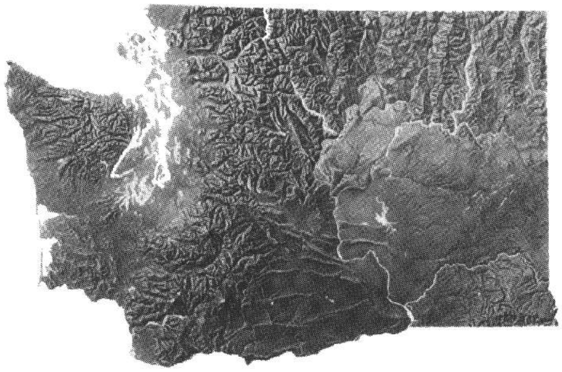
NATURAL RESOURCES



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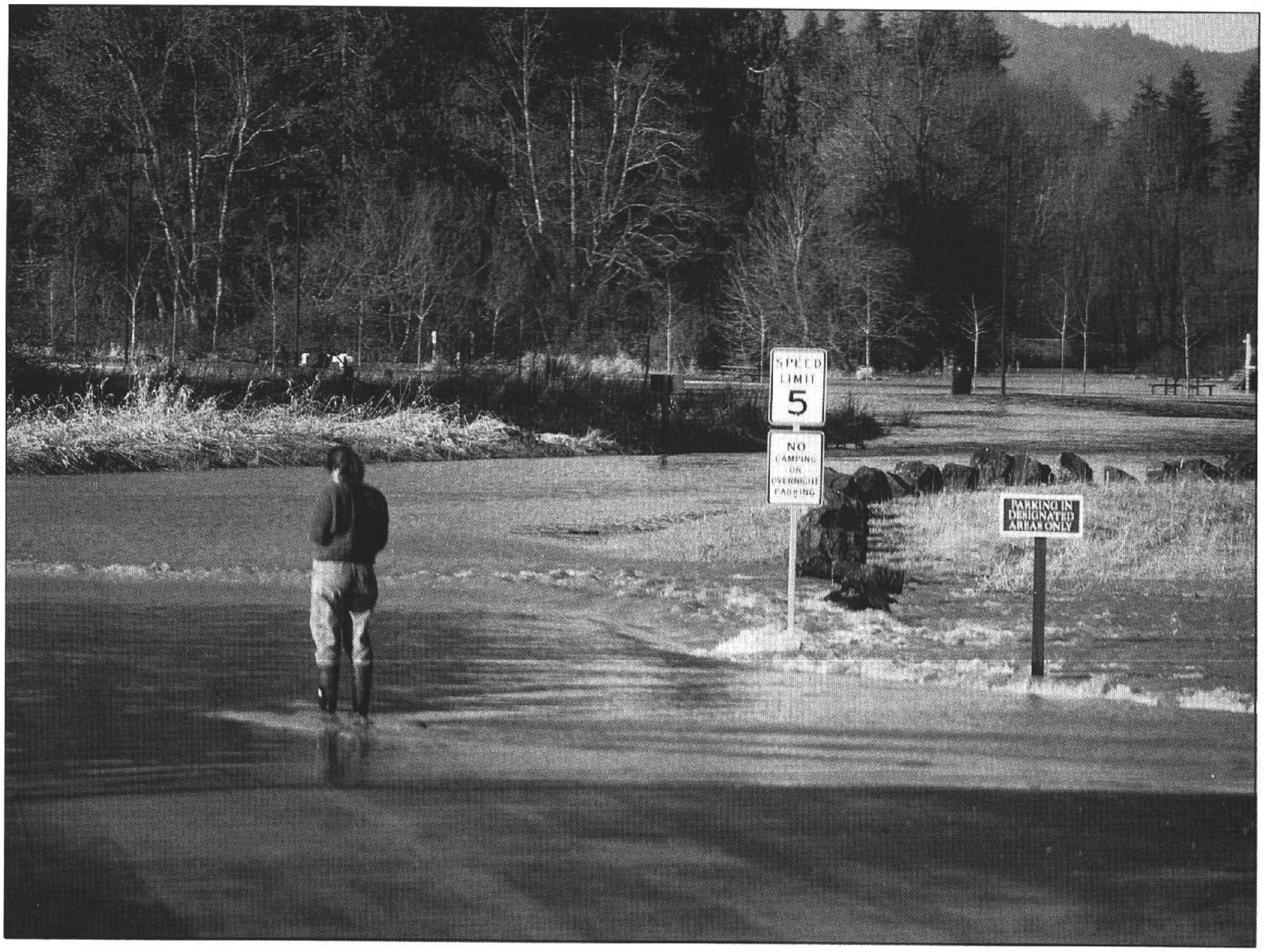

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Natural Resources
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Cover Photo: View to the west of flooding in Pioneer Park in the Deschutes River valley in Tumwater, early February 1996. The river channel runs west to the left of this photo, behind the trees. Note the strong flow to the north, perpendicular to the channel, indicated by the wake off the person's boots. More photos on p. 22.

Division's Geologic Mapping Activities in Transition

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Funding from the National Geological Mapping Act is helping us reach our goal of completing a 1:100,000-scale digital geologic map layer for the state. (For a progress report, see the article by J. Eric Schuster in this issue on page 20.) Washington's State Geologic Mapping Advisory Committee, during its October 8, 1996, meeting, recommended that the division follow the priorities established for our successful submittal for funding for federal Fiscal Year (FY) 96, namely, a program of converting 1:100,000-scale maps to digital ARC/INFO coverage format and a continuing emphasis on 1:24,000-scale geological mapping in areas affected by urban development and projected growth.

Currently 1:24,000-scale geological work is under way in the Spokane and Bellingham areas. In conjunction with our geohydrologic studies covering the Spokane–Rathdrum sole-source aquifer, we are mapping the Mead 7.5-minute (1:24,000 scale) quadrangle.

In the Bellingham area, new 7.5-minute geologic maps are being produced for the Deming and Kendall quadrangles. As per our STATEMAP contract, completion of these projects is expected by the end of June 1997.

During their October 1996 meeting, the State Geologic Mapping Advisory Committee endorsed for detailed geologic mapping the following 7.5-minute quadrangles for federal FY97: in the Spokane area, the Dartford quadrangle; in the Bellingham area, the Bow and Alger quadrangles; and, near Port Angeles, the Sequim quadrangle. The committee also recommended a proposal to digitize an additional eleven 1:100,000-scale quadrangles. Our proposal for funding of these projects under the National Geologic Mapping Act was submitted to the U.S. Geological Survey on October 30.

We project that by the end of calendar year 1997 we will have achieved a major milestone by having total geologic state coverage at a scale of 1:100,000. At that time we can direct even more division resources at detailed geological mapping to address societal needs while completing digital ARC/INFO coverage of the state at the larger scale. ■

Second Symposium on the Hydrogeology of Washington State

This symposium is scheduled for August 25–27, 1997, at The Evergreen State College in Olympia. Deadline for abstracts for oral and poster presentations is April 1, 1997. Instructions will be available in January 1997. Coordinators and volunteers are needed for the technology and trade show, field trips, and workshops.

For more information, please e-mail Nadine Romero at nrom461@ecy.wa.gov or phone (360) 407-6116, fax (360) 407-6903, or mail to the Department of Ecology, PO Box 47600, Olympia, WA 98504-7600. Watch the Ecology web page for updates: http://www.wa.gov/ecology/.

Geohydrologic Review of the Cedar River Ground-water Basin

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INTRODUCTION

In recent decades it has become increasingly clear that supplies of easily obtainable surface water for urban use are reaching their limits. Competing water allocation demands for fisheries and by environmental protection have curtailed development of several water-resource projects, such as the City of Bellevue's plans for a dam on the Middle Fork Snoqualmie River. Interest in ground-water resources is increasing, as deep-resource investigations like recent studies in the North Bend area show. The current Washington State Department of Ecology moratorium on allocating and developing ground water demonstrates how critical it is to acquire comprehensive ground-water information.

Western Washington has several underexplored sedimentary basins that contain thick unconsolidated sediments, which are potential targets for ground-water development. One such basin lies along the middle and lower Cedar River, between Landsburg and Renton. Several water districts already tap this resource or have plans to do so, including the City of Renton, the Cedar River Water and Sewer District, and King County Water District 90. In addition, several hundred domestic and irrigation wells have been drilled in the basin.

The Cedar River basin in southwest King County lies south and east of the City of Renton (Figs. 1 and 2). The area covered in this investigation is defined roughly on the south and west by the Cedar River below Trude. The east boundary of the study area is Issaquah Creek, its tributary Carey Creek, and Walsh Lake. The May Creek valley delimits the north side of the basin, and the downstream basin boundary is defined roughly by Interstate 405. The basin lies within five townships: T23N, R5–7E and T22N, R6–7E.

To date, most wells in the basin draw water from only the uppermost 100 to 200 ft of sediments, leaving deeper strata of a total sequence of 700–1,000 ft of material relatively untouched and unexplored. Few drill holes penetrate below 200 ft, and fewer borings reach bedrock. Only one published study (Luzier, 1969) has attempted to outline the basin and characterize its deep sediments.

The purposes of this paper are to summarize the available data for the basin, to outline the limits of the basin, to suggest possible models for its formation, and to identify possible studies to expand knowledge of the ground-water resources in the basin. We offer a template (or perhaps target) as a starting point for future discussion and study of the stratigraphy and ground-water resources of the area.

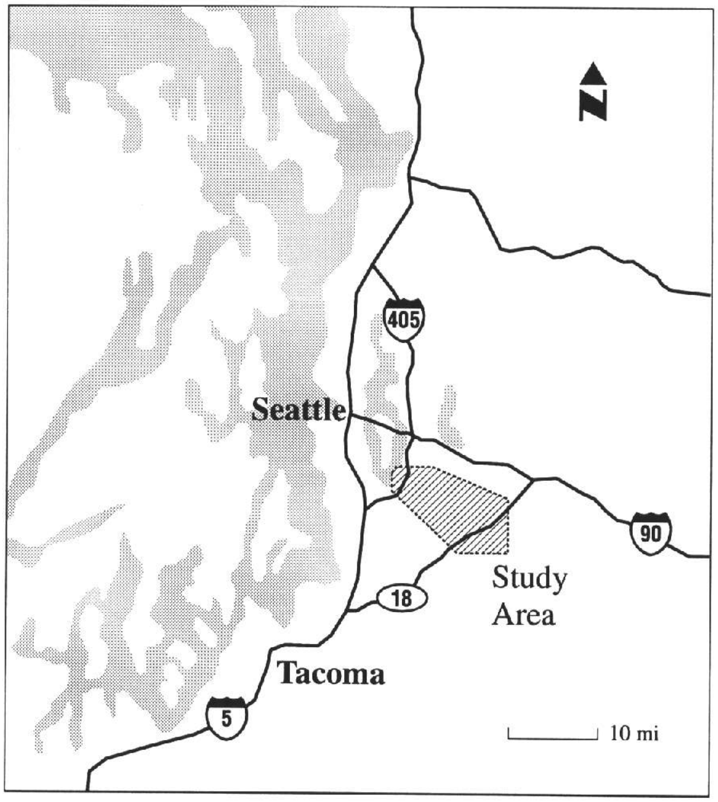


Figure 1. Location of the Cedar River basin.

STUDY METHODS

The initial research for this report was done as part of a Wellhead Protection Plan developed for King County Water District 90 (Evans and Jensen, 1996). To add to this database, we collected all borehole well logs available from the Ecology files. Initially, we ignored all borings less than 100 ft deep. As the study progressed, we began to set aside borings less than 200 ft deep, except those carefully logged by a knowledgeable driller or containing essential information or that were the only boring in a critical location. If specific information about the well location was lacking and if other wells were present nearby, the log was not used.

All logs in the Ecology files contain quarter-quarter section location data, and many logs have street address information. We plotted the borehole locations for the logs collected on a base map, using addresses and (or) other information with the logs, cross referenced with road maps of the study area. Figure 2 shows the locations of the selected wells.

The selected logs were reviewed for stratigraphic information to identify tight (aquitard) and water-bearing units. Where possible, correlations were made between borings in order to define stratigraphic units and develop cross sections. However, the quality of the present data allows only the most preliminary cross sections and stratigraphic interpretations.

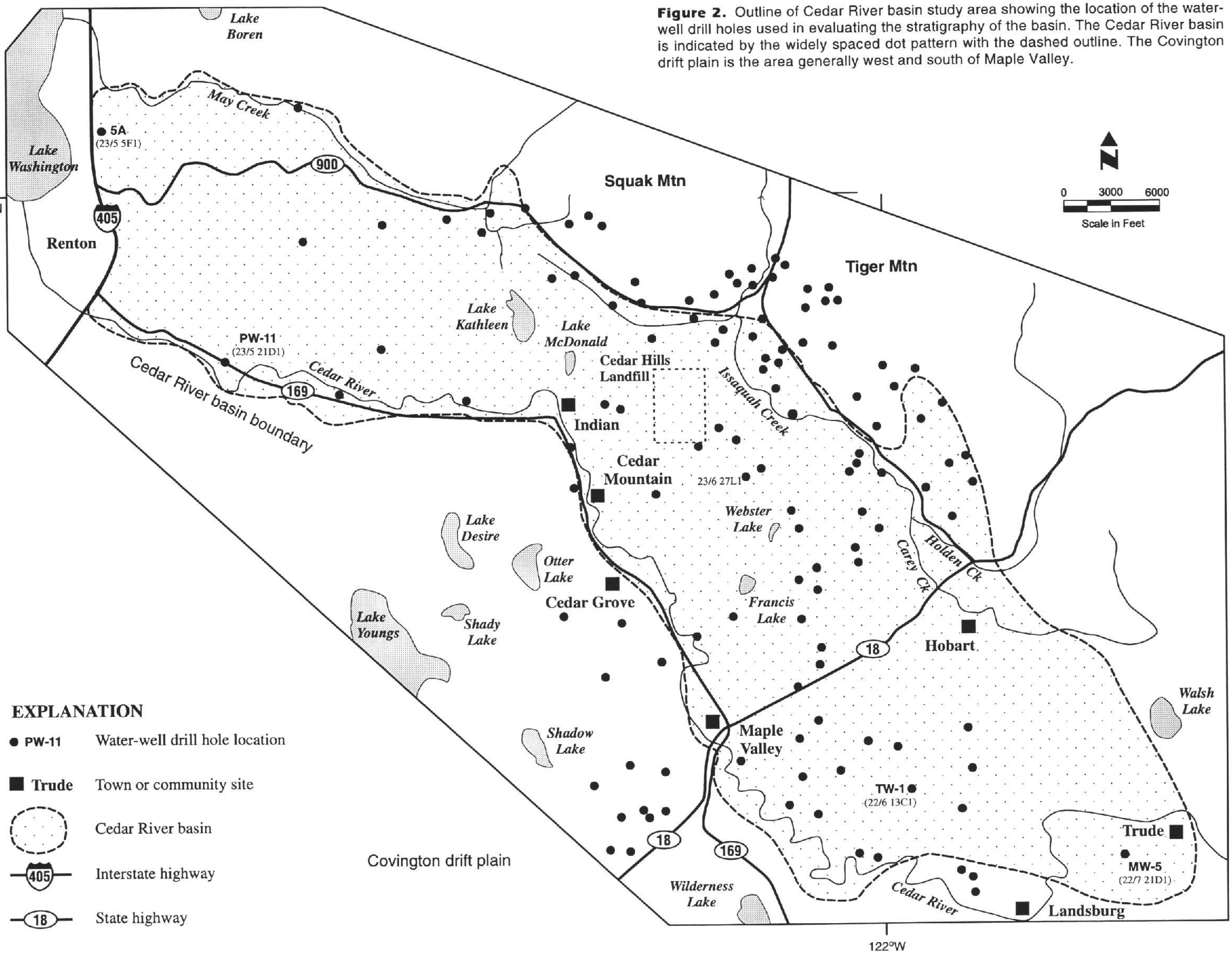


Figure 2. Outline of Cedar River basin study area showing the location of the water-well drill holes used in evaluating the stratigraphy of the basin. The Cedar River basin is indicated by the widely spaced dot pattern with the dashed outline. The Covington drift plain is the area generally west and south of Maple Valley.

In addition to the well logs, we examined other data, including geologic maps, such as those by Walsh (1983, 1984), Booth (1995), Rosengreen (1965), Vine (1962), and Mullineaux (1970). We reviewed ground-water studies by Luzier (1969) and Woodward and others (1995), as well as various reports by King County, the Seattle-King County Health Department, and several water districts in the area. Geophysical studies provided some insight to the thickness of the sediments and the tectonic setting of the basin. The reports used are listed in the references section.

DESCRIPTION OF THE STUDY AREA

In the Cedar River aquifer area, annual rainfall ranges from approximately 40 to 50 in. in the lower reaches of the basin to 80 in. near the Cascade foothills (Brown and Caldwell, unpub. data, 1979). Rainfall is concentrated November to April.

The Cedar River basin contains rolling glacial upland areas that are incised along the edges by modern river and creek valleys. Late Pleistocene proglacial drainage channels cut across the grain of the uplands, most notably through the Cedar Grove area and bedrock of Tiger Mountain. The elevation of the uplands, a series of elongate, glacially shaped southeast-trending ridges, is approximately 500 to 700 ft. The Cedar River gathers most of the surficial waters from the south side of the basin area, chiefly from short, steep tributaries. The Hobart area, in the northeast portion of the basin, is drained by Carey and Issaquah Creeks. May Creek drains most of the East Renton plateau on the northwest.

The Cedar River is the largest stream in the study area. It discharges into the Lake Washington valley at Renton, where the flood plain is about 60 ft above sea level. The flood plain west of the Cedar Hills Landfill is roughly 2,200 ft wide and fairly level. Steep bluffs border the valley to the north and south. Near the old mining town of Cedar Mountain, the river turns south and is narrowly confined between bedrock walls; the river bed drops some 200 ft in a mile. Above this water gap and south to Maple Valley, the valley widens again to more than 2,000 ft. From there the valley turns east into the Cascade mountains. The valley walls slope generally about 30°. Side valleys locally breach the valley wall, and alluvial fans have built up on the flood plain. Terraces locally border the valley.

May Creek valley is flat and boggy in its upper reaches. The marshes are up to 1,500 ft wide and occupy the upper one-third of the stream's length. The creek begins to be incised where Coal Creek Road crosses it, south of Lake Boren, and is a deep valley where it discharges into the Lake Washington valley.

The area around Hobart is also broad, rolling terrain, with marshes and meadows. Its south portion is drained by Carey Creek, which joins with Holden Creek to form northwest-flowing Issaquah Creek. Issaquah Creek breaches the bedrock ridges of Tiger and Squak Mountains through a water gap carved by glacial outwash waters.

Land Use in the Project Area

Homesteaders arrived in the late 1800s and cleared farm lands in 40- to 80-acre parcels (King County Dept. of Public Works, 1993). As the lower Cedar River area was cleared of old-growth timber in the 1800s and early 1900s, settlement expanded. Agriculture then dominated much of the basin, and dairy farms became established in parts of the lower Cedar River basin, particularly on the wide flood plains immediately east of Renton.

Several coal mines were opened on prospects surrounding the hamlet of Cedar Mountain. The original prospect was found and developed in 1884. In 1918, coal was found north of Lake Desire, south of the basin boundary. The mine opened on these seams, called the New Black Diamond Mine, was once the largest coal mine in the state. Other coal prospects were worked in the upstream reaches of the basin, especially around Landsburg.

Today, the land use is primarily residential and low-intensity agricultural, with some light industry and commercial sites. Some high-density single-family development has occurred on the East Renton plateau, especially around Lake Kathleen and in the East Renton highlands (King County Dept. of Public Works, 1993, map 3). Maple Valley also contains small high-density developments. Most of the remaining area is zoned for low-density single-family developments or has stands of second growth forest. Several landfills have been developed in hollows between the glacial ridges, including the closed Hobart Landfill and the giant Cedar Hills Landfill.

Physiography of the Basin

The Cedar River hydrologic basin occupies a roughly hook-shaped trough between bedrock exposures. From Renton to Cedar Hills Landfill, the basin is about 15,000 to 17,000 ft wide. The basin is narrowest, about 10,000 ft, where it curves south near Lake McDonald–Cedar Hills Landfill. The southeast portion of the basin gradually broadens out to as much as 25,000 ft near its southern boundary.

The basin is closely confined along the May Creek–Issaquah Creek boundaries by the prominent bedrock outcrops of Squak Mountain, Tiger Mountain, and associated ridges. Well logs and profiles prepared for the Issaquah Creek ground-water study (Seattle-King County Environmental Health Div., 1994) show that bedrock is shallow beneath the creek. The south boundary between Renton and Cedar Hills Landfill is marked by the bedrock ridge beneath Lake Desire. The south boundary between Maple Valley and Walsh Lake is also closely constrained; bedrock crops out or shallowly underlies the area south of the Cedar River from Lake Wilderness into the foothills.

The west boundary of the basin between Maple Valley and Cedar Mountain is more open. According to interpretations by Woodward and others (1995, profile section D-D′), bedrock is as much as 100 ft below sea level. However, Booth (1995) suggests that the threshold of bedrock along this margin is at an elevation of 200 ft. Resolving of this difference has important hydrologic implications, which are discussed later. The basin is also open in the Renton area, where it connects with the deep trough of the Kent Valley–Lake Washington basin.

Geophysical studies of unconsolidated sediments by Hall and Othberg (1974) and Yount and others (1985) skirt the edges of the study area, so the thickness of the sediments and the elevation of the bedrock are interpreted from sparse borehole data. Information in the Brown and Caldwell Cedar River Well Field Phase II report (1980) suggests that bedrock in the Landsburg area is at 45 ft. The basin sediments are 660 ft thick here. Near Maple Valley, the exploratory boring 22/6 13C1 done (TW-1) for the Cedar River Water and Sewer District penetrated 700 ft of sediments. Bedrock was found at an elevation of 30 ft. The basin between Landsburg and Cedar Hills Landfill may have a consistent bedrock interface near sea level.

Luzier (1969) reported that the thickness of the unconsolidated material in the lower Cedar River basin between Renton and Cedar Hills Landfill exceeds 1,000 ft. He reported that a well located on the Cedar River flood plain (NW1/4SW1/4 sec. 23, T23N, R5E) penetrated 665 ft of unconsolidated sediments without reaching bedrock. Assuming a collar elevation of 150 ft (based on the reported location of the wellhead) bedrock here would be more than 400 ft below sea level. Two wells (PW-11 and PW-12) drilled for the City of Renton near the municipal golf course reached bedrock at 364 ft and 348 ft, respectively. These two wells establish a bedrock elevation of roughly 300 ft below sea level near the south margin of the basin. The City of Renton well near the mouth of the basin is 410 ft deep and did not reach bedrock. This well is reported to have been collared at about 160 ft; thus bedrock must be more than 250 ft below sea level.

It is not clear if the Cedar River basin is a single trough with a bedrock floor having a continuous gradient. The picture is further complicated by shallow and exposed bedrock in the Cedar Mountain area and passing beneath the Cedar Hills Landfill. On the basis of current information, we do not know if this bedrock subcrop continues eastward. One borehole (23/6 27L1) in the Cedar Grove channel reported bedrock at an elevation of approximately 160 ft. Other nearby borings did not confirm the bedrock, so the importance of this well log is uncertain. However, if a subsurface ridge of bedrock does run east from Cedar Mountain across the basin, it significantly alters geologic and hydrogeologic interpretations in the area. Foremost, it splits the trough into two deep basins, changing ground-water flow pattern interpretations. The possible extension of a subsurface bedrock ridge also has structural and basin genetic implications, which will be discussed later. It may be better to view the Cedar River area as two separate basins, or at least as a stepped basin.

GEOLOGY AND HYDROGEOLOGY

Bedrock surrounding the basin is mainly of Eocene (40 million years) age. It is overlain by a sequence of glacial and interglacial unconsolidated sediments. Figure 3 shows the surficial distribution of geologic units in the study area and structures important to our interpretation of the origin of the basin.

Bedrock Stratigraphy and Structure

Most of the bedrock in the project area belongs to the Renton Formation of the Puget Group. The formation consists of interbedded sandstone, siltstone, carbonaceous claystone, and coal. It is as much as 2,250 ft thick. The upper half of the formation consists mainly of shale and sandy shale. The lower portion contains numerous sandstone and coal beds. Correlation of coal beds is open to question, but there may be as many as five main coal seams (Walsh, 1983, 1984). The Renton Formation underlies the hills to the south of the basin from Renton to Cedar Mountain. It crops out on both sides of the Cedar River north of the hamlet of Cedar Mountain and passes beneath the glacial ridges of the Cedar Hills Landfill. The Renton Formation also confines the basin south of Maple Valley, in the Lake Wilderness and Trude–Landsburg areas.

Bedrock north of the aquifer basin, in the Lake Boren–Squak Mountain area, mainly consists of volcaniclastic and flow rocks of the Tukwila Formation, which underlies the Renton Formation. Veneered with till and ice-contact materials, these rocks continue east and south to wrap around the upper portions of Issaquah and Carey Creeks. Shallow bedrock and outcrop closes off the upstream end of the basin around Walsh Lake.

The bedrock ridge beneath Lake Desire is the south limb of a southeasterly plunging anticline (Walsh, 1984). The coal seams dip to the south, but numerous small faults disrupt the strata and proved to be a problem for the mining operations. The mines around Cedar Mountain were developed along the axis of the anticline, and most played out where the seams terminated against a fault. The axis of the fold projects into the main portion of the lower Cedar River valley. Immediately downstream of the mine area, at the hamlet of Indian, the axis trace abruptly disappears beneath 700 ft of unconsolidated material.

North of the Cedar River basin, the Tukwila Formation is folded into the prominent Newcastle Hills anticline. The south limb of the fold is onlapped by the glacial sediments of May Creek valley. As the Tukwila rocks wrap around the east side of the basin, they form the Taylor syncline. This structure trends WNW and has associated folds and faults, such as the Sherwood anticline and the Hobart fault (Vine, 1962).

Unconsolidated Deposits

At least four major glaciations have covered the Puget Lowland. The most recent advance was the Vashon Stade of the Fraser Glaciation. During this time, an ice sheet nearly 3,000 ft thick in the project area shaped the rolling upland topography visible today.

The present position and form of the Cedar River area were established during the advance and retreat of the Vashon ice sheet. The elongate drumlinoid ridges that give the area its rolling topography were formed during glacial recession (Booth and Goldstein, 1994). As the ice retreated, a succession of proglacial lakes formed in the Puget basin, linked by a succession of drainage channels. In the Cedar River area, waters draining from glacial Lake Sammamish carved the water gap through which present-day Issaquah Creek leaves the basin, and then flowed south through Hobart and Covington channels, near present-day Maple Valley, and out onto the Covington drift plain (Thorson, 1989; Booth, 1995). The water discharged into glacial Lake Russell, a freshwater body that occupied the area of the present Puget Sound. As the ice pulled back, a new channel opened through Cedar Grove and westward along the present alignment of the Cedar River valley. Waters flowing in this channel deposited large deltas at Cedar Grove and above the mouth of the Cedar River at Renton. At that time the valley floor was 400 ft in elevation at Cedar Grove, declining to 300 ft at Renton. The waters also incised a notch in the bedrock ridge, which fixed the subsequent course of the river by confining it at that location.

With continued ice retreat, the Strait of Juan de Fuca was opened, and Lake Russell drained, to be replaced by the salt water of Puget Sound. The level of the sound was several hundred feet lower than the lake it replaced, and downcutting began in the streams that drained the basin, including the Cedar River. The Cedar River cut rapidly into the glacial sediments

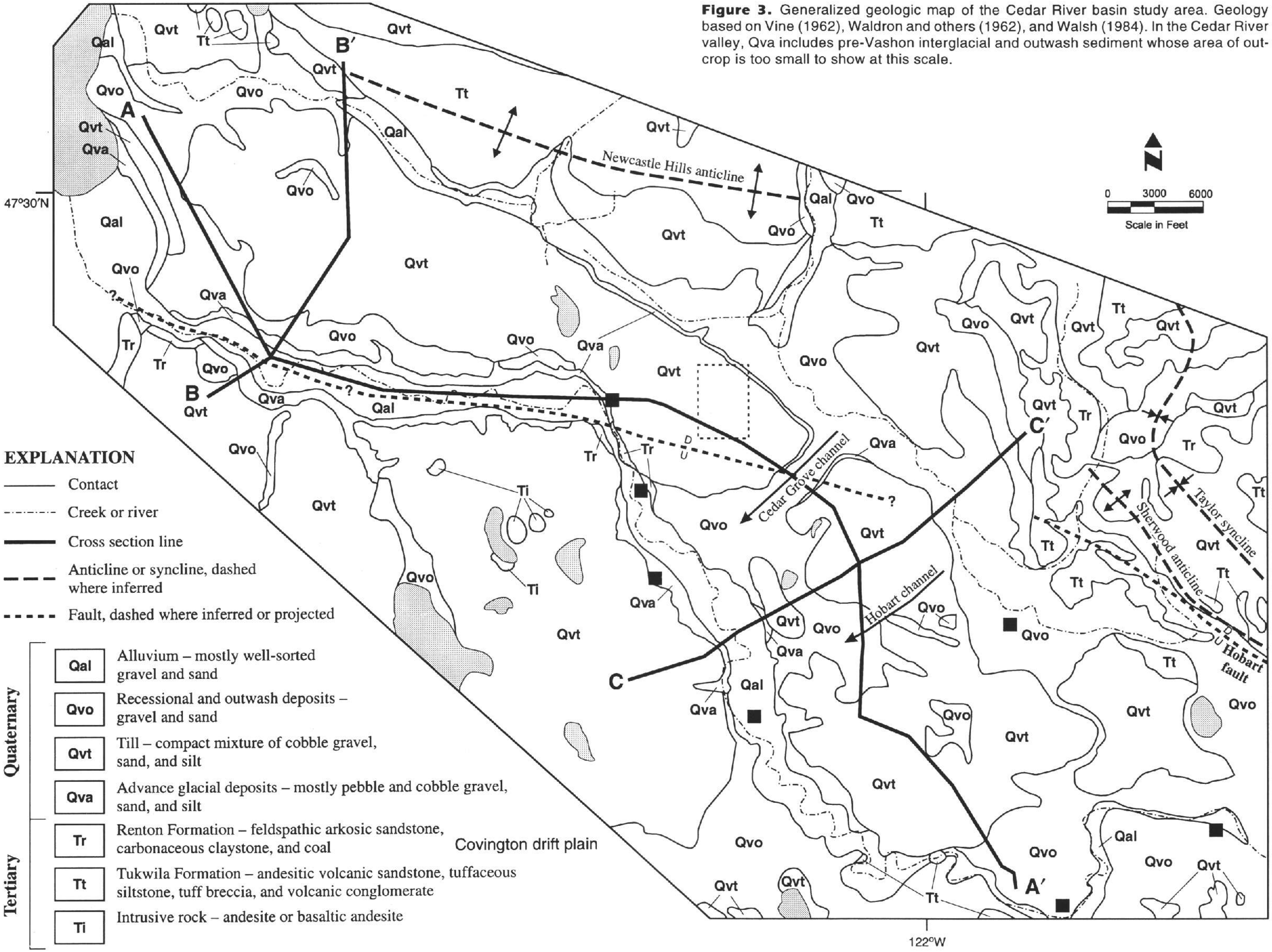
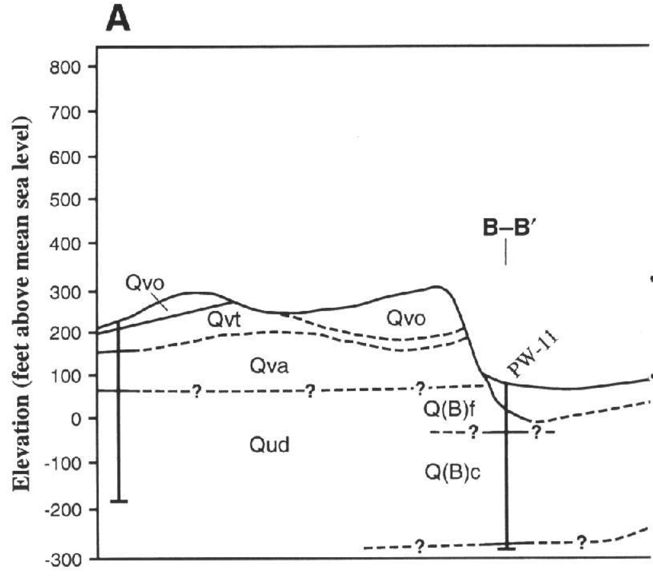


Figure 3. Generalized geologic map of the Cedar River basin study area. Geology based on Vine (1962), Waldron and others (1962), and Walsh (1984). In the Cedar River valley, Qva includes pre-Vashon interglacial and outwash sediment whose area of outcrop is too small to show at this scale.

Figure 4. Schematic cross sections for lines A–A′, B–B′, and C–C′ on Figure 3, showing the relationship of geologic units. Q(A)c, Q(A)f, Q(B)c, and Q(B)f are hydrostratigraphic units after Woodward and others (1995). Qud is undifferentiated unconsolidated sediments. On Figure 3, they are included in unit Qva because areas of outcrop are too small to show at the scale used. Q(A)f and Q(B)f consist mainly of fine interglacial sediments, and Q(A)c and Q(B)c consist mainly of coarse outwash deposits. Other units are explained in Figure 3. Well locations are shown on Figure 2. Several structural configurations are possible for the inferred reverse fault shown in A–A′ and B–B′. The dip shown for faults is diagrammatic; the faults may be south-dipping thrusts. The juxtaposition of Tertiary bedrock and Quaternary sediments suggests that the fault was active at least during the early part of the Quaternary. An equally plausible scenario is that the fault was inactive during the Quaternary and the bedrock formed a fault escarpment or structural high. We prefer the interpretation that movement along the fault continued through the Quaternary.



along the course that had been established during glacial retreat.

The present Cedar River valley appears to have occupied its present course only since the last glaciation. Previously, the river flowed northward through the Snoqualmie River basin (Mackin, 1941; Hirsch, 1975). The ice sheet forced the upper course of the river south, into the filled bedrock valley area, where the river has cut down through a sequence of glacial and interglacial sediments. At least three tills are exposed in the north valley wall west of Cedar Mountain (Luzier, 1969; King County Dept. of Public Works, 1993). Glacial recessional outwash chokes the outwash channels and valleys between glacial ridges.

Fine to coarse alluvial and (or) recessional sediments are sandwiched between the till units. These represent both proglacial and interglacial depositional environments. The proglacial material is chiefly sand and gravel composed of exotic rock material. The interglacial sediments are fine to coarse and contain wood debris and peaty material. Individual beds appear to be lens-shaped and have not been traced laterally for any distance.

STRATIGRAPHY OF THE UNCONSOLIDATED DEPOSITS

For this study, we developed our description of the stratigraphy of the unconsolidated deposits from the log of the test well drilled by GeoEngineers for the Cedar River Water and Sewer District. This well is located east of Maple Valley, along 262nd Avenue S.E. It is designated TW-1 in the report to Cedar River Water and Sewer District and is called well 22/6 13C1 in this report, consistent with Ecology nomenclature. The well is collared at approximately 715 ft elevation. We interpreted the descriptions of the strata penetrated in the well in terms of identifiable geologic units and (or) hydrostratigraphic units for the deeper strata. (See Fig. 5.)

This interpretation was then correlated with other deep borings, as possible. In particular we used the well built for the City of Seattle, MW-5, near Trude (Brown and Caldwell, 1980), collared at 705 ft, which we call 22/7 21D1, and the City of Renton well PW-11, collared at 79 ft, which we call 23/5 21D1. Because 23/5 21D1 is located on the incised Cedar River flood plain, it is low in the section, and its sediments do not correlate with any of the Vashon or other higher strata. Where appropriate, we have also referred to Renton Well 5A (23/5 5F1), which is collared at 236 ft and penetrates possible Vashon strata. Figure 4 shows our interpretation of the stratigraphy and possible correlations. The units we defined based on the log of 22/6 13C1 seem to correspond well to the lithohydrologic units defined by Woodward and others (1995) for use in studying the Covington drift plain.

Recessional Outwash and Holocene Alluvium

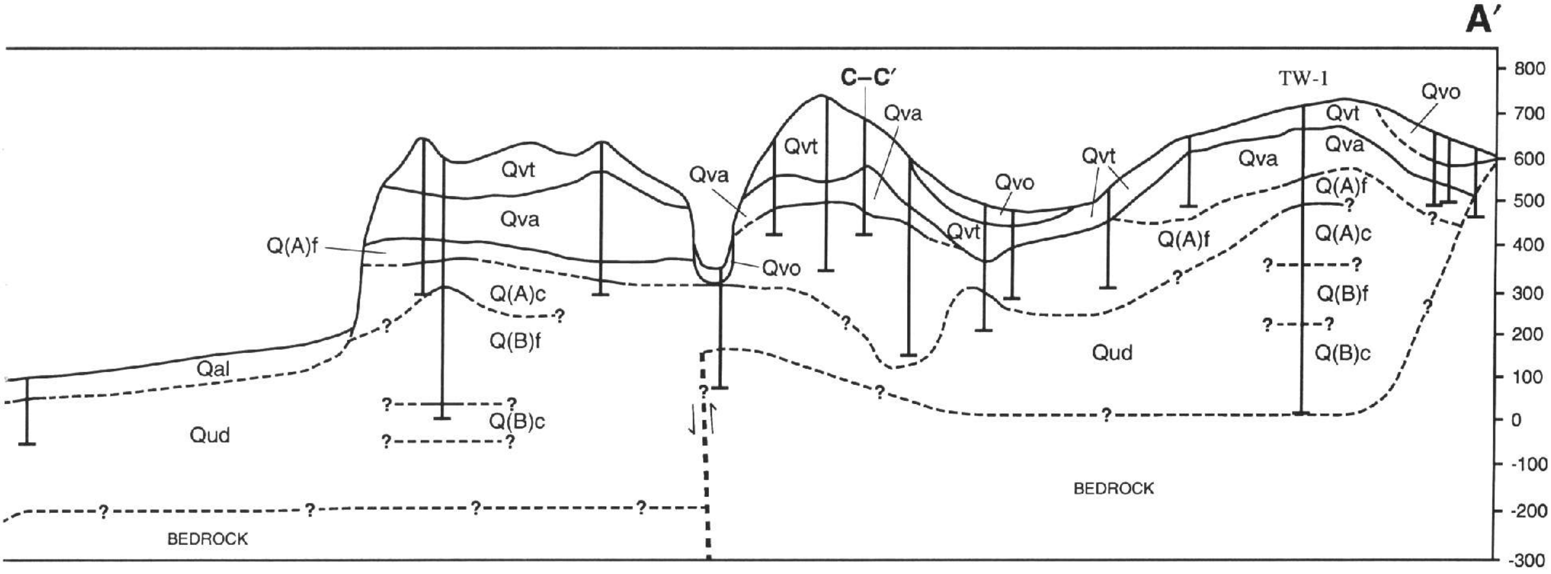
These sediments compose the uppermost aquifer in the basin, which is widely developed for irrigation and domestic water use. It is an unconfined aquifer, and several hundred wells have been drilled into it. However, the focus of this report is the deeper basin.

Till

Mapping by Walsh, Booth, and others indicates that Vashon till underlies the surface near the Cedar River Water and Sewer District well 22/6 13C1 (TW-1). Geotechnical drilling in the area conducted by Evans as part of the Hobart Landfill Leachate Pipeline Project confirms the presence of till there. In well 22/6 13C1, the uppermost till appears to be approximately 60 ft thick and is described as consisting of brown silty sand and gravel with lenses of gray silt. The till either crops out or subcrops throughout the Cedar River basin, except where the river and stream valleys have been incised. It is exposed in the uplands and drumlinoid ridges and is buried beneath the recessional outwash in the hollows between uplands. In the City of Seattle well 22/7 21D1 (MW-5), this till appears to occur between 62 and 115 ft (see Fig. 5). In the City of Renton log for 23/5 21D1 (PW-11), this unit is not present. However, in well 23/5 5F1 (5A) a blue and a gray till layer occur between 0 and 67 ft, one or both of which may be Vashon in age. The unit is the same as Woodward and others' (1995) Qvt till.

Uppermost Aquifer—Advance/Recessional Alluvium

Between 60 and 148 ft, well 22/6 13C1 (TW-1) penetrated a unit described as gray coarse sand with fine gravel and lenses of silt. We interpret this stratum as Vashon advance outwash, but we do not correlate it with the Esperance Sand of the Seattle area because it occurs at a higher elevation. Except for



EXPLANATION

Contact, dashed where inferred

Drill hole location

Fault, dashed where inferred

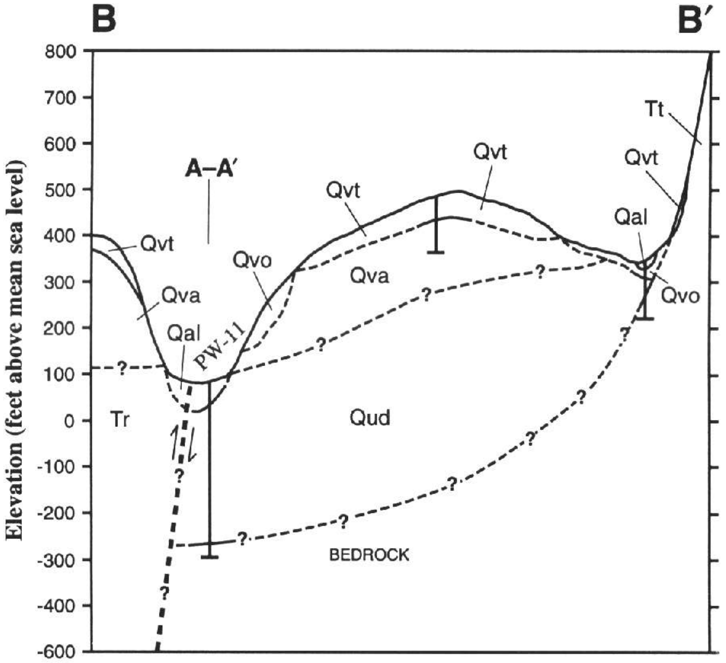
Qud Undifferentiated, unconsolidated sediments; locally contains pre-Vashon deposits, including underlying fine interglacial and coarse outwash sediments

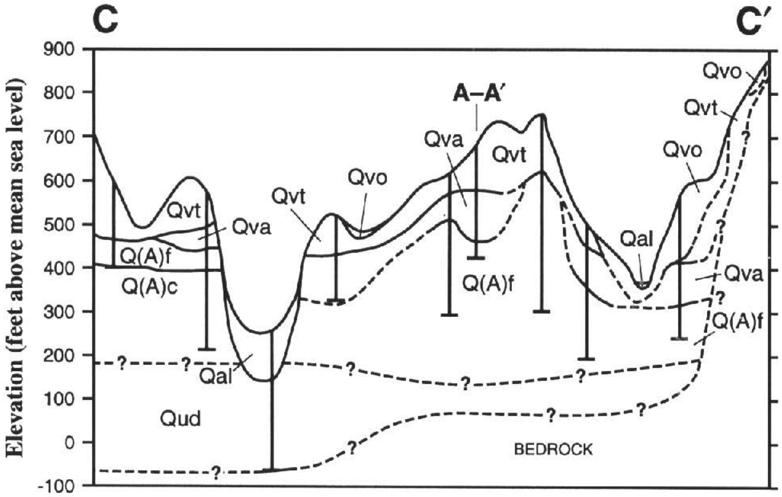
Q(A)f Upper unit, mostly fine interglacial sediments

Q(A)c Upper unit, mostly coarse outwash deposits

Q(B)f Lower unit, mostly fine interglacial sediments

Q(B)c Lower unit, mostly coarse outwash deposits





modern alluvium and (or) recessional outwash, this is the uppermost aquifer unit in much of the Cedar River basin. Because it is below the till, it is generally at least semiconfined. In 22/7 21D1 (MW-5), this unit appears to be thicker, occupying the zone between 115 and 247 ft. This unit also has no counterpart in either of the Renton borings, but it corresponds with Woodward and others' (1995) Qva aquifer.

Glaciolacustrine Units

Gray silt and clay, typical of glaciolacustrine strata, were found in 22/6 13C1 (TW-1) between 148 and 200 ft. We interpret this unit as being equivalent to the Vashon glaciolacustrine unit termed the Lawton Clay. In well 22/7 21D1 (MW-5), the corresponding unit occurs between 247 and 345 ft, making this unit appear thicker in the City of Seattle well (as was the outwash unit). However, the 22/7 21D1 log describes several individual beds within the clay unit, and further studies may revise the stratigraphy and correlations. In well 23/5 5F1 (5A), the layers that might correlate with this unit contain abundant wood and are not likely to be glaciolacustrine. (One of the authors, however, has recovered isolated wood pieces from Lawton clay beneath the Seattle Center.) This bed can be identified with Woodward and others' (1995) Q(A)f unit.

Deeper Units

Below the Vashon units, correlation of the units with named formations becomes even more difficult. In general, interglacial materials can be positively identified where the unit contains organic constituents and (or) the lithologies appear to be locally derived. In general, we have attempted to separate glacial from nonglacial and aquifers from aquitards. Our correlations in Figure 5 are tenuous pending further study.

In 22/6 13C1 (TW-1), the beds between 200 and 370 ft consist of brown to gray silt and clay, silty sand and gravel, fine to medium sand with some gravel, and silty fine to medium sand with a minor amount of gravel. The interval is reported to be water bearing, especially from 260 to 292 ft, and we tentatively interpret it as representing interglacial alluvial sediments. Although no definitive markers are reported in the lithologic description, the general impression is one of a material stratified more like alluvium than glacial outwash. This unit does not appear to correlate with any beds in 22/7 21D1 (MW-5) near Trude, but it may be represented in Renton well 23/5 5F1 (5A) by water-bearing sand and gravel between 280 and 407 ft. The unit is likely the same as Woodward and others' (1995) Q(B)f strata.

An 85-ft-thick aquitard unit is found between 370 and 455 ft in 22/6 13C1 (TW-1). The unit is described as consisting of gray silt to silty clay and may be either glacial or interglacial. We suggest that this bed connects with one or more of the beds of silt and clay in 22/7 21D1 between 345 and 660 ft. We interpret the silty clay unit found in 23/5 21D1 between 78 and 116 ft as equivalent with this bed, as is Woodward and others' (1995) Q(B)f strata.

The deepest major unit penetrated in 22/6 13C1 consists of gray fine to coarse gravel or gravel with sand and contains sporadic silt lenses and wood fragments. The unit is water bearing and has no counterpart in 22/7 21D1. At present, we correlate the unit with the sand and gravel aquifer between 271 and 364 ft in Renton well 23/5 21D1 and with Woodward and others' (1995) Q(B)c unit.

Below this aquifer, a thin (20 ft) layer of gray silty gravel and silt overlies bedrock.

Distribution of the Units

As difficult as it is to define and correlate stratigraphic units, it is even more difficult to establish areal distribution of the strata. The problem is made more complicated still by the uncertainty as to there being one basin or two. In general, borehole logs in the Issaquah Creek–May Valley areas tend to report thick sequences of clay materials, similar to those found in the City of Seattle well 22/7 21D1 (MW-5). Water-bearing units appear to be more numerous along the Cedar River side of the basin. However, units are likely discontinuous, and a more complete interpretation awaits further study.

ORIGIN OF THE BASIN

As described above, the Cedar River hydrologic basin lies in a deep bedrock valley, the genesis of which is unclear. One interpretation, that it was carved by river and (or) glacial erosion, presents some problems, especially for the lower basin between Cedar Hills Landfill and Renton. First, the floor of the valley lies well below sea level, suggesting that riverine excavation of the basin (without tectonic assistance) during the Quaternary is unlikely. Eustatic sea level was low enough for river erosion to take place only during glacial maxima, when the area was buried by ice. In addition, the ancestral Cedar River may not have flowed through this area, so what river was large enough to excavate the basin?

A second explanation for the genesis of the basin, glacial erosion, gets around the issue of sea level. Certainly, glaciers were a major force in shaping the trough and forming the basin's recent topography. Glacial action may well have been the major factor in the genesis of the upper basin, south of Cedar Hills Landfill. Here the axis of the basin is roughly parallel to the direction of glacier retreat as indicated by the drumlinoid ridges that form the upland topography. However, the axis of the basin between Cedar Hills Landfill and Renton lies across the line of glacial flow, and the basin is protected to the north and south by high bedrock hills.

The bedrock outcrop on the north exposes the Newcastle Hills anticline, and bedrock dips under the basin sediments. To the south of the Cedar River, the coal mines of the Cedar Mountain and Lake Desire area were developed along the nose of a southeastward plunging anticline (Walsh, 1983; Washington Division of Geology and Earth Resources coal mine map collection). Many mine galleries end at small normal faults, several of which are down-thrown to the north. In particular, workings of the mines near Cedar Mountain terminate with suspicious abruptness on the north, though the mine maps do not suggest a fault. Borehole data from south of the Cedar River suggest that the bedrock surface plunges steeply beneath the basin. While the bedrock in this area could simply dip below the unconsolidated sediments of the trough, we suggest that the south margin of the lower basin is fault bounded (Fig. 3).

In support of this suggestion, the seismotectonic map of Puget Sound (Gower and others, 1985) shows a large fault in the Kent–Renton valley to the west of the lower Cedar River basin, with the down-thrown side on the north. Gower and others (1985) show an inferred extension of the fault curving northeast to join the Seattle fault near Issaquah. However, a shift of the fault trend to the south brings the fault trace into alignment with the Cedar River basin between Renton and Cedar Hills Landfill. Such an alignment explains the sudden end of both the coal measures and fold axis in the Cedar Mountain mine. A fault here is consistent with our extension of the subsurface bedrock ridge eastward from Indian beneath Cedar Hills Landfill. The fault may continue east along bedrock lineaments or may link with the Hobart fault mapped by Vine (1962) and Gower and others (1985). (See Fig. 3.) This structural style is similar to that of the Seattle fault and other fractures mapped by Gower and others (1985).

More speculatively, bedrock subcrop drops away very rapidly along the south boundary of the basin. The well drilled by Brown and Caldwell (1980) for the Seattle Water Department (MW-5) penetrated 660 ft of sediments before hitting bedrock at elevation 46 ft. Bedrock crops out a relatively short distance to the south. The bedrock is part of a band of rock that reaches from the Lake Sawyer area (a few miles south of the study area) to the east into the Cascade foothills. The configuration also suggests a fault-bounded margin for the south boundary of the upper basin. If this interpretation is correct, it extends the series of en echelon normal faults suggested in Gower and others (1985), sub-parallel to the Seattle fault, all down-dropped to the north. Gower and others (1985) show an in-

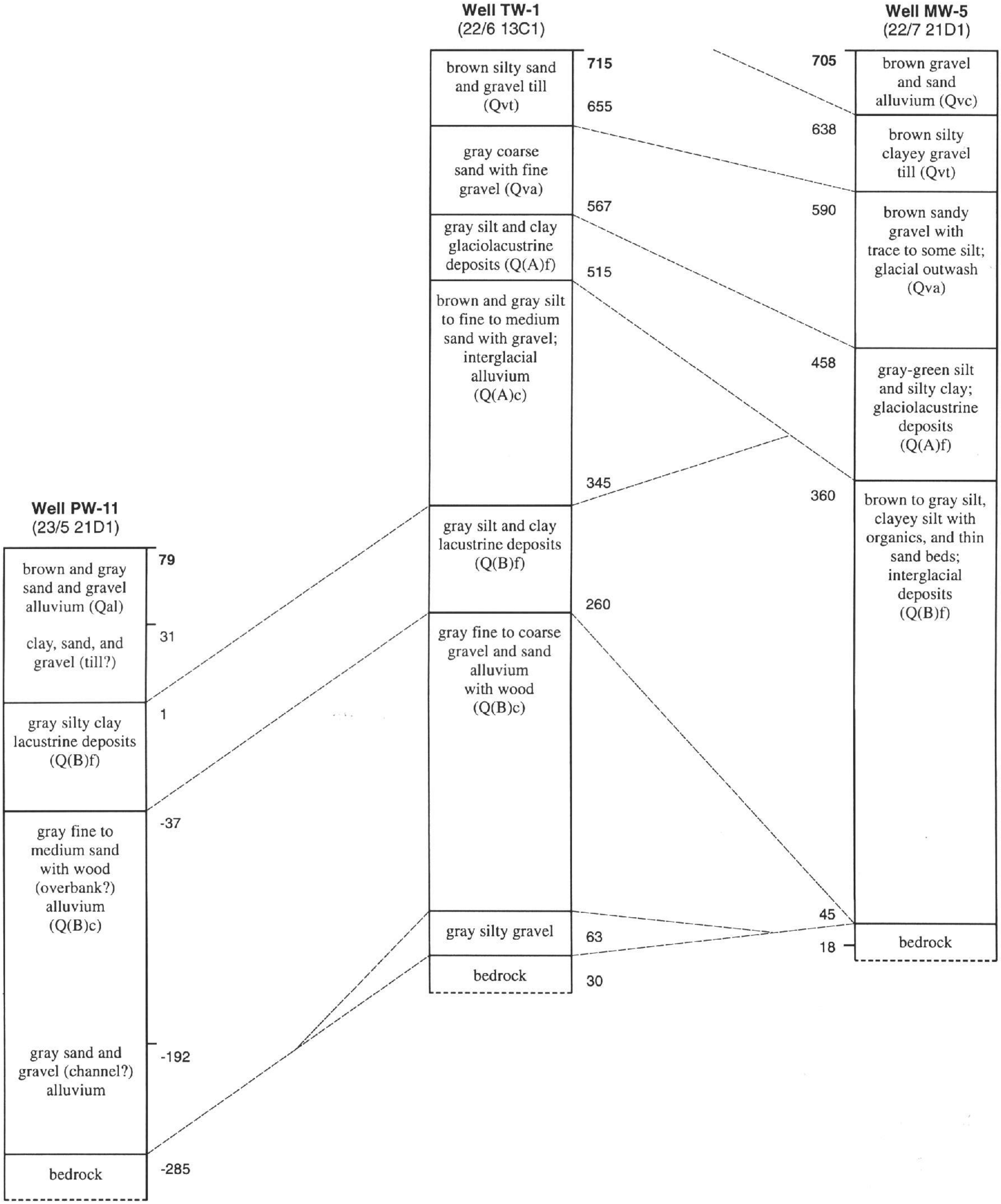


Figure 5. Preliminary stratigraphic correlations between regionally significant deep water-well borings: City of Renton well PW-11 (23/5 21D1), Cedar River Water and Sewer District well TW-1 (22/6 13C1), and City of Seattle test well MW-5 (22/7 21D1). Numbers give elevation in feet above mean sea level; top number is the ground-surface elevation. Geologic units are those shown in Figure 3; Q(A)c, Q(A)f, Q(B)c, and Q(B)f are hydrostratigraphic units after Woodward and others (1995).

ferred fault in the area, but it is short and no sense of motion is suggested. Future research should address this possibility.

More recent work by Johnson and others (1994) suggests that the faults are south-dipping thrust features, rather than normal faults. This suggestion does not materially alter our suggested interpretation, as the relative displacement within the basin remains the same.

HYDROGEOLOGY

The key to understanding the hydrogeology of the basin lies in determining the lateral extent of the sediment layers. As described above, this is problematic. The well-log section shown in Figure 5 shows how difficult correlation can be when working in a complex terrain with poorly controlled records. Our review suggests that some lateral continuity is present, but little more.

We have shown that the layers identified in our standard borehole, 22/6 13C1, correspond well to the units defined by Woodward and others (1995). But this correlation cannot yet be extended much beyond the Maple Valley area.

Two questions control defining the hydrologic character and flow regime of the Cedar River basin. These are (1) Are there two basins or one? and (2) How deep is the bedrock threshold between the Maple Valley area and the Covington Drift Plain? If there are two basins, and the threshold is below sea level, as suggested by Woodward and others (1995), then the area of the Cedar River basin south of Cedar Hills Landfill should be considered part of the Covington basin. Ground-water flow can be expected to be generally southwest, even in the deepest parts. The part of the basin between Renton and Cedar Hills Landfill is then a separate basin, with generally westward ground-water flow and recharge areas north of Cedar Hills Landfill.

However, if the bedrock ridge subcropping below Cedar Hills Landfill is breached in places, and (or) the bedrock threshold is at an elevation of 100 or more ft, as suggested by Booth (1995), then there is one Cedar River basin. If so, ground-water flows can be expected to be northward in the Maple Valley portion of the basin, especially at depth, and westward from Cedar Hills Landfill. Recharge areas then include all of the Cedar River–Issaquah Creek–May Valley drainages.

SUGGESTED FURTHER STUDIES

Clearly, much work remains to be done to define and understand geologic and hydrologic conditions in the Cedar River basin. And the Cedar River basin is not unusual in the relatively poor quality of the data and lack of understanding of its geological conditions. The stratigraphy, origin, depositional environment, and hydrologic potential of most of western Washington's glacially and tectonically formed basins are not well understood.

In the Cedar River area, we are fortunate that the U.S. Geological Survey has recently published a study of the adjoining Covington area (Woodward and others, 1995), which we used to help define our preliminary stratigraphy. But even this work was based on inadequately logged well data and contributed little to the stratigraphic and tectonic framework of the basin. Other basins are even less well known.

Only by fully understanding these geologic and hydrologic conditions in the Cedar River and other basins can we hope to rationally assess the water-resource potential of an area. Only by knowing the resource potential and its limitations can we make informed decisions concerning the allocation of ground-water resources in the basin. We must have more information to identify potential aquifers for development of municipal or other water supplies and protect those we already have.

As this discussion makes clear, the first issue that should be addressed for the Cedar River basin is, is there one basin or two? Geophysical studies and limited drilling could go far to resolving this problem.

Determining where the best potential aquifers are is more difficult. Defining the stratigraphy of the area and the best target areas for exploration, here and elsewhere in western Washington, requires several more carefully sited borings in conjunction with geophysical investigations.

ACKNOWLEDGMENTS

This report was prepared with the assistance of several organizations and persons who should receive credit. Drafting was done by Chris Jansen and Caleb Gleason, provided through the support of Roy F. Weston Company. Several employees of government agencies also provided assistance in the form of advice and introductions. Washington Department of Ecology Bellevue office librarians helped track down well logs and arranged reproduction services. City of Renton well logs were provided by Carolyn Boatsman of the City of Renton's Wellhead Protection Program. At the direction of Rosemary Allison of the Cedar River Water and Sewer District, GeoEngineers made available their report on the exploratory well drilled east of Maple Valley. Brown and Caldwell made available their early 1980s studies on the upper part of the basin done for the Seattle Water Department. Eric Schuster of the Washington Division of Geology and Earth Resources read the draft report.

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Landform Map of Washington

The oblique-perspective landform map of Washington by Dee Molenaar has been revised and reprinted. The back side of the sheet presents information about the geologic history and landscapes of the state. The full-color 24 x 37 in. map is available from Molenaar Landform Maps, POB 62, Burley, WA 98322 for $6.50. Shipping costs (UPS) and tax will be added to the invoice. Sets of Molenaar's maps are in the King County Library collections. This map joins the Molenaar landform maps already published for the Olympic Peninsula, Mount St. Helens, the Puget Sound region, and Mount Rainier. Molenaar's oblique aerial views also enhance the 1988 U.S. Geological Survey Water-Supply Paper 2265, "The Spokane Aquifer, Washington; Its geologic origin and water-bearing and water-quality characteristics".

Staff Notes

Nancy Eberle, Cartographer 2, is leaving the Division to take the position of Supervisor of the Photo and Map Sales unit of Resource Mapping Division, just down the hall. Nancy has been with the Division for more than 15 years. Thanks, Nancy, for all your good work!

Rebecca Christie, Library Information Specialist, is on a nine-month sabbatical to pursue her education in technical writing. **Lee Walkling**, formerly a volunteer, will be filling in for her while she is gone

Carl Harris, Cartographic Supervisor, won second place in cartographic design for GM-43, Liquefaction susceptibility of the Auburn and Poverty Bay 7.5-minute quadrangles, Washington, and GM-44, Liquefaction susceptibility of the Sumner 7.5-minute quadrangle, Washington, at NW ARC/INFO 96, the 11th annual Arc/Info user conference, Oct. 9–11, 1996.

A Field Guide to Washington State Archaeology

A field guide to Washington State archaeology (version 2), by M. Leland Stilson, Dan Meatte, and Robert G. Whitlam, published in 1996 by the Washington Department of Natural Resources, is now available at public libraries. The publication was sponsored by the Department and the Washington State Parks and Recreation Commission, the Washington State Department of Community, Trade and Economic Development, and the Maryhill Museum of Art. This 75-page book describes typical Native American sites on the coast, in the mountains, and in the Columbia River basin, as well as presenting information about historical and underwater archaeology in Washington. A list of books and further reading, a glossary, and a web site URL are also included. The appendix consists of the policies, rules, and regulations governing archaeological materials in Washington and also briefly discusses Ringold Formation correlatives throughout the region, setting the stage for future regional sedimentologic interpretations.

Hisingerite — A Rare Iron Mineral from Walker Valley, Skagit County, Washington

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Hydrothermally altered outcrops of volcanic rock at a site in Walker Valley in the Cascade foothills of western Skagit County are well known as a source of geodes and gem-quality agate, but scant attention has been paid to the occurrence of hisingerite, a rare hydrous iron silicate. Recognition of this mineral at Walker Valley dates to the early 1980s when Carl and Emma Lischke donated large geodes from the site to the Burke Museum at the University of Washington.

Geology student Grace Stangle was intrigued by these spectacular specimens and persuaded the Lischkes to show her where the rocks had been found. When Stangle noted the abundance of an unusual black mineral, she enlisted the expertise of Julian D. Barksdale, professor emeritus of the Department of Geological Sciences and affiliate curator at the Burke Museum. Barksdale and Stangle made another visit to Walker Valley to collect additional specimens. Using chemical tests, x-ray analysis, and transmission electron microscopy, they were able to demonstrate that the material was hisingerite. After Professor Barksdale's death in 1983, the discovery was largely forgotten, but a summary of the work appeared in the newsletter of the Pacific Northwest Chapter of the Friends of Mineralogy (Bodisch, 1984).

The geology of the Walker Valley site was described in a recent *Washington Geology* article (Mustoe and others, 1996). Geodes containing crystals of clear quartz, amethyst, calcite, siderite, and goethite occur in an andesite dike that intruded along a fault zone in early Tertiary sandstone of the Chuckanut Formation. Hisingerite occurs abundantly as black varnish-like coatings on the surfaces of fractures, as pea-size glassy blebs in the andesite, and as massive or botryoidal layers as much as 1 cm thick within geodes (Figs. 1 and 2). Associated minerals include quartz, calcite, and siderite, and many specimens show evidence of a complex geologic history (Fig. 3).

Hisingerite has previously been reported in Washington from the Cardinal mine in Stevens County, where it occurs as dark-brown vitreous masses with chalcopyrite, malachite, and iron oxide in a mineralized zone between a barite vein and adjacent sericitized argillite (Moen, 1964). Neotocite, a closely related hydrous silicate that contains manganese rather than iron, has been reported as veinlets in bementite manganese ore bodies of the northern Olympic Peninsula (Green, 1945). Neither of these occurrences has been described in detail.

Hisingerite has perplexed mineralogists since its discovery in Sweden in the mid-1800s (Sustchinsky, 1910). Despite numerous chemical analyses and x-ray diffraction studies, the mineral's atomic structure remains enigmatic. Although hisingerite has been reported from a diverse range of geologic environments, the physical and chemical conditions required for its formation are also not well understood.

Physical and Optical Properties

Hisingerite in igneous rocks can easily be mistaken for obsidian because of its dark color, glassy luster, and prominent conchoidal fracture. However, the light weight (specific gravity approximately 2.0–2.7) and hardness of only 2.5 to 3 provide important distinguishing characteristics. Hisingerite contains large amounts of adsorbed water, and most specimens that have been exposed to air for long periods develop shrinkage cracks.

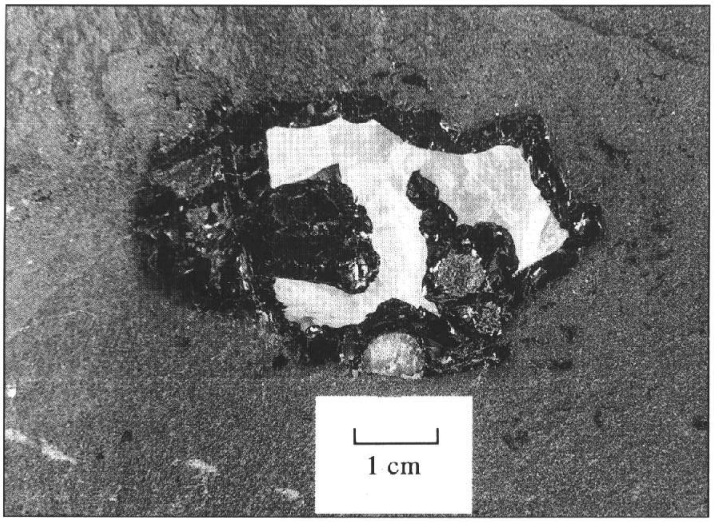

Figure 1. This amygdule contains a thick outer layer of hisingerite and a central region filled with crystalline white calcite. A small hemisphere of radial siderite (spherosiderite) is visible just above the scale bar.

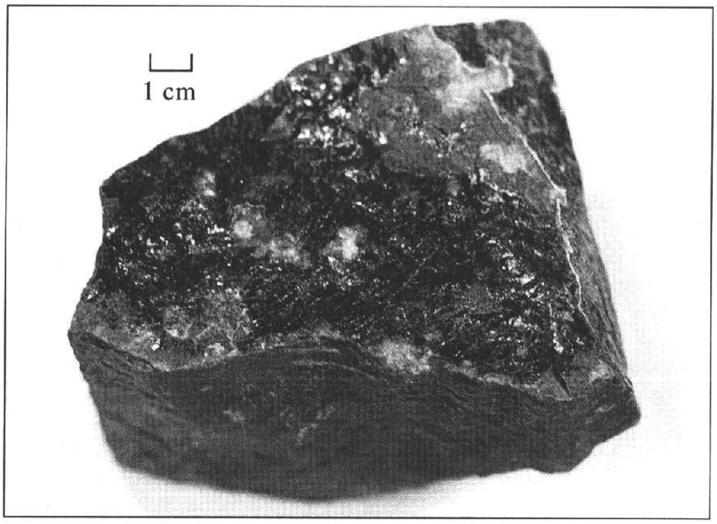

Figure 2. Glossy black hisingerite veneers on the surface of a fracture in the andesite host rock. These narrow fractures provided a conduit for hydrothermal fluids that allowed the mineralization of larger cavities.

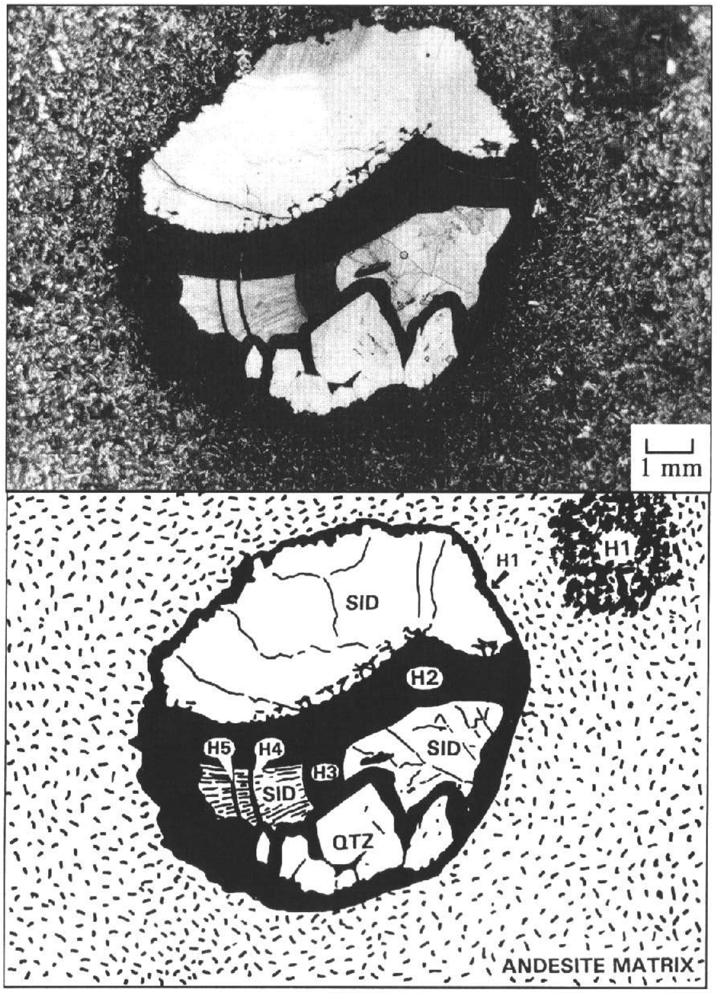

Figure 3. This specimen shows the complex mineralization sequence typical of Walker Valley geodes. In addition to development of euhedral quartz crystals and radial siderite, five episodes of hisingerite precipitation are evident. SID, siderite; QTZ, quartz; H1–H5, hisingerite.

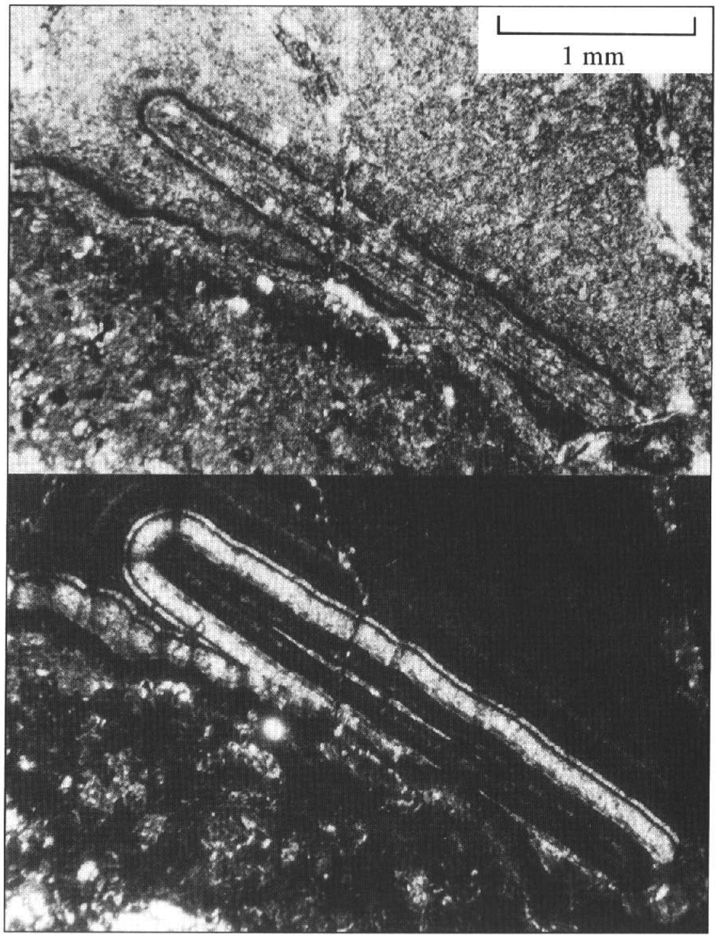

Figure 4. *(Top)* Hisingerite viewed under ordinary illumination, showing concentric banding. *(Bottom)* Alternating light and dark zones are visible when this sample is viewed under polarized light. This birefringence indicates variations within hisingerite's atomic structure. Regions that appear opaque are noncrystalline, and the light-colored bands are evidence of microscopic crystal structure or strain patterns.

Hisingerite also has an intriguing ability to change color. Freshly broken chunks of Walker Valley andesite contain small blebs of translucent green hisingerite that become opaque black within an hour or two. Some specimens develop a brownish tinge after several months. Green-to-black color changes have previously been noted in hisingerite from sulfide ore and rhyolitic tuff in two Japanese deposits (Sudo and Nakamura, 1952; Kohyama and Sudo, 1978). Freshly exposed claret-red hisingerite from an Idaho silver mine changes to dark greenish or black within a few minutes, eventually becoming dark brown (Hewett and Schaller, 1925). These color changes are probably caused by iron oxidation and dehydration, but the process appears to be complex. For example, at Talnakh, Siberia, the color of hisingerite in fresh samples tends to be related to the composition of the host rock—hisingerite is brown or green in altered gabbro and dolerite, yellowish orange to light green in quartz-rich zones, and reddish brown in massive sulfides (Ryabov and Kulakov, 1974).

The refractive index (RI) of freshly exposed Walker Valley hisingerite varies from 1.52 to 1.53, dropping to 1.46 or 1.47 in specimens that were exposed to the atmosphere for two years. RIs reported for hisingerite from other locations range from 1.47 to 1.70, and in some instances the values have been observed to shift after specimens have been exposed to the atmosphere. Osborne and Archambault (1950) reported that freshly collected samples from the Tétreault mine, Quebec, had RI values of 1.65, dropping to 1.51 when they were measured again about six months later. In contrast, Ryabov and Kulakov (1974) found that RI values tended to increase as Siberian samples aged. They also observed that reddish brown hisingerite had RIs that ranged from 1.50 to 1.70, whereas greenish varieties yielded values of 1.47 to 1.57. These shifts are most likely caused by dehydration and oxidation.

In thin sections, Walker Valley hisingerite generally appears as homogeneous isotropic masses, but birefringent zones occur in some specimens (Fig. 4). This optical characteristic has been observed in hisingerite from other locations. For example, Schwartz (1924) noted that 75 percent of the specimens from Parry Sound, Ontario, were isotropic and 25 percent were anisotropic. Walker Valley samples containing birefringent zones yield the same weak diffuse x-ray diffraction peaks as pure isotropic masses, indicating that the zones probably do not represent well-crystallized regions within the hisingerite or the presence of another mineral. The anisotropic regions may have resulted from tension polarization that developed during the solidification of a gelatinous precursor (Ryabov and Kulakov, 1974).

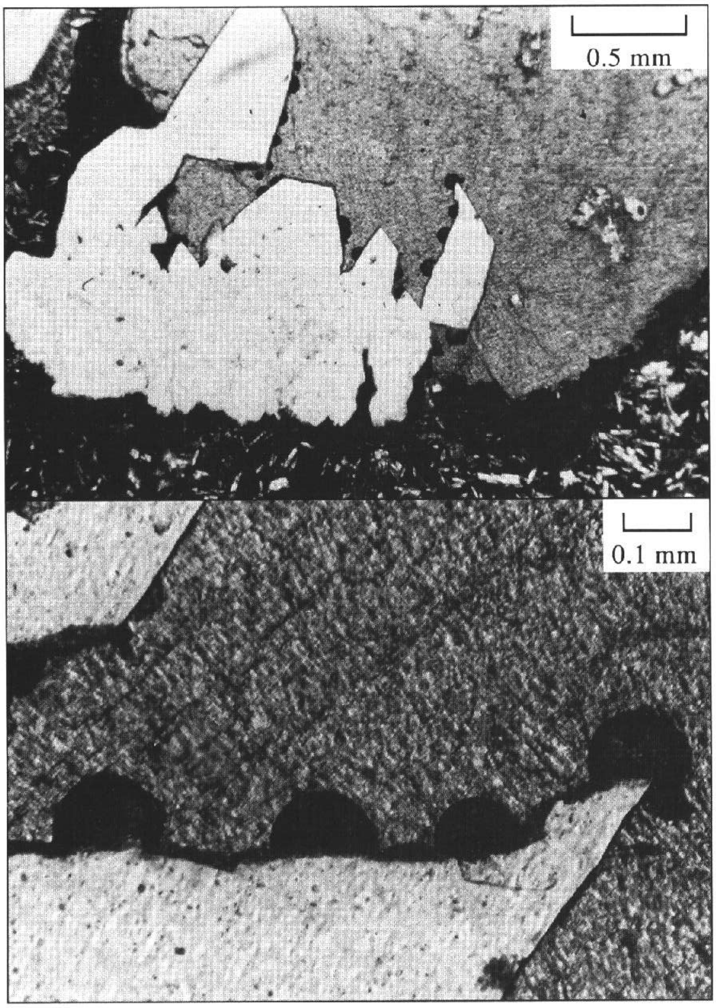

Figure 5. *(Top)* Microscopic hemispheres of hisingerite have grown on the faces of quartz crystals, later becoming enclosed by calcite. *(Bottom)* This enlargement shows that a thin continuous film of hisingerite coats the quartz crystals underlying the amorphous hisingerite hemispheres. These hemispheres indicate the very earliest development of the botryoidal habit characteristic of many Walker Valley hisingerite specimens.

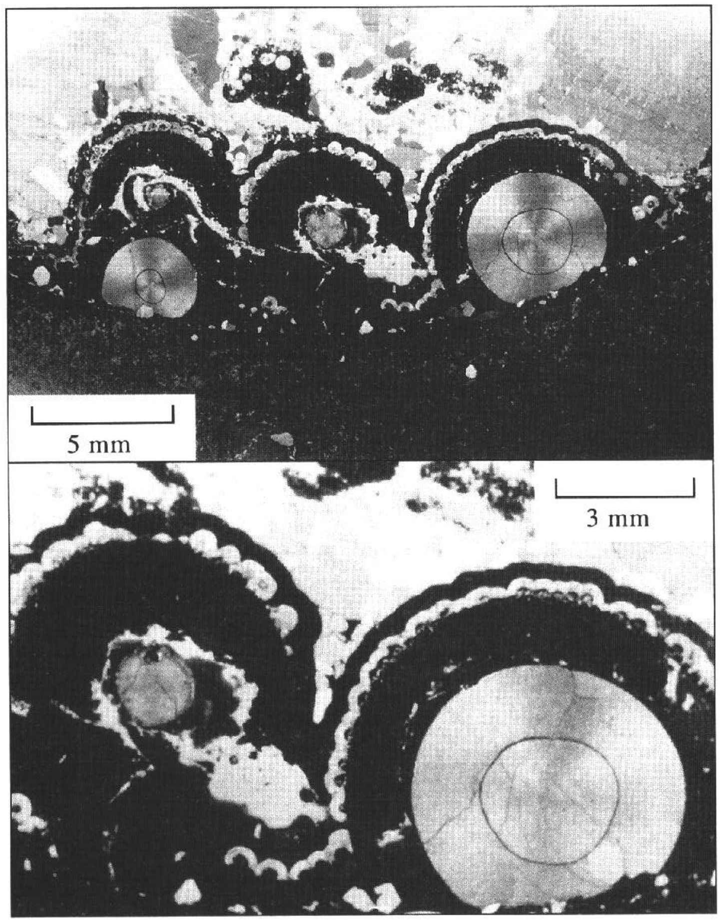

Figure 6. *(Top)* Hisingerite occurs in this specimen as concentric bands associated with spherical masses of siderite attached to the wall of a small cavity. The "iron-cross" extinction patterns visible in the siderite are an optical effect caused when the radiating crystals are viewed under polarized light. Clear crystalline quartz deposited during a later stage of mineralization occupies the upper one-third of the photograph. *(Bottom)* In this enlargement, lace-like zones bordering the main siderite/hisingerite spheres can be seen to consist of many adjacent siderite hemispheres sandwiched between two hisingerite layers.

Microscopic examination of Walker Valley specimens suggests that in the earliest stages of its formation, hisingerite was precipitated as relatively simple layers on the interior surfaces of fractures and cavities in the andesite. Later, hisingerite developed on hydrothermally deposited crystals of quartz and siderite, in places producing layers that have complex geometric shapes. Thick masses of hisingerite commonly show internal banding, and botryoidal textures are also very common. Figure 5 shows microscopic hemispheres of isotropic hisingerite on quartz crystals within an amygdule. Pseudobotryoidal texture observed in another specimen actually consists of layers of hisingerite coating spherical masses of siderite (Fig. 6).

Crystal Structure

Chemical analyses (Table 1) indicate that hisingerite has a variable composition, with an approximate formula of $FeSiO_3{\cdot}H_2O$, but its relationship to other mineral families is not clear. Hisingerite's physical properties are generally similar to those of opal, another silicate that is soft and has high water content and a glassy or resinous luster. However, x-ray diffraction studies show that, unlike amorphous opal, hisingerite has an incipient crystal structure. X-ray diffraction patterns consist of only a few broad, weak peaks, and hisingerite specimens from different locations show a significant degree of variability, making interpretations of lattice structure somewhat uncertain.

The diffuse diffraction peaks are reminiscent of x-ray patterns obtained from aged glass samples where molecular bonds have started to develop, in contrast to the sharper diffraction peaks typical of cryptocrystalline substances.

The most common view is that hisingerite originates from a gel-like precursor and that nucleation within the gel eventually produces small crystallites that give the substance the very low degree of structural order indicated by x-ray analysis. However, the details of this incipient crystallization are not well understood.

X-ray diffraction data from various hisingerites are shown in Table 2. These samples lack the strong 12Å–17Å basal reflections typical of clay minerals. The 7.5Å peak and the 3.50Å–3.58Å peaks observed for some samples have been used as evidence for an incipient mica-like atomic structure (Whelan and Goldich,1961), but Lindqvist and Jansson (1962)

Table 1. X-ray powder diffraction data for hisingerite. * Analyzed at Western Washington University using Rigaku Geigerflex diffractometer with graphite curved-crystal monochromator, Cu radiation. Data from Whelan and Goldich (1961), Ryabov and Kulakov (1974), Kohyama and Sudo (1975), Shayan (1984)

Location	d-spacings (Å)							
Walker Valley, Washington*		4.25		2.56			1.52	
Blaine Co., Idaho		4.40	3.53	2.58		1.70	1.53	
East Mesabi, Minnesota	7.53	4.33	3.50	2.55			1.55	1.21
Beaver Bay Complex, Sample 1, Minnesota		4.51		2.54		1.70	1.53	
Beaver Bay Complex, Sample 2, Minnesota		4.42		2.48			1.54	1.21
Nicholson mine, Saskatchewan, Canada		4.40	3.55	2.58		1.70	1.53	
Parry Sound, Ontario, Canada		4.55		2.59			1.54	
Montauban-les-Mines, Quebec, Canada				2.51			1.54	
Weal Jane, Cornwall		4.43		2.56			1.53	
Riddarhyttan, Sweden		4.45	3.53	2.56		1.74	1.54	
Langanshyttan, Sweden		4.39	3.58	2.57		1.71	1.54	
Kawayama mine, Japan		4.40		2.60			1.50	
Oya, Japan	16.1	4.51		2.55	2.45	1.71	1.51	
Talnakh, Siberia		4.50	3.50	2.57	2.22		1.55	1.47
Geelong, Victoria, Australia		4.49		2.58			1.53	

argue that these reflections indicate the presence of chlorite as an impurity. They suggest that both x-ray data and measurements of cation exchange capacity support the hypothesis that hisingerite has an incipient mica structure. Most other investigators believe that the lattice is more likely to be clay-like, with the absence of basal reflections being the result of a very low degree of crystallinity.

Gruner (1935) concluded that hisingerite is a variety of nontronite (an iron-rich montmorillonite clay), and Kohyama and Sudo (1975) speculated that hisingerite has a variable clay structure intermediate between trioctahedral iron-rich saponite and dioctahedral nontronite. Brigatti (1981) applied multivariate statistical analysis to 77 previously published chemical analyses of hisingerite and various iron-rich clay minerals. Her results suggest that hisingerite is a member of the smectite clay family, having a trioctahedral lattice structure and chemical characteristics that show a compositional affinity to iron-rich saponite.

The low degree of crystallinity indicated by x-ray diffraction patterns supports suggestions that hisingerite forms from the dehydration of a colloidal gel. Eggleton (1987) postulated a mechanism of "bubble formation", where partially ordered clusters of hollow spheres develop during shrinkage of a noncrystalline gel containing silica, iron, and aluminum. If the ratios of these elements are equivalent to that for a clay mineral such as smectite or kaolinite, the gel may develop an incipient lattice structure. According to Eggleton's hypothesis, gels high in iron and low in silica and alumina may dehydrate to form ferrihydrate, whereas gels high in silica and aluminum but low in iron produce allophane. Hisingerite is predicted to form from gels containing abundant iron and silica and little aluminum, with an initial lattice structure that consists of corner-linked polyhedra made up of tetrahedral silica and trivalent iron octahedrally coordinated with oxygen.

Although some hisingerites remain stable in a predominately amorphous state, other varieties eventually crystallize to produce nontronite. The stability is perhaps related to the diameter of the initial microspheres because spheres having diameters of less than about 240Å may be unable to act as nucleation sites (Eggleton and others, 1983).

Origin of Hisingerite

Considering its status as a rare member of the mineral kingdom, hisingerite is found in a surprisingly diverse range of geologic settings in North America, Asia, Europe, and Australia. In addition to these terrestrial occurrences, hisingerite has been suggested as a possible component of Martian soil, perhaps explaining that planet's characteristic reddish-brown color (Burns, 1986).

Previously reported hisingerite occurrences can be divided into four genetic categories:

1. *Hisingerite produced by alteration of iron minerals during metamorphism of crystalline rocks.* Examples include pyroxene skarns in Sweden (Lindqvist and Jansson, 1962) and gabbro from the Beaver Bay Complex, Minnesota (Whelan and Goldich, 1961).
2. *Hisingerite formed in ore bodies where pyrite, pyrrhotite, siderite, or other ferruginous minerals provide a source of iron.* These deposits include ores of uranium (Bowie, 1955), lead and zinc (Osborne and Archambault, 1950), tin (Sudo and Nakamura, 1952), copper (Whelan and Goldich, 1961), and copper-nickel (Ryabov and Kulakov, 1974; Aplonov and Sereda, 1983).
3. *Hisingerite formed from the weathering of iron-rich rocks.* Hisingerite has been reported as a component of clay-rich rhyolitic tuff at Oya, Japan (Kohyama and Sudo, 1975) and as coatings on andesite boulders in stream beds in the North Island, New Zealand (Henmi and others, 1979). The mineral has also been identified as an interstratified layer in halloysite from weathered pyroclastic rocks on the South Pacific island of Vanuatu (Quantin and others, 1984). In these environments, hisingerite generally consists of small grains or thin coatings that are recognizable from x-ray and chemical data rather than from characteristics observable in hand specimens.

Table 2. Chemical analyses (oxide percentages) and physical properties of hisingerite. Data from Whelan and Goldich (1961), Lindqvist and Jansson (1962), Kohyama and Sudo (1975), Shayan (1984), Burns (1986). Walker Valley samples were analyzed at Western Washington University by atomic absorption spectrophotometry, using lithium metaborate fusion to dissolve 0.100 g samples. H_2O^+, H_2O^-, specific gravity, and refractive index were determined from a single 1.00 g sample. N.D., not determined

Oxide	Walker Valley, Wash. 1	Walker Valley, Wash. 2	Geelong, Australia	Kawa-yama, Japan	Blaine Co., Idaho	Beaver Bay, Minn.	East Mesabi, Minn.	Parry Sound, Ontario	Montauban-les-Mines, Quebec	Elvestrop, Sweden
SiO_2	30.93	30.42	34.20	27.99	38.14	42.23	38.19	35.57	37.54	35.24
Al_2O_3	1.69	2.50	4.16	–	N.D.	3.65	0.0	0.12	0.00	2.00
TiO_2	0.0	0.07	0.28	–	N.D.	0.13	0.01	0.38	0.56	0.0
Fe_2O_3	N.D.	N.D.	17.10	34.25	36.66	23.28	19.91	39.20	37.02	35.51
FeO	N.D.	N.D.	4.15	0.54	0.84	5.90	24.64	4.80	4.66	0.30
ΣFe_2O_3	30.70	27.42	21.01	34.85	37.59	29.83	47.26	44.53	42.19	35.84
MnO	0.25	0.24	0.08	N.D.	trace	0.92	0.66	N.D.	0.75	0.34
MgO	1.54	1.46	5.70	–	2.45	5.21	2.36	1.60	2.81	3.77
CaO	0.69	1.12	0.91	2.33	–	2.52	0.61	0.85	1.52	1.99
Na_2O	0.74	0.76	0.67	N.D.	N.D.	0.27	N.D.	N.D.	N.D.	0.0
K_2O	0.04	0.75	0.26	N.D.	N.D.	0.07	N.D.	N.D.	N.D.	0.04
H_2O^+	4.08	4.05	5.30	7.11	8.53	5.82	8.40	11.60	9.20	10.42
H_2O^-	27.54	27.45	25.40	27.89	13.20	13.54	5.53	6.00	6.00	9.03
Spec. Grav.	2.00–2.07	2.00–2.07	N.D.	N.D.	N.D.	N.D.	2.67	2.50	2.53–2.55	2.6–2.8
Ref. Index	1.52–1.53	1.52–1.53	N.D.	N.D.	1.57	N.D.	1.66	1.50–1.57	1.66	1.62–1.64

4. *Hisingerite hydrothermally precipitated in fractures and vesicles in volcanic rocks.* Hisingerite occurs as 2–15-mm-thick crusts in joints in Cenozoic basalt at a quarry at Geelong, Australia (Shayan, 1984; Shayan and others, 1988).

In some locations precipitation of hisingerite appears to have resulted from a combination of processes. In the copper-nickel ores of the Talnakh district of Siberia, hisingerite is found in association with hydrothermally deposited opal, chalcedony, quartz, calcite, and zeolites in amygdules in basalt; as pseudomorphs of olivine, clinopyroxene, hornblende, and other iron-rich minerals in gabbros; and as veinlets cross-cutting massive sulfide ore. These different modes of occurrence were all produced by hydrothermal activity during the final stages of metamorphism, and sulfide minerals were the main source of iron and silica coming from adjacent Paleozoic sedimentary rocks. Hisingerite occurs chiefly near this contact (Ryabov and Kulakov, 1974).

Discussion

The Walker Valley outcrop shares several important characteristics with hisingerite-bearing basalts at Geelong, Australia. Although macroscopic vesicles are not present at Geelong, in both locations hisingerite has been hydrothermally deposited in open spaces in Cenozoic volcanic rocks. Siderite occurs at both sites as discrete crystalline masses and as thin interlaminations in the hisingerite. X-ray diffraction patterns from Geelong hisingerite closely resemble x-ray data from Walker Valley material. These patterns show only three diffuse diffraction peaks and lack various peaks that have been reported for hisingerite from other locations (Table 2). A possible explanation is that hisingerite from Geelong and Walker Valley typically consists of pure masses that were precipitated in voids rather than resulting from *in situ* alteration of the host rock. Where hisingerite originated from decomposition of mafic silicate minerals or iron-rich sulfides or by surface weathering, the mineral is likely to contain extraneous constituents. These relict minerals may account for some of the anomalous peaks observed in x-ray diffraction patterns. For example, hisingerite that developed as an alteration product of gabbro might contain small amounts of pyroxene or feldspar. These well-crystallized minerals would appear as small, sharp peaks superimposed on the diffuse hisingerite x-ray pattern. However, chemical analyses (Table 1) do not show consistent compositional differences among hisingerites from various geologic settings.

Another possibility is that the geologically young material at Geelong and Walker Valley represents an early phase of the development of the mineral. The diffraction peaks observed for other samples may represent the appearance of various crystallites created as the initially amorphous material slowly began to attain an increasing degree of atomic order. An argument for this interpretation is the fact that hisingerite diffraction peaks are almost always weak and broad, a characteristic of incipient lattice development.

Hisingerite from Walker Valley shares certain characteristics with material from several other deposits. Most of these deposits have not been adequately described in the geologic literature, limiting our ability to make comparisons. For example, hisingerite samples from Weal Jane, Cornwall, and Kawayama Mine, Japan, give x-ray patterns similar to material from Geelong and Walker Valley. The mineralogy of Cornish and Japanese sites has not been reported, although in both locations, hisingerite occurs in association with ore bodies. Chemical analyses (Table 1) indicate the compositional similarity of hisingerites from Walker Valley, Geelong, and Kawayama mine; their hydrothermal origin is consistent with the high concentrations of adsorbed water, H_2O^-.

Conclusions

The Walker Valley occurrence provides new clues for unraveling the structure and origins of hisingerite, but definitive answers remain beyond our reach. A particularly important reminder from this site is that hard-to-identify minerals may go unreported in geologic literature. Although a few dedicated rockhounds recognized the shiny black material as hisingerite, most visitors to the Washington Mineral Council's Walker Valley claim have ignored the mineral in their search for agate and geodes. Given the long delay in recognizing hisingerite at a much-visited public collecting site where specimens are abundant, we can only wonder how many exotic minerals remain to be reported from other localities.

Acknowledgments

For years I was mystified by the dark, glassy material that I observed at Walker Valley until the mineral was finally identified for me by Dick Rantz, a Bellingham collector. Danny and LaVonda Vandenburg of Sedro-Woolley provided specimens and helpful information about the collecting site, based on their long experience collecting Walker Valley minerals. Antoni Wodzicki, Geology Department, Western Washington Univ., reviewed the manuscript.

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Ground water hydrology	18 weeks		8/18	$1375	$480

Progress on the State Geologic Map

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I last reported on state geologic map progress in September 1994 (Schuster, 1994a). Budgetary difficulties have slowed the work, still there is some progress to report.

Since September 1994, we have finished and released open-file maps for the remaining 1:100,000 quadrangles in southeastern Washington. They are the Priest Rapids (Reidel and Fecht, 1994), Connell (Gulick, 1994), and east half of the Yakima (Schuster, 1994b) quadrangles. Editorial and cartographic work is nearly finished on the 1:250,000 southeast quadrant colored geologic map, and we expect to go to press with it within 3 months.

Work continues on the compilation of quadrangles in the northwest quadrant, with the geologic staff working toward finishing the northwest 1:100,000 open-file reports by the end of calendar 1997. Several of the northwest quadrangles are already available as open-file or published maps from the U.S. Geological Survey. We will not reissue these maps, but we will translate the geologic unit symbology to the age-lithologic scheme we are using for our state geologic mapping program. As soon as all northwest-quadrant 1:100,000 maps are finished, we will begin the preparation of the northwest-quadrant 1:250,000 topographic base map and geologic map. The status of northwest-quadrant 1:100,000 maps is shown in Table 1.

Finally, we are making concrete progress toward digital 1:100,000-scale geologic coverage of Washington State. We have been awarded a U.S. Geological Survey STATEMAP contract to supply digital geology for 17 full or partial 1:100,000 quadrangles in the year ending June 30, 1997. The 17 quadrangles are Astoria, Centralia, Chehalis River, Ilwaco, Mount Baker, Mount St. Helens, Port Townsend, Priest Rapids, Richland, Sauk River, Seattle, Skykomish River, Snoqualmie Pass, Spokane, Tacoma (S1/2), Vancouver, and Westport. We selected these quadrangles because there was at least some USGS or DGER digital geologic data available for each, and there has also been significant demand for digital geologic information. As quadrangles are completed, the digital information will become available through the Department of Natural Resources. We will pass along details of availability as they become known.

We have applied for USGS STATEMAP funding for the period July 1, 1997, through June 30, 1998, to supply digital geology for 11 more 1:100,000 quadrangles: Chelan, Chewelah, Colville, Mount Adams, Mount Rainier, Nespelem, Oroville, Republic, Robinson Mtn., Twisp, and Wenatchee. At least partial digital geology now exists or will soon exist for two or three of these quadrangles. We hope to have digital 1:100,000 geology available for the whole state within 3 or 4 years.

Table 1. Status of northwest-quadrant 1:100,000-quadrangle geologic compilation maps.

1:100,000 quadrangle	Compiler	Status
Bellingham	Pat Pringle	Work is pending
Cape Flattery	Hank Schasse	Field work finished, compilation in progress
Chelan, W1/2	Joe Dragovich	USGS map available (Tabor and others, 1987), preliminary symbol translation done
Copalis Beach, N1/2	Josh Logan	Field work in progress
Forks	Wendy Gerstel	Field work in progress
Mount Baker	Dave Norman	USGS map available (Tabor and others, 1994)
Mount Olympus	Wendy Gerstel	Field work in progress
Port Angeles	Hank Schasse	Field work finished, compilation in progress
Port Townsend	Hank Schasse	USGS maps available (Whetten and others, 1988; Pessl and others, 1989), preliminary symbol translation done
Robinson Mtn., W1/2	Joe Dragovich	USGS map in progress (R. A. Haugerud)
Roche Harbor	Josh Logan	Field work finished, compilation in progress
Sauk River	Hank Schasse	USGS map available (Tabor and others, 1988), preliminary symbol translation done
Seattle	Tim Walsh	USGS maps available (Yount and others, 1991, 1993)
Shelton, N1/2	Josh Logan	Field work in progress
Skykomish River	Joe Dragovich	USGS map available (Tabor and others, 1993), preliminary symbol translation done
Snoqualmie Pass, N1/2	Joe Dragovich	USGS map available (Frizzell and others, 1984), preliminary symbol translation done
Tacoma, N1/2	Tim Walsh	Work is pending
Twisp, W1/2	Joe Dragovich	DGER map available (Dragovich and Norman, 1995)
Wenatchee, NW1/4	Tim Walsh	USGS map available (Tabor and others, 1982), preliminary symbol translation done

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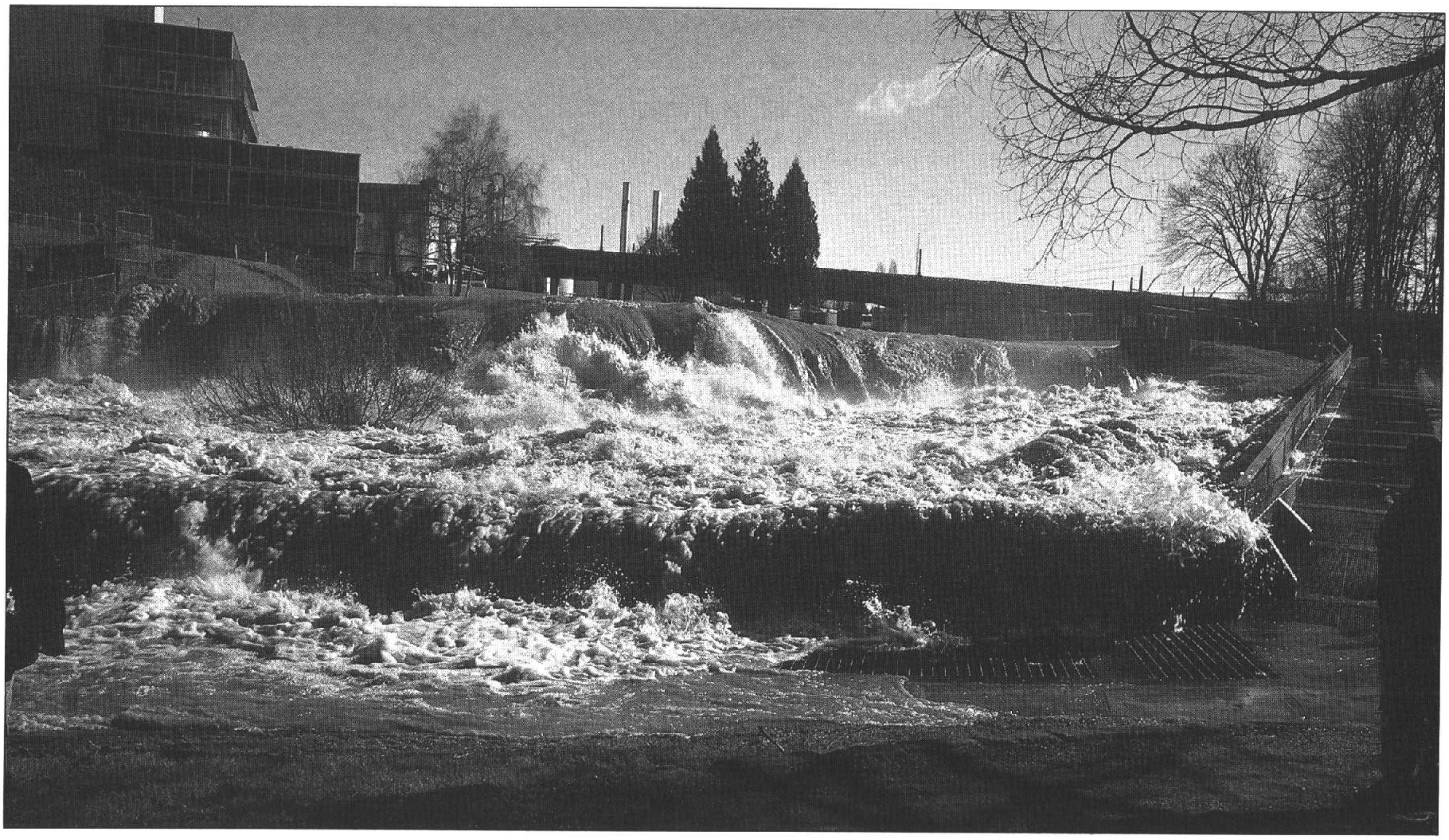
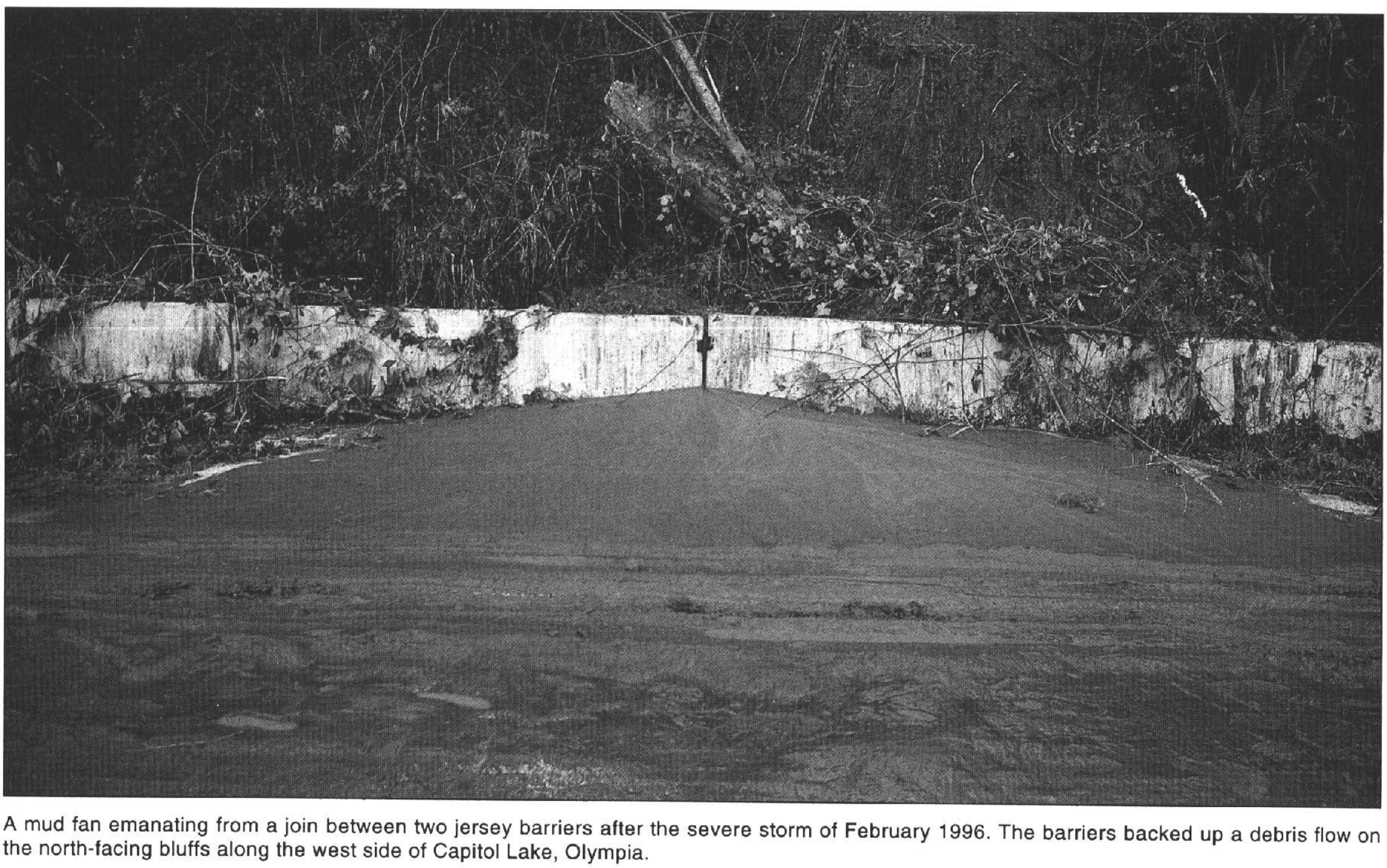
The Floods of February 1996



Floods of February 1996 raised the level of the plunge pool of Tumwater Falls by about 30 feet. The Pabst Brewing Company building is to the left. Note the water on the right splashing onto the grates in the sidewalk over the fish ladder.



A mud fan emanating from a join between two jersey barriers after the severe storm of February 1996. The barriers backed up a debris flow on the north-facing bluffs along the west side of Capitol Lake, Olympia.

ADDENDUM TO OIL AND GAS EXPLORATION IN WASHINGTON, 1992–1996

No petroleum exploration occurred in Washington during 1995. In 1996, Washington Natural Gas, Inc., commenced an aggressive delineation and expansion program at their Jackson Prairie underground gas storage facility south of Chehalis in Lewis County. This facility is critical to providing an uninterrupted supply of natural gas in the Puget Lowland during winter peak-demand periods. Also, Hunt Oil Company spudded its State 36-1, a wildcat permitted to 15,000 feet. This well is likely to be the most remote exploration well drilled in the conterminous United States during 1996. It will penetrate the Puget Group within the core of the Morton anticline in Lewis County and is scheduled to drill into a heretofore untested section referred to as the "South Cascade (magnetostratigraphic) conductor." FEL, from east line; FNL, from north line; FSL, from south line; FWL, from west line

Company	Permit no.	Unique no.	Well Name	Legal Description	Ground elevation	Total depth (estimated)	Date issued	Status
WNG–Jackson Prairie Gas Storage	439	041-00166	R. Gunther #3 SU #910	2.918′ FSL, 1.099′ FEL, sec. 8, T12N, R1W, Lewis County	535′	(3,500′)		Canceled
WNG–Jackson Prairie Gas Storage	440	041-00167	Longview Fibre #17 SU #912	201′ FEL, 736′ FSL, sec. 17, T12N, R1W, Lewis County	522′	(3,500′)		Canceled
WNG–Jackson Prairie Gas Storage	441	041-00168	J. Alexander #1 SU #911	1,158′ FSL, 1,093′ FWL, sec. 9, T12N, R1W, Lewis County	530′	(3,500′)		Canceled
Palo Petroleum Inc & Texaco Exploration and Production Inc	442	033-00049	Palo -Texaco Black Diamond #6-1	2,300′ FSL, 400′ FWL, sec. 6, T21, R7E, King County	860′	(4,000′)	08-04-92	Canceled
Palo Petroleum Inc & Texaco Exploration and Production Inc	443	033-00050	Palo -Texaco Black Diamond #11-1	660′ FSL, 1,605′ FEL, sec. 11, T21N, R6E, King County	700′	(4,000′)	08-04-92	Canceled
Rival Resources Inc	444	073-00098	Ferndale #2	1,320′ FEL, 1,320′ FSL, sec. 25, T39N, R2E, Whatcom County	100′	(1,850′)	11-19-92	Suspended
Hunt Oil Company	445 445-A	041-00169	HOC Clevinger #1 #1-1	2,279′ FWL, 2,333′ FSL, sec. 1, T12N, R4E, Lewis County	1,125′	(15,000′)	5-13-94 Reissued 11-17-95	Extended to 11-13-95
WNG–Jackson Prairie Gas Storage	446	041-00170	Longview Fibre #17 SU #911	1,750′ FEL, 1,000′ FSL, sec. 17, T12N, R1W, Lewis County	530′	(3,050′)	11-23-94 Extended 5-23-96	Canceled
WNG–Jackson Prairie Gas Storage	447	041-00171	Manke #1 SU #910	482′ FEL, 121′ FSL, sec. 21, T12N, R1W, Lewis County	427′	3,225′	11-23-94 Extended	PB 12-16-95
No. 910 REDRILL #1						3,255′	.5-23-96	Completed 1-9-96
WNG–Jackson Prairie Gas Storage	448	041-00172	SU #69	748′ FSL, 2,137′ FEL, sec. 8, T12N, R1W, Lewis County	527′	2,000′	7-1-95	Completed 10-19-95
WNG–Jackson Prairie Gas Storage	449	041-00173	SU #70	754′ FSL, 2,525′ FEL, sec. 8, T12N, R1W, Lewis County	528′	2,035′	7-1-95	Completed 11-9-95
WNG–Jackson Prairie Gas Storage	450	041-00174	SU #71	918′ FNL, 2,357′ FEL, sec. 8, T12N, R1W, Lewis County	517′	1,837′	7-1-95	Completed 11-29-95
WNG–Jackson Prairie Gas Storage	451	041-00175	SU #72	360′ FSL, 2,340′ FEL, sec. 8, T12N, R1W, Lewis County	525′	(2,100′)	7-1-95	Canceled
Hunt Oil Company	452	041-00176	State 36-1	1,749′ FWL, 1,100′ FNL, sec. 36, T13N, R4E, Lewis County	1,168′	(15,000′)	2-27-96	Drilling
WNG–Jackson Prairie Gas Storage	453	041-00177	SU #912	1,520′ FNL, 100′ FEL, sec. 8, T12N, R1W, Lewis County	525′	(3,372′)	9-3-96	Completed 10-12-96
WNG–Jackson Prairie Gas Storage	454	041-00178	Longview Fibre #18 SU #913	1,650′ FNL, 1,300′ FWL sec. 17, T12N, R1W, Lewis County	535′	(3,025′)	9-3-96	Completed 11-03-96
WNG–Jackson Prairie Gas Storage	455	041-00179	Longview Fibre #19 SU #914	2,130′ FSL, 2,580′ FEL, sec. 17, T12N, R1W, Lewis County	510′	(2,970′)	9-3-96	Completed 11-19-96

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What is the origin of the name Osceola for the Holocene mudflow?

Osceola is a crossroads village that lies about 4 miles south of Enumclaw. The pronunciation is Oh-sceola, unlike the Indian tribal name. Several artifacts were found below the mudflow at a site near the town.

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Each issue also contains a listing of recently additions to the library's collection and announcements of upcoming meetings. The 1995 citations are included in our printed bibliography Open File Report 96-6.

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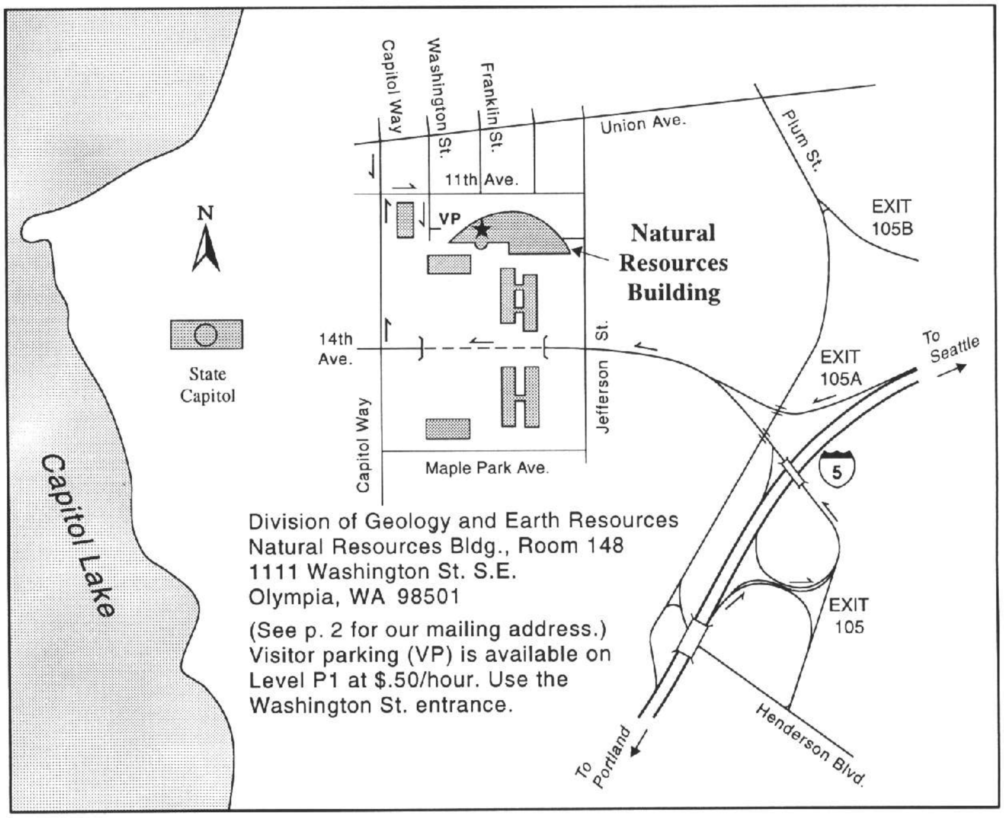

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Division Releases

Preliminary bibliography and index of the geology and mineral resources of Washington, 1991–1995, Open File report 96-6, compiled by Connie Manson. Only 120 copies of this 353-page report have been printed. The price is $12.97 + .03 tax (Washington residents only) = $14.00. (*Note:* We have not released OFR 96-5; it is in final review with the author.)

Maps of the surficial geology and depth to bedrock of False Bay, Friday Harbor, Richardson, and Shaw Island 7.5-minute quadrangles, San Juan County, Washington, by David P. Dethier, Daniel P. White, and Christopher M. Brookfield (Department of Geology, Williams College, Williamstown, MA) has also been released as Open File Report 96-7. The two 1:24,000 maps are accompanied by a 7-page report that contains descriptions of the map units and information about fossils in these Quaternary deposits. The price is $2.76 + .24 tax (Washington residents only) = $3.00.

The Miocene and Pliocene Ringold Formation and associated deposits of the ancestral Columbia River system, south-central Washington and north-central Oregon, by Kevin A. Lindsey. will soon be released as Open File Report 96-8. This 45-page report reviews previous studies of the formation, its age and stratigraphy and describes five facies associations and their distribution. Four appendices contain diagrams of measured sections, core geologic logs, cross sections, and isopach and structure contour data. The price is $5.52 + .48 tax (Washington residents only) = $6.00.

Yes, these are out of sequence. OFR 96-5, a geologic map of the Pomeroy area in southeastern Washington, is awaiting final approval by the senior author, Peter Hooper.

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