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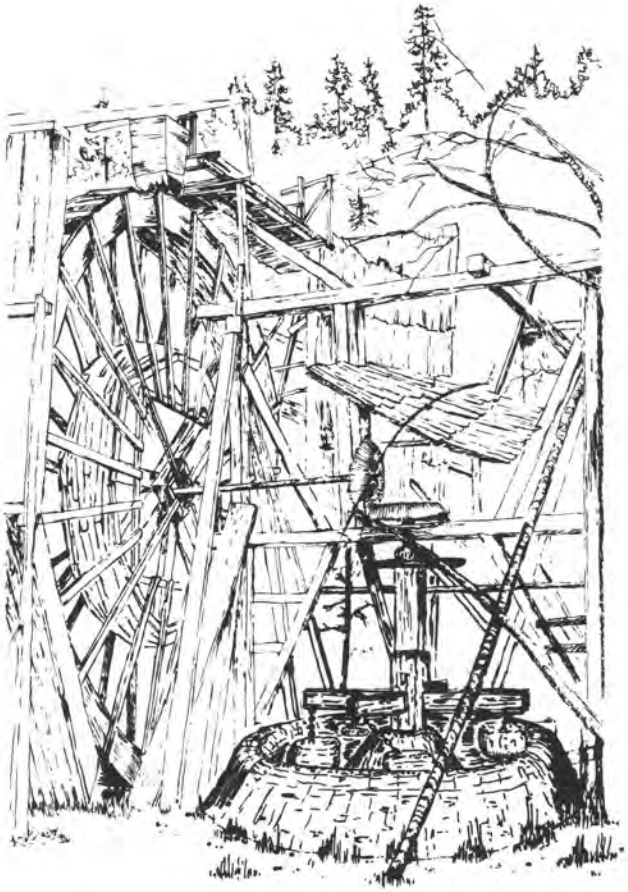

BLEWITT TOWNSITE ARRASTRE

This massive grooved stone is all that remains of a water-powered arrastre that was used to grind gold ore during the early gold mining days at Blewett, Chelan County. Chunks of gold ore were ground into powder in this stone basin by heavy drag stones geared to a water wheel. The gold that was freed by the grinding was recovered by amalgamation with mercury. The Blewitt arrastre was built in 1861 when some 260 miners were working here. Its use was discontinued in 1880. Sketch on right shows arrastre powered by overshot water wheel.

BRIAN BOYLE
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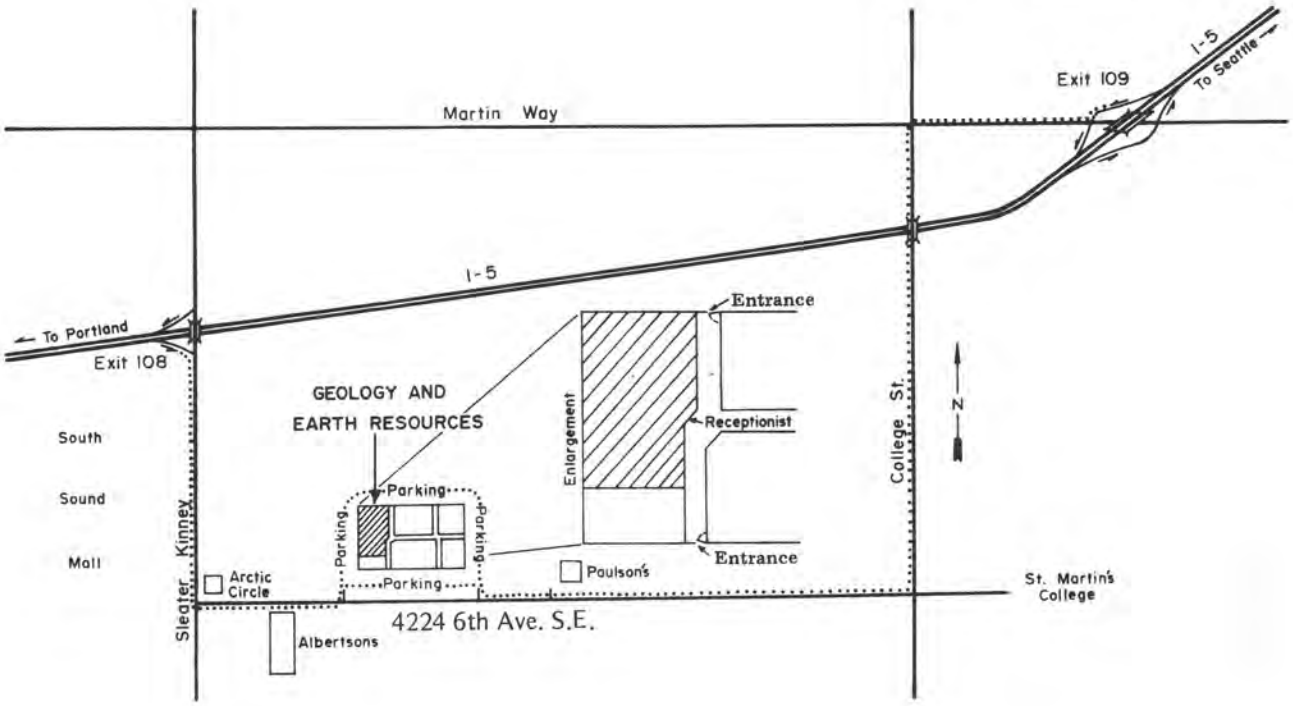

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MINERALS AND ENERGY EXPLORATION ACTIVITIES IN WASHINGTON, 1981

by Ellis R. Vonheeder[1/]

MINERAL EXPLORATION SUMMARY

A minimum of 60 different exploration companies were active in Washington State this past year. As in previous years, the amount of exploration was in direct relation to the market activity.

Gold and silver exploration and mining received much emphasis, and two heap-leaching operations (in Ferry and Okanogan Counties) were started. There were many small- to medium-size dredging operations and numerous weekend recreational gold panners.

Several molybdenum prospects were examined with some core drilling accomplished. A few major energy companies continued work on lead-zinc properties. Uranium exploration appeared down from last year, with most activities being a continuation of projects started in previous years.

Barite received the most exploration and development of the nonmetallic minerals this year. Continuing record-setting demands for that commodity by the oil exploration industry has initiated a sharp increase in barite mining and exploration in the northeast part of the state, with a high-capacity milling facility slated to start in mid-1982.

Oil and gas drilling and leasing took on renewed emphasis with the drilling of the Shell well near Yakima. At the present time 550,000 acres of state-owned mineral rights have been leased for oil and gas exploration, with approximately one-half of the acreage lying east of the Cascade Mountains.

Coal exploration activity dropped slightly from last year. A geothermal exploration project is underway in the Black Diamond area. Spokesmen for this joint-venture express optimism for success.

METALLIC MINERALS

Cominco, Ltd., of Canada took over Bethex and acquired all of their properties in the United States. These properties are now under control of Cominco American, Inc.

Conoco Oil has closed most of its mineral exploration offices in the United States, and it is anticipated that the Spokane office will be closing in May or June of 1982.

Homestake's uranium exploration office in Spokane has been closed. The joint-venture exploration agreement with the Boise-Cascade Corporation has been dropped.

Chelan County

Getty Oil has been drilling on the South Forks of Gold and Squaw Creeks above Lake Chelan. The target is an unusual occurrence of silver, lead, and zinc disseminated in altered Tertiary andesite. Some high silver assay values are reported. An IP resistivity survey was conducted on the property this past summer.

Goldex Inc., of Chelan, diamond-drilled and did other exploratory work at their Lake Ann prospect late last summer. The copper-lead-zinc target is a short distance from Washington Pass near the North Cross-State highway (SR 20).

FIGURE 1. – Mineral exploration and mining activity in Okanogan and Chelan Counties, 1981.

[1/] Department of Natural Resources, Lands Division geologist.

Ferry County

Day Mines is producing gold and silver at the Knob Hill mine near Republic.

John Domek of Astra Corp. (Spokane) is developing a new technology to process and recover microfine gold in tailings. Domek plans to work the claims and tailings piles at the First Thought mine near Orient.

The Flagg Hill mine, a former exploration target, has been leased to a small exploration company headed by Stuart Jackson.

An unknown company worked the lead ore at the Romulus mine on the Colville reservation last summer. A small stockpile of high-grade galena is present on the property.

Rocky Mines of Republic stopped an unsuccessful mining, milling, and smelting program and commenced a heap-leaching operation for gold and silver. The contractor for the leaching operation was Little Bullion Co., of Conconully.

FIGURE 2. – Mineral exploration and mining activity in Pend Oreille, Stevens, Ferry, Lincoln, and Spokane Counties, 1981.

Azure Resources, Ltd. of Vancouver, B. C. is currently engaged in exploration at the Lone Star mine, in the Danville area. The prospect has promising values of copper.

According to Mount Tolman project manager Charles Stott, their environmental impact statement has been completed, although the projected start-up date of early 1984 for their copper-molybdenum property has been delayed.

Okanogan County

The Copper Glance property near the Eight-Mile Creek area north of Winthrop was drilled this summer to outline a disseminated copper deposit. A 1,500-foot exploration tunnel to a breccia pipe has been proposed. The ore body contains up to 6.4 percent copper and 1.2 percent silver. Thus far, an area 1,200 by 3,000 feet has been explored and developed. It is believed that United Mining and Development, Ltd., and Denison Mines are in joint-ventureship on the project.

A small gold-silver cyanide heap-leaching operation was operated at the Minnie mine, near Carlton, by owner Fred Higby during the latter part of the year. The gold-pregnant cyanic liquor is treated with activated charcoal and is then subjected to "electrowinning," an electrolytic process that yields approximately 90 percent gold recovery.

The Bodie mine on Toroda Creek, north of Wauconda, has been taken over by Western Land Resources. Western Land has apparently blocked out 70,000 tons of gold-silver ore averaging a combined 2½ oz per ton.

Utah Minerals, a subsidiary of General Electric of Canada, is drilling in altered volcanics northeast of Twisp, near Bowman Lake. The property has been leased previously by Bear Creek.

A small-scale mining and milling operation was begun at the Silver Bluff mine in the Galena district to process relatively high-grade silver ore.

Houston International Minerals (now Tenneco) has been doing exploration in the area around Bodie and Wauconda this summer, as they have for the past several years.

Azure Resources, Ltd., of Vancouver, B. C., is currently engaged in exploration for molybdenum in the Tonasket area.

The strategic metal potential of the northeast Washington area was investigated by a consultant from the east coast. Included in the investigation were cobalt and tin, as well as other commodities.

Shell Minerals is evaluating a gold and silver geochemical survey made in the Bodie-Sheridan area.

The lessees of the Alder mine have been drilling a gold-silver target in the past year.

FIGURE 3. – Mineral exploration and mining activity in Pierce, Thurston, Lewis, Cowlitz, Clark, Skamania, and Yakima Counties, 1981.

Skamania County

Utah Minerals, Ltd., of Vancouver, B. C. continued copper exploration efforts at their Camp Creek prospect in the McCoy Creek area.

Spokane County

It has been reported that Minatome has been conducting extensive exploration on the Spokane Indian Reservation. The Terrace Hill area has been targeted as a potential drilling area.

Stevens County

Orazada Mines, Inc. was recently organized to reopen the old tunnels of the Orazada mine in the Deer Trail district. Enough capital has been raised for development work, and retimbering the old tunnels will allow the sampling phase to begin. Glen Galbraith also claims the existence of a barite vein associated with a 4-foot quartz-pyrite vein on the Orazada property.

Madre Mining, Ltd., of Calgary and Sacramento, purchased the Deer Trail mine near Fruitland. A 100-ton-per-day mill to process silver from the dumps was erected in 1981. A small underground mining operation is planned.

The Blue Grouse mine, known formerly as the Tungsten King, has been leased by owner Wes Butler to Kemmerer Coal Co. of Kemmerer, Wyoming. The company is engaged in concurrent development and production of tungsten at the property. Ore grades as high as 70 percent WO_3 have been recorded from the state mineral lease.

Midnite Mines, Inc. moved its corporate offices to Bellevue earlier this year. Midnite is currently conducting uranium exploratory work at the Midnite mine near Wellpinit.

Arbor Resources, of Vancouver, B. C., purchased the Melrose mine in the Northport area from Shawnee Mining Co., of Northport. Drilling and trenching on the state mineral lease and sampling of the Melrose has been started by Arbor.

Houston International Minerals has been exploring for molybdenum deposits, in southern Stevens County area.

Dawn Mining Co. is producing U_3O_8 from the Ford mine, in the Wellpinit area. Concurrent exploratory drilling is in progress.

United Copper & Silver is producing copper and silver from the United mine, in the Eagle Mountain area. Owner Ole Alum of Chewelah is also drilling a copper target in this area.

Western Nuclear continues production of uranium at the Sherwood mine, in the Wellpinit area.

Irving Scott and partners are reopening the old workings of the Queen and Seal mine near Fruitland. The next step is sampling and exploration of the property.

Houston International Minerals (now Tenneco) has been doing lead, zinc, and silver exploration on their claims at Flagstaff and O'Toole Mountains, as well as on other properties in Stevens County.

Cominco American has been exploring lead-zinc-silver occurrences in carbon breccia-type deposits.

Chevron Minerals had a large number of geologists working on the lead-zinc-silver Bonanza property, located north of Colville.

Garratt Geoservices USA, of Ely, Nevada, had a team of geologists in the county early in the summer. Four targets were examined and basic landwork was accomplished.

Joy Mining is planning to mine and mill the uraniferous bog deposits in Flodelle Creek.

Shell Minerals conducted exploration on uranium deposits in the Kettle Dome of Stevens County.

Western Nuclear and Rocky Mountain Energy continued exploration on the Graeber lease, in northern Stevens County. High values of uranium exist there in the layered amphibolites of the Kettle Dome.

Rocky Mountain Energy of Colorado undertook

geochemical sampling and geologic mapping at their Jenny, Laurie, and Donna claims.

Newcoast American Inc. undertook geologic mapping, soil sampling, and geophysical work on the Copper Find group west of Northport on Belshazar Mountain. Ore minerals include chalcopyrite and minor tetrahedrite, which occur in and near an altered monzonite stock.

FIGURE 4. – Mineral exploration and mining activity in Whatcom, Skagit, and Snohomish Counties, 1981.

Whatcom County

Lions Mines of Vancouver has postponed work on their 200-ton-per-day mill in favor of continued exploration at the Newlight mine.

Duval, of Vancouver, B. C., did diamond-drilling at the Slate Creek prospect.

Small-Scale Gold Operations

With the price of gold still stable relative to last year's prices, 1981 saw many weekend gold-panners and prospectors turning out to find a few elusive "colors."

In the Liberty district of Kittitas County, numerous placer operations were noted. Swauk and Williams Creeks again saw a flurry of activity, while Shasser and Peshastin Creeks in the Blewett district had a number of floating suction dredges.

In Okanogan County, the Department of Natural Resources issued six placer mining leases on the Similkameen River between Nighthawk and the Canadian border, and below Similkameen Dam to Lake Osoyoos. The Department of Natural Resources issued three placer mining leases this year in Stevens County. All were near the junction of Onion Creek and the Columbia River, about 5 miles south of Northport.

Slate Creek in Whatcom County was especially active this past summer with weekend panners. Sluicing and dredging operations were noted in Ruby Canyon and other smaller drainages.

TABLE 1. – *Mining and exploration companies active in Washington, 1981*

Allied Minerals	Madre Mining, Ltd.
Agro Minerals	Meridian Land and Minerals
Amax Coal	Midnite Mines, Inc.
AMCA/Luscar Coal	Milchem, Inc.
Arbor Resources	Minatome
ARCO Coal	Morse Brothers, Inc.
Astra Corp.	Newcoast American, Inc.
Azure Resources, Ltd.	North American Exploration
Bear Creek Mining	Northair Mines, Ltd.
Burlington Northern Corp.	Northwest Alloys, Inc.
C-E Minerals	Northwest Olivine
Chevron Minerals	Orazada Mines, Inc.
Cominco, Ltd.	Quintana Minerals
(Cominco American)	Petrominerals
Dawn Mining Co.	Rocky Mines
Day Mines	Rocky Mountain Energy
Denison Mines	Sandia Corp.
Duval	Sabine Production Co.
Exxon Coal	Shell Minerals
Exxon Minerals	Shell Oil Co.
Fluor Corporation	Snowbird Resources, Ltd.
Freeport Mining	Sunburst Petroleum, Ltd.
Garratt Geoservices	St. Joe Minerals
General Electric-Canada	Toledo Resources, Ltd.
Getty Oil	TRW, Inc.
Goldex, Inc.	Tri-H Mining Co.
Gulf Minerals and Resources	U.S. Steel
Horseheaven Drilling Co.	United Copper & Silver
Houston International	United Mining and
Minerals (now Tenneco)	Development, Ltd.
Inspiration Development	Utah-International, Inc.
Interpace Corp.	Utah Minerals, Ltd.
Joy Mining Co.	Western Land Resources
Kemmerer Coal Co.	Western Nuclear
Lions Mines	Weyerhaeuser

NONMETALLIC MINERAL PRODUCTION

It was reported last year that barite appeared to be the only nonmetallic commodity with significant development. Since that time, northeastern Washington, and especially Stevens County, has been experiencing a "boom" of sorts in barite exploration and development.

As reported by the U.S. Bureau of Mines Section of Nonmetallic Minerals in August of this year, U.S. mine production of barite increased to a record-setting 4.1 million tons. Use of barite as a weighting agent in oil and gas well drilling fluids consumed 3.95 million tons of the total domestic production in 1980.

In Stevens County, C-E Minerals-Combustion Engineering, of Athens, Georgia, purchased the Flagstaff Mountain deposit from the Sell Bros., of Northport. During the summer of 1981, C-E accomplished 20,000 feet of percussion drilling on the Flagstaff property. Quality of the barite, production plans, and reserve tonnages are being kept confidential for the present time.

C-E has also purchased the Calhoun mill at Leadpoint. They plan to process barite and other industrial products from sources within a 50-mile radius of the Northport-Leadpoint area. Their immediate goal is to offer a minus 325 mesh barite drilling additive with a 4.2 minimum specific gravity.

It is also reported that C-E has acquired 75 percent of the Uribe deposit on Bruce Creek and is negotiating for the adjacent Ohman property.

There are two other known producers of barite ore in Stevens County. The Pease-Loon Lake deposit of barite near Valley was mined by Tri-H Mining, and the Madsen barite deposit near Chewelah was mined by Bill Peterson of Orient. Both operators ship their ore to Montana Barite.

The O'Toole Mountain barite deposit, known also as the Riverview and Ellingwood claims, is located 9 miles south of Northport. These claims are reported to have been drilled and explored by Mil-Chem of Battle Mountain, Nevada.

Other Nonmetallic Developments

Ernest Gehrke, owner of the Allied Minerals Quarry near Springdale, reports that the market for his dolomite soil conditioner product has been good. Union Oil Minerals has shown some serious interest in the property regarding an unspecified metallic mineral.

Agro Minerals of Oroville continues to mine gypsum for soil conditioner from Poison Lake in the Ellisforde area.

The Northwest Olivine Co. in Skagit County is now owned by, and is a division of, International Mineral and Chemical Company of Mandelein, Illinois.

The Interpace Corp. sold their Renton plant to North American Refractories Co. The refractory clay pits at Palmer and Issaquah in King County and those near Deer Park in Spokane County, were also part of the sale. The Mica pit, 6 miles south of Fairfield, a source of materials for structural facings and refractory bricks, was retained by Interpace.

LSM Industries of Spokane has been guaranteed a multi-million dollar loan to begin construction of a plant to fabricate abrasive-containment and transportation vessels. No start-up date has been given. The abrasive-resistant lining in the vessels will be fabricated from common basalt. Raw material supply for the process is not thought to be a problem.

TABLE 2. – *Nonfuel mineral production in Washington, 1980-1981 (a)*

	1980		1981 (b)	
Mineral	Quantity	Value	Quantity	Value
Cement (Portland) ..... short tons..	1,546,000	$89,208,000	1,676,000	$102,500,000
Clays (c)..... do	301,000	1,571,000	255,000	1,690,000
Gem stones	NA	150,000	NA	150,000
Gold ..... troy ounces	W	W	13,600,000	6,300,000
Pumice ..... short tons ..	23,000	W	23,000	W
Sand and gravel (d) ..... do.....	19,019,000	46,731,000	18,200,000	47,400,000
Stone:				
Crushed ..... do.....	11,062,000	29,024,000	10,600,000	29,230,000
Dimension ..... do.....	6,000	248,000	6,000	240,000
Undistributed (e).....		40,430,000		31,489,000
Total		$207,362,000		$218,999,000

(a) U.S. Bureau of Mines production figures as measured by mine shipments, sales, or marketable production (including consumption by producers).

(b) NA, not available; W, withheld to avoid disclosing company proprietary data, value included in "Undistributed" figures.

(c) Excludes fire clay, value included in "Undistributed" figures.

(d) Excludes industrial sand, value included in "Undistributed" figures

(e) Includes masonry cement, fire clay, diatomite, gypsum, lead (1980), lime, olivine, peat, industrial sand and gravel (1980), silver, and values indicated by symbol W.

TABLE 3. – *Auctions by Department of Natural Resources of state-owned lands for oil and gas exploration, 1981*

Bidder	Approximate acreage	County
	January	
Knight Royalty Corp., Denver	15,700	Kittitas, Yakima
Love Oil Co., Denver	10,480	Kittitas
Amoco Production Co., Denver	9,900	Pacific
Snowbird Resources, Ltd. Calgary, Alberta	9,400	Kittitas, Yakima
Lang & Martin Denver	5,750	Pacific, Jefferson
William L. Corry (assigned to May Petroleum, 50 percent; PRM Exploration, 25 percent; Exploration Co. Unlimited, 25 percent, all of Dallas)	2,200	Kittitas
Shell Oil Co., Houston	1,100	Kittitas
	54,530	
	June	
Arco Co., Denver	21,870	Pacific, Jefferson, Clallam, Grays Harbor
Snyder Oil Co., Denver	7,000	Pacific, Grays Harbor
Inca Oil & Gas Fort Worth	6,400	Kittitas, Grant
Sohio Petroleum Denver	6,200	Yakima, Grant
Roseland Oil & Gas Dallas	6,000	Yakima, Kittitas
Getty Oil Co., Bakersfield	5,600	Grays Harbor
Northwest Exploration Co., Denver	5,600	Kittitas, Yakima
G. B. Howell, Dallas	5,400	Kittitas, Yakima

TABLE 3. – *Auctions by Department of Natural Resources of state-owned lands for oil and gas exploration, 1981 – Cont'd.*

Bidder	Approximate acreage	County
Emetco Petroleum, Denver	4,000	Kittitas
Leo Oil Co., Toppenish	2,600	Yakima
Champlin Petroleum, Denver	1,920	Wahkiakum
Amoco Production Co., Denver	1,400	Jefferson
Olympia Oil & Gas Co., Ellensburg	1,100	Kittitas
Anschutz Corp., Denver	1,000	Pacific, Jefferson, Clallam
William L. Corry (assigned to Transcontinental Oil), Denver	1,000	Kittitas
Walter L. Farrington, Tyler, Texas	1,000	Kittitas, Yakima
Love Oil Co. Denver	1,000	Grant
	79,090	
	August	
Floyd Cardinal Del Mar, California	70,900	Clallam
Hannon & Associates Denver (assigned to Anschutz Corp.), Denver	16,100	Pacific, Grays Harbor
Rudman Resources Dallas	15,900	Clallam
Jerry Ryan, Denver	3,400	Clallam
American Petrofina, Houston	2,650	Yakima
	108,950	

OIL AND GAS DRILLING

There were 13 oil and gas drilling permits issued in the state in 1981. Two wells, Snowbird Resources Ltd. Moses Lake No. 1 in Grant County and Shell Oil Co. Bissa No. 1-29 in Kittitas County, are still drilling at last report. Sunburst Petroleums Ltd. Sunburst No. 1 has reached its total depth of 7,500 feet and is waiting on a workover rig.

The Shell Oil Co. Yakima Mineral Co. No. 1-33 was started in 1980. It reached a total depth of 16,199 feet and is currently being tested.

Status of other oil and gas drilling permits [well sites and wells in progress] is shown in fig. 5.

FIGURE 5. – Oil and gas exploration activity in Washington, 1981.

Leasing

There are currently 550,000 acres of state-owned land under lease for oil and gas exploration. Approximately 260,000 acres are east of the Cascades, and 140,000 acres were leased in Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum Counties. Another 150,000 acres were leased along the Columbia River from Cathlamet to Grayland and in the waters off of Pacific County.

Three public auctions were held in Olympia in January, June, and August. The results of those auctions are shown in table 1.

COAL EXPLORATION

No new coal mining operations were started this year in Washington, although coal production increased by a small percentage over 1980.

Amax Coal of Denver completed their drilling project between Bellingham and Lynden in the Whatcom Basin. Approximately 15,000 feet of drilling in 11 holes was accomplished. Some 1,300 feet was core-drilled. North American Exploration also drilled in Whatcom County this past summer; it is believed their client is a major Oklahoma petroleum company.

Weyerhaeuser continues to conduct exploration drilling on their forest lands in Cowlitz County.

Bear Creek Mining was again active in the Vader-Ryderwood-Winlock area of southern Lewis County.

Petrominerals of Santa Ana, California has announced plans to eventually mine coal at Roslyn and Cle Elum. AMCA/Luscar Coal, based in Kentucky, has evaluated the coal reserves in the area and believes there is a potential reserve base of 30 to 35 million tons. According to Petrominerals, the cement industry of the Pacific Northwest represents the best market, as many cement-makers are switching from oil to coal to create clinker. Another potential market for Roslyn coal is the Far East, but the coal would have to be washed to bring it up to acceptable Asian market standards. No startup date for the operation has been announced.

The underground coal gasification (UCG) experiment at the WIDCO mine northeast of Centralia has been taken over by Lawrence Livermore National Laboratory of California. Above-ground block tests have been designed and suitable areas have been chosen. Six burns are planned; extensive instrumentation includes thermocouple wells and observation wells, as well as gas flow, temperature, pressure, and chemistry monitors. The ultimate goal of the experiment is the successful gasification of multiple seams approximately 600 feet below ground level in the Tono Basin, two miles east of the WIDCO mine/powerplant complex in the Hanaford Valley. A successful experiment would allow a transferral of UCG technology to many of Washington's coal seams that are presently too deep, too steep, or too thin to be stripped or conventionally mined. Ultimate use of the generated gas would probably be as boiler feedstock for electrical power generation.

COAL RANK AND THERMAL MATURATION IN KING COUNTY, WASHINGTON

By

Timothy J. Walsh and William M. Phillips[1/]

INTRODUCTION

Oil and gas exploration has been conducted for many years in King County (McFarland, 1981). Although results from the 25 wells drilled in the area have been disappointing, interest in the region continues because of the presence of potential petroleum source rocks. Exploration to date has concentrated upon locating and drilling favorable structural or stratigraphic traps where hydrocarbons could be localized. Very little has been published concerning the level of organic thermal maturity in potential petroleum-bearing rocks. Without the proper level of organic thermal maturity, petroleum will not accumulate in large quantities despite rich source rocks or favorable reservoir conditions (Philippi, 1965; Bostick and Damberger, 1971). In order to assist future exploration efforts, we have conducted a study of thermal maturity in King County using coal rank data from the Puget Group of Eocene Age.

COAL RANK AS AN INDICATOR OF THERMAL MATURITY

Coal rank studies have proven useful for oil and gas exploration because the occurrence of hydrocarbons is largely limited to the same temperature range as coal (Landes, 1967; Castano and Sparks, 1974; Hood and others, 1975). Like petroleum maturity, coal rank is principally a result of prograde thermal metamorphism (Williamson, 1967; Teichmuller and Teichmuller, 1968). Hence, coal rank is a function of burial depth, time, and geothermal paleogradients. The coals of King County range in rank from subbituminous through high-volatile bituminous. For these coals, rank is determined by the heating value (British Thermal Units or BTU) on a moist, mineral-matter-free basis (Williamson, 1967).

SOURCE OF DATA AND GENERAL GEOLOGY

Since 1911, the U.S. Bureau of Mines and the U.S. Geological Survey have published numerous coal analyses of channel samples from mines and prospects in King County (Smith, 1911; Fieldner and others, 1931; Cooper and Abernathy, 1941; Daniels and others, 1958). We have used this body of data, together with analyses from a private coal exploration program (U.S. Smelting, Refining, and Mining Co., USSRAM, 1962), to characterize the variation in coal rank in King County.

All coals used for rank calculations are contained within the Puget Group of Eocene age, a nonmarine unit consisting of intertonguing arkosic sandstones, shales, coals, and volcanic rocks (Vine, 1969; Mullineaux, 1970; Buckovic, 1979; Phillips and Walsh, 1981). Data from the northern half of our study area, called the Tiger Mountain-Taylor Mountain area, are from the Renton Formation, the uppermost formation in the Puget Group (fig. 1). To the south, in the Green River area, the Puget Group has not been subdivided and the analyses represent coal from throughout the Group.

In much of our study area, the Puget Group is underlain by the Raging River Formation of Eocene age, a marine unit composed of dark-gray sandstone, siltstone, and claystone, containing benthic Foraminifera (Vine, 1962). The Raging River Formation is the most likely source rock for petroleum in the area.

Concordantly overlying the Puget Group in our study area are continental volcanic rocks intertonguing to the west with marine volcanic sediments (Warren and others, 1945; Vine, 1969; Mullineaux, 1970). The base of the unnamed continental volcanic section has been dated as earliest Oligocene (Wolfe and others, 1961); the upper age limit for the rocks is not known. The marine volcanic sediments have been dated as Oligocene (Mullineaux, 1970).

Structurally, the study area is characterized by north-trending folds broken by west-trending faults. The northwest portion of the study area deviates from this pattern with a nearly west-trending fold structure. A generalized geologic map of the study area is presented in fig. 2.

COAL RANK VARIATION

Vine (1969, p. 44) found a general relationship between coal rank in King County and stratigraphic position, i.e., "the higher the coal bed stratigraphically, the lower its rank." Other workers (Evans, 1912; Fieldner and others, 1931; Warren and others, 1945) have qualitatively noted a rapid increase of coal rank toward the

[1/] Geologists with the Division of Geology and Earth Resources.

STRATIGRAPHY

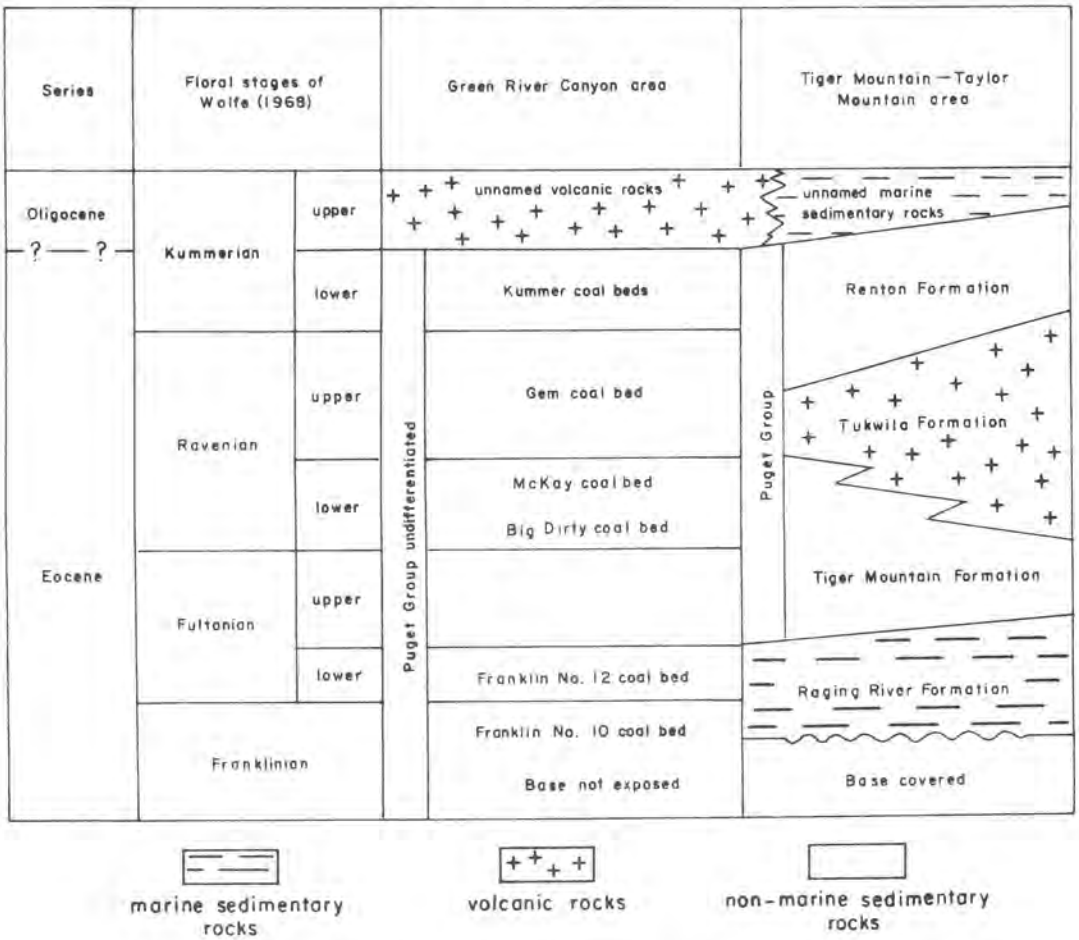

FIGURE 1. — Correlation of bedrock units in a portion of King County, Washington, modified from Vine, 1969. The Green River Canyon area is immediately to the south of the Tiger Mountain-Taylor Mountain area, separated by the Cedar River.

east of the study area. We have quantitatively examined both the vertical coal rank variation (variation with stratigraphic position) and the lateral or geographic distribution of coal rank. Our findings are in agreement with the earlier workers' observations.

Vertical coal rank variation was examined by plotting coal rank versus depth of coal bed below the top of the Puget Group and calculating a gradient in BTU/100 feet. To be valid, such calculations must use data from as small a geographical area as possible to avoid error from any lateral rank variation present. Analyses of coal from core recovered from drill holes are ideal. Unfortunately, rank data from drill holes (USSRAM, 1962) are limited to the vicinity of Black Diamond in the southern portion of our study area. Therefore we have used rank data from closely spaced mines, or from within a single mine to supplement the drill hole information.

Calculated vertical rank gradients are presented in table 1. We ascribe the variation in gradients primarily to localized igneous activity. Numerous dikes and sills are present in the study area (fig. 2). Other factors leading to vertical gradient variation include error introduced by lateral rank changes (for mine data), possibly erroneous stratigraphic correlations (for drill hole data), and inadequate sampling.

The lateral or geographic variation of coal rank across the study area was characterized using trend surface analysis of data from coal mine samples. A trend surface is a mathematically smoothed contour plot. The order of a trend surface determines its complexity. A first-order surface is planar, a second-order surface a simple fold or saddle; higher order surfaces have progressively more complex geometric forms. For a detailed discussion of trend surface analysis, see Davis (1973).

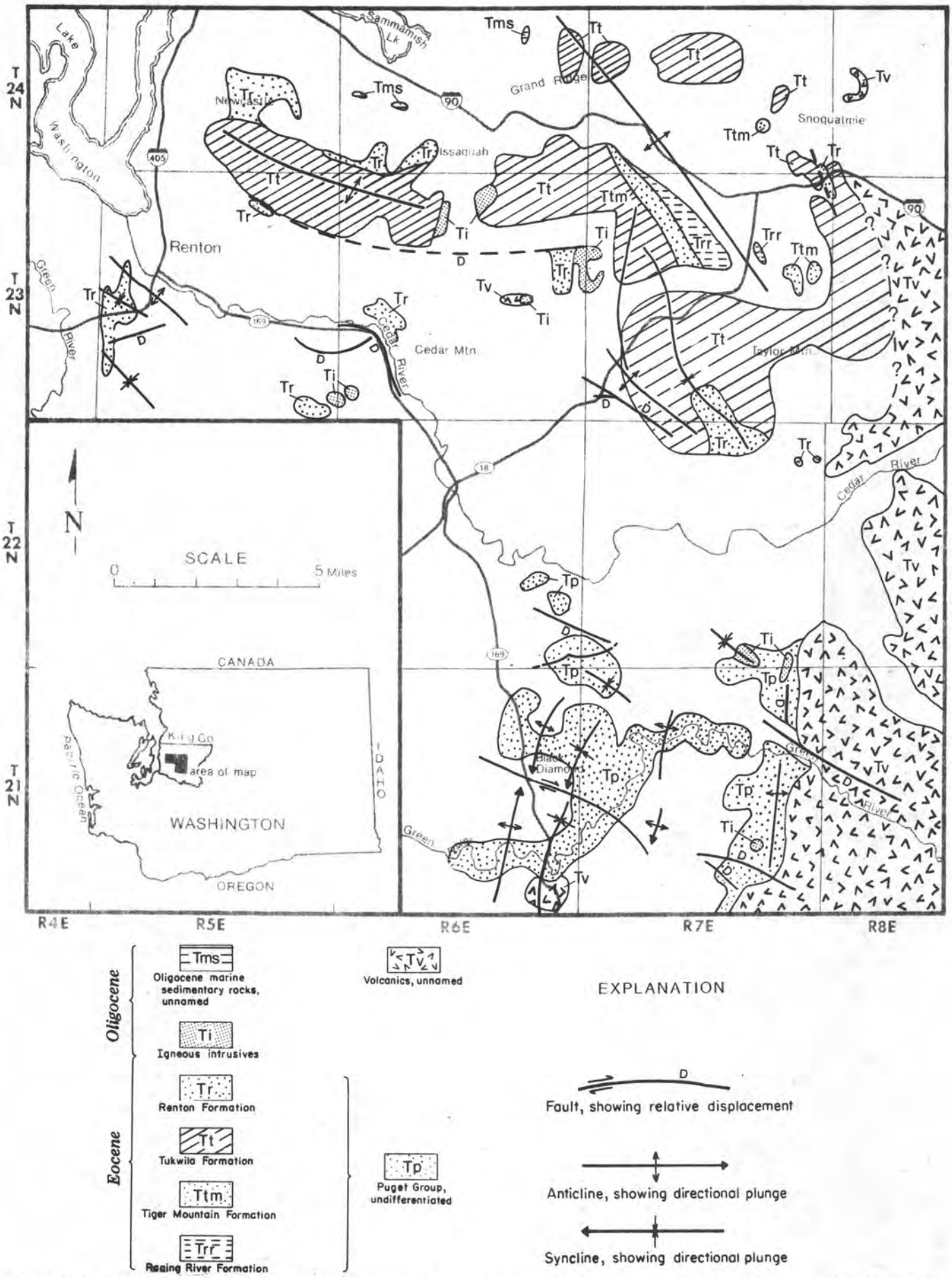

FIGURE 2. – Generalized geologic map of a portion of King County, Washington, modified from Warren and others, 1945, and Vine, 1969.

TABLE 1. – *Vertical coal rank gradients*

Area	Gradient[1/]	N[2/]	r[3/]
Green River mines	82	32	0.88
Renton mine	216	13	0.77
Black Diamond drill holes			
No. 1	162	14	0.78
No. 2	115	28	0.72
No. 4	63	15	0.64
No. 6a	73	21	0.88
No. 9	60	12	0.86

1/ Gradient units: BTU/100 feet of stratigraphic separation.

2/ N = Number of analyses

3/ r = Correlation coefficient (1.00 = perfect fit of gradient values to observed data).

We present here the contour plots of the second- and third-order surfaces for coal rank in our study area (figs. 3 and 4). These surfaces account for 63.4 and 66.4 percent of the variability in coal rank, respectively. The relatively large percentage of variation not explained by the surfaces is due to clustering of analyses at individual sites. Because we were only able to determine the locations of sample points to quarter-section accuracy, many locations are represented by more than one analysis. For the 255 analyses used, there are 79 unique locations. Because folding and faulting are common in the study area (fig. 2), coals from widely spaced stratigraphic horizons are often in close proximity. Therefore, the trend surfaces tend to pass through "best fit" BTU values derived from analyses of several coal beds representing more than one stratigraphic horizon. As a result, the influence upon the surfaces from highly variable rank gradients associated with specific stratigraphic position (table 1) is lessened. Consequently, the trend surfaces are able to resolve lateral variation in coal rank.

Examination of the geologic map (fig. 2) and the trend surfaces (figs. 3 and 4) indicates that coal rank is largely independent of structure in our study area. The pattern of coal rank variation, from the eastern portion of R. 6 E. and eastward for approximately 7 miles, is parallel to the Cascade Mountains. Through this zone, rank increases rapidly and fairly uniformly toward the Cascades. This pattern suggests deeper burial and(or) higher geothermal gradients during coalification for sediments in the east.

In the southeastern portion of the study area, about 5,000 feet of continental volcanics and volcanic sediments were deposited concordantly upon the Puget Group in post-Eocene time (Vine, 1969). North of Newcastle, at least 4,000 feet, and perhaps as much as 8,000 feet, of Oligocene marine volcanic and sedimentary rocks concordantly overlie the Puget Group (Weaver, 1937; Warren and others, 1945). Therefore, burial depth of the Puget Group in our study area does not increase dramatically to the east, if at all.

We attribute the eastward rise in coal rank to thermal metamorphism resulting from volcanism and plutonism along the N-S Cascade trend. The magnitude of the Cascade thermal aureole may be estimated by calculating the geothermal gradient in effect during coalification. This calculation requires determining the maximum Puget Group burial depth and the length of time over which the Puget Group was at the maximum depth. As such data for our study area are quite imprecise, only a range of values can be estimated.

Deposition of the Cascade volcanic pile was essentially complete by 15 million years ago (Fiske and others, 1963; Hammond, 1979). We assume the average thickness of the volcanic rocks overlying the Puget Group to be 5,000 feet, and use an age of 35 million years, corresponding to earliest Oligocene, for the base of the volcanic section (Wolfe and others, 1961). Uplift of the Cascade Mountains in southern Washington is believed to have begun between 20 and 4.5 million years ago (Hammond, 1979). We assume that the beginning of uplift corresponds to an end of maximum burial depth for the Puget Group. We therefore assign a time of burial of about 15 to 30 million years for sediments at the top of the Puget Group. Maximum burial depth and hence maximum temperature would have been in effect for 10 million years or less.

The relationship between coal rank, temperature, and time of coalification is presented in fig. 5 (Castano

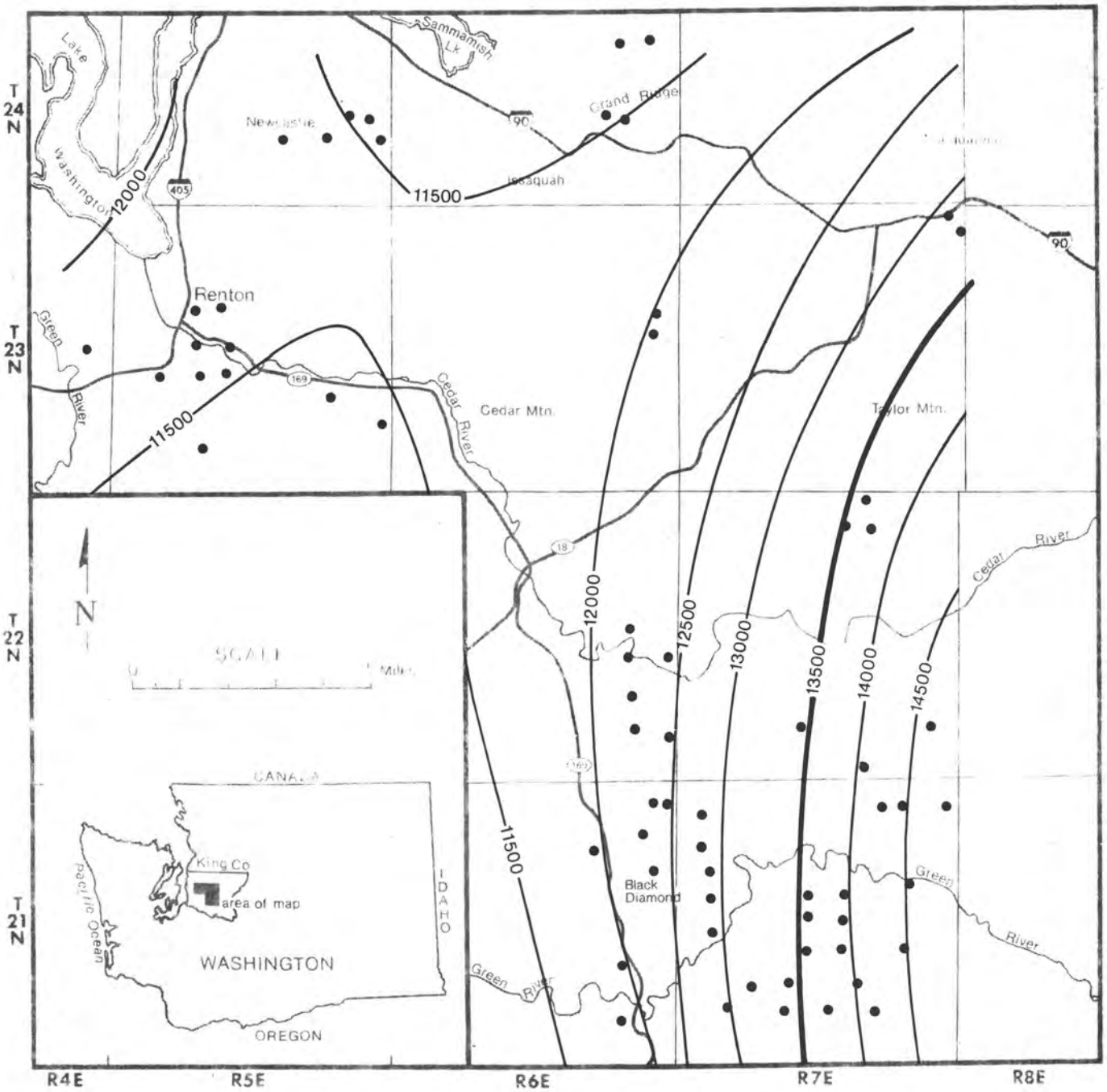

FIGURE 3. – Second-order trend surface of BTU (moist, mineral-matter-free basis) in a portion of King County, Washington. Dots are locations of coal samples analyzed. Level of significance exceeds 99.99 percent.

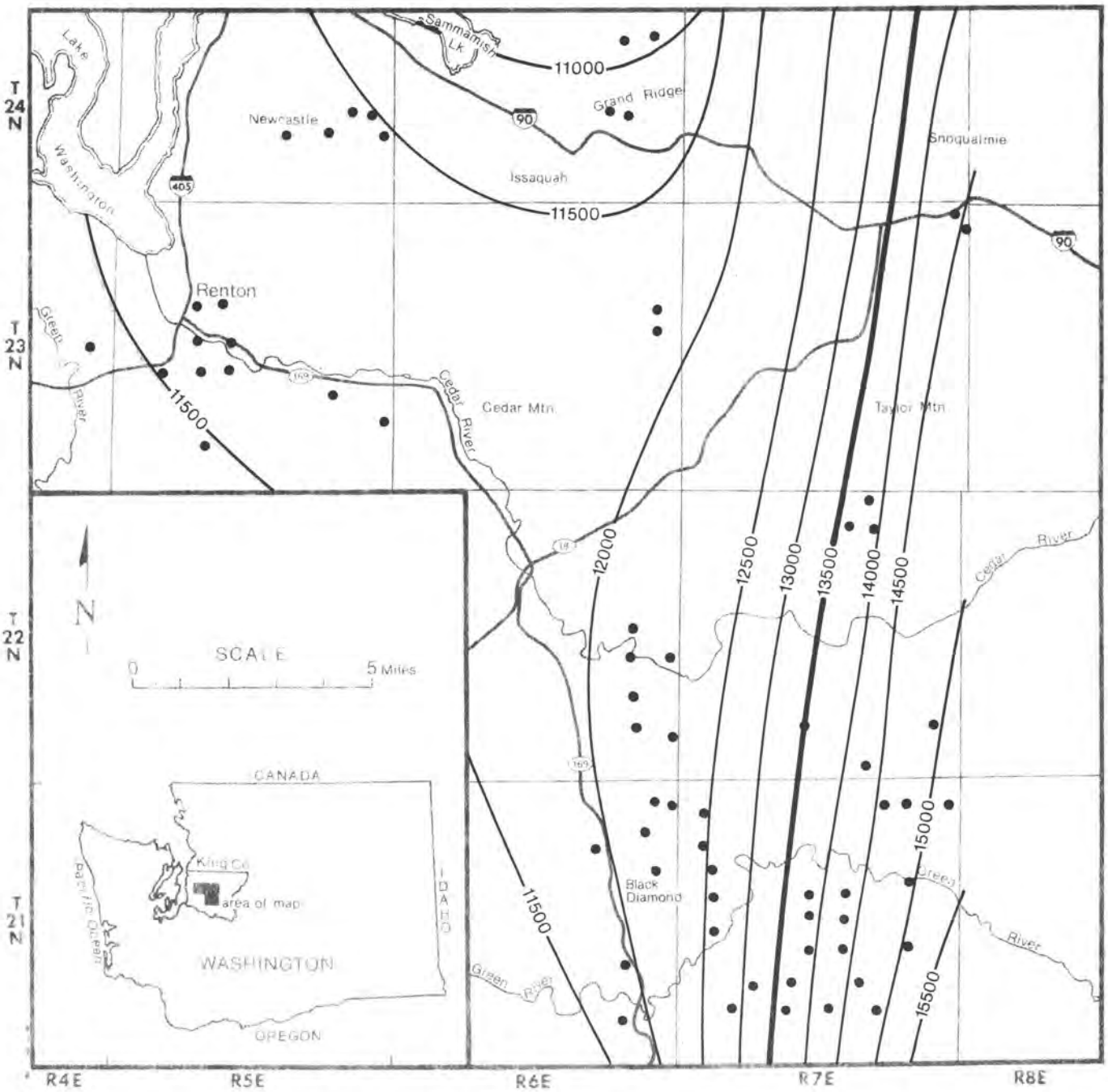

FIGURE 4. – Third-order trend surface of BTU (moist, mineral-matter-free basis) in a portion of King County, Washington. Dots are locations of coal samples analyzed. Level of significance exceeds 99.99 percent.

and Sparks, 1974). The figure is derived from laboratory studies of coalification kinetics calibrated with geological data.

Using fig. 5 and BTU value of 11,500 for a coal near the top of the Puget Group, we calculate a minimum geothermal gradient of from 2.5 to 3.2°F/100 feet or 45.9 to 65.6°C/kilometer (time = 15 to 30 million years; average surface temperature = 10°C or 50°F; depth = 1,525 meters or 5,000 feet). A similarly buried coal with a BTU of 14,000 yields gradients 3.8 to 4.9°F/100 feet or 68.9 to 88.9°C/kilometer. Bottom-hole temperatures from a deep well drilled in the study area (Geothermal Resources KSD No. 1 well) give a present-day geothermal gradient of about 1.3°F/100 feet or 23.0°C/kilometer. In short, Oligocene to Miocene igneous activity centered along the Cascade Mountain trend produced geothermal gradients in the study area at least twice that present in the study area today.

HYDROCARBON MATURITY

The rank of coal has been used to estimate thermal maturation in petroleum exploration at least since 1915 (White, 1915). Bostick and Damberger (1971) summarized much of the previous work and found reasonably good agreement of oil and gas types with associated coal rank. Fig. 6 shows some of their correlations, plus subsequent analyses by Landes (1967) and Hood and others (1975). These correlations have usually been applied to reservoir rock and thus are applicable only if the hydrocarbons and their precursors have resided in or near the reservoir throughout the process of coalification. It is most useful to interpret coal rank in terms of the minimum level of maturation necessary to generate hydrocarbons (Hood and others, 1975). Philippi (1965) showed that significant quantities of oil were not generated at subsurface temperatures below approximately 115°C for Miocene rocks in the Los Angeles and Ventura Basins. He also pointed out that for older rocks the minimum temperature is lower. Reference to fig. 5 shows that, for the 20-million-year-old source rocks that Philippi studied, 115°C correlates approximately with the high-volatile bituminous coal with a BTU value of about 13,000. This corresponds well with previous work (fig. 2).

In the vicinity of the 13,000 BTU contour, our trend surface models (figs. 3 and 4) predict that the maturation of source rocks is adequate to begin to generate large quantities of oil. West of this contour, the appropriate level of maturation is reached only at greater

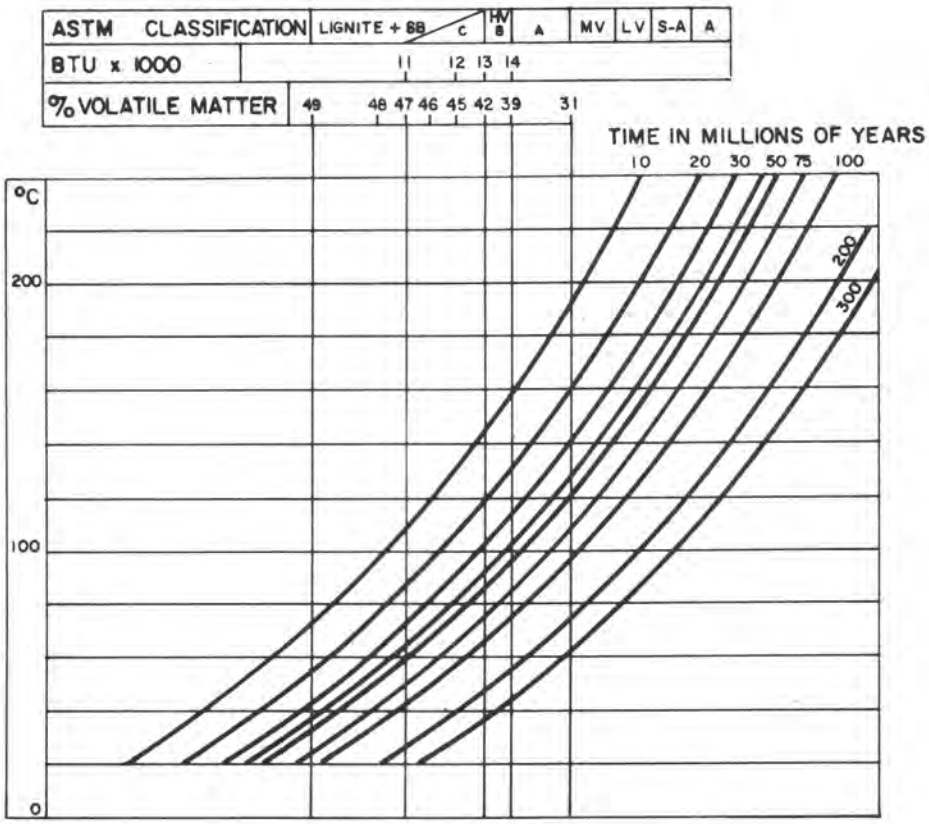

FIGURE 5. – Karweil nomogram. Relation between rank, temperature, and time of coalification, modified from Castano and Sparks, 1974.

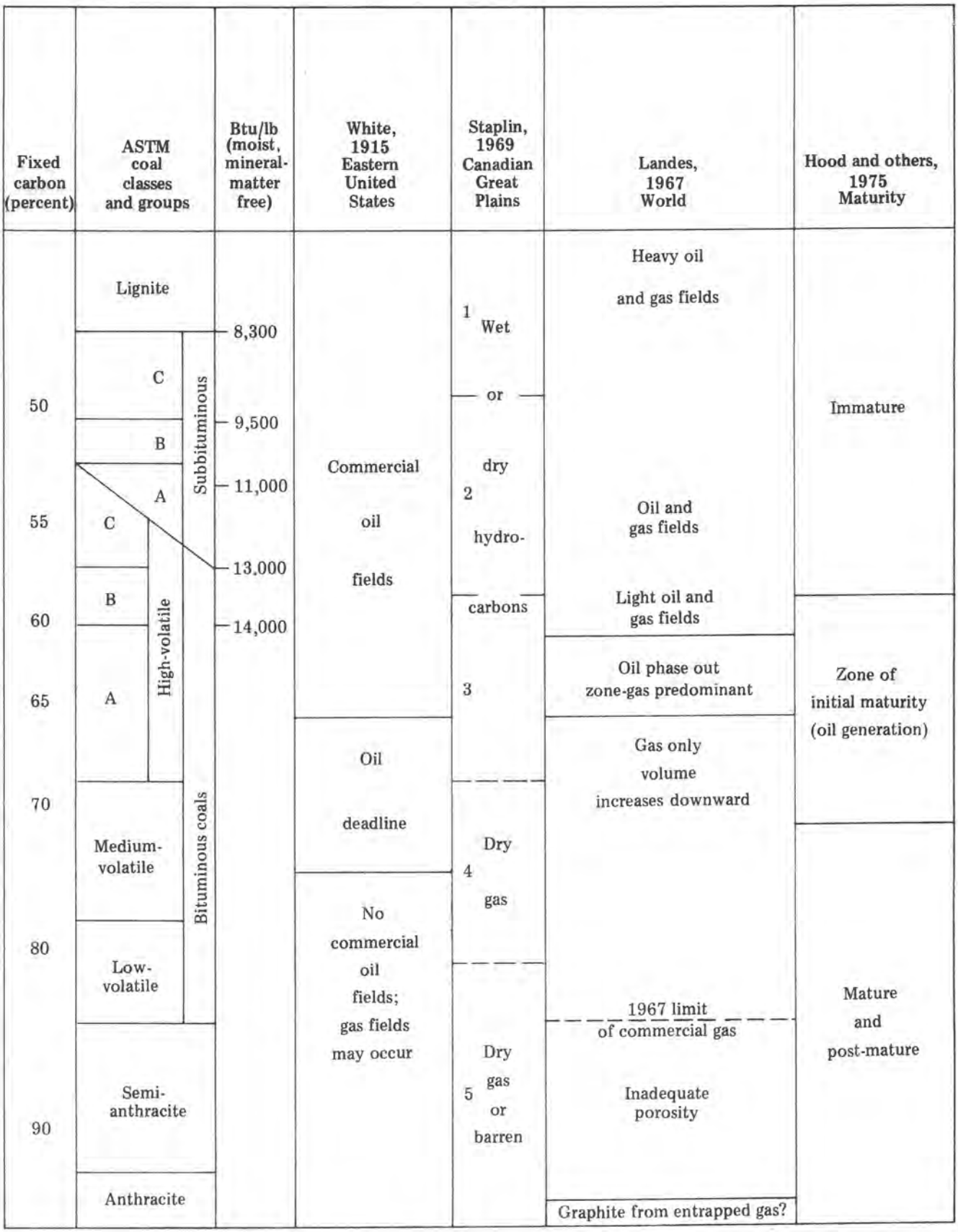

FIGURE 6. – Coal rank classes and parameters correlated with the occurrences of hydrocarbons in strata associated with the coal. The last column lists the level of maturation of hydrocarbons relative to coal rank. Note that only high-volatile B bituminous coal is in the oil zone in all columns.

depths than the coal measures. Wildcat wells approximately 4 miles southeast of Renton did not penetrate traces of live oil above depths of 5,700 feet. On both of the trend surface models, these wells are in the vicinity of the 11,500 BTU contour lines. Wells drilled approximately 3 miles south of Black Diamond had traces of live oil as shallow as 1,200 feet. These wells correspond to our 12,000 BTU contour. In the town of Snoqualmie, which is on the 13,000 BTU contour on the second-order surface, and the 14,000 BTU contour on the third-order model, a water well hit an oil show at 690 feet (Washington Oil World, 1930).

Of course, accumulation of hydrocarbons also requires favorable reservoir rock and trap conditions. Based solely on thermal maturation, however, we believe potential oil pay zones to be shallow in the vicinity of the 13,000 BTU contour, and progressively deeper to the west.

CONCLUSIONS

Coal rank in King County is strongly influenced by proximity to the Cascade Mountains. BTU contours are parallel to the Cascade trend in a zone approximately 7 miles wide from the foothills to the west. Rank increases rapidly to the east within this zone. During the Oligocene and Miocene, the Cascades were the locus of igneous activity which resulted in accumulation of a thick pile of volcanic rocks. The combination of burial by volcanic rocks and the thermal aureole associated with magmatic activity upgraded coal rank from subbituminous to a maximum of high-volatile A bituminous.

Because hydrocarbon maturation, like coal rank, is principally a thermal process, we conclude that potential oil pay zones are expected to be shallow in R. 7 E., in King County, but to become deeper to the west where geothermal gradients were lower.

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TED LIVINGSTON CHANGES JOB

After 10½ years as State Geologist, Ted will pursue other activities. He will be working on special projects involving mineral and energy resource evaluation of state lands.

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The following theses were recently added to our division library and are now available for reference work:

Adams, N. B., 1976, The Holden mine, from discovery to production, 1896-1938: University of Washington Doctor of Philosophy [History], 235 p.

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Simpson, D. P., 1976, Hydraulics of two small gravelly tidal inlets: University of Washington Master of Science, 142 p.

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The following reports are now available for inspection in our library:

Campbell, N. P.; Bentley, R. D., 1981, Late Quaternary deformation of the Toppenish Ridge uplift in south-central Washington: (reprinted from *Geology*, v. 9, p. 519-525) 6 p.

Cheung, J. B.; Hurlburt, G. H.; Scott, L. E.; Veenhuizen, S. D., 1981, Application of a hydraulic borehole mining apparatus to the remote extraction of coal (prepared by Flow Industries, Inc., Kent, Wash.; submitted to U.S. Bureau of Mines in September 1976): U.S. Bureau of Mines Open-File Report 117-81, 87 p.

Dethier, D. P.; Bethel, John, 1981, Surficial deposits along the Cowlitz River near Toledo, Lewis County, Washington: U.S. Geological Survey Open-File Report 81-1043, map scale 1:62,500, 26 p.

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Korosec, M. A.; Kaler, K. L.; Schuster, J. E.; Bloomquist, R. G.; Simpson, S.; Blackwell, D. D., compilers, 1981, Geothermal resources of Washington: Washington Division of Geology and Earth Resources Map GM-25, scale 1:500,000. [Prepared for publication by National Oceanic and Atmospheric Administration (NOAA) and work supported by U. S. Department of Energy.]

Schuster, J. E.; Korosec, M. A., 1981, Preliminary report on heat flow drilling in Washington during 1981: Washington Division of Geology and Earth Resources Open-File Report 81-8, 26 figs., 15 tables, 36 p.

EMPLOYMENT OPPORTUNITY – STATE GEOLOGIST

The Washington State Department of Natural Resources will be accepting applications for the appointive position of State Geologist through February 24, 1982. We are requesting your assistance in locating interested and qualified candidates for this position.

The State Geologist manages the programs and the 26-person staff of our Geology and Earth Resources Division based in Olympia, Washington. The division is involved in a wide range of applied geologic research, service, and regulatory activities. Current research efforts include mineral, fossil fuel, geothermal geology, and an environmental geology program that emphasizes identification of geologic hazards. Regulatory activities include the Washington Geothermal Resources, Surface Mined Land Reclamation,and the Oil and Gas Conservation Acts.

We are interested in considering candidates with proven professional and managerial skills. Due to the nature of the position, we will be looking for a geologist familiar with current geologic and industry concepts and trends. Strong interpersonal skills and the ability to deal productively with representatives of governmental, industrial, and public interest groups are critical to the success of our State Geologist. At a minimum, candidates should possess a professional degree in a geologic science and 5 years professional experience, which includes 2 years of responsible managerial experience.

The current salary range for this position is $29,676 to $37,980 per year. Normal employment benefits to include retirement and insurance plans are provided.

Interested and qualified candidates should submit their resumes to the Washington State Department of Natural Resources, Attention Personnel Section, Olympia, Washington 98504, prior to February 24, 1982.

ACTIVE PERMITS AND APPLICATIONS FOR OIL AND GAS DRILLING

Operator	Permit no.	County	Well name	Location	Ground elevation (feet)	Estimated total depth (feet)	Spud date	Date permit issued
The Great Western Oil Co.	349	Yakima	Savaria No. 2	846 FNL and 1,740 FWL of[1/] sec. 8 (14-18E)	1,720	16,000		Pending
Horse Heaven Drilling Company	350	Benton	Moon No. 1	168 FSL and 650 FEL of sec. 30 (7-26E)	200	2,000		1-13-82
Fairview Oil & Gas	351	Clallam	State No. 1	2,021 FSL and 2,370 FEL of sec. 16 (30-5W)	903	10,000		1-8-82

[1/] Land description indicates that the location is 846 ft from the north line and 1,740 ft from the west line of sec. 8, township 14 north, range 18 east, Willamette meridian.

Department of Natural Resources
Division of Geology and Earth Resources
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