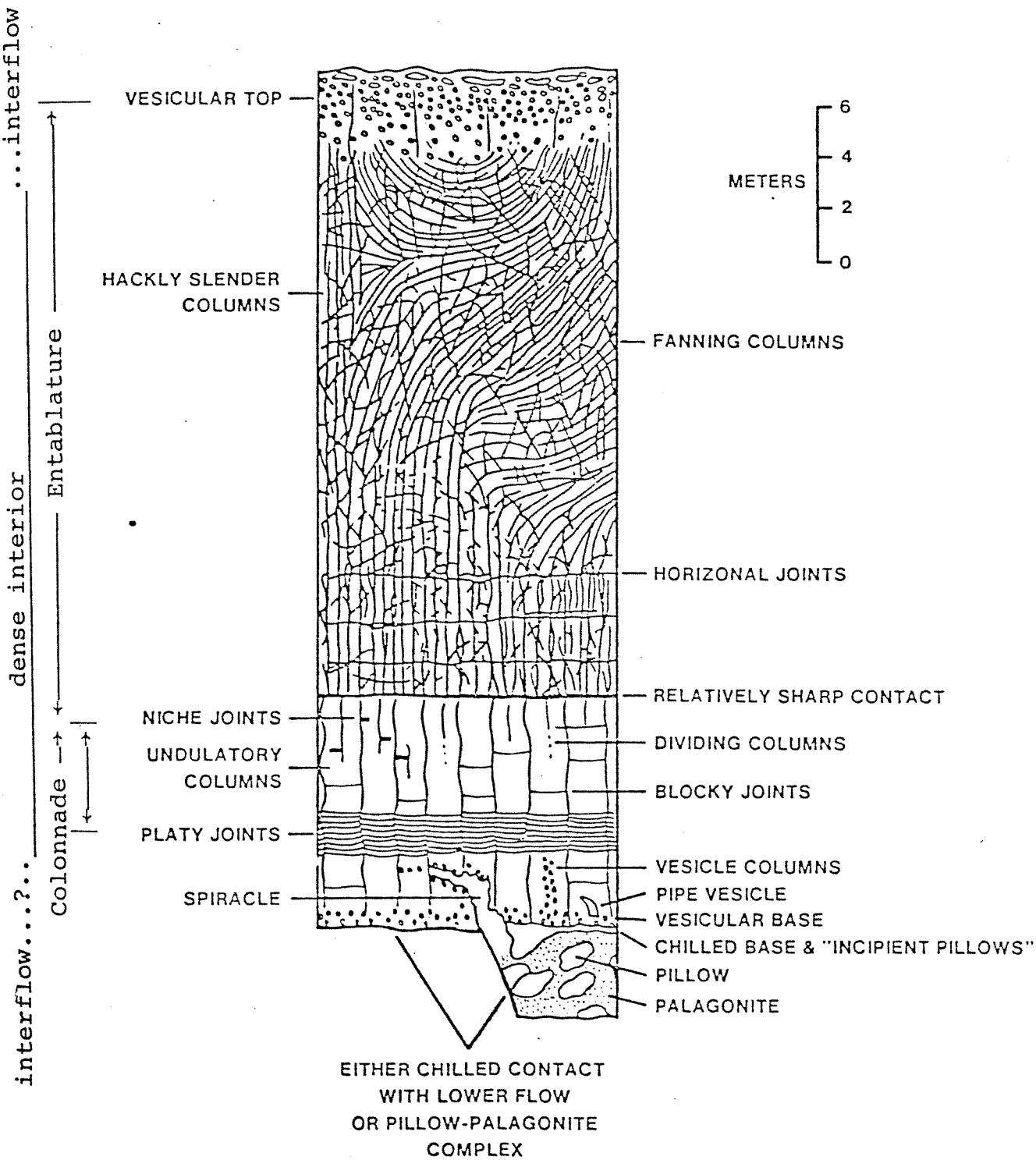


Figure 5. - Macrostructure of a basalt flow (after Swanson, and Wright, 1976).

The importance of this occurrence from the standpoint of the Superconducting Super Collider is that the Vantage Member is a major water-bearing zone and the thickness of the overlying Priest Rapids Member is not sufficient to accomodate the Superconducting Super Collider ring; the ring will ultimately have to be sited in the lower flows of the Yakima Basalt, that is, in the Grande Ronde Basalt.

Priest Rapids Member: The basalts exposed in the site area have been mapped as the Priest Rapids Member of the Wanapum Basalt Formation. The Wanapum is the most extensively exposed and the second most voluminous formation of the Yakima Basalt Subgroup. Priest Rapids basalts, estimated to be 13.5 to 14.5 million years old, are the youngest of the Wanapum.

Priest Rapids basalts are grayish-black in color, medium- to coarse-grained, and have a non-porphyritic texture. Where weathered, the basalt is mottled brown, and the outer surface shows a red-brown color. On a freshly broken surface it has a distinctive greenish cast. At its type locality, the Priest Rapids Member consists of four flows with a total thickness approaching 245 feet (75 m). Columns can be as much as 10 feet (3 m) in diameter. The columns may break into large prismatic sections with spherical fractures known as ball and socket joints.

The Vantage Sandstone Member of the Ellensburg Formation: The Vantage Sandstone Member is of late Miocene age and separates the upper flows of the Grande Ronde Basalt from the lower flows of the Wanapum. Where exposed, the Vantage Sandstone is pale yellow in color. The Member consists of medium-grained quartz-feldspar-mica sand, or of a weakly cemented tuffaceous sand containing hornblende. This distinctive tuffaceous sand is generally overlain by tuffaceous silt and clay mixed with quartz and mica. Carbonized twigs and plant impressions commonly occur in a black earthy zone near the top of the tuffaceous silt and clay. The Vantage Sandstone is laterally continuous but thins to the east. In the Vantage-Priest Rapids area the member measures 35 feet (11 m) in thickness.

Grande Ronde Formation: The Grande Ronde Basalt is the oldest member of the Yakima Basalt Subgroup and is dated between 14 and 16.5 million years before present. Grande Ronde basalts are the most voluminous and underlie most of the Columbia Plateau. However, because it is covered by younger flows, it only crops out along the plateau margin or in deep canyons.

The known thickness of the Grande Ronde ranges from tens of feet (meters) to more than 3,300 feet (1,000 m). Within the plateau, the thickest exposures are generally composed of 30 to 40 flows. Most basalt flows are fine grained, aphyric, black, and dense. The Grande Ronde has a tendency toward small, splintery, columnar jointing and in many places it can be recognized by spectacular fan jointing. The most distinctive mineralogical characteristic of the Grande Ronde is its high percentage of glass and almost complete absence of olivine.

PLEISTOCENE DEPOSITS

Pleistocene glacio-fluvial deposits consist of unconsolidated silt, sand, and gravel that unconformably overlie the Priest Rapids Member basalts. These materials record deposition in channels carved by flood waters during Pleistocene time. In this report these deposits have been classified as glacio-fluvial sand and gravel.

In the Lincoln County site area, glacio-fluvial gravel and sand were deposited at points where channels widened. In these places, a reduced water velocity resulted in deposition of the sediment bed load. Glacio-fluvial gravels are typically poorly sorted, locally display foreset bedding and consist mostly of basalt. Pebbles, cobbles, and boulders in the deposits are subrounded to well rounded and many have percussion marks.

Loess is characterized by the lack of stratification and an undeveloped soil profile. It is typically a gray-brown color and thickest on the leeward side of hills. A layer of white volcanic ash, a few inches to a foot in thickness, occurs in the upper part of the loess. This has been interpreted as originating from Mount Mazama (Crater Lake) approximately 6,600 years ago.

HOLOCENE DEPOSITS

Eolian deposits

In the site area, eolian materials are composed of loess and dune sand deposited during the Holocene epoch. Deposits consist of silt-sized particles which settled to the land surface after being carried and distributed by the wind. It includes some intermixed sand and clay sized particles originating from Pleistocene-age lacustrine sand.

Dunes: Dune sand is blown along the ground surface largely by creep and saltation (bouncing). In the project area active dunes occur along the Columbia River. The sand particles consist of reworked deposits from lacustrine sand and silt.

Other Holocene deposits: These deposits consist of stream alluvium, colluvium, and landslide debris.

STRUCTURE

The Lincoln County site is located in the Palouse subprovince of the Columbia Plateau. The subprovince is characterized by an overall lack of structural deformation.

The basalts in the Lincoln County site have been described as being relatively flat lying. The land surface rises to the east at about 30 feet per mile forming a monocline. Tracing individual basalt flows indicates a slight but generally westerly to southwesterly dip that appears to be about the same slope as the land surface; thus the land surface in large part reflects the surface of the basalt underneath.

SEISMICITY

Earthquake distribution maps show that little or no earthquake activity has been experienced in the Lincoln County site area. The area is classified as a low seismic risk zone.

GRANT COUNTY SITE

by T. Hall

The Quincy Basin in Grant County has been designated as a proposed site for the 20 mile diameter Superconducting Super Collider ring. The basin lies 4 miles south of the town of Ephrata and occupies a structural low between the Beezley Hills to the north and Frenchman Hills to the south; it has Moses Lake and the Columbia River as its east and west boundaries, respectively. Interstate 90 runs east-west and bisects the circle. This is the only site in the state that could be built by trenching in near surface materials.

TOPOGRAPHY AND SOILS

The Quincy Basin is a relatively flat area and measures 18 miles from north to south and 25 miles along an east-west axis. The elevations range from 1,230 feet to 1,148 feet (375-350 m) above sea level.

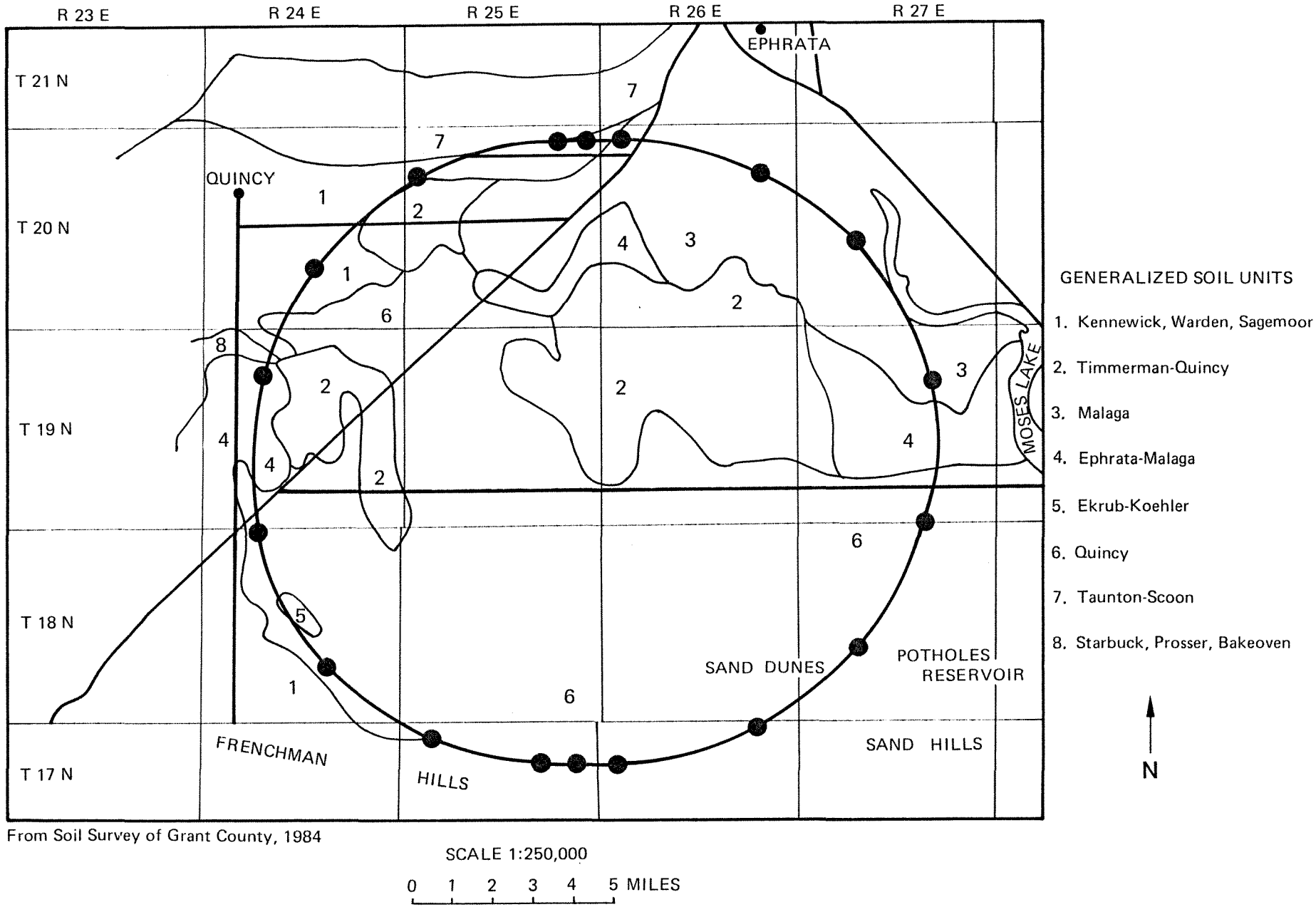
A general soils map (see fig. 6) of the proposed site area shows eight soil types. Each of these types is characterized as being deep, well drained, having a level to steep topography, and consisting predominantly of sand. The soils formed as a result of glacial, lacustrine, eolian, and alluvial processes. The soils support irrigated and non-irrigated crops, rangeland, and wildlife habitat. Each map unit on the generalized soils map represents a unique natural landscape. Each of the units is described below.

SOIL TYPES

(1) Kennewick, Warden, Sagemoor: This unit is very deep, well drained, nearly level to moderately steep, and is commonly found as terraces. This unit is in the northwest part of the circle and covers approximately 10 to 12 miles of the circumference. Slopes range from nearly level to 25 percent. Elevations are 650 to 1,400 feet (198 to 426 m) above sea level.

(2) Timmerman-Quincy: This soil unit is very deep, somewhat excessively drained, and found as terraces and active dunes. This unit has three locations in the site area; one at the center of the circle, and two patches lying near the circle's inside perimeter. Slopes up to 35 percent are common. Elevations are 800 to 2,200 feet (244 to 670 m) above sea level.

(3) Malaga: This unit is very deep, well to excessively well drained, and found as terraces and escarpments. This unit is restricted to the northeast portion of the circle and covers nearly one-third of the total circumference. Elevations are 450 to 1,300 feet (137 to 396 m); slopes are 0 to 35 percent.



From Soil Survey of Grant County, 1984

Figure 6.

(4) Ephrata-Malaga: This unit is very deep, well drained to somewhat excessively drained, and found as terraces and terrace escarpments. This basic type has three locations; one at the north central area inside the circle (not intersecting), one at the eastern perimeter, and another at the western perimeter of the circle. Malaga soils are generally found on the lower-lying terraces; Ephrata soils are on the slightly higher terraces. Slopes are 0 to 35 percent. Elevations are 450 to 1,300 feet (137 to 396 m).

(5) Ekrub-Koehler: This unit is shallow to moderately deep, somewhat excessively drained, and found as terraces. Ekrub-Koehler soils occur at one location along the southwest portion of the ring. Slopes can be nearly level to 25 percent. Elevations are 600 to 2,200 feet (183 to 670 m) above sea level.

(6) Quincy: Quincy soils are very deep, somewhat excessively drained, and found as terraces and active dunes. This unit comprises almost the entire southern portion of the circle. Slopes vary from nearly level to 35 percent. Quincy soils are composed of fine sand. They vary in elevation from 300 to 2,200 feet (91 to 670 m).

(7) Taunton-Scoon: These soils can range from very shallow to moderately deep. Taunton-Scoon soils are well drained and found as terraces and alluvial fans. This unit is located near the northern limits of the ring along the foot of the Beezley Hills monocline. Slopes up to 35 percent are common. A layer of hardpan is found 20 to 40 inches from the surface and averages 27 inches thick. Elevations vary from 800 to 3,000 feet (244 to 914 m) above sea level.

(8) Starbuck, Bakeoven, Prosser: The group varies from shallow to moderately deep. Soils are well drained and found on benches, hillsides, and ridgetops. Slopes are 0 to 65 percent. This unit occurs at one location along the western perimeter of the ring. Elevations 550 to 2,900 feet (168 to 884 m) above sea level.

SOIL PROPERTIES

The Soil Conservation Service has determined soil properties by field examination and laboratory testing. Included in this report are two tables from the Soil Survey of Grant County (Gentry, 1984) which cover soil properties that may be of importance to Superconducting Super Collider site construction.

Soil features

Depth to bedrock is given in table 1 if bedrock is within five feet of the surface. Depth is based on soil borings and observations made during soil mapping. Rock has been specified as soft or hard. Units of Superconducting Super Collider concern are described as hard, requiring blasting or special equipment for excavation.

TABLE 1 -- SOIL FEATURES

Soil name and map symbol	Bedrock Depth IN	Bedrock Hardness	Cemented pan Depth IN	Potential frost action	Risk of corrosion Uncoated steel	Risk of corrosion Concrete
#1 Kennewick, Warden, Sagemoor	>60	Soft	----	High	High	Low
#2 Timmerman, Quincy	>60	Soft	----	Low to Moderate	Moderate to High	Low
#3 Malaga	>60	Soft	----	Low	Moderate	Low
#4 Ephrata-Malaga	>60	Soft	----	Moderate	High	Low
#5 Ekrub-Koehler	>20	Hard	10-20	Low	High	Low
#6 Quincy	>60	Soft	----	Low	Moderate	Low
#7 Taunton-Scoon	20-60	Hard	10-40	Moderate	High	Low
#8 Starbuck, Bakeoven, Prosser	4-40	Hard	----	Moderate to High	Moderate to High	Low

* NOTE: Features of soils shown on Figure 6, page 22.

TABLE 2 -- BUILDING SITE DEVELOPMENT IMPACTS BY SOIL TYPE

Soil name and map symbol	Shallow excavations	Dwellings without basements	Dwellings with basements	Small commercial buildings	Local roads and streets
#1 Kennewick, Warden, Sagemoor	slight	slight	slight	slight	severe; frost action
#2 Timmerman-Quincy	severe, cutbanks cave	slight	slight	slight	moderate; frost action
#3 Malaga	severe, cutbanks cave	slight to moderate: slope, large stones	moderate slope	severe slope	moderate slope
#4 Ephrata-Malaga	severe; cutbanks cave	slight	slight	slight	moderate; frost action
#5 Ekrub-Koehler	severe; cemented pan, cutbanks cave	moderate; cemented pan	severe; cemented pan	moderate; slope, cemented pan	moderate; cemented pan frost action
#6 Quincy	severe; cutbanks cave	moderate; slope	moderate; slope	severe; slope	moderate; slope
#7 Taunton-Scoon	severe; depth to rock, cemented pan	severe; cemented pan	severe; depth to rock, cemented pan	severe; cemented pan	severe; cemented pan
#8 Starbuck, Prosser, Bakeoven	severe; depth to rock, slope	severe; slope	severe; depth to rock, slope, slope large stones	severe; slope	severe; slope, frost action

* NOTE: Severe impacts require special engineering techniques to prevent damage to structures.

Cemented pans are cemented or indurated subsurface layers within a depth of five feet. Pans are classified as thin or thick. Thick pans are described as being greater than three inches in thickness if they are indurated, or greater than 18 inches in thickness if discontinuous or fractured. Pans of these thicknesses require blasting or special equipment for excavation. Soil units 5 and 7 are in this category.

Frost action potential is the likelihood of upward or lateral expansion of the soil caused by the formation of segregated ice lenses (frost heave) and collapse of the soil and loss of strength when thawing. Well drained, very gravelly, or very sandy soils are the least susceptible. Frost heave and low soil strength during thawing cause damage mainly to pavements and other rigid structures.

Risk of corrosion pertains to the soil-induced electro-chemical or chemical reaction that dissolves or weakens uncoated steel or concrete. The rate of corrosion of uncoated steel is related to soil moisture, particle size distribution, acidity, and electrical conductivity of the soil. The rate of corrosion of concrete is based on the sulfate and sodium content, texture, moisture content, and acidity of the soil. Steel in installations that intersect soil boundaries or soil layers is more susceptable to corrosion than steel in installations that are entirely within one kind of soil or within one soil layer.

Table 2 gives information dealing with building site development and types of soil limitations that pertain to building structures. The limitations are considered slight if soil properties and site features are generally favorable and limitations are minor; moderate if soil properties or site features are not favorable and special design, planning, or maintenance is needed; and severe if soil properties or site features are so unfavorable or difficult to overcome that special design, significant increases in construction costs, and possibly increased maintenance are required.

Shallow excavations are trenches or holes dug to a maximum depth of five or six feet. Dwellings and small commercial buildings are structures built on shallow foundations on undisturbed soil. Local roads and streets may consist of a cut or contain fill material laid upon the existing surface. This surface reacts due to frost action and shrink and swell potential of the soils. The ratings are based on soil properties, site features, and observed performance of the soils.

GEOLOGIC HISTORY

At the Grant County site, four major geologic events transpired which resulted in the present-day landscape. (1) the extrusion of flood basalts during the Miocene, (2) tectonic deformation during the Miocene and early Pliocene epochs, (3) lacustrine, fluvial, and eolian deposition, and intermittent deformation during the Pleistocene, and (4) the glacio-fluvial erosion and deposition during the late Pleistocene epoch.

Late in the Pleistocene epoch, large Cordilleran ice sheets advanced southward from Canada to the Columbia River north of Ephrata (see fig. 3). Some of the extensions, or lobes, of this glacial complex blocked parts of the Columbia River causing lakes to form. When these and other glacial lakes (Columbia, Spokane, Missoula, and Bonneville) overflowed or broke their ice dams, tremendous amounts of glacial meltwater were released, eroding away the basalt and forming what is called the Channeled Scablands of eastern Washington.

The Columbia River, swollen by glacial meltwater, first overflowed its banks and deposited gravels and sands in the Quincy Basin. Then, at a later date, debris-laden streams from Grand Coulee, Dry Coulee, Crab Creek, and other sources diverted a huge influx of water into the basin. This water was temporarily ponded, then flowed out through three existing channelways to the west (Crater Coulee, Potholes Coulee, and Frenchman Springs Coulee). The meltwater brought in volumes of basaltic gravel and sand. As this water accumulated, deposits settled to the bottom of the basin. In places the thickness of these deposits approaches 150 feet.

STRATIGRAPHY

The deposits in the Quincy Basin consist of three major types: (1) Yakima Basalts of the Columbia River Basalt Group; (2) fluvial gravels older than glacio-fluvial deposits, and (3) glacio-fluvial gravels of late Pleistocene age deposited by catastrophic flooding.

Columbia River Basalt Group

Exposures of Columbia River basalts at the Grant County site are limited to three main areas. Basalt crops out along the Frenchman Hills anticline south of the site. Other exposures occur near the northern tip of Moses Lake. These two occurrences are outside the limits of the ring and are of minor importance. The last exposure of basalt, within the study area, occurs along the Beezley Hills. The outcrop occupies approximately one mile of the Superconducting Super Collider ring. This particular unit is the Roza Member of the Yakima Basalt Subgroup.

Roza Member: The Roza Member of the Yakima Basalt Subgroup (Wanapum Formation) overlies the Frenchman Springs Member and underlies the Priest Rapids Member (see stratigraphic column, fig. 4). The Roza basalt is a dark bluish-gray color and weathers to a deep reddish-brown. It is medium- to coarse-grained and has a porphyritic texture. The phenocrysts are one centimeter in length, one-half centimeter in width and are composed of plagioclase feldspar.

The Roza basalt has an average thickness of 100 feet (30.5 m) and displays a columnar jointing system. Columns are five to ten feet in diameter and tend to break into slabs and chips along platy joints normal to the column axis. In many places, these horizontal platy zones grade upward into a network of curvilinear joints forming spiraling patterns.

Quaternary deposits

Deposits in the Quincy Basin are fluvial fans. The fill shows a southward decrease in grain size and change in stratification. The maximum known thickness of these deltaic deposits is 143 feet (43.5 m). On the geologic map of the site area these Quaternary deposits are divided into three different units: (1) fluvial gravel, (2) fluvial and lacustrine sand, (3) lacustrine fine sand and silt.

Older glacio-fluvial deposits: These deposits consist of cobbles and boulders of basalt, caliche, and granite and were included with the glacio-fluvial gravel on the geologic map of Grolier and Bingham (1971),(see plate 4 of this report). The bedding surfaces of these deposits dip away from the Columbia River, indicating deposition by a large river flowing opposite to the direction implied by the present longitudinal profile of Crater and Potholes Coulees. It is possible that these deposits represent an earlier flow of glacial runoff into the Quincy Basin.

Younger glacio-fluvial deposits: The younger glacio-fluvial deposits consist of the unconsolidated silt, sand, and gravel that unconformably overlie the older rocks and unconsolidated materials. These finer grained deposits indicate a decreased water velocity as the basin filled. The clasts are well rounded to subrounded and many have percussion marks. Gravels and sands are well sorted and are composed largely of basalt, with less than one percent granitic and metamorphic materials. Lacustrine fine sands and silts are characterized as being calcareous, loosely compacted, and slightly cohesive.

Holocene deposits

Deposits of Holocene age consist of young loess, dune sand, and stream alluvium. Holocene loess is composed of silt-sized material that settled to the land surface after being carried and distributed by the wind. It includes some sand and intermixed clay-sized particles derived from beds of Pleistocene lacustrine silt.

STRUCTURE

The Quincy Basin, is a structural depression situated between the Beezley Hills to the north and the Frenchman Hills to the south. The basin measures 18 miles by 25 miles and is filled with unconsolidated sediments ranging from 20 feet to 143 feet (6 to 44 m) in thickness. The basin is characterized by structural warping and subsidence near the center and by folding and faulting to the north and south. The Beezley Hills consists of a more open fold that relaxes eastward and, near Ephrata, is expressed as a monocline. The Frenchman Hills and Saddle Mountains are somewhat tighter flexures and commonly are transected by northwest- to north-south-trending shear zones and minor folds. For a cross-section showing structure, see cross sections of the Quincy Basin accompanying this report.

SEISMICITY

Seismic activity for the Grant County site area consists of clusters or "swarms" of micro-earthquakes. These quakes are shallow, of low intensity and are located in the top two kilometers of crust. Most earthquakes are centered along anticlinal ridges such as the Saddle Mountains, south of the site area.

PIERCE-THURSTON COUNTY SITE

by T. Hall

The Puget Lowland is the geographical setting for the Pierce-Thurston County site. The study area includes Pierce, Thurston, and northern Lewis Counties. The western limit lies six miles west of the Willamette Meridian. The eastern boundary is located along a north-south line between Buckley and Ashford.

TOPOGRAPHY AND SOILS

Most of the area is a poorly drained drift plain of moderate relief. The plain is a product of glaciofluvial processes, with deposits consisting chiefly of ground moraine and outwash channels. The southern and eastern limits of the area transect Tertiary formations of volcanic and sedimentary origin. Collectively, the unconsolidated glacial deposits comprise 75 percent of the area, the remainder consists of Tertiary bedrock. Elevations in the area range from sea level near Puget Sound, to over 3,281 feet (1000 m) above sea level in the mountainous regions. In constructing the 20 mile in diameter ring for the Superconducting Super Collider, the Nisqually and Deschutes Rivers will each have to be crossed twice.

The drift plain is typified by a gently rolling to subdued topography containing numerous small lakes that occupy depressions called kettles, and sub-parallel elongate hills, called drumlins. The basin consists of over 1,500 feet (457 m) of gravel deposits from Pleistocene glaciations. The thickness of the unconsolidated deposits has been mapped using data obtained from wells logs by Hall and Othberg (1974), (see figure 7).

Soils of the Puget Lowland have developed under high rainfall conditions. They range from slightly to strongly acidic at the surface but generally become less acidic with depth. The color varies from light grayish brown to nearly black, and can be brown or yellowish brown in many areas. The color is affected by the drainage and type of natural vegetation, the more poorly drained areas are darker in color, and the well drained soils are brown.

The mountainous areas are characterized by steep slopes. In some locations landslides and slumps are common. Soils have typically slight to medium acidity and most have a brown or yellowish-brown subsoil. In these areas, soils are covered by dense stands of timber.

GEOLOGIC HISTORY

The Puget Lowland lies in a structural downwarp extending south into the Willamette Valley of Oregon. The two corresponding upwarps are represented by the Cascades and Olympic Mountain Ranges in Washington and the Cascades and Coast Ranges in Oregon. This structural depression was formed in early Miocene time (16.5 to 15 million years ago) when east-west

compressional forces resulted in folding, faulting, and local intrusion of diorite sills and dikes. An erosional surface of low to moderate relief formed on the bedrock, upon which lacustrine and alluvial sand and gravel accumulated in late Miocene time (11 to 5 million years ago). The deposition of these sediments was interrupted at least once in the southern and eastern part of the study area by deposition of volcanic mudflows, volcanic ash, and pumice gravel, the source of which was to the east of the study area.

By Pliocene time (5.3 million years ago), the Cascade Range had been uplifted to a height comparable to that of today. Valleys were eroded in the range similar in size to present valleys.

By early Pleistocene time (1.6 million years ago), the landscape had matured somewhat. World-wide climatic conditions favoring periodic production of glaciers in areas normally free of perennial ice, became prevalent. The resulting glacial episodes produced large continental ice sheets which flowed southward, as well as smaller localized alpine glaciers at higher altitudes beyond the southern limit of the larger masses of ice.

A major continental ice sheet known as the Cordillerian Glacial Complex formed in western British Columbia. This mass of ice was centered in the broad upland between the Canadian Coast Range and the Rocky Mountains. Smaller outlet glaciers discharged from this central mass of ice. Ice of the Puget Lobe was, for the most part, supplied by the outlet glaciers of the Fraser River area. This mass was joined by free flowing ice from a mountain ice sheet on Vancouver Island.

At least four major glaciations occurred in the Puget Lowland during Pleistocene time. The geologic record indicates that between each of these glacial episodes there was an interglacial period with a climate very similar to that of today (Crandell and others, 1958, p. 384).

STRATIGRAPHY

General features

The rocks exposed in the site area range from early Tertiary (Eocene, 58 million years ago) to Quaternary (Holocene) age. The total thickness of these deposits, collectively, approaches 12,000 feet (3658 m). The units consist of sedimentary deposits of marine and continental origin and interbedded volcanic rocks. These rocks are folded and faulted near the southern limit of the site area and in most places are buried by poorly consolidated till and alluvium. Eocene rocks are intruded by dikes and sills of basalt and gabbro.

The central portion of the study area is composed of glacial debris up to 1,500 feet (457 m) in thickness (see fig. 7), (Hall and Othberg, 1974). The southern extent of the gravels represents the limit of the Puget Lobe

glaciations. Nearly all of the exposed glacial deposits correspond to the latest glacial episode, the Vashon Stade. The deposits thin southward and disappear near 46°45'N. (Porcupine Ridge).

Most of the Tertiary (58 to 2 million years ago) strata were laid down near the marine shoreline. As a result, deposits typically grade from marine to non-marine to estuarine in origin and reveal many submergent and emergent continental modes.

EOCENE SERIES

McIntosh Formation

The McIntosh Formation consists chiefly of dark-gray, well indurated tuffaceous siltstone and claystone with thin beds of tuff. Some sandstone beds are massive but most are laminated, consisting of thin layers of siltstone and fine grained tuff or fine grained sandstone. The unit weathers to iron stained platy fragments and crumbly soil, which are mottled light-gray or light yellowish orange.

The upper part of the McIntosh Formation consists of 250 feet (76.2 m) of massive arkosic sandstone. Dark-gray basaltic sandstone and light-gray arkosic sandstone are commonly intercalated in the lower part of the formation. Pyroclastic material interbedded with the McIntosh ranges from fine grained tuff to lapilli tuff.

The McIntosh Formation is located principally in the southeastern portion of the study area. The maximum thickness is measured at 4,500 feet (1,372 m) and the base is not exposed.

Carbonado Formation

The Carbonado Formation consists of moderately indurated interbedded sandstone, siltstone, mudstone, and shale which contain carbonaceous shale and coal seams. The sandstone is light-gray to brown in color with black siltstone, mudstone, and coal layers, and usually weathers to tan or light buff. It is commonly micaceous and locally presents a "salt and pepper" appearance. Sandstone strata are generally thick bedded, well sorted, and commonly cross-bedded. The Carbonado Formation displays changes in thickness of bedding within short distances.

The Carbonado Formation is restricted to the southeastern tip of the study area and outcrops are generally confined to valley walls of main streams and meltwater channels. The Carbonado measures over 5,000 feet (1,500 m) in thickness and the base is not exposed. Coal seams can be up to 15 feet (4.5 m) in thickness, although most are 1 to 5 feet thick.

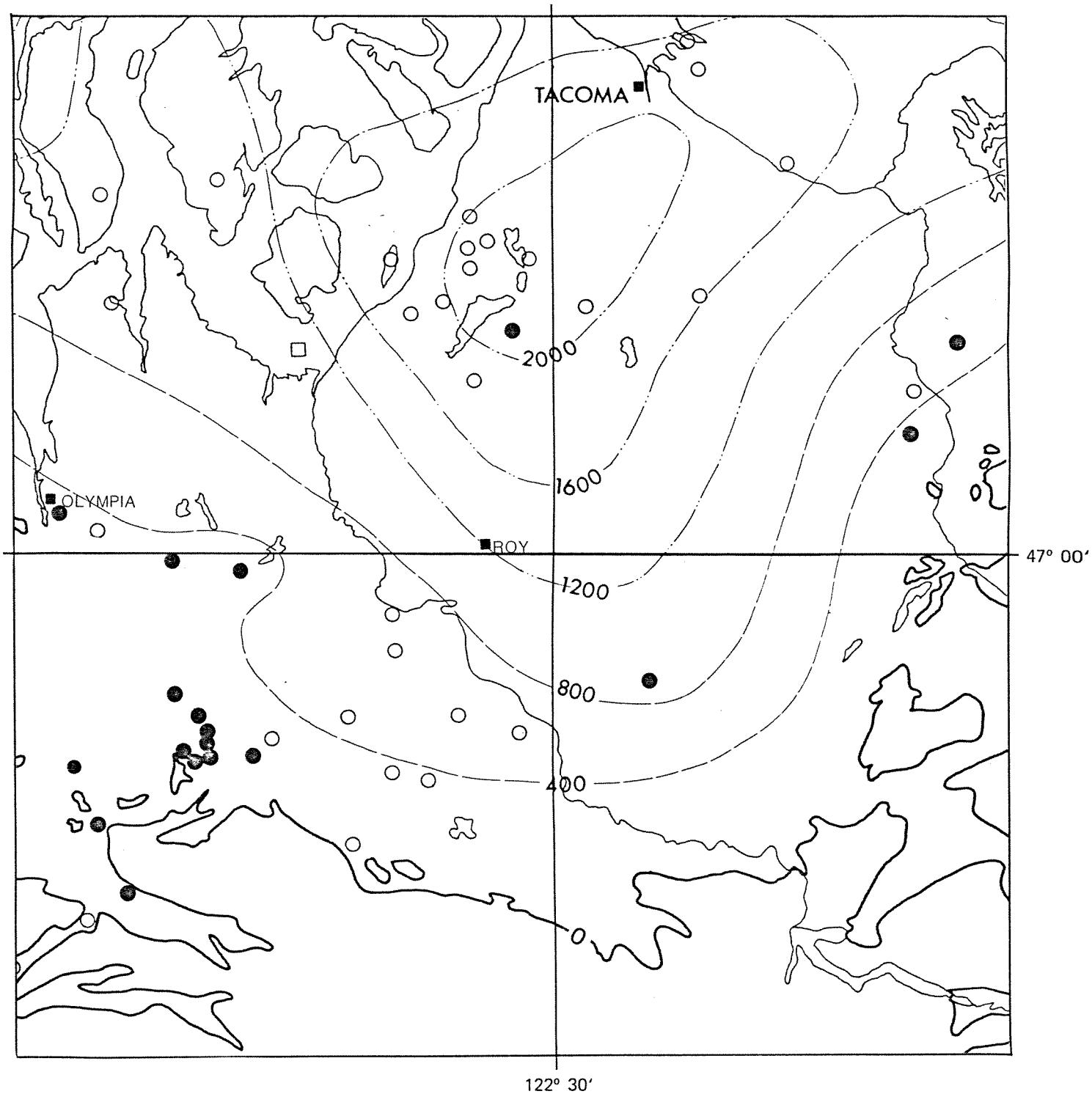


Figure 7. - Isopach map showing the thickness of unconsolidated glacial materials in the Puget Sound Lowland. The map is based on records from about 280 oil and water well logs, mapped surface exposures of bedrock, and subsurface seismic profiling data. ● - Water wells drilled to bedrock, ○ water wells not drilled to bedrock. (After Hall, J. B. and Othberg, K. L., 1974).

Northcraft Formation

The Northcraft Formation consists chiefly of ferromagnesian lavas, flow breccia, and pyroclastic rocks in the upper part and basaltic conglomerate, sandstone, and pyroclastic material in the lower part.

The lava flows are primarily calcic andesite with minor basalt. They are locally vesicular and platy and often porphyritic. Vesicular flows with amygdules composed of calcite, zeolites, and chalcedony are common. Flow breccias are often present containing massive blocks of platy andesite and basalt. Many rocks show well developed flow cleavages.

The Northcraft Formation approaches 1,500 feet (457 m) in thickness and distribution is confined to the southern portion of the study area.

Skookumchuck Formation

The Skookumchuck Formation consists of marine, non-marine, and brackish-water sedimentary rocks with intercalated coal beds. It overlies the Northcraft Formation with an apparent angular unconformity. The Skookumchuck Formation has a maximum thickness of 3,500 feet (1067 m) and is exposed in the southwest portion of the study area.

The Skookumchuck Formation consists of a lower and an upper sandstone unit. These two lithologies are separated by a westward thickening wedge that is predominantly siltstone. Lateral and vertical variations within short distances are common. All gradations between sandstone and siltstone are found but sandstone beds dominate.

The sandstone of the Skookumchuck Formation is fine- to medium-grained, micaceous and carbonaceous, basaltic and arkosic, and locally contains fine grained tuff. It is generally friable but may be cemented with calcite or iron oxide. Calcite may comprise up to 40 percent of some sandstone beds. The sandstone shows poor to good sorting, usually being better sorted in the more massive areas. When fresh, the sandstone is medium- to bluish-gray and weathers to mottled light-gray, light yellowish-orange, and brown iron-stained sand.

Spiketon Formation

The Spiketon Formation is a series of alternating beds of light gray arkosic sandstone, gray to brown or black siltstone, mudstone, shale, carbonaceous shale, and coal. It overlies the Northcraft Formation in the southeast portion of the proposed Pierce-Thurston County site area. The formation is approximately 3,600 feet (1,100 m) in thickness.

The Spiketon Formation is lithologically indistinguishable from the Carbonado Formation. These two units can be differentiated when flows of the Northcraft Formation are found between them.

OLIGOCENE SERIES

Lincoln Creek Formation

The Lincoln Creek Formation is exposed along the Willamette Meridian approximately one-half mile north of the Thurston-Lewis County line. This one location is the only occurrence of the Lincoln Creek Formation in the site area.

The Lincoln Creek Formation consists of deltaic, near-shore, and continental deposits of basaltic sandstone with interbeds of pyroclastic rocks. This portion is termed the basaltic sandstone member. The unit is composed of well indurated massive fine-grained basaltic sandstone and siltstone. The strata vary from light greenish-gray to medium olive brown. Calcareous concretions and nodules occur locally, and the fine-grained beds are commonly cemented by calcite. The sandstone is composed of volcanic material with lesser amounts of feldspar, quartz, and mica.

The tuffaceous siltstone member consists predominantly of fine-grained to very fine-grained tuffaceous sandstone and siltstone. This lower member is not well exposed in the area.

The Lincoln Creek Formation overlies the Skookumchuck and is measured at 2,000 feet (610 m). The contact is in most places marked by a granule sandstone or a pebble conglomerate.

MIOCENE SERIES

Mashel Formation

The Mashel Formation consists of a predominantly fine-grained upper part and a coarse-grained lower part. The upper part is composed mostly of clay, sand, and lignite (coal). The lower part of the formation is typically a medium- to coarse-grained, poorly cemented basaltic gravel.

The exposures of the Mashel Formation are confined to areas along the Nisqually River and Tanwax Creek in southern Pierce and northern Thurston Counties. The formation is believed to have been deposited in a piedmont environment after the uplift of the ancestral Cascade Range. The thickness of the Mashel Formation is estimated at 200 feet (61 m).

PLEISTOCENE SERIES

Logan Hill Formation

The Logan Hill Formation is a partly consolidated, weathered, and iron-stained gravel and sand. This unit is believed to represent debris from alpine glaciers in the highland areas of the western Cascade Range. The outwash from the glaciers formed alluvial fans throughout much of the Centralia-Chehalis area. The formation is composed largely of reddish- to yellowish-brown, iron-stained gravel and minor amounts of interbedded sand

and silty clay. Most of the pebbles and rocks in the Logan Hill are derived from the Northcraft Formation. The gravel can be massive or cross bedded and deposits are well sorted.

The sand of the Logan Hill Formation contains a high percentage of material eroded from underlying formations. In some areas it overlies the Skookumchuck, making it difficult to differentiate the two units.

In the site area the Logan Hill Formation is found in the southwest corner, south of Tenino and west of the Willamette Meridian. The thickness varies from 0 to 250 feet (76 m).

OTHER PLEISTOCENE GLACIAL DEPOSITS

The Puget Lowland has long been an area of controversy regarding number and extent of Pleistocene glaciations. For the purpose of this report it is not necessary to differentiate deposits of each proposed glacial stade. For our objective, the deposits will be divided into two basic divisions: deposits of pre-Fraser age (pre-Vashon Stade) and Vashon age glacial deposits. Pre-Fraser age deposits will be subdivided regarding their origin: ice cap or alpine derivation, or deposits left by advance and retreat of the Puget Lobe.

Pre-Fraser Drift of Alpine or Ice Cap Origin

The deposits include the Wingate Hill drift and Evans Creek drift mapped by Crandell (1958), and other undifferentiated deposits of pre-Vashon age.

These glacial deposits have been referred to as undifferentiated drift. This includes till, moraines, advance and recessional drift, and glacial outwash. These deposits are poorly consolidated to unconsolidated and in most cases are deeply oxidized and weathered. These deposits are confined to the eastern limits of the proposed site area and are found in the higher elevations.

Pre-Fraser Drift of Continental Origin

These glacial deposits include the pre-Salmon Springs, Orting, Stuck, and Fraser drift deposits mapped by Crandell (1958), Walters and Kimmel (1968), and Noble and Wallace (1961). These glacial deposits represent advances of the Puget Lobe and collectively approach 600 feet (183 m) in thickness. Deposits consist of fluvial gravels and sands, clay, till, and peat. For the most part, they are stratified and subject to lateral variations. Incorporated in the deposits are discontinuous lenses or pods of till. Blue clay is commonly found.

Pre-Fraser drift of continental origin - continued

These deposits are most abundant in the southwest portion of the area, south of the Fort Lewis military base and west of the Willamette Meridian, although exposures exist in other areas as well.

VASHON GLACIAL DEPOSITS

Vashon glacial deposits are the most abundant lithologic unit in the Pierce-Thurston County site area and represent the last advance of the Puget Glacial Lobe. During the advance and recession of this glacier, two types of drift were formed: till, deposited at the base of the ice, and stratified drift deposited by the meltwater. Till in the Vashon Drift is a very compact, unsorted, and unstratified concrete-like mixture of pebbles and cobbles in a matrix of silt and sand. The till ranges from a few feet to more than 90 feet (27.5 m) in thickness.

Types of Deposits:

Ground moraine: Ground moraine is characterized by an undulatory surface and consists of unsorted, unstratified glacial drift, predominantly till. It is deposited by direct action of glacial ice.

Advance stratifed drift: Advance stratified drift consists principally of sand, pebble, and cobble gravel, and scattered boulders. It locally includes laminated sediments and layers of boulder gravel. No intercalated lenses or layers of till have been seen in Vashon deposits of this type.

Recessional stratified drift: Sand and gravel deposited during northward retreat of the margin of the Puget Lobe is termed recessional outwash. It can be subdivided into two principal groups: (1) ice contact (glacial till), sand and gravel deposited in ice-walled depressions, and (2) proglacial, those deposits formed beyond the limits of the glacier.

Glacial till: Dominantly unsorted and unstratified drift is termed glacial till. It is generally unconsolidated, deposited by and underneath the glacier without reworking by meltwater. It consists of a heterogeneous mixture of clay, silt, sand, gravel, and various sizes of boulders.

MUDFLOWS AND GRAVEL OF MOUNT RAINIER PROVENANCE

Alderton Formation (lower Pleistocene, 1.6 million years). The Alderton Formation represents mudflows and stream alluvium from Mount Rainier.

Lily Creek Formation (middle Pleistocene, 1.3 million years). The lithology of the Lily Creek Formation indicates derivation from lavas and pyroclastic flows of Mount Rainier. The formation fills valley cuts in Tertiary bedrock of the Cascade foothills. It consists mostly of mudflows. Exposures are limited to the northeast part of the study area. The greatest known thickness is measured at 273 feet (83 m).

Osceola Mudflow (4,800 years). The Osceola Mudflow is an unsorted and unstratified mixture of subrounded to subangular stones in a purplish-gray, plastic, clayey-sand matrix. The lower part of the deposit contains abundant cobbles and boulders. Stones in the upper portion are fewer in number and smaller in size and show Mount Rainier origin. The Osceola Mudflow typically overlies Vashon Drift and is confined to the northeast portion of the study area. The unit measures up to 75 feet (23 m) in thickness.

Electron Mudflow (135-530 years). The Electron Mudflow is an unsorted mixture of subangular rock fragments in a matrix of purplish-gray clayey sand. The exact source of the Electron flow has not been determined although it is presumed to have originated at Mount Rainier. The thickness of the flow ranges from a few feet to 26 feet (8 m).

HOLOCENE DEPOSITS

Holocene deposits of stream alluvium, landslide debris, and terrace deposits are scattered throughout the area. In some places artificial fill in the form of mine dumps has been mapped.

STRUCTURE

The Pierce-Thurston County site lies in a structural basin formed in early Miocene time. Glaciation during the Pleistocene epoch filled the trough with gravels to a depth which exceeds 1,500 feet (457 m) in some locations. The maximum thickness of these deposits is undetermined.

SEISMICITY

The seismic activity of the Puget basin in the proposed Pierce-Thurston County site area is covered in the Lewis County site portion of this report.

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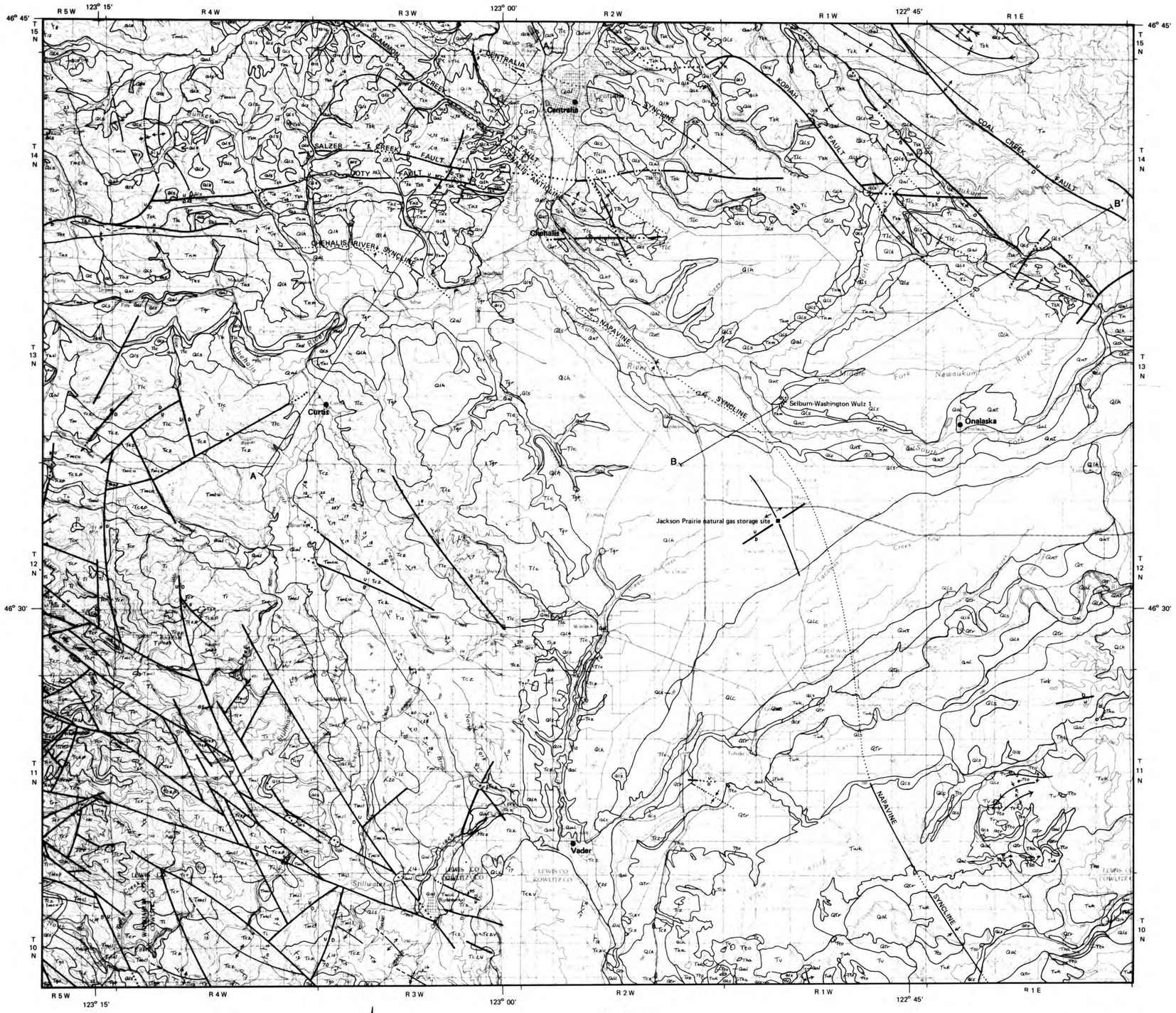
BRIAN J. BOYLE, Commissioner of Public Lands
ART STEARNS, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES
RAYMOND LASMANIS, State Geologist

A GEOLOGIC FEASIBILITY STUDY FOR THE SUPERCONDUCTING SUPER COLLIDER
PLATE 1 OPEN FILE REPORT 85-3



Geology from various sources (see references)
Compilation and cartography by N. Herman

SCALE 1:100,000

1 0 1 8 16 KILOMETERS

1 0 1 5 10 MILES

N

CROSS SECTIONS A-A′ AND B-B′ ARE SHOWN ON PLATE 2.

GEOLOGIC MAP OF LEWIS COUNTY SITE

by R. Lasmanis and T. Hall

June 1985

EXPLANATION

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

QUATERNARY

Recent

Alluvium
- **Qal** — Gravel, sand, and silt along stream courses; low-level terraces and fan material; swamp deposits locally

Landslide debris
- **Qls** — Debris composed of Quaternary and Tertiary rocks

Pleistocene

Vashon drift
- **Qdvo** — Outwash deposits of sand and gravel, and till; composed chiefly of metamorphic and igneous rocks of foreign origin. Deltaic deposits of sand and gravel locally. Deposits containing abundant locally derived basalt and andesite in a few places

Terrace deposits, undifferentiated
- **Qtr** — Fluvial and glaciofluvial gravel and sand with interbedded silt and clay

Newaukum Terrace unit
- **Qnt** — Glaciofluvial sand and gravel in matrix of clay and silt. Forms well-defined terrace along Cowlitz and Newaukum Rivers. Pebbles and cobbles less rounded and less weathered than in older, higer terraces

Lacamas Creek unit
- **Qlc** — Principally glaciofluvial terrace deposits of gravel and sand, locally cemented by clay matrix. Much of upper part badly weathered

Logan Hill Formation
- **Qlh** — Glaciofluvial deposits consisting of gravel, sand, and silt, with some till. Gravel is composed chiefly of locally derived porphyritic volcanic rocks; unit weathered and iron stained in upper 30 to 60 ft

TERTIARY

Pliocene

Nonmarine sedimentary rocks
- **Tnm** — Poorly consolidated blue-gray and blue-green sandstone, siltstone, and conglomerate; some waterlaid tuff; weathering to yellowish orange to reddish orange; contains fossil plants

Miocene

?

Grande Ronde Basalt
- **Tgr** — Black, aphanitic to finely porphyritic basalt flow, vesicular in part, columnar jointing, pillow structures common

Astoria Formation
- **Tas** — Light olive-gray to dark gray very fine- to coarse-grained sandstone and sandy siltstone, locally crossbedded, some tuffaceous, micaceous sandstone with local tuff beds
- **Tasl** — Lower unit, carbonaceous sandy siltstone with clay-pebble, glauconitic sandstone locally at base

Oligocene

Lincoln Creek Formation
- **Tlc** — Light-olive-gray to dark greenish-gray tuffaceous siltstone; generally bedded in lower part and massive in upper part; contains thin units of very fine grained sandstone, lenticular concretionary beds, glauconitic sandstones, basaltic sandstone and conglomerate beds near base

Eocene

?

Thin-bedded to massive tuffaceous, arkosic, and carbonaceous sandstone and siltstone, chiefly of lacustrine and fluvial origin. Basaltic sandstone and conglomerate near contact with underlying basalt. Upper part of section less consolidated, consisting chiefly of lake deposits of clay, silt, sand lenses, and abundant fragments and logs of fossil wood

Cowlitz Formation
- **Tcz** — Massive to thin-bedded arkosic sandstone and siltstone containing interbedded carbonaceous material and coal beds. Sandstone locally fossiliferous and grades laterally into marine siltstone. Local basaltic sandstone and conglomerate beds
- **Tczv** — Basalt flows, basaltic sandstone, basaltic conglomerate, interbedded with sandstones, siltstones, and coals
- **Tczp** — PeEll volcanics, basalt flows

Northcraft Formation
- **Tn** — Andesite and porphyritic basalt lava flows, pyroclastic rocks, flow breccias, basaltic conglomerate, and sandstone

McIntosh Formation
- **Tmcu** — Dark-gray to light-olive gray foraminiferal massive to bedded tuffaceous siltstone and claystone. Contains interbeds of massive pebbly arkosic and basaltic sandstone
- **Tmcl** — Regularly bedded basaltic tuffaceous sandstone and siltstone, bedded water-lain tuffs, massive tuff, and tuff-breccia, and thin lenticular basalt flows

Crescent Formation
- **Tcr** — Massive porphyritic augite basalt with pillow structure; locally, near top of sequence, microcrystalline basalt flows are interbedded with pyroclastic rocks and tuffaceous and basaltic sedimentary rocks

Montesano Formation
- **Tm** — Friable, light-olive-gray to yellowish-gray, well-sorted, fine- to coarse-grained sandstone, commonly cross-bedded with thin interbeds of conglomerate, tuff fragments

Wilkes Formation
- **Twk** — Thin-bedded to massive, tuffaceous, carbonaceous, clay, siltstone, sandstone and conglomerate; chiefly of lacustrine and fluvial origin contains beds of fossil wood

Volcanics, unspecified
- **Tv** — Black aphanitic to finely porphyritic basalt, vesicular in part and jointed; porphyritic generally, platy andesite

Toutle Formation
- **Tto** — Massive dark greenish-gray fossiliferous basaltic sandstone and conglomerate with a few tuffaceous siltstone and lapilli tuff beds. Calcareous nodules and beds locally present. Contains lignite coal beds and high-alumina clay deposits. Locally contains interbedded basalt flows

Hatchet Mountain Formation
- **Tha** — Massive flows, flow breccias, tuff breccias, tuffs, and associated pyroclastic sedimentary rooks. Rock sequence thickens rapidly from north to south and from west to east

Skookumchuck Formation
- **Tsk** — Massive to thin-bedded arkosic sandstone and siltstone containing interbedded carbonaceous material; coal beds near top and base of formation. Sandstone locally fossiliferous, grading laterally into marine siltstone. Basaltic sandstone and conglomerate beds locally present in lower part of formation. Includes fissile tuffaceous siltstone which crops out in west-central part of area

INTRUSIVE IGNEOUS ROCKS

Oligocene

Intrusive igneous rocks
- **Ti** — Fine- to coarse-grained dikes and sills of basaltic and gabbroic composition

LEGEND

- Contact
- Axis of syncline, showing plunge; dashed where approximately located, dotted where concealed
- Axis of anticline, showing plunge; dashed where approximately located, dotted where concealed
- Strike and dip of beds
- Fault; approximately located, dotted where concealed, U - upthrown side; D - downthrown side
- Test well for oil or gas

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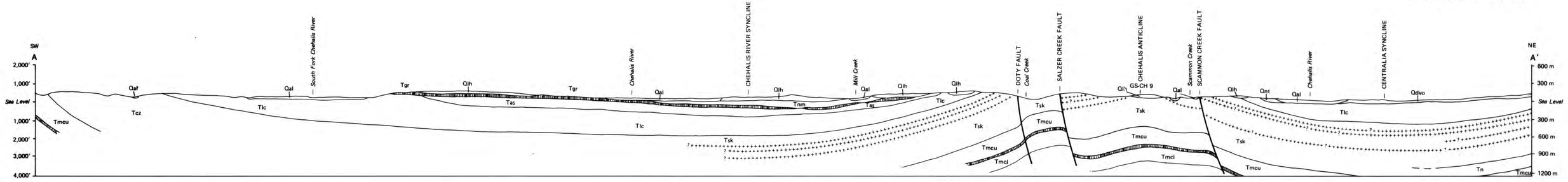
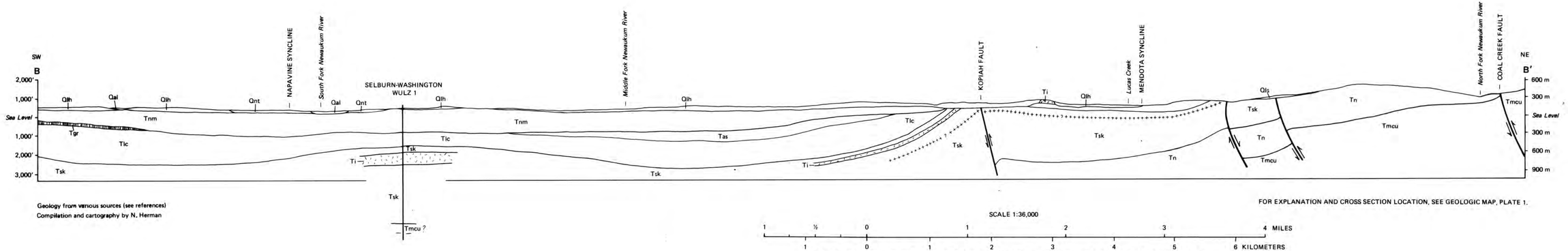
PLATE 2 OPEN FILE REPORT 85-3





Geology from various sources (see references)
Compilation and cartography by N. Herman

FOR EXPLANATION AND CROSS SECTION LOCATION, SEE GEOLOGIC MAP, PLATE 1.

SCALE 1:36,000

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CROSS SECTIONS OF LEWIS COUNTY SITE

by R. Lasmanis and T. Hall

June 1985

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
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ART STEARNS, Supervisor

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A GEOLOGIC FEASIBILITY STUDY FOR THE
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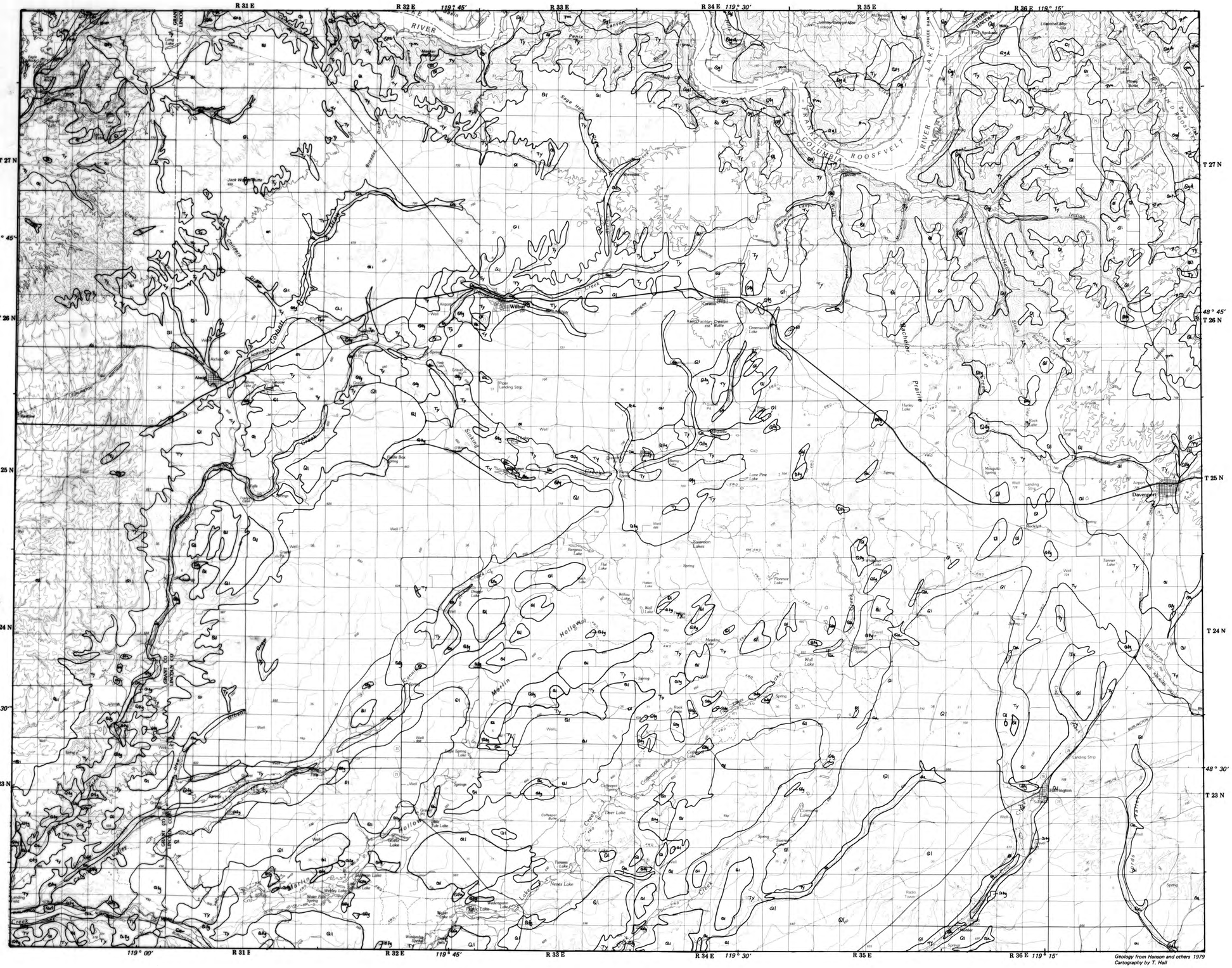
PLATE 3 OPEN FILE REPORT 85-3



EXPLANATION

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

QUATERNARY — Holocene

Alluvium (Qa)
Primarily stream deposits of silt, sand, and gravel in floodplains, terraces, and valley bottoms. Includes local lacustrine, paludal, and eolian deposits in depressions

Dune Sand (Qd)
Active and stabilized dunes of predominantly fine to medium sand; mostly quartz and basalt grains reworked from older sedimentary deposits

Landslide Deposits
Unstratified and poorly-sorted clay, silt, sand and gravel deposited by rotational and translational slides and flows

Alluvial Fan Deposits (Qaf)
Primarily unconsolidated sand and gravel. Surface is relatively undissected and exhibits little or no petrocalcic soil development (caliche)

Loess (Ql)
Loess deposits consisting of eolian silt and fine sand up to 75 meters in thickness. Generally not mapped where less than approximately 2 meters thick. Locally contains multiple petrocalcic horizons and tephra beds

QUATERNARY — Pleistocene

Catastrophic Flood Gravels (Qfg)
Predominately coarse gravel and sand deposited by higher-energy waters of catastrophic floods

Terrace and Bar Deposits, Undifferentiated (Qtb)
Glaciofluvial, fluvial, and ice-contact stratified silt, sand, and gravel deposits of various lithologies in terraces and bars

Glaciolacustrine Terrace Deposits (Qgl)
Silt, sand, and gravel deposited in glacial lakes that formed along the Columbia River and its tributaries. Surface of the terraces may exhibit local modification by fluvial and catastrophic floodwaters

Glacial Deposits (Qgd)
Till, outwash, and ice-contact stratified deposits in moraines, till plains, and meltwater channels and terraces

UNCONFORMITY

TERTIARY — Miocene

YAKIMA BASALTS OF THE COLUMBIA RIVER BASALT GROUP (Ty)
Lava flows of the Saddle Mountains, Wanapum, and Grande Ronde Basalt Formations. Includes sedimentary interbeds of the Ellensburg and Latah Formations, local colluvium, caliche, and widespread thin loess

TERTIARY — Pre-Miocene

Pre-Miocene Rocks, Undifferentiated (pm)
Primarily Precambrian through Mesozoic metamorphic and plutonic rocks, and early Tertiary sedimentary and volcanic rocks

LEGEND

Contact

SCALE 1:100,000

1 ½ 0 1 2 3 4 MILES

1 .5 0 1 2 3 4 KILOMETERS

N

GEOLOGIC MAP OF LINCOLN COUNTY SITE

by R. Lasmanis and T. Hall

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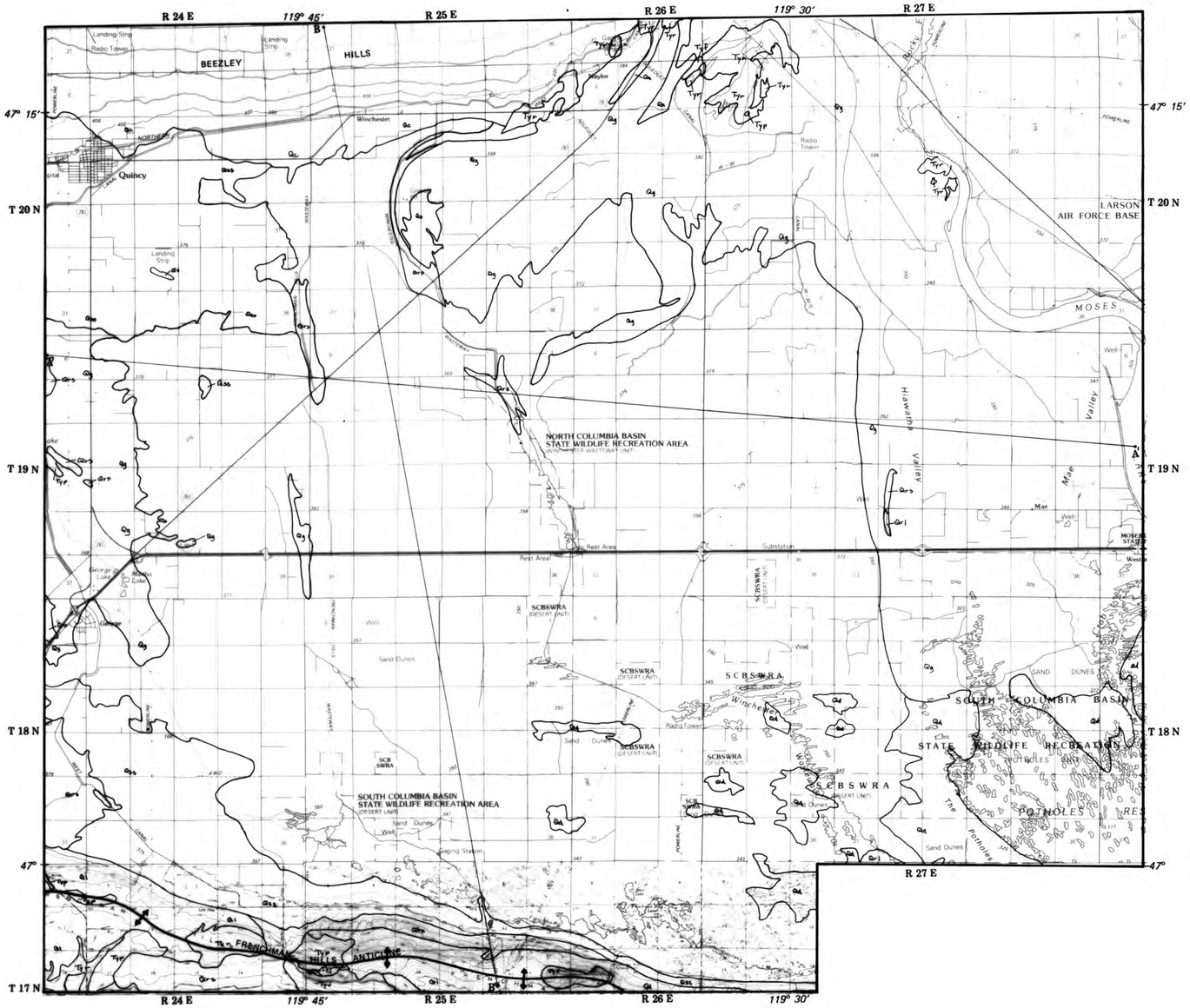
A GEOLOGIC FEASIBILITY STUDY FOR THE
SUPERCONDUCTING SUPER COLLIDER
PLATE 4 | OPEN FILE REPORT 85-3



EXPLANATION

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

QUATERNARY

Holocene

- **Qa** — Alluvium; sand and silt. Includes fossiliferous lacustrine silt and peaty silt
- **Qc** — Colluvium; silt to boulder size; mostly subrounded to angular basalt fragments
- **Qd** — Dune sand; fine to medium sand; mostly quartz, feldspar, and basalt
- **Ql** — Loess; chiefly silt, includes some sand and clay. Consists in part of volcanic ash. Some loess may be older than the glaciolacustrine deposits

Pleistocene

- **Qg** — Fluvial gravel; ranges from boulder gravel to fine sand; generally rounded basalt fragments, but locally contains granitic and metamorphic rocks or caliche and Ringold fragments. Includes older caliche capped gravel
- **Qs** — Fluvial and lacustrine sand; fine to coarse horizontally bedded basaltic sand and silt
- **Qss** — Lacustrine fine sand and silt; buff to light-gray; rhymically bedded or laminated friable sand and silt, which may contain lenses of basaltic sand and gravel and ice rafted erratics ranging from boulder to granule size. Cut by numerous laminated clastic dikes

UNCONFORMITY

Ringold Formation

- **Qrs** — Sand and silt; reddish brown to light-gray, poorly consolidated, tuffaceous, largely eolian

UNCONFORMITY

TERTIARY

Miocene to Pliocene

YAKIMA BASALT OF THE COLUMBIA RIVER BASALT GROUP

- **Typ** — Priest Rapids Member; grayish black when fresh, red brown when weathered; medium- to coarse-grained; large columns common
- **Tyr** — Roza member; one or two flows, dark blue gray when fresh, deep red-brown when weathered; medium- to coarse-grained porphyritic; transparent plagioclase phenocrysts, lath shaped. Platy parting, mostly normal to axis of columns
- **Tyu** — Yakima Basalt; Undifferentiated

LEGEND

Contact

Axis of anticline, showing plunge, dashed where approximate, dotted where concealed

Well on geologic cross section

N

SCALE 1:100,000

1 ½ 0 1 2 3 4 MILES

1 .5 0 1 2 3 4 KILOMETERS

Geology from Grolier and Bingham 1971
Cartography by T. Hall

GEOLOGIC MAP OF GRANT COUNTY SITE

by R. Lasmanis and T. Hall

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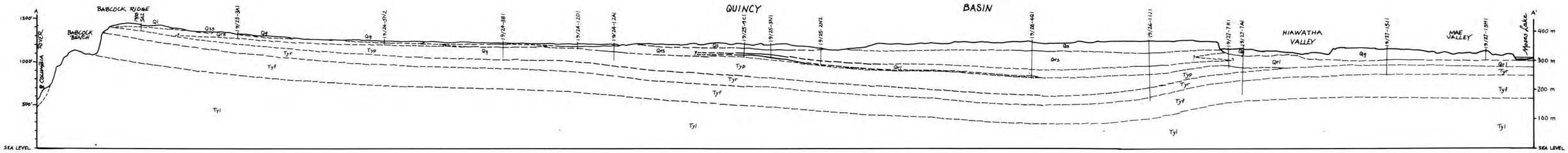
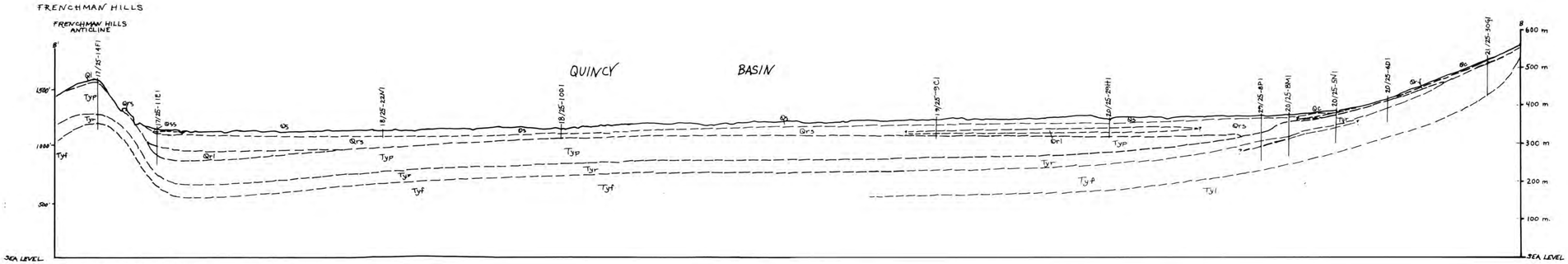
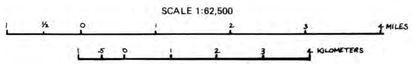
A GEOLOGIC FEASIBILITY STUDY FOR THE
SUPERCONDUCTING SUPER COLLIDER
PLATE 5 OPEN FILE REPORT 85-3







FOR EXPLANATION SEE GEOLOGIC MAP

Geology from Grolier and Bingham, 1971
Cartography by T. Hall

CROSS SECTIONS OF GRANT COUNTY SITE

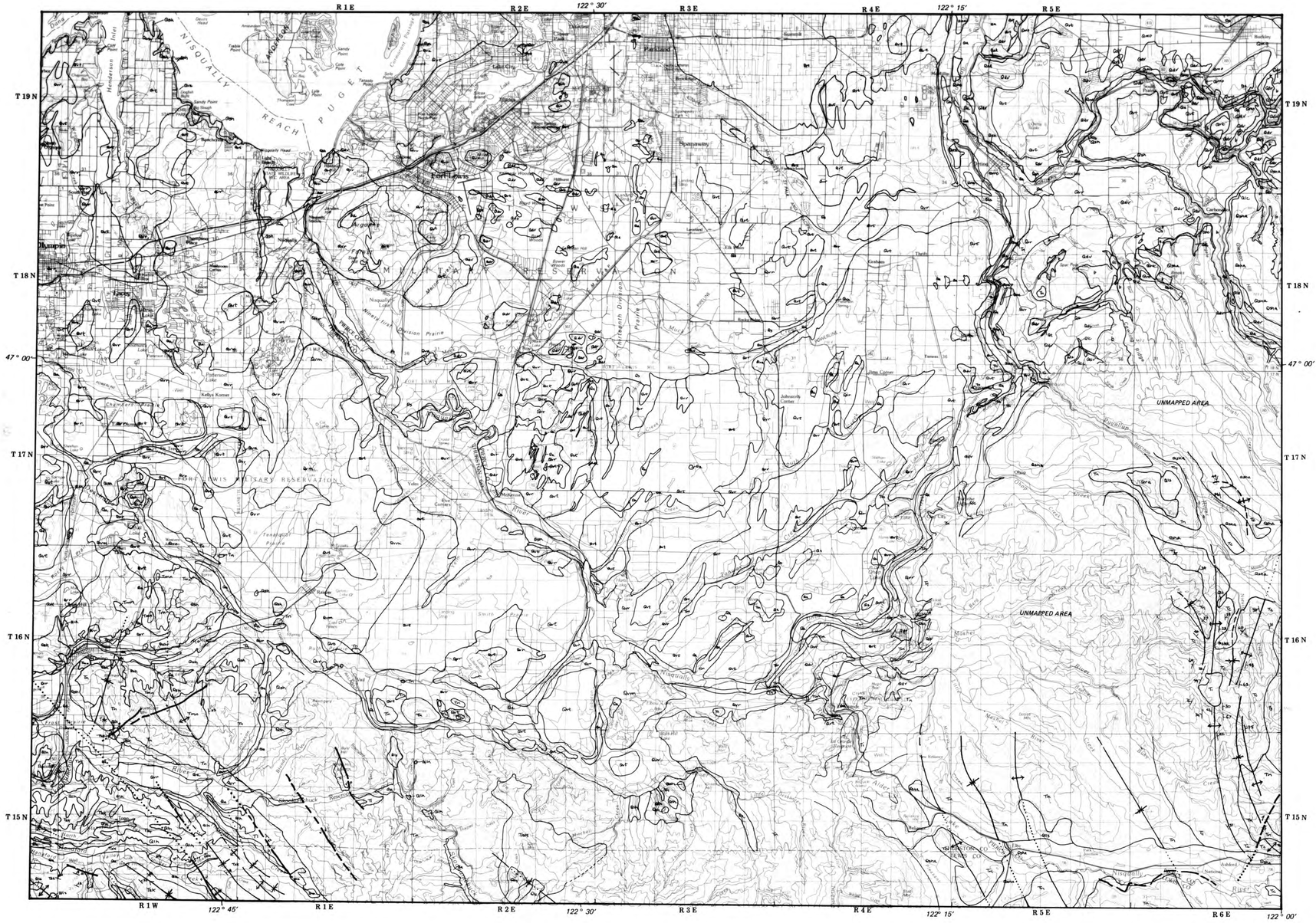
by R. Lasmanis and T. Hall

June 1985

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
BRIAN J. BOYLE, Commissioner of Public Lands
ART STEARNS, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES
RAYMOND LASMANIS, State Geologist

A GEOLOGIC FEASIBILITY STUDY FOR THE
SUPERCONDUCTING SUPER COLLIDER
PLATE 6 OPEN FILE REPORT 85-3



GEOLOGIC MAP OF PIERCE-THURSTON COUNTY SITE

by R. Lasmanis and T. Hall

June 1985

EXPLANATION

SEDIMENTARY AND IGNEOUS ROCKS

QUATERNARY

Holocene

Artificial fill

Qaf — Artifical fill and mine dumps

Landslide debris

Qls — Undifferentiated debris composed of Quaternary and Tertiary rocks

Alluvium

Qa — Gravel, sand, silt along stream courses. Locally includes swamp deposits

Electron mudflow

Qme — Unsorted mixture of andesitic rock fragments in a clayey sand matrix. Derived principally from Mount Rainier

Osceola mudflow

Qmo — Unsorted mixture of andesitic rock fragments in a clayey sand matrix. Derived principally from Mount Rainier

Vashon drift

Debris left from Vashon Glaciation. Mixture consists of till, morraines, and stratified drift deposited by water at ice front

Qvr — Recessional outwash, gravel and sand

Qvrs — Recessional outwash, sand and silt

Qva — Advanced Outwash

Qvm — Morraine

Qvt — Glacial Till

Qdv — Undifferentiated Glacial Deposits

Pleistocene

Terrace deposits

Qt — Sand and pebble to boulder gravel with interbedded silt and clay

Lily Creek Fm

Qlc — Sand and gravel and compact mudflows of Mount Rainier provenance. Wholly or partly altered to clay to depths of 10-50 feet below ground surface

Alderton Fm

Qad — Principally oxidized sand and gravel and very compact mudflows of Mount Rainier provenance, and a few highly compressed peat beds

Pre-Fraser drift of alpine or ice cap origin

Qsha — Deposits left from alpine or ice cap glaciers of Pre-Vashon age. Deposits consist of till and stratified drift

Pre-Fraser drift of continental origin

Qsh — Deposits left from Puget Lobe Glaciations of Pre-Vashon age. Deposits consist of till, morraines, and stratified drift deposited at ice front by water

Logan Hill Fm

Qlh — Glaciofluvial deposits consisting of gravel, sand, and silt with some till. Decomposed gravels chiefly of locally derived porphyritic volcanic rocks; unit weathered and iron stained in upper 30-60 feet

UNCONFORMITY

TERTIARY

Miocene

Mashel Fm

Tm — Clay, sand, and lignite in upper part. Medium to coarse grained, poorly cemented gravel in lower part

Oligocene

Lincoln Creek Fm

Tuffaceous Siltstone Member

Massive gray tuffaceous marine siltstone and fine-grained tuffaceous sandstone. Few persistent calcareous beds and tuff beds

Basaltic Sandstone Member

Tl — Massive dark-greenish gray fossiliferous basaltic sandstone with a few tuffaceous siltstone beds and basaltic conglomerate

Eocene

Spiketon Fm

Ts — Alternating beds of gray to brown micaceous arkosic sandstone, siltstone, shale carbonaceous shale and coal. Intertongues with Northcraft

Skookumchuck Fm

Tsk — Massive to thin bedded arkosic sandstone and siltstone containing interbedded carbonaceous material; coal beds near top and base of formation. Sandstone locally fossiliferous grading laterally into marine siltstone. Basaltic sandstone and conglomerate beds locally present in lower part of formation

LOCAL UNCONFORMITY

Northcraft Fm

Tn — Andesite and basaltic flows, pyroclastic flows, basaltic conglomerate and sandstone. Rock sequence thickens east to west

Carbonado Fm

Tc — Interstratified, light colored beds of micaceous sandstone, siltstone, mudstone, carbonaceous shale and coal

BASE NOT EXPOSED

McIntosh Formation

Tmn — Dark gray foraminiferal tuffaceous siltstone and claystone. Contains interbeds of massive pebbly arkosic and basaltic sandstone in upper and lower parts. Calcareous nodules and thin tuff beds present locally in siltstone.

BASE NOT EXPOSED

INTRUSIVE IGNEOUS ROCKS

Ti — Gabbro and porphyritic basalt

b — Bedrock

LEGEND

Contact

fault

Dashed where approximately located; dotted where concealed; U - upthrown side; D - downthrown side; arrows show direction of relative movement

Axis of anticline, showing plunge, dashed where approximate, dotted where concealed

Axis of syncline, showing plunge, dashed where approximate, dotted where concealed

Strike and dip of beds

N

SCALE 1:100,000

1 ½ 0 1 2 3 4 MILES

1 .5 0 1 2 3 4 KILOMETERS

Geology from various sources (see bibliography)
Compiled and cartography by T. Hall