April 1981 Volume 9 Number 2

WASHINGTON GEOLOGIC NEWSLETTER

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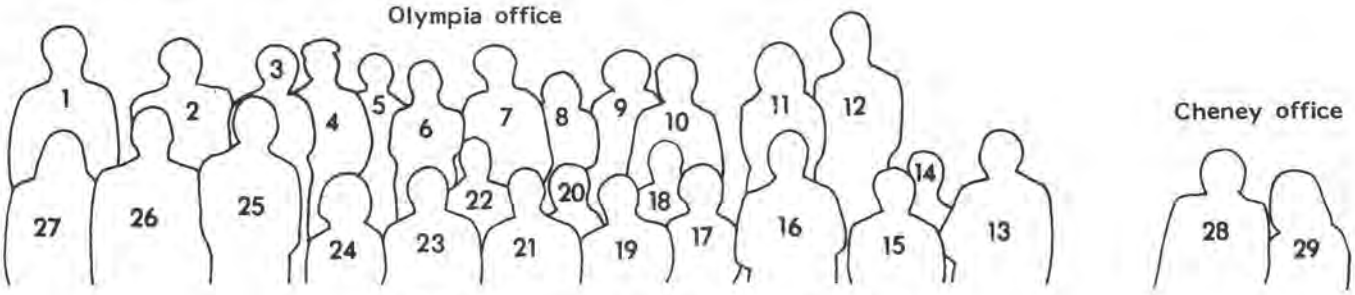

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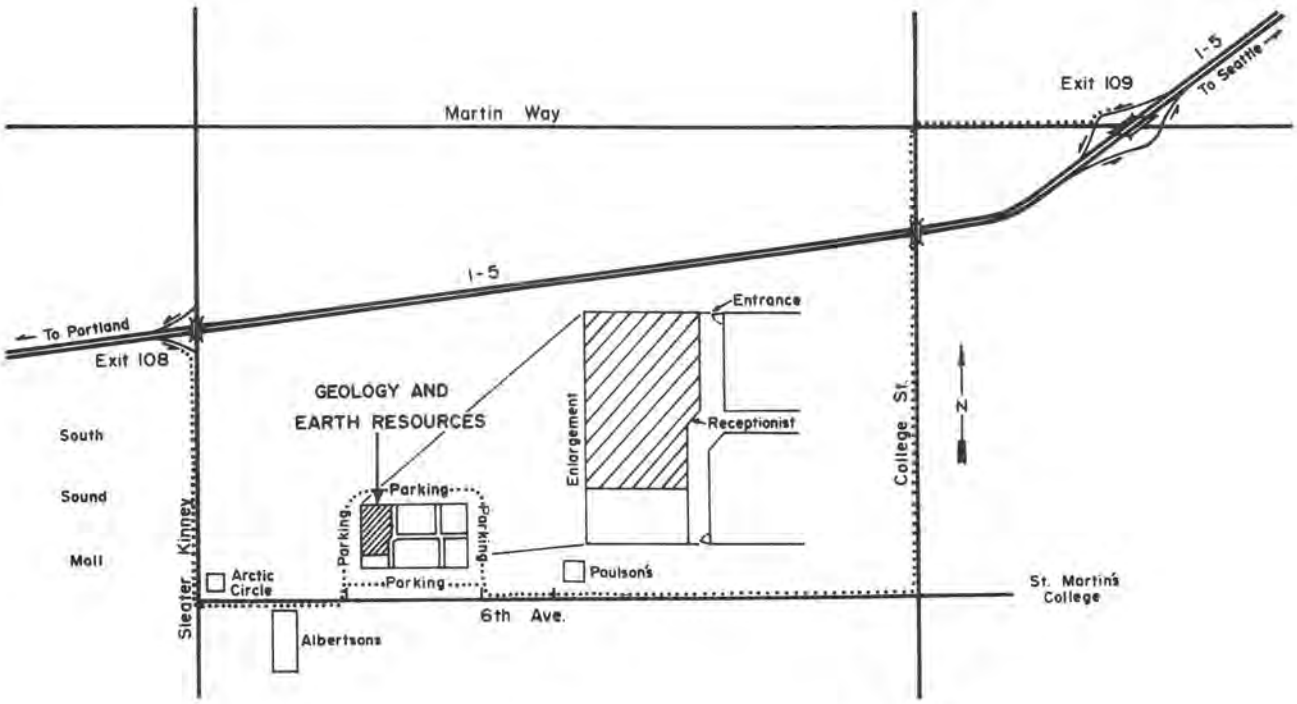

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The Washington Geologic Newsletter, a quarterly report of geologic articles, is published by the Division of Geology and Earth Resources, Department of Natural Resources. The newsletter is free upon request.

The division also publishes bulletins, information circulars, and geologic maps. A list of these publications will be sent upon request.

COAL GEOLOGY OF KING COUNTY, WASHINGTON

by

William M. Phillips and Timothy J. Walsh

Washington State coal reserves were estimated in 1961 to be about 6 billion tons (Beikman and others, 1961). On the basis of this estimate, the King County coal fields contain about 15 percent of the total state reserves and one-third of the bituminous reserves. While reserve figures will change substantially as bedrock below the extensive glacial cover of western Washington is explored, it is apparent that King County contains one of the major coal deposits in the state. Coal resources in King County were last studied about a decade ago (Vine, 1969; Livingston, 1971). Since that time, new information has become available. In addition, King County is rapidly becoming urbanized. Detailed coal resource and mining information is needed for the basis of land-use decisions. The authors are currently engaged in a study of King County coal which will update reserve and resource figures and define the location and extent of past mining activities.

COAL MINING HISTORY

Coal was first discovered in King County in 1853 by Dr. M. Bigelow while he was clearing his land near what is now Renton. Such was the demand for energy that Bigelow's coal fetched a delivered price of $30 per ton in San Francisco (Bagley, 1929). In 1861 L. B. Andrews discovered coal on a hillside just west of the present city of Issaquah. Because there were no roads connecting the discovery to a port, this coal had to be barged down Issaquah Creek to Lake Sammamish, to Lake Washington, down the Black River to the Duwamish River, and finally to port. Coal was discovered at Coal Creek shortly thereafter, and it also went to market by this circuitous route. Development proceeded slowly, however, until the first railroad in the Puget Sound region was completed in 1872. Coal exports leaped from 4,918 tons in 1871 to 14,830 tons in 1872, and by 1879, exports were up to 132,263 tons. Of the 790,639 tons exported during the decade, 733,794 tons were produced at the Newcastle mines, the remainder coming from the Renton area mines (Bagley, 1929).

In 1880, the San Francisco-based Black Diamond Company sent an expedition to Washington to explore for a better coal than that being shipped from Newcastle. In July of that year, they discovered the coal of the Franklin coal zone along the Green River. The lower quality coals of the superjacent Kummer coal zone of this area had been known since 1873, but had not as yet been mined (Thorndale, 1965). There was limited production at Franklin and Black Diamond by 1883, and with the completion of the rail link to Seattle in 1885, the Green River district soon became the major coal-producing region on the Pacific coast. It reached a peak annual production of 925,000 tons in 1903, and more than half of all the coal mined in King County to date has been from the Green River district (Beikman and others, 1961).

With the development of California oil at

the turn of the century, demand for King County coal waned. From a peak of 1.45 million tons in 1907, King County production declined steadily. Today only a single mine near Black Diamond remains in operation with 1980 production of only 6,000 tons.

STRATIGRAPHY

The coal fields of King County may be conveniently grouped into two areas: the Newcastle Hills-Cedar Mountain-Taylor area to the north and, to the south, the Green River fields (fig. 1). The Cedar River drainage is an approximate dividing line between the two areas.

Important stratigraphic differences exist between the north and south coal-bearing areas (fig. 2). In the south, the oldest exposed rocks belong to the Puget Group, a sequence of nonmarine deltaic sandstones, shales, and coals. About 6,200 feet of the Puget Group is well exposed in the canyon of the Green River. The Green River section contains 55 percent feldspathic or arkosic sandstone, 35 percent siltstone, and 10 percent shale, carbonaceous shale, and coal. Significant quantities of volcaniclastic rocks or lava flows are entirely absent except in the uppermost 350 feet of the section where volcanic debris interfingers with arkosic sandstones (Vine, 1969). The coal beds are the most useful stratigraphic markers in

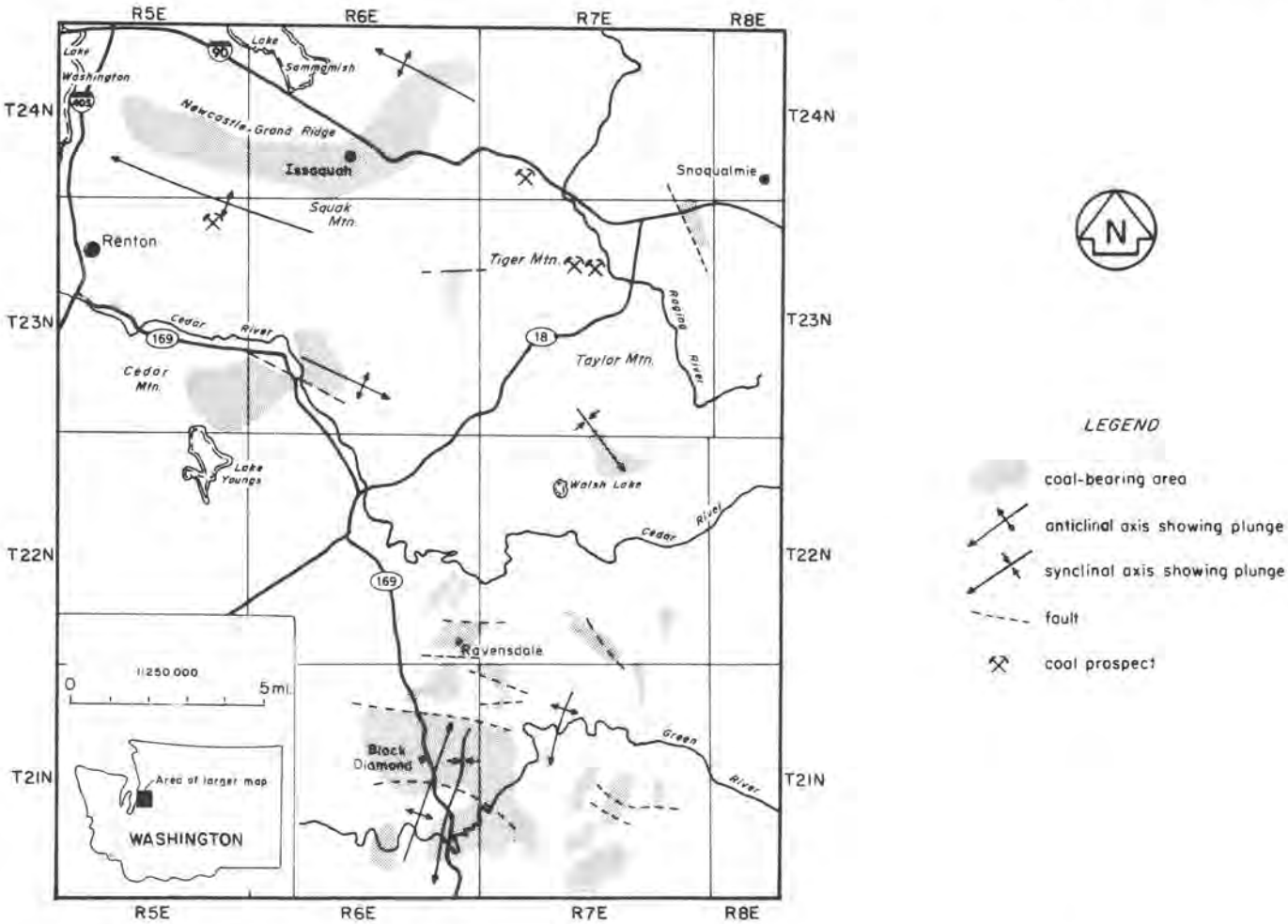


FIGURE 1.—Major coal-bearing areas of King County. Major folds, faults, and coal prospects are also shown.

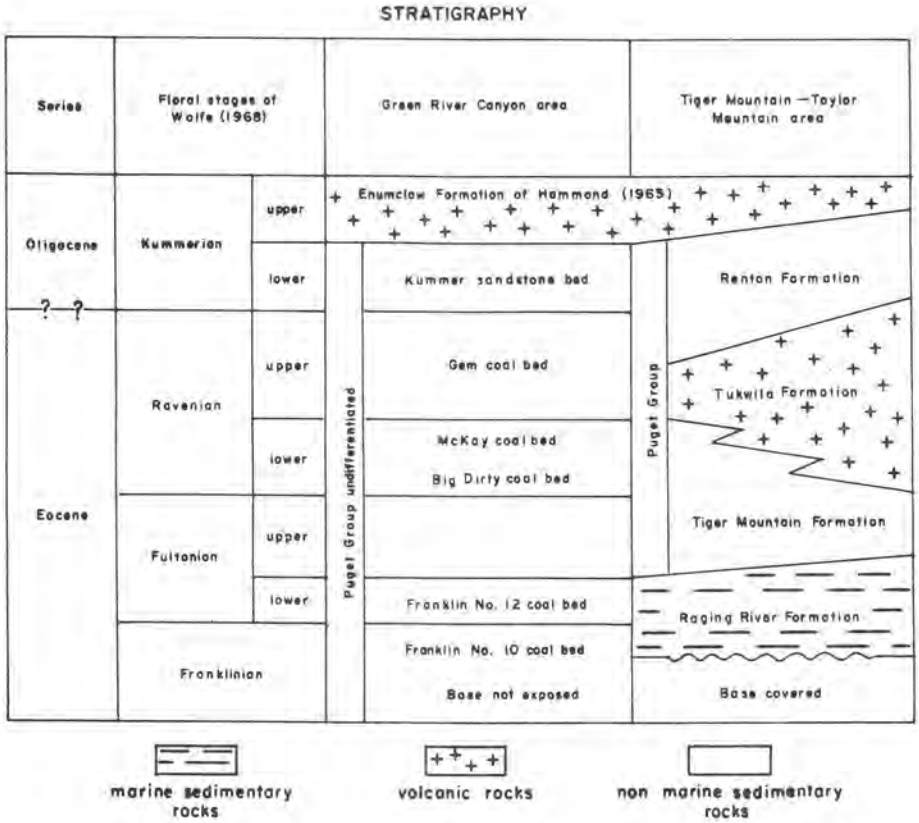


FIGURE 2.—Correlation of the Puget Group in the Green River Canyon area and equivalent rocks in the Tiger Mountain-Taylor Mountain area (after Vine, 1969).

the section. Previous workers (Evans, 1912; Weaver, 1937) divided the Green River section into "series" and formations but these subdivisions are not mappable outside the immediate vicinity of the Green River section (Vine, 1969).

Abundant fossil leaves are present in the Puget Group of the Green River area. On the basis of floral megafossils, Wolfe (1968) found the Green River section to range from early Eocene to early Oligocene age. Recent work (Triplehorn and others, 1980) based upon the dating of volcanic ash partings from Green River coals suggests that the 6,200 feet of section is entirely late Eocene.

The Puget Group is overlain with slight or no unconformity (Warren and others, 1945; Vine, 1969) by a sequence of continental lava and breccia flows with subordinate tuff, tuff-breccia and volcanic sedimentary rocks (Enumclaw Formation of Hammond, 1963). Fossil leaves (Wolfe, 1968) indicate that the overlying volcanics are in part early Oligocene.

To the north, in the Tiger Mountain-Taylor Mountain uplands, the oldest exposed rocks belong to the marine Raging River Formation (Vine, 1962). It is composed of as much as 3,000 feet of dark-gray sandstone, siltstone, and claystone, largely of volcanic origin. On the basis of foraminiferal assemblages, the Raging River Formation is assigned a middle Eocene age (Wolfe, 1968). It is gradationally overlain by the continental Tiger Mountain Formation, which is composed of about 1,100 feet of sandstone, shale, and coal. In the superjacent 1,700 feet, Tiger Mountain Formation is interbedded with epiclastic volcanic rocks of the Tukwila Formation. The main body of Tukwila Formation, as much as 8,000 feet thick near Issaquah,

overlies this interstratified zone. Vine (1969) correlates these rocks with the Fultonian and Ravenian stages of the Green River section (middle to upper Eocene). Overlying the Tukwila Formation is the Renton Formation, a coal-bearing sequence of sandstone and shale. It ranges in thickness from about 2,250 feet in the Taylor Mountain area (fig. 1) to about 3,200 feet near Issaquah. All of the extensively mined coal in the northern part of the study area has been in the Renton Formation. Wolfe (1968) assigns the formation to the upper Kummerian floral stage (lowermost Oligocene). Tiger Mountain, Tukwila, and Renton Formations comprise the Puget Group in the northern part of the area. To the east, the Renton Formation is overlain by continental volcanic rocks similar to those overlying the Puget Group in the Green River section (Warren and others, 1945). To the west, the Renton Formation is overlain by marine sandstone, shale, conglomerate and tuffaceous sandstone. These rocks are tentatively correlated with the late Eocene to early Miocene Lincoln Creek Formation (Beikman and others, 1967; Mullineaux, 1970).

Throughout the study area, the bedrock is blanketed by Quaternary deposits consisting of glacial till, terrace gravels, stratified drift, lacustrine sand and silt, and peat.

STRUCTURE

The coal fields of King County are characterized by structural complexities that have made mining difficult and expensive. Because of widespread folding, seam dips often exceed 30°, thus necessitating underground mining. Faults of varying displacements are also very common in King County. When encountered in underground workings, much time, effort, and money often had to be expended to locate faulted coal seams.

The northern half of the King County coal fields are dominated by northwest-trending folds. At the Newcastle Hills and to the east, the folds plunge to the northwest. South of these areas the folds plunge to the southeast. This reversal approximately coincides with an intrusive body postulated by Vine (1969) to be an eruptive center of the Tukwila Formation. The style of faulting in the area is varied, although it is principally dip-slip and commonly trends east-west. A large reverse fault dipping steeply to the north, probably flanks the Newcastle Hills on the south along most of its length, truncating the mines at Tiger Mountain. East-west trending reverse faults of undetermined displacement also terminated mining in the vicinity of Cedar Mountain. Mine maps at Newcastle and Cedar Mountain show many small displacement normal faults, commonly trending northwest.

In the southern or Green River area, coal-bearing sediments of the Puget Group have been folded into a series of generally north-south trending, south-plunging, asymmetric anticlines and synclines. Map distances between fold axes range from 2 to ¼ miles, with folds becoming more numerous toward the eastern edge of the area where the Puget Group dips beneath the thick volcanic cover of the Cascade Mountains. Fold limbs typically dip between 30° to 75°. Locally strata are vertical or overturned. Axial planes of the folds are generally steeply inclined to the east. Most of the folds have narrow hinges with a chevron-like appearance in cross-sectional view (Vine, 1969).

East-west and northwest-southeast trending faults disrupt and complicate the general south-plunging fold pattern. For example, in a fault-bounded area near Ravensdale, fold structures have sinuous axes that range from north-south to east-west in trend. Most faults in the Green River area are high angle and normal with maximum throws of about 750 feet. One northwest-trending strike-slip fault with about 1,000 feet of right-lateral strike-slip

displacement has been well documented from coal-mine workings. Several reverse faults that roughly parallel the trend of fold axes have also been recognized (Anderson, 1959; Vine, 1969). In general, the incidence of faulting increases in an easterly direction across the Green River area.

Deformation of the Puget Group in King County can be dated locally as younger than early Oligocene and older than late Miocene. The dating is based on the angular unconformity between Puget Group rocks and the overlying upper Miocene Hammer Bluff Formation along the Green River in T. 21 N., R. 6 E. (Mullineaux and others, 1959; Vine, 1969; Mullineaux, 1970). Evidence from adjacent areas suggests that several deformational events occurred during the Oligocene and Miocene. In the Mount Rainier area, the Oligocene Ohanapecosh Formation was folded and deeply eroded before deposition of middle Oligocene through early Miocene rocks. All of the rocks were then folded and faulted in late Miocene time (Fiske and others, 1963). K-Ar and apatite fission track dates of 30-40 m.y. and 15-18 m.y. for central Cascade plutons (Baadsgaard and others, 1961; Erickson, 1968) also indicate two deformational events.

COAL GEOLOGY

In the northern part of the area, almost all of the commercially minable coal is found in the Renton Formation. The coal fields were the Newcastle-Grand Ridge, Renton-Cedar Mountain, Tiger Mountain, Taylor, Niblock, and Raging River. Mining in the Raging River district was in the Tiger Mountain Formation. The stratigraphic position of the coals of the Niblock district is uncertain. Almost all of the mining was underground, either by drift or by slope. The principal exception is the strip mine in the Newcastle Hills, which extended about 1 mile along the crop line of the 22-foot-thick Bagley seam. The strip pit is currently being used as a landfill.

NEWCASTLE - GRAND RIDGE

The most productive field was Newcastle-Grand Ridge. In the Newcastle Hills, there are 10 beds within a stratigraphic interval of about 1,200 feet (fig. 3). These beds dip northward 35° and 45°. At Issaquah, the strike of the beds swings to the north along Grand Ridge. Here, the dip steepens to as much as 80° to the west. At least nine beds occur there, although only seven were mined. There remains an area approximately three-quarters of a mile along strike where little development occurred on Grand Ridge, and, a similar stretch in the Newcastle Hills about 2 miles west of Issaquah. Beikman and others (1961) estimate remaining reserves in the district at about 300 million tons, one-fourth of which is located in these undeveloped areas on the four principal beds, ranging in thickness from 4 to 22 feet. The average analysis (as-received basis) for all seams is 9900 Btu/lb, 0.6 percent sulfur, 12 percent ash, and 13 percent moisture, corresponding to subbituminous A rank. Because of the abundance of partings, Newcastle-Grand Ridge coals have usually required washing. In addition, Grand Ridge coal dips too steeply for conventional mining, but it may be amenable to underground gasification or hydraulic mining.

CEDAR MOUNTAIN FIELD

Cedar Mountain was an important coal field as early as the 1880's and reached a peak annual production of nearly 400,000 tons in 1930 (Beikman and others, 1961). The coal is of better quality than that at Newcastle, ranging from subbituminous A to high-volatile bituminous C. The analyses average 10,900 Btu/lb, 0.8 percent

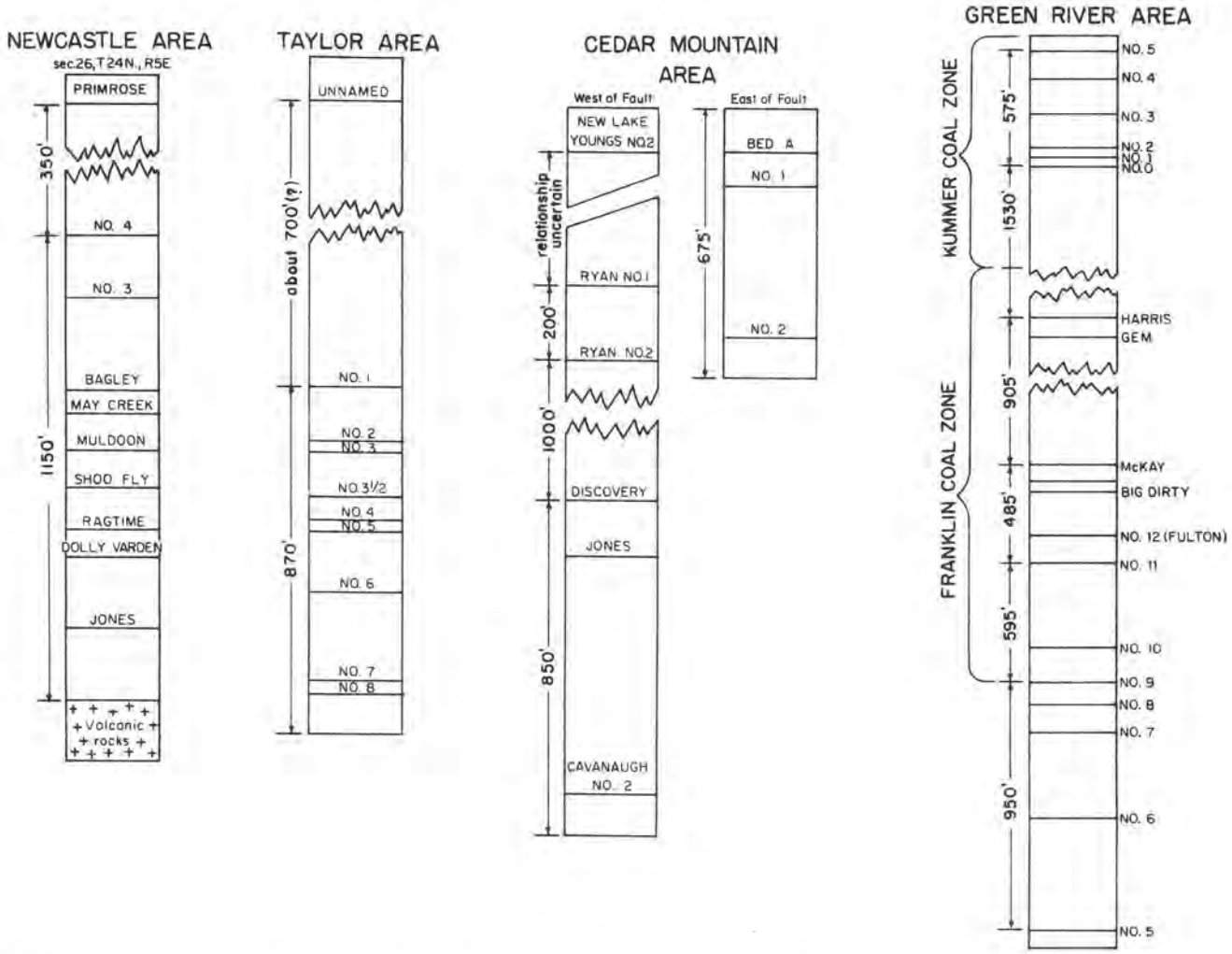


FIGURE 3.—Principal coal beds of King County (after Beikman and others, 1961; Morris and Ames, 1980).

sulfur, 11 percent ash, and 10 percent moisture. The commercial seams ranged in thickness from 3½ feet to 12 feet. The mines are located in an open, south- to southeast-plunging symmetric anticline, with dips ranging from 15° to 45° on its limbs.

Development was slowed by a large northwest-trending fault across which coal beds could not be traced (fig. 1). Three seams were subsequently discovered northeast of the fault, two of which were extensively mined. Six seams were mined to the southeast of the fault. Beikman and others (1961) and Vine (1969) both estimate about 66 million tons in remaining reserves. Petroleum exploration wells drilled about 3 miles southwest of these mines reveal as many as 12 coal beds in the Renton Formation, raising the possibility of significant reserves hidden by glacial deposits.

TAYLOR FIELD

The Taylor field contains at least 10 beds of high volatile B and high volatile A bituminous coal in a southeast-plunging syncline with limbs dipping about 70°. The coal averages about 11,400 Btu/lb, 1.1 percent sulfur, 5.2 percent moisture, and 16 percent ash. It was mined along with interbedded shales and kaolinized sills for the manufacture of baked-clay products.

Because of its high ash content, it was not competitive for any but this application, and probably no more than 1 million tons of coal was ever mined. High ash content would not be an insurmountable detriment for underground gasification, in which the ash absorbs some of the heat produced but does not have to be cleared away. Data on the extent of the Taylor coals are scant, and Beikman and others (1961) confidently estimate only 19 million tons of reserves.

Coal has been mined intermittently in other smaller coal fields. The regions from just west of Tiger Mountain to Snoqualmie (fig. 1) have produced small amounts of coal from the Renton and Tiger Mountain Formations, but structural complexity and igneous intrusions increase eastward and mining was never profitable.

GREEN RIVER

The principal coal seams of the Green River area are shown in figure 3. The informally defined "coal zones" (Franklin and Kummer) are recognized only in the vicinity of the canyon of the Green River. Many other seams exist locally and some may correlate with the principal coal beds (Wolfe, 1968). Determining the extent and stratigraphic relationships of coal beds in the Green River area is difficult due to structural complexity, poor exposure, lack of subsurface data in key areas, and the discontinuous nature of the Puget Group deltaic facies.

Coal rank is generally a function of stratigraphic position in the Green River area, with the top coal beds having the lowest rank of coal. Thus, coals of the Kummer coal zone are subbituminous. Most of the coals below the Kummer zone are high volatile B bituminous in rank.

The average Green River coal has about 12 percent moisture, 0.5 percent sulfur, 12 percent ash, and a heating value of 11,600 Btu/lb (statistics based on "as received" analyses from Franklin No. 10, McKay, Gem, Kummer No. 1, and Kummer No. 4 coal seams; data from Beikman, 1963). The McKay seam contains the highest quality coal in the region and is the most extensively mined. It is a low ash (4.5 percent) and low sulfur (0.6 percent) coal with a heating value of 12,070 Btu/lb (average of 25 "as received" analyses; Vine, 1969). Coking coals are not found in the Green River district in any significant quantities.

Coal bed thicknesses in the Green River area range from several feet or less to as much as 11 feet of clean coal. Most economically important beds are between 3 and 8 feet thick. Coal seams generally consist of interstratified coal, impure coal, bone, carbonaceous claystone, and rare gray shale or claystone. Because of the intimate association of coal and partings, all Green River coals must be washed.

Due to superior heating values, relatively low ash content, and favorable structural conditions, the coals of the Franklin coal zone (fig. 3) have been the most economically important. The Franklin No. 10, Franklin No. 12, McKay, and Gem seams were extensively mined in the vicinity of Black Diamond from about 1883 through the 1930's. Nearly all coal was produced from underground mines using both drift and slope techniques.

The mines were located in two major fault-bounded fold structures, the Kummer syncline and the Black Diamond anticline. The Kummer syncline is a large, broad-hinged, south-plunging structure lying several miles to the south and east of Black Diamond. The syncline is asymmetric to the west with dips on the east limb ranging from 30° to 55° while west limb dips are from 15° to 75°. Numerous east-west trending normal faults, fracture zones, and several igneous sills, along with

the steep dips, made mining difficult. Mine drainage, fire, and gas problems were also encountered. A small amount of strip mining has also taken place on the Kummer syncline. Palmer Coking Coal Co. of Black Diamond, strip mined portions of the Franklin No. 12 seam in the 1950's. Currently, the company is strip mining underground mine barrier pillars in the McKay and Gem seams.

The Black Diamond anticline (sometimes called the Kummer anticline) is a faulted, doubly plunging, north-south to northeast trending, asymmetric fold. It lies just west of the Kummer syncline. The town of Black Diamond is located just west of its axial trace. Extensive mining of the McKay seam was conducted for over 30 years on the west limb of the anticline. A main slope depth of 1,500 feet below sea level was reached with maximum overburden thickness of 2,100 feet (Evans, 1912). The Black Diamond mines were among the deepest coal mines in the world at the time of operation.

Many other coal seams were mined in the Green River area in structures other than the Kummer syncline and Black Diamond anticline. The largest of these mining operations worked the coal beds at Ravensdale, which roughly correlate (Wolfe, 1968) with the stratigraphic interval containing the McKay bed. The Ravensdale structure is a complex series of northwest-plunging folds bounded by faults of undetermined magnitude and displacement direction. North of Ravensdale, five coal beds probably correlative with the McKay-Franklin No. 12 stratigraphic interval were mined both by underground and surface methods. The beds are vertical or steeply dipping and strike northeast. Numerous mines were also operated in the eastern half of the Green River area. However, as in areas north of the Cedar River, structural complexity and igneous intrusion increases to the east and most of the mining operations were not profitable.

Coal mining in the Green River area has generally been confined to the Franklin and Kummer coal zones. Due to a lack of subsurface data, no economically important coal beds were known to exist below the Franklin No. 9 coal bed before 1947. In 1947, a dry oil and gas exploration hole, Pacific Coast Coal Co. No. 1, was drilled in T. 21 N., R. 6 E. to a depth of 4,319 feet. The log of this hole revealed the presence of a number of thick coal beds below the Franklin No. 9 bed. Subsequent drilling in 1960 and 1961 along the Black Diamond anticline confirmed the existence of at least five previously uncorrelated coal beds with minable thicknesses (USSRAM, 1962). In descending stratigraphic order, the beds are the 810, Franklin Nos. 8, 7, 6, and 5 (fig. 3). In addition, drill logs show at least eleven coaly or carbonaceous beds in the 2,500 feet of section below Franklin No. 5. The coal quality and lateral continuity of the eleven coal zones have not been determined, however.

While the coal quality of Franklin Nos. 5 through 8 and the 810 have not been conclusively demonstrated, analyses from drill cores indicates that the coals are high volatile bituminous in rank. All seams are high in ash (20 to 30 percent), have low moisture (1 to 4 percent), and are low in sulfur (0.3 to 1.5 percent). After washing, the coals should yield an 11,000 to 11,500 Btu/lb clean product with a weight recovery of 75 percent to 80 percent (Morris and Ames, 1980). Seam thickness (including partings and bone) range from 1.4 to 23.2 feet.

The estimated reserve of seams 810 and Franklin Nos. 5 through 8 to a depth of 3,000 feet is 179 million tons of in-place coal (Morris and Ames, 1980). Some 72 million tons or about 40 percent of the total resource should be recoverable using modern mining techniques (Shannon and Wilson, 1977).

The entire Green River area contains an estimated 400 million tons of in-place coal

(Beikman and others, 1961; Vine, 1969), exclusive of seams 810 and Franklin Nos. 5 through 8. Using a 40 percent recovery rate, and including the reserve figure for the 810 and older seams given above, about 232 million tons of minable coal is estimated for the Green River area.

This estimate can be expected to change substantially as new data become available. New subsurface information will help define the extent of coals under glacial cover. As the base of the Puget Group has not been penetrated in any well, significant quantities of coal may exist below the Franklin No. 5 seam.

Successful subsurface correlation of coal seams will require improved stratigraphic control in the undifferentiated Puget Group. Thin ash partings have recently been recognized and dated in coals from the Green River area (Triplehorn and others, 1980). The partings may be extensive enough to serve as stratigraphic markers. Also promising is the technique of palynologic biostratigraphy. Palynomorphs have been found in the Puget Group of the Green River area (Newman, 1977). The palynomorphic data could be very useful in further refining the megafloral stages of Wolfe (1968), particularly as pollen can be recovered from drill core.

Coal too deep or too structurally complex to be mined conventionally may be extractable using a variety of new technologies including hydraulic mining and underground coal gasification. Additionally, recent research indicates that methane may be present in Green River coals (Choate and Johnson, 1980). Using a maximum coal-methane content of 60 cubic feet methane per ton of coal, a possible methane resource estimate for the Green River area is about 24 billion cubic feet.

DIVISION COAL GROUP ACTIVITIES

The Division of Geology and Earth Resources (DGER) currently has five staff members studying the coal resources of Washington. The general goals and aims of the DGER coal group are to collect and disseminate coal information to the public and to industry, to refine existing estimates of coal reserves and resources, and to aid in the exploration for new coal deposits within the State of Washington. Work in progress includes the following:

Geology and coal resources of the Wilkeson-Carbonado area, Pierce County, Washington, Henry W. Schasse (DGER geologist). Project initiated February, 1981. Objectives are to produce a detailed geologic map and cross sections, a series of coal resource maps, and to update coal reserve estimates.

Coal exploration on state-administered lands in Whatcom and Skagit Counties, Washington, Ellis Vonheeder (DGER geologist). To be published as Report of Investigations (in preparation).

Township by township descriptions of coal resources contained on state-administered lands, Centralia basin, Lewis County, Washington, Ellis Vonheeder (DGER geologist).

DGER coal mine map collection, Ellis Vonheeder. Cataloging and organization of the several thousand original coal mine maps in the DGER collection. Mine maps are to be photographed on microfilm by U.S. Bureau of Mines in Spokane to facilitate cataloging.

Washington coal analysis data base, DGER coal group staff. Project initiated February, 1981. A computerized coal analysis data base is currently being developed by Division staff. The system will allow statistical analysis, sorting by over 70 variables, and rapid information retrieval for the large volume of Washington coal analytical data.

Trace element geochemistry of Washington coals and related sediments, Tim Walsh and Bill Phillips. Using XRF analysis, trace element concentrations in coals and related sediments will be investigated. Project initiated February, 1981.

Coal resources of Asotin County, Washington, Keith Stoffel (DGER geologist). Investigation of lignites contained in interbeds within the Miocene Saddle Mountain basalts of the Grande Ronde River area.

Geology and coal resources of King County, Washington, Bill Phillips and Tim Walsh. Objectives are to produce a detailed geologic map and cross sections, a series of coal resource maps, and to update coal reserve estimates.

REFERENCES

Anderson, J. Q., 1959, Puget Sound area has several prospective oil and gas basins: World Oil, v. 149, no. 1, p. 111-113, 117, July 1959; Washington Division of Mines and Geology Reprint 5, 4 unnumbered pages.

Baadsgaard, Halfdan; Folinsbee, R. E.; Lipson, J. I., 1961, Potassium-argon dates of biotites from Cordilleran granites: Geological Society of America Bulletin, v. 72, no. 5, p. 689-701.

Bagley, C. B., 1929, History of King County, Washington: S. J. Clarke Publishing Co., Seattle, v. 1, 305 p.

Beikman, H. M.; Gower, H. D.; Dana, T. A. M., 1961, Coal reserves of Washington: Washington Division of Mines and Geology Bulletin 47, 115 p.

Beikman, H. M.; Rau, W. W.; Wagner, H. C., 1967, The Lincoln Creek Formation, Grays Harbor basin, southwestern Washington. U.S. Geological Bulletin 1244-I, 14 p.

Choate, Raoul; Johnson, C. A., 1980, Geologic overview, coal and coalbed methane resources of the western Washington coal region; draft: TRW Energy Systems Group, 1 v., 6 plates.

Evans, G. W., 1912, The coal fields of King County: Washington Geological Survey Bulletin 3, 247 p.

Evans, G. W., 1924, Coal mining in the State of Washington. In Shedd, Solon, The mineral resources of Washington, with statistics for 1922: Washington Division of Geology Bulletin 30, p. 184-206.

Erikson, E. H., 1968, Petrology of the composite Snoqualmie batholith, central Cascade Mountains, Washington: Southern Methodist University Ph. D. thesis, 111 p.

Fiske, R. S.; Hopson, C. A.; Waters, A. C. 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p.

Hammond, P. E., 1963, Structure and stratigraphy of the Keechelus volcanic group and associated Tertiary rocks in the west-central Cascade Range, Washington: University of Washington Ph. D. thesis, 264 p.

Morris, D. J.; Ames, P. R., 1980, Additional coal resources in the Green River district, King County, Washington: Pacific Northwest Metals and Minerals Conference, Seattle, May 7-9, 1980, 20 p.

Mullineaux, D. R., 1965, Geologic map of the Black Diamond quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-407.

Mullineaux, D. R., 1970, Geology of the Renton, Auburn, and Black Diamond quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 672, 92 p.

Mullineaux, D. R.; Gard, L. M., Jr.; Crandell, D. R., 1959, Continental sediments of Miocene age in the Puget Sound Lowland, Washington: American Association of Petroleum Geologists Bulletin, v. 43, no. 3, p. 688-696.

Newman, K. R., 1977, Palynologic biostratigraphy of some early Tertiary nonmarine formations in central and western Washington: Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1113.

Shannon and Wilson, Inc., 1977, Preliminary evaluation of Roslyn and Green River coal fields, Washington: Report prepared for City of Seattle Department of Lighting, Shannon and Wilson, Inc., 2 volumes.

Triplehorn, D. M.; Turner, D. L.; Frizzell, V. A., 1980, Stratigraphic significance of radiometric ages for Eocene coals in western Washington. In Carter, L. M., editor, Proceedings of the 4th Symposium on the geology of Rocky Mountain coal, 1980: Colorado Geological Survey Resource Series 10, p. 87.

Thorndale, C. W., 1965, Washington's Green River Coal Company, 1880-1930: University of Washington M.A. thesis, 168 p.

U.S. Smelting, Refining, and Mining Co., 1962, Third progress report, Washington coal investigations, Black Diamond-Franklin area, King County: Report prepared for Puget Sound Power and Light Co., U.S. Smelting, Refining, and Mining Co., USSRAM Division, 8 p.

Vine, J. D., 1962, Stratigraphy of Eocene rocks in a part of King County, Washington: Washington Division of Mines and Geology Report of Investigations 21, 20 p.

Vine, J. D., 1969, Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 624, 67 p.

Warren, W. C.; Norbisrath, Hans; Grivetti, R. M.; Brown, S. P., 1945, Preliminary geologic map and brief description of the coal fields of King County, Washington: U.S. Geological Survey coal investigation map, scale 1:31,680.

Wolfe, J. A., 1968, Paleogene biostratigraphy of nonmarine rocks in King County, Washington: U.S. Geological Survey Professional Paper 571, 33 p.

Wolfe, J. A.; Gower, H. D.; Vine, J. D., 1961, Age and correlation of the Puget Group, King County, Washington. In Short Papers in the geologic and hydrologic sciences: U.S. Geological Survey Professional Paper 424-C, p. 230-232.

A POSSIBLE GEOLOGIC EXPLANATION FOR THE WILDCAT DRILLING BY SHELL IN YAKIMA CANYON

A great deal of interest has been generated by the Shell Oil Co. wildcat well being drilled in Yakima Canyon. Logical questions one might ask about the location of the well would be: Why would they drill in the Yakima Basalt, and what could they be looking for as a reservoir rock? Looking at a geologic map of the state provides some interesting possibilities.

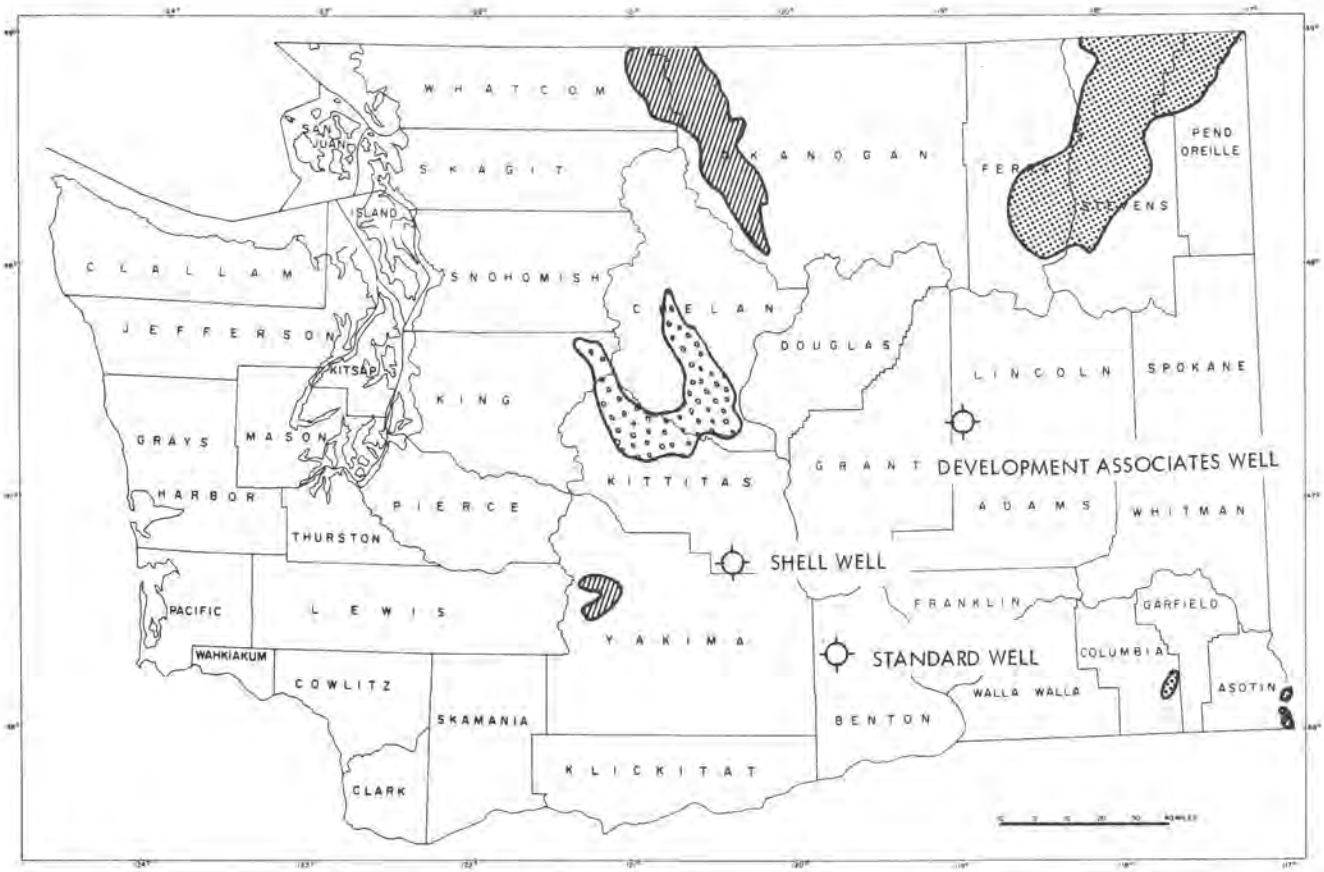
Consider the structural picture first. The well, although spudded in Yakima Basalt, is located either on or very close to the axis of the Umtanum Ridge anticline. The anticline is very obvious in the basalt and one must assume that Shell has found evidence that it continues into whatever rocks are underneath the basalt. One must also assume that the company has found evidence that the rocks under the basalt are sedimentary in origin. The critical questions then are: How thick is the basalt and what is under it in this area.

One well drilled in the Columbia Basin area is known to have penetrated the Yakima

Basalt. The Development Associates Inc. Development No. 1 (Basalt Explorer No. 1) drilled in section 10, township 21 north, range 31 east, about 80 miles northeast of the Shell well, went out of basalt into a sandstone at 4,465 feet. At a total depth of 4,682 feet it was reported to be in granite. Another well, the Standard Oil Co. of California Rattlesnake Unit No. 1, drilled about 40 miles to the southeast of the Shell well, is thought by some workers to have gone out of the Yakima Basalt and into andesitic volcanics at about 5,000 feet, but others believe it was still in the basalt at its total depth of 10,655 feet. Currently, there are some unanswered questions about the stratigraphic column penetrated by the Standard well so its usefulness is diminished for the time being in determining the thickness of the Yakima Basalt.

Don Swanson of the U.S. Geological Survey, who has done extensive mapping of the Yakima Basalt, suggests that a composite section of the unit in the basin would be about 4,500± feet thick. Because the Shell well is near the western margin of the Columbia Basin where the basalt may be lapping onto the edge of the basin and thus thinning, the thickness of the basalt is probably close to 4,500 feet even if the 10,655-foot thickness in the Standard Rattlesnake well proves to be correct. This would put any sedimentary unit beneath the basalt at the Shell site within easy reach of the drill.

The rocks surrounding the Yakima Basalt in the Columbia Basin vary from Tertiary sediments to Precambrian high-grade metamorphics; in windows cut into the basalt by stream erosion in the southeastern part of the state,



General distribution of Paleozoic, Mesozoic, and lower Tertiary sediments of eastern Washington

both Paleozoic and Mesozoic rocks have been exposed. Looking at regional trends in the rocks surrounding the basin, it appears that lower Tertiary continental rocks of the Swauk and Roslyn Formations and the Chumstick Formation of Whetten and Wenatchee Formation of Gresens could be encountered in the well. These rocks extend beneath the basalt only about 35 miles to the north. Another possibility would be a section of Mesozoic rocks, similar to those in the upper Methow Valley, existing under the basalt. This thick sequence has black shales that could have served as oil and gas source beds, as well as sandstone that might serve as reservoir rocks. A thick sequence of Mesozoic(?) argillite, graywacke, slate, volcanic flows, and arkose that constitute the Russell Ranch Formation crop out in the Tieton River valley about 40 miles to the west of the well. No fossils have been found in the unit so the age is based on stratigraphic position and degree of metamorphism. Rocks stratigraphically above the Russel Ranch Formation are Eocene in age; the base of the formation is not exposed. The degree of metamorphism is somewhat similar to that of the Mesozoic rocks in the Methow Valley; that is, metamorphosed more than the Tertiary rocks in the state and generally less than the Paleozoic rocks. This, of course, is an extremely tenuous correlation.

Paleozoic sedimentary rocks crop out about 140 miles to the northeast in Ferry, Stevens, and Pend Oreille Counties and about 130 miles to the southeast in the Tucannon and Snake River valleys. These rocks are quartzites, arkoses, dolomites, and limestone.

The Paleozoic rocks have been subjected to too much metamorphism to provide much hope for the occurrence of oil or gas. The most likely sources are the Mesozoic and Tertiary rocks. Based on structural trends and proximity to the well, the Tertiary rocks of the Swauk and Roslyn Formations and the Chumstick Formation of Whetten and Wenatchee Formation of Gresens appear to be the most likely to occur under the basalt at the Shell well site. Because these units are all continental in origin, it is most probable that if a discovery is made it will be natural gas. The gas would have been generated from the many coal and carbonaceous beds that occur in these units.

READINGS ON TERTIARY AND MESOZOIC SEDIMENTARY ROCKS IN EASTERN WASHINGTON

Barksdale, J. D., 1975, Geology of the Methow Valley, Okanogan County, Washington: Washington Division of Geology and Earth Resources Bulletin 68, 72 p.

Bressler, C. T., 1951, Petrology of the Roslyn arkose, central Washington: Pennsylvania State College Ph. D. thesis, 147 p.

Foster, Robert J., 1960, Tertiary geology of a portion of the central Cascade Mountains, Washington: Geological Society of America Bulletin, v. 71, p. 79-126.

Gresens, R. L., 1976, A new Tertiary formation near Wenatchee, Washington: Geologic Society of America Abstracts with Programs, v. 8, no. 3, p. 376-377.

Gresens, R. L., 1977, Tertiary stratigraphy of the central Cascade Mountains, Washington State, Part IV Wenatchee formation. In Brown, E. H.; Ellis, R. C., editors, Geological excursions in the Pacific Northwest: Western Washington University press, p. 109-126.

Gresens, R. L., 1980, Deformation of the Wenatchee formation and its bearing on the tectonic history of the Chiwaukum graben, Washington, during Cenozoic time—Summary: Geological Society of America Bulletin, Part 1, v. 91, p. 4-7.

Kuenzi, W. D., 1959, Geology of the Kelly Hill area, Stevens County, Washington: Montana State University M.S. thesis, 111 p.

Laravie, J. A., 1976, Geologic field studies along the eastern border of the Chiwaukum graben, central Washington: University of Washington M.S. thesis, 56 p.

Patton, T. C.; Cheney, E. S., 1971, L-D gold mine, Wenatchee, Washington—New structural interpretation and its utilization in future exploration: Society of Mining Engineers Transactions, v. 250, p. 6-11.

Shumway, R. D., 1960, Geology of the Lime Hill area, Asotin County, Washington: Washington State University M.S. thesis, 54 p.

Simmons, G. C., 1950, The Russell Ranch formation: Washington State College M.S. thesis, 25 p.

Walker, Charles W., 1980, Geology and energy resources of the Roslyn-Cle Elum area, Kittitas County, Washington: Washington Division of Geology and Earth Resources Open-File Report 80-1, 59 p.

Washington Division of Geology and Earth Resources, 1978, Geology of Washington: Washington Division of Geology and Earth Resources Reprint 12, 51 p.

Whetten, J. T., 1976, Tertiary sedimentary rocks in the central part of the Chiwaukum graben, Washington: Geological Society of America Abstracts with Programs, v. 8, no. 3, p. 420-421.

Whetten, J. T., 1977, Sedimentology and structure of part of the Chiwaukum graben, Washington: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 527.

Whetten, J. T.; Laravie, J. A., 1976, Preliminary geologic map of the Chiwaukum 4 NE quadrangle, Chiwaukum graben, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF 794.

1981 ANNUAL TRGS FIELD CONFERENCE AND TECHNICAL SESSION ANNOUNCEMENT

The Tobacco Root Geological Society (TRGS) will hold its Sixth Annual Field Conference and Technical Session at Idaho State University, Pocatello, Idaho, September 9-12, 1981. Papers are invited for the technical session on any aspect of northwest geology. Please submit GSA style abstracts to address below by June 30, 1981.

An interesting field trip schedule is being planned and the proposed trips include: a phosphate mine tour, Tertiary geology of the Pocatello area, tour of the ISU vertebrate collection, thrust belt field trip, volcanics of the Snake River Basin, glacial features of the Sawtooth Mountains.

TRGS is a regional society interested in all aspects of northwest geology (Montana, Idaho, Wyoming, Oregon, and Washington). Members receive a subscription of the Journal NORTHWEST GEOLOGY. Send abstracts to, and for further information contact:

Dr. William J. Fritz, Corresponding Secretary
The Tobacco Root Geological Society, Inc.
c/o Amoco Production Company
Amoco Building
Denver, Colorado 80202
(303) 830-5032

REPORT ON MOUNT ST. HELENS ASH NOW AVAILABLE

Report of Investigations 24, "Mount St. Helens ash—Properties and possible uses," by Wayne S. Moen and Glennda B. McLucas, is now available for purchase from the Department of Natural Resources, Division of Geology and Earth Resources, for $5. The publication consists of 28 figures, 20 tables, and 60 pages.

The frontispiece has four photomicrographs, in color, of ash from the May 18th eruption, collected at Vantage, Washington.

As a result of the May 18, 1980, eruption of Mount St. Helens, a total of about 0.33 cubic mile (195 million cubic yards) of volcanic ash fell on 49 percent of the land area of Washington State. The bulk of this ash, which in places was as much as 3 inches deep, fell mainly in Yakima, Grant, Adams, Whitman, and Spokane Counties of eastern Washington. As a result of cleanup operations in these counties, over 375,000 cubic yards of ash has been stockpiled, with the hope that it may have some use.

The ash consists chiefly of glass and plagioclase feldspar accompanied by accessory minerals such as pyroxene, amphibole, magnetite, and quartz. The ash is typically light gray and resembles portland cement in color and fineness. The bulk of eastern Washington ash falls in the 0.044 to 0.061 mm size range (325 to 250 mesh).

Several nonmetallic mineral-oriented companies have considered possible uses for the ash. These uses include: Abrasives, glass and ceramics, fillers, pozzolan, asphalt admixture, and fertilizer and insecticide carriers. Testing is in progress for a variety of these uses. To date, selling the ash as a souvenir of the eruption of Mount St. Helens has proven to be most profitable.

Because volcanic ash throughout the world has been put to as many as 40 different uses, Wayne S. Moen and Glennda B. McLucas, geologists for Washington Division of Geology and Earth Resources have investigated properties of the ash and considered its possible uses by mineral-oriented industries. Report of Investigations 24 includes physical and chemical properties of the ash, many possible uses, and availability and limitations to use of Mount St. Helens ash.

MOUNT ST. HELENS FACT SHEET

Location
- Skamania County, Washington
  - Latitude 122°11' W.; longitude 46°12' N.

Type of volcano
- Quaternary stratovolcano: composed of dacitic pyroclastic debris, dacite, domes, andesite flows, and a few basalt flows

Oldest known deposit
- 37,600 years old

Last major eruption
- 1842-1843 eruption on North Flank (creation of Goat Rocks dome)

Last reported activity
- 1857—Steam and ash eruption

Pre-1980 eruption elevation
- 2,950 meters (9,677 feet)

1980-81 activity
- First earthquake
  - March 20 (Richter 4.0)
- First phreatic eruption
  - March 27
- First magmatic eruption
  - May 18
- Subsequent eruptions
  - 2nd May 25
  - 3rd June 12
  - 4th July 22
  - 5th August 7
  - 6th October 16-19
  - 7th December 28-January 4
  - 8th February 5-7

May 18 eruption statistics
- Time of eruption
  - 8:32 P.d.t.
- Duration of most active phase
  - 9 hours
- Maximum elevation of ash cloud
  - 20 km above sea level (65,000 feet)
- Volume of ash ejected
  - 2 km^3 (0.5 $miles^3$)
- Volume of pyroclastic debris
  - 0.3 km^3 (0.07 $miles^3$)
- Volume of debris flows (avalanche-landslide)
  - 2.5 km^3 (0.61 $miles^3$)
- Volume missing from cone
  - 2.7 km^3 (0.66 $miles^3$)
- Volume of all erupted products
  - 4.8 km^3 (1.2 $miles^3$)
- Area devastated by lateral blast
  - 400 km^2 (156 $miles^2$)
- Area dusted by ash fallout
  - 1.3 million km^2 (0.5 million $miles^2$)

Depth of ash deposit
0-10 cm (0-4 inches) uncompacted (outside of a 20-mile radius from the mountain)
Depth of debris flow
Average = 60 meters (200 feet)
Maximum = 150 meters (500 feet)
Depth of pyroclastic flows
30^+ meters (100^+ feet)
Depth of lateral blast deposits
0-1.5 meters (0-4.5 feet)
Average
0.2-0.9 meters (10-35 inches)
Velocity of lateral blast cloud
"Muzzle" 225 m/sec (500 mph)
Across North Fork of the Toutle River valley 140 m/sec (310 mph)
Average 100 m/sec (225 mph)
Velocity of pyroclastic flows
40 to 80 m/sec (90-180 mph) (determined from observations of July 22 and August 7 flows)
Velocity of debris flow
90 m/sec (200 mph)
Temperature of lateral blast cloud
Average 150-250°C
Highest 350°C
Elevation of crater rim
2,560 meters (8,400 feet)
Elevation loss from previous summit
400 meters (1,300 feet)
Elevation of crater floor (5/80)
1,770 meters (5,800 feet)
Elevation loss from previous summit
1,190 meters (3,900 feet)
Height of crater walls
790 meters (2,600 feet)
Width of crater (rim to rim, east to west)
1.6 km (1 mile)
Spirit Lake
Pre-1980 elevation
975 meters (3,198 feet)
Post-1980 elevation
1,037 meters (3,400 feet)
Elevation gain
~60 meters (~200^+ feet)
Pre-1980 depth
~90 meters (~300 feet)
Post-1980 depth
~30 meters (~100 feet)
Energy released May 18
1.8×10^{25} ergs
1.8×10^{18} joules
Equivalent to
420 megaton nuclear explosion
21,000 times the energy released by the Hiroshima nuclear explosion, 1945

Total energy of other 1980 eruptions
0.2×10^{25} ergs

Total energy released, 1980
2.0×10^{25} ergs

Other Mount St. Helens comparisons

—By total energy, Mount St. Helens is within the top 10 eruptions since 1800.

—On the average, an event of this magnitude occurs only once every 2 decades, worldwide.

—By volume, Mount St. Helens is within the top 20 to 40 eruptions since 1800.

—Events with this type of a volume occur a few times each decade worldwide.

—The May 18, 1980 eruption created one of the largest breached craters (amphitheaters) of any historic eruption worldwide.

—The May 18, 1980 eruption of Mount St. Helens produced the largest volcanically induced debris avalanche of any historic eruption worldwide.

This data has been compiled from a number of different sources, including the U.S. Geological Survey (from monthly volcano reports, Scientific Event Alert Network Bulletins, and personal communications), Abstracts published in EOS Magazine (especially from the annual American Geophysical Union meeting in San Francisco, December 1980), and from a book by Michael A. Korosec entitled, "Volcano Mount St. Helens, the Geologic Story," in press.

Many of the values are preliminary or approximate, subject to future refinements. If the reader has a more accurate value, or if there are other statistics which can be contributed, please write to the Division of Geology and Earth Resources, c/o Michael A. Korosec or Robert (Josh) Logan. A corrected and updated fact sheet will appear in a future issue of the Geologic Newsletter.

MOUNT ST. HELENS DOME STATISTICS

Dome name	Major growth period	Diameter (or largest dimension) (ft.) (meters)	Height (ft.) (meters)	Elevation (ft.) (meters)	Volume ($X10^3 m^3$)
June	6/12/80— 6/19/80	1,200 (365)	155 (45)	6,220 (1,896)	4.7
August	8/ 8/80— 8/ 9/80	400 (120)	200 (60)	6,165 (1,880)	0.7
October	10/18/80—10/19/80	775 (235)	120 (37)	6,400 (1,952)	1.5
December (SE. lobe)	12/28/80— 1/ 4/81	725 (200)	280 (85)	6,560 (2,000)	3.5
(NW. lobe)	1/ 2/81— 1/ 4/81	250 (75)	130 (40)	6,430 (1,960)	3.5
Composite	—	1,220 (370)	280 (85)	6,560 (2,000)	5.0
February (lobe)	2/ 5/81— 2/ 7/81	925 (280)	330 (100)	6,675 (2,035)	5.0
Composite	—	1,270 (385)	400 (121)	6,675 (2,035)	10.0

Note: The values are approximate, and reflect the size of the domes after they had settled (subsided and spread laterally), except for the February dome, which was still changing as of this compilation (3/4/81). Data from various U.S. Geological Survey sources.

RIVER CLEANUP CONTINUES

Cleaning up after Mount St. Helens has been a monumental task. Working throughout the winter months, the U.S. Army Corp of Engineers has managed to complete most of the needed channel cleaning and flood prevention projects. These projects include the restoration of navigation channels in the Columbia River, building of needed flood prevention levees and bank stabilization along the shores of the Cowlitz River, restoration of adequate channel capacity, and construction of numerous debris dams and sediment basins in the drainage system. Completion of most of the projects was timely. Restoration of the Columbia River navigation channels was completed by the end of November 1980. Maintenance dredging of a sump near the mouth of the Cowlitz and the sides of the navigation channel continues in order to prevent refilling during periods of high flow.

The Cowlitz River recovery plan called for a channel capacity of 50,000 cfs from the mouth to mile 21.5. This goal was achieved on December 1, 1980, with 35,000,000 yd^3 having been removed. Maintenance dredging has continued since then. Much of the dredged material has been used to build or raise existing levees along the Cowlitz River. Most of the levee work has been completed with 4,483 acres used as disposal sites. Several uses have already been found for the disposal sites, including the location of a new shopping center near Kelso and a dirt bike trail. As of this writing, approximately 50,000,000 yd^3 of debris have been removed from the Cowlitz River and the first 2 miles of the Toutle River.

Major projects on the Toutle River include debris-retaining dams, sediment basins, a fish collecting facility, a diversion levee, and some channelization. A total of eight sediment basins were completed on the lower portions of the north and south forks and mainstream of the Toutle River. The debris dams on the north and south forks were completed on November 5 and October 1, 1980, respectively. Contractors have removed about 2.1 million cubic yards from behind the north fork dam and 830,000 yd^3 from behind the south fork dam, with maintenance dredging continuing on an as-needed basis.

A more permanent, roller-compacted con-

crete spillway is being constructed on the north fork dam, and the dam is being raised 5 feet to provide more holding capacity. The spillway is scheduled for completion on April 4, 1981. A fish collecting facility is currently being constructed at the south fork debris dam and is scheduled for completion by the end of April 1981. A channelization and diversion levee at the Green River fish hatchery was completed at the end of January 1981.

The total cost of these projects to date is $148 million.

OREGON GEOLOGY REVIEWED

Geology of Oregon, by E. M. Baldwin, published by Kendall Hunt, now in its third printing, is an excellent review of the subject. The text clearly describes those rock formations and geologic processes that have resulted in the numerous geologic features of the state. Many outstanding photographs and diagrams vividly present a pictorial review of crustal features of the earth.

This book is a must—a well illustrated and referenced presentation on rock formations and geologic processes, which together tell the historical geology story of the state of Oregon.

Weldon W. Rau

NEW GEOCHEM PUBLICATION RELEASED BY DIVISION

Bulletin 74, "Reconnaissance geochemical survey of gully and stream sediments, and geologic summary, in part of the Okanogan Range, Okanogan County, Washington," by C. Dean Rinehart of the U.S. Geological Survey, is now available for purchase from the Department of Natural Resources, Division of Geology and Earth Resources, for $2.

A reconnaissance geochemical stream-sediment sampling survey was conducted in a 440 square mile area in the central part of the Okanogan Range. The report presents the results of the survey in the context of their geologic setting, which includes the historic Conconully-Ruby mining district. The geochemical sampling program is part of a broader study of the geology and mineral deposits of part of Okanogan County sponsored jointly by the U.S. Geological Survey and the Washington Division of Geology and Earth Resources.

All samples were analyzed colorimetrically for cold-acid-extractable copper and citrate-soluble heavy metals, and for 30 elements by spectrographic analysis. All samples were also analyzed for gold by the atomic absorption method. The study revealed several anomalous areas of mineralization associated with known mineralized terrane and several anomalous areas occurring in terrane not previously known to be mineralized.

The 24-page report has 4 figures, 3 tables, and 3 plates. Plate 1, at a scale of 1:96,000, is a geologic map; plate 2, showing cold-acid-extractable copper in gully and stream sediments, is an overlay to plate 1; and plate 3, showing citrate-soluble heavy metals in gully and stream sediments, is also an overlay to plate 1.

RECENT THESES ADDED TO DIVISION LIBRARY

The theses listed below were recently added to our division library and are available for reference work.

Anderson, G. R., 1980, A stratigraphic and tectonic analysis and synthesis of a portion of the nonmarine Neogene of the northwestern United States: University of Washington Master of Science, 157 p.

Baumann, F. W., 1971, A petrologic study of major rock and alteration types found on the Margaret mine property, Skamania County, Washington, U.S.A.: University of British Columbia class paper, 38 p.

Beka, F. T., 1980, Upper Palaeozoic metasedimentary and metavolcanic rocks and associated mineral deposits between Glasgo Lakes and Little Sheep Creek, Stevens County, Washington: Washington State University Doctor of Philosophy, 172 p.

Birk, R. H., 1980, The petrology, petrography, and geochemistry of the Black Jack breccia pipe, Silver Star plutonic complex, Skamania County, Washington: Western Washington University Master of Science, 107 p.

Brandon, M. T., 1980, Structural geology of middle Cretaceous thrust faulting on southern San Juan Island, Washington: University of Washington Master of Science, 130 p.

Carroll, P. R., 1980, Petrology and structure of the pre-Tertiary rocks of Lummi and Eliza Islands, Washington: University of Washington Master of Science, 78 p.

Cole, M. L., 1979, Nearshore glacial marine sedimentation, based on late Pleistocene deposits of the Puget Lowlands, Washington and British Columbia: Rice University Master of Arts, 178 p.

Croll, T. C., 1980, Stratigraphy and depositional history of the Deming Sand in northwestern Washington: University of Washington Master of Science, 57 p.

Davis, E. P., 1939, Some studies of gold and its associated minerals: Part 1—Studies of sections and tailings, Chelan Division, Howe Sound Company, Holden, Washington; Part 2—Tellurides: University of British Columbia Master of Arts thesis, 51 p.

Frederick, J. E., 1980, Perennial snowcover variations during the last 130 years at Mount Rainier, Washington: University of Washington Master of Science, 67 p.

Jacobsen, E. E., 1980, Net shore drift of Whatcom County, Washington: Western Washington University Master of Science, 73 p.

Johnson, C. R., 1980, Mineralogy and geochemistry of Wildcat Lake, Whitman County, Washington: Washington State University Master of Science, 131 p.

Johnston, D. A., 1978, Volatiles, magma mixing, and the mechanism of eruption of Augustine volcano, Alaska: University of Washington Doctor of Philosophy, 177 p.

Knutsen, G. C., 1979, Friability of the Addy Quartzite, Stevens County, Washington: Washington State University Master of Science, 87 p.

Nelson, D. O., 1980, Strontium isotopic and trace element geochemistry of the Saddle Mountains and Grande Ronde Basalts of the Columbia River Basalt Group: Oregon State University Doctor of Philosophy, 224 p.

O'Keefe, Monica Elizabeth, 1980, Structural geology and mineral deposits of Red Top Mountain, Stevens County, Washington: Washington State University Master of Science, 152 p.

Price, S. A. M., 1977, An evaluation of dike-flow correlations indicated by geochemistry, Chief Joseph swarm, Columbia River basalt: University of Idaho Doctor of Philosophy, 320 p.

Richman, L. R., 1981, Sedimentary analysis of pre-Missoula gravels in the southeastern part of the Pasco Basin, Washington: Washington State University Master of Science thesis, 82 p.

Shovic, H. F., 1979, Genesis, classification, and variability of the Kitsap series, Washington: Washington State University Doctor of Philosophy (Soils) thesis, 167 p.

Swan, V. L., 1980, The petrogenesis of the Mount Baker volcanics, Washington: Washington State University Doctor of Philosophy, 630 p.

Wang, Hau-Ran, 1980, Magnetic modeling of total field anomalies; application to estimation of basalt thickness near Reardan, Washington: Eastern Washington University Master of Science thesis, 48 p.

Wheeler, M. T., 1980, Late Cenozoic gravel deposits of the lower Snake River, Washington: Washington State University Master of Science, 102 p.

RECENT U.S. GEOLOGICAL SURVEY OPEN-FILE REPORTS ADDED TO OUR DIVISION LIBRARY

The following Geological Survey Open-File Reports are now available for inspection in our division library. However, if you wish to purchase any of these reports, please write or call:

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Prepayment is required. Open-file reports are announced, with price, in the monthly list, "New Publications of the Geological Survey." A free subscription to the list may be obtained on application to: Mailing List Unit, U.S. Geological Survey, 329 National Center, Reston, VA 22092.

Dethier, D. P.; Frank, David; Pevear, D. R., 1981, Chemistry of thermal waters and mineralogy of the new deposits at Mount St. Helens—A preliminary report: U.S. Geological Survey Open-File Report 81-80, 23 p.

Gerin, Marybeth, 1977, Bathymetric map of Pacific coast—Vancouver Island to Tillamook Bay: U.S. Geological Survey Open-File Report 77-115, 2 sheets, map scale 1:500,000.

Minard, J. P., 1981, Distribution and description of the geologic units in the Maltby quadrangle, Washington: U.S. Geological Survey Open-File Report 81-100, 4 p., 1 plate, scale 1:24,000.

Snavely, P. D., Jr.; Wagner, H. C., 1980, Generalized isopach map of Tertiary sedimentary rocks, western Oregon and Washington and adjacent continental margin: U.S. Geological Survey Open-File Report 80-899, 2 pages, plus 1 map, scale 1 inch=20 miles.

Youd, T. L.; Wilson, R. C., 1980, Stability of Toutle River blockage—Mount St. Helens Hazards investigations: U.S. Geological Open-File Report 80-898, 14 p.

U.S. Department of Energy; U.S. Geological Survey, 1980, Plan for identification and geological characterization of sites for mined radioactive waste repositories: U.S. Geological Survey Open-File Report 80-686, 73 p.

DIVISION OPEN-FILE REPORTS FOR SALE IN OLYMPIA OFFICE

Washington Division of Geology and Earth Resources open-file reports are now for sale in our Olympia office. Our newsletter will list each new open file as it becomes available; all previous reports will also be for sale. All orders must be prepaid; please contact this office for the prices.

McLucas, Glennda B., 1981, Detailed fault map of the Hoquiam, Vancouver, Yakima, and The Dalles quadrangles: Washington Division of Geology and Earth Resources 81-1, 5 maps, scale 1:250,000, price $3.00.

CURRENT DIVISION OF GEOLOGY AND EARTH RESOURCES PROJECTS (1981)

Bunning, Bonnie—Updating uranium resources of Washington [report in preparation].

Fiksdal, Allen—Slope stability of five major river valleys of western Washington; erosional studies of the Mount St. Helens blast deposit.

Fiksdal, Allen; Logan, Josh; Rigby, Jim—Volcanic hazards in Washington.

Ford, Don; McFarland, Carl—Updating and revision of oil and gas drilling regulations.

Korosec, Mike; Schuster, J. Eric—Geothermal assessment in Washington.

Logan, Josh—Mount St. Helens videotape/photographic documentation.

Logan, Josh—Trace elements and petrography of Mount St. Helens pyroclastic flow deposits.

Manson, Connie—"Index to geologic and geophysical mapping of Washington" [in press].

Moen, Wayne—Twisp and Methow mining districts, Okanogan County, Washington.

McLucas, Glennda—Fault and lineament analysis of the south Cascade Range [in preparation].

Rau, Weldon; McFarland, Carl—Geologic mapping, Humptulips quadrangle and vicinity.

Rau, Weldon; McFarland, Carl—Coastal well correlations.

Thorsen, Jerry—Continuing Island County study and circuit rider program.

The first article in this newsletter, "Coal geology of King County, Washington," lists the current coal projects of Henry Schasse, Ellis Vonheeder, Tim Walsh, Bill Phillips, and Keith Stoffel.

U.S. GEOLOGICAL SURVEY 7½-MINUTE TOPOGRAPHIC QUADRANGLES
(Maps received in the division library March 25, 1981)

Name	New edition	Photo revised	Latitude (indicates southeast corner)	Longitude	County
Blue Goat Mountain	1980		48°37'30"	119°37'30"	Okanogan
Boot Mountain	1980		48°07'30"	119°15'00"	Okanogan
Calispell Peak	1964	1980	48°22'30"	117°30'00"	Stevens
Camp Seven	1980		48°15'00"	119°15'00"	Okanogan
Chapman Lake	1980		47°15'00"	117°30'00"	Spokane; Whitman
Fairfield	1980		47°22'30"	117°07'00"	Spokane
Keystone	1980		48°30'00"	119°22'30"	Okanogan
Lyman	1980		48°30'00"	122°00'00"	Skagit
Okanogan	1980		48°15'00"	119°30'00"	Okanogan
Omak	1980		48°22'30"	119°30'00"	Okanogan
Omak Lake	1980		48°15'00"	119°22'30"	Okanogan
Omak Mountain	1980		48°22'30"	119°15'00"	Okanogan
Plaza	1980		47°15'00"	117°22'30"	Spokane; Whitman
Ruby Hill	1980		48°22'30"	119°37'30"	Okanogan
Setters, Idaho-Washington	1980		47°22'30"	117°00'00"	Spokane
Spangle West	1980		47°22'30"	117°22'30"	Spokane
Synarep	1980		48°30'00"	119°15'00"	Okanogan
Tekoa Mountain, Washington-Idaho	1980		47°15'00"	117°00'00"	Spokane; Whitman
Trefry Canyon	1980		48°00'00"	119°15'00"	Douglas; Okanogan
Tyler	1980		47°22'30"	117°45'00"	Spokane; Lincoln
Valley	1965	1980	48°07'30"	117°37'30"	Stevens
White Lakes	1980		48°07'30"	119°30'00"	Okanogan

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