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The Basalt Waste Isolation Project site, Hanford Reservation, Washington. The drill is situated at the proposed shaft site on the Cold Creek syncline. The hills in the background are the Rattlesnake Mountains, wells on which produced 1.3 billion cubic feet of natural gas between 1929 and 1941. See related articles in this newsletter. (Photograph courtesy of the U.S. Department of Energy)

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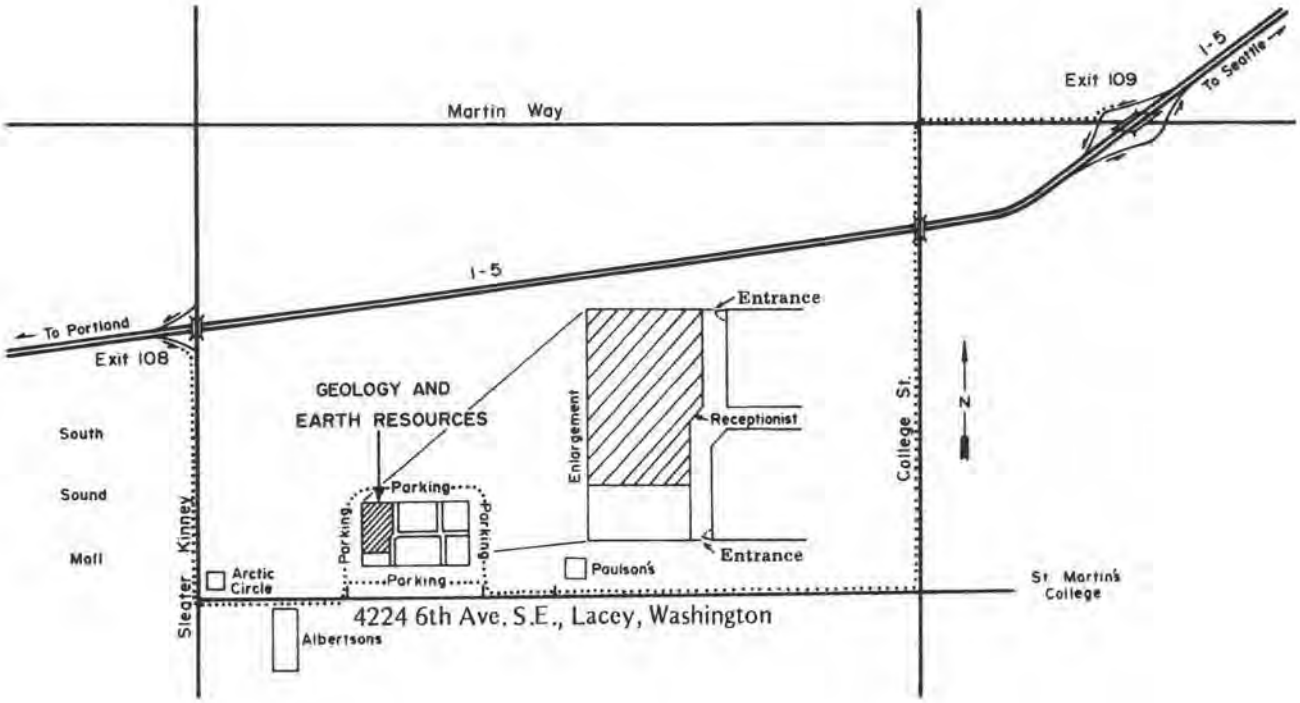

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The Division also publishes bulletins, information circulars, reports of investigations, and geologic maps. A list of these publications will be sent upon request.

Geologists reviewing the Hanford area from Gable Mountain during a groundwater survey of the area in October 1921. The White Bluff–Hanford area was then being developed for farming as part of the Soldier Settlement Project, under which soldiers returning from World War I could obtain farm lands. Gable Mountain later became the site of the "Near Surface Test Facility". At that location, an underground test site in the Pomona Flow was set up to test rock mechanics for a high-level nuclear waste repository at Hanford. Gable Mountain has religious significance to the Yakima Nation. (Photograph by Olaf P. Jenkins)

HIGH-LEVEL NUCLEAR WASTE REPOSITORY CONCEPT: DEEP GEOLOGIC DISPOSAL

(Modified by Raymond Lasmanis
from information supplied by the
Washington State Nuclear Waste Board
and Advisory Council)

The federal Nuclear Waste Policy Act of 1982 sets forth a schedule and plan for permanent disposal of the nation's spent fuel and highly radioactive wastes by the end of the century. Under the Act, the U.S. Department of Energy (USDOE) is responsible for construction of two deep repositories. USDOE has been examining potential repository sites across the country in a variety of geologic media, including salt, basalt, tuff (hard volcanic ash), and granite. During February 1983, the USDOE identified nine potential sites in six states to be studied for the first repository.

On May 28, 1986, the USDOE nominated five of the nine sites as candidate sites for more extensive study. On the same day, President Reagan selected three of these five recommended locations for additional, more detailed federal evaluation, called site characterization. The Hanford reservation in Benton County was selected, along with Yucca Mountain, Nevada, and Deaf Smith County, Texas. Also, on May 28, the USDOE announced that they would discontinue evaluating granite sites for a second repository in the eastern U.S. This unilateral action has forced the State of Washington to seek relief in the courts. The Governor and the Washington State Nuclear Waste Board have requested Congress to halt the USDOE repository program until such time that all sites can be included in the program, including the eastern granite sites.

This article provides information about nuclear waste and the Hanford site, as well as references to sources of detailed descriptions of both the waste materials and the site.

WHAT IS NUCLEAR WASTE?

The Washington State Nuclear Waste Board and Advisory Council offer these (modified) definitions of high-level nuclear and other wastes:

Commercial spent fuel: Spent fuel consists of material that has been used in nuclear power plants to generate electricity. Spent fuel has exhausted its "useful life." This material contains most of its original uranium, as well as additional radioactive elements such as strontium, cesium, and plutonium, produced during its use in the power plant. Each year a typical nuclear reactor creates about 30 tons of commercial spent fuel. The original, fresh fuel consists of pellets of uranium oxide, which are loaded into zirconium or stainless steel alloy tubes and bundled together into assemblies about 12 feet long. When the spent fuel is removed from the reactors, these assemblies are both extremely hot and highly radioactive. Much of the heat and radiation decays after about 5 years of storage, but the spent fuel remains potentially hazardous for a long period of time. Storage pools consist of about 40 feet of water in basins of reinforced concrete, with walls approximately 6 feet thick and lined with stainless steel. The water cools the spent fuel and shields against its penetrating radiation. Currently, the utilities are responsible for the temporary onsite storage of spent fuel generated by their power plants until permanent facilities are available. The USDOE has developed a contract with nuclear power utilities to accept the spent fuel by 1998 for more permanent storage. Spent fuel is classified as high-level nuclear waste.

Reprocessed high-level nuclear waste: High-level waste technically results when spent fuel assemblies are reprocessed in hot nitric acid, dissolving the fuel pellets and removing the unused uranium and plutonium. The liquid high-level waste generated from reprocessing must be solidified to glass or a similar solid before shipment and disposal. Borosilicate glass has received the most attention as a medium for immobilizing nuclear waste. About 600,000 gallons of commercial liquid high-level waste exist in storage today at West Valley, New York. No commercial reprocessing has been conducted in this country since 1972. A 1981 Presidential statement supported commercial reprocessing by the private sector; however, no proposals have been received from industry to date.

Defense Waste: Defense wastes are generated by U.S. government activities such as nuclear research and weapons production. These can be high-level or low-level waste. About 48 million gallons of high-level defense wastes are in storage at Hanford. The Nuclear Waste Policy Act calls for a study on the commingling of high-level defense waste in the repositories. Commingling would combine defense waste with commercial reprocessed high-level waste and spent fuel for disposal. In January 1985, the President decided that commingling of defense waste can take place. This option would significantly increase the amount of high-level waste in a geologic repository.

Spent fuel and high-level reprocessed waste should not be confused with low-level radioactive wastes, which are disposed of in shallow land burial sites. Low-level wastes are produced by research, medical procedures, hospitals, and industry, as well as nuclear power plants. There are larger volumes of low-level wastes, compared to high-level waste, but they contain lower levels of radiation. Hanford is the site of a low-level disposal facility managed in accordance with the recently passed federal Low-Level Waste Policy Act.

The Washington State Department of Ecology is the operator of the site under the Northwest Interstate Compact. Waste generated outside the Northwest Interstate Compact area has had a surcharge levied against it since March 1, 1986. The volume of shipments is down by 50 percent for the first quarter of 1986.

WHAT WILL THE WASTE STORAGE FACILITY BE LIKE?

High-level waste poses risks to health, safety, and the environment if not properly managed. Congress has concluded that placing packaged spent fuel and solidified waste in stable rock formations, deep underground, will meet long-term health and safety criteria.

The Hanford site is on the Columbia Plateau, a region underlain by a thick sequence of strata deposited between 8.5 and 16.1 million years ago, in Miocene time. The lower strata consist entirely of basalt "flows" (originally lava, now solid layers of rock), and the upper strata include increasing amounts of sedimentary deposits interbedded with the basalt. Semiconsolidated sediments overlie the basalt sequence and attain thicknesses of as much as 525 meters (1,200 feet). Approximately 50 basalt flows, with a total thickness of about 5,000 meters (16,000 feet) have been identified in the Pasco Basin where the Hanford site is located (Fig. 1). One of these basalt flows, the Cohassett Flow of the Grand Ronde Formation (Fig. 1), has been identified as the candidate flow for the repository. Geologic structures at the Hanford site consist of long, narrow anticlines and broad synclines (trough-like folds) that trend roughly east-west. Faults associated with anticlinal fold axes probably developed concurrently with folding.

Prior to the construction of a repository, the three sites selected by the President will undergo a 5-year site characterization phase estimated to cost $1 billion each. During this phase, exploratory shafts will be drilled to access the Cohassett Flow so that it can be tested for mechanical strength and hydrologic characteristics. A drill rig (Fig. 2) is on the site, but exploratory shaft drilling has not begun, pending resolution of litigation filed by Washington, Nevada, Texas, other states, and environmental groups. A sketch of a possible configuration of underground facilities for testing hydrologic, rock stability, and other repository characteristics of the Cohassett Flow is shown in Figure 3.

But what does permanent disposal of high-level nuclear waste in a deep geologic repository mean? A "repository," according to the USDOE's conceptual design, will be a complex of surface facilities including waste handling and storage buildings, a concrete plant, offices, parking lots, and a visitors center, in addition to the deep subsurface storage areas. Unloading areas will accommodate waste brought to the repository by train or truck. A total of about 2,000 acres will be needed for the repository. About 400 acres of that total will be required for surface facilities, and the 2,000-acre controlled area will have an 800-foot buffer zone surrounding it. Fences and security systems will be needed to control access to the repository facilities.

At Hanford a major part of the repository would be 2,970 to 3,213 feet (about 1,000 meters) vertically underground. It will be a large rectangular area, with about 2,000 acres of space taken up with drifts (tunnels), shafts, and work areas. Individual underground rooms will be used for waste containers. Each room will be about 10 feet high. Workers will reach the underground areas via a personnel and equipment elevator shaft; a separate shaft will be used to lower canisters of high-level waste. Ventilation shafts will also be needed.

When waste packages arrive at the repository, they will be inspected and transferred underground through the waste shaft. Specialized vehicles, shielded to protect workers from radiation exposure, will transport the waste to the disposal rooms. Once in the rooms, waste canisters will be placed in holes drilled in the rock and covered with a rock, bentonite, or concrete cap. A multiple-barrier scheme is intended to protect people and the environment from the wastes. These barriers include immobilization of the high-level waste in glass, a disposal container for glass or spent fuel, backfill in the hole, and the mass of surrounding rock. Both radiation and temperature effects are important, as the waste is both highly radioactive and produces high heat. The repository must also be designed to be safe in extreme conditions such as earthquakes, floods, or volcanic eruptions. The USDOE plans extensive monitoring to make sure that the repository operates as designed. Environmental monitoring, surface measurements, and hydrologic monitoring will all be part of the ongoing program to become aware of any problems.

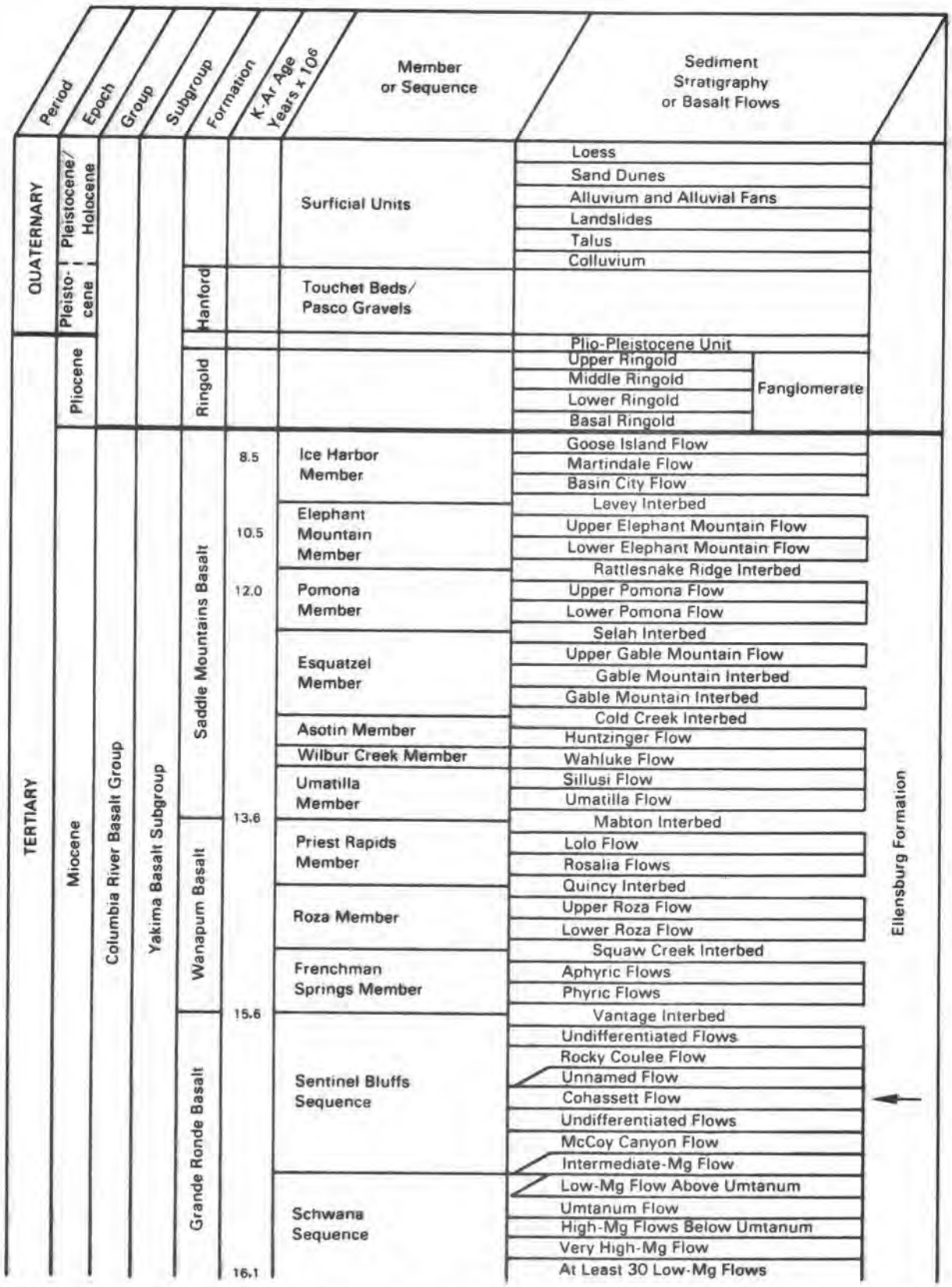

FIGURE 1 .—Stratigraphic units in the Pasco Basin. Arrow indicates position of the Cohassett Flow. (From USDOE, 1986, Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes, p. 0.3)

FIGURE 2.--Drill rig purchased by the Department of Energy for drilling the test shaft during site characterization work mandated by President Reagan on May 28, 1986. (Photograph courtesy of the Washington Department of Ecology, Nuclear Waste Management Office)

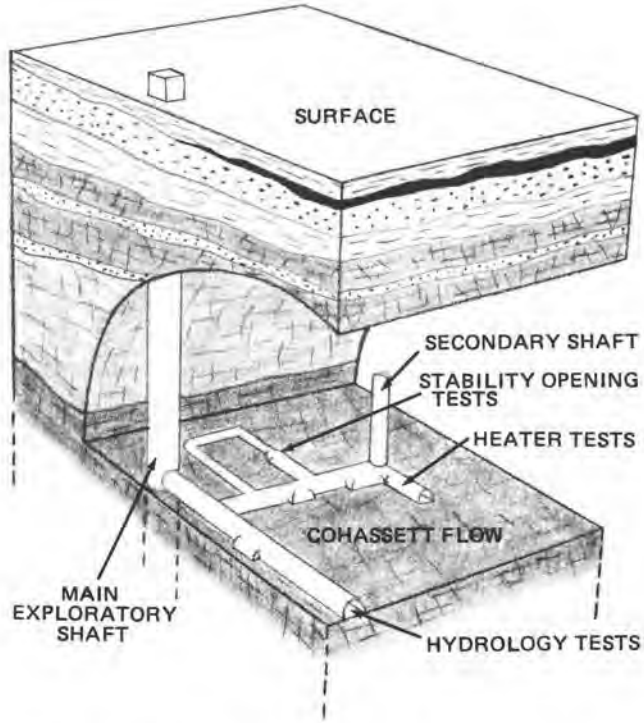

FIGURE 3.--Sketch of the design for an exploratory shaft to determine the suitability of geologic conditions for high-level nuclear waste storage at the Hanford site. The Cohassett Flow of the Grand Ronde Basalt has been selected for testing; it is approximately 250 feet thick and 3,000 feet below the surface. Geologic and hydrologic characteristics of the site are described in the Draft Environmental Impact Statement. Testing of the flow's characteristics is expected to take at least 5 years.

Other questions about the repository characteristics remain to be answered in later phases of investigation and design. Current preliminary estimates of construction and operating employment range from 1,700 to 5,000 workers during 6 years of construction, with 870 to 1,100 persons employed during 30 years of operation. A basalt site, such as Hanford, would require the higher end of the employment range. Impacts of the development on local communities and regional economics will be explored in later phases of site investigation. Analysis of potential risks, planning for transportation, health effects, security plans, and other important issues continue to be examined as the federal government evaluates potential sites.

At the present time, a large amount (440,000 cubic yards) of high-level defense waste is at Hanford. This waste is in tank farms at the surface (Fig. 4). These farms are surrounded by earthen berms. Another 60,000 cubic yards of high-level defense waste will be generated during the next 12 years at Hanford.

Comments are presently being solicited from the public by the USDOE on their "Draft Environmental Impact Statement, Disposal of Hanford Defense High-Level Transuranic and Tank Wastes, Hanford Site", dated March 1986.

FIGURE 4.--Storage tanks during the construction phase at Hanford. These tanks are used to store high-level defense waste on a temporary basis. Deep geologic disposal is one of the alternative methods of storage under consideration for such waste in the Draft Environmental Impact Statement for this facility. (Photograph courtesy of the U.S. Department of Energy)

The problem of safe disposal of nuclear waste has to be addressed. As each day passes, additional amounts of high-level waste are generated by nuclear power plants and the Defense Department. This waste will be dangerous for more than 10,000 years, and only geological repositories that can guarantee isolation of the waste from the biosphere should be considered.

DIVISION OF GEOLOGY AND EARTH RESOURCES INVOLVEMENT

The Geology and Earth Resources Division has taken an active role in deliberations concerning permanent disposal of high-level nuclear waste on the Hanford Reservation in Benton County. The state geologist, Raymond Lasmanis, began serving on the state's High-Level Nuclear Waste Management Task Force in October 1982. Since that time, and through several name changes, the official state body that monitors Hanford activities has become the Nuclear Waste Board. Commissioner Brian J. Boyle is a member of the Board, and Raymond Lasmanis serves as a designee. The flow of information to the Nuclear Waste Board and the routing of concerns to the USDOE is outlined below in a chart supplied by the Board. The work of

evaluating federal documents and serving with the Nuclear Waste Board and related committees has required a considerable commitment of time by the state geologist. During the

last 12-month period, more than 55 days have been spent on this activity. Each document describing the site and storage plan has been reviewed, and the state geologist has sent his comments to the USDOE.

The USDOE's response to the Division's concerns and issues raised in response to the Draft Environmental Assessment are listed under Lasmanis, Raymond, on pages C.10-234 through C.10-236, Volume 3, of the Final Environmental Assessment, released on May 28, 1986. A total of 54 individual issues were identified; each issue in the list is indexed to a page in the statement.

If the state's litigative efforts to halt construction are not successful, site characterization will proceed. The staff of the Division will have to increase its vigilance in monitoring the tests and in reviewing the data generated by the USDOE and its contractors.

WHERE TO GET INFORMATION ABOUT NUCLEAR WASTE AND HANFORD

These documents provide detailed information about the site and plans for waste storage:

- Site Characterization Report for the Basalt Waste Isolation Project (November 1982)
- Draft Environmental Assessment, Reference Repository Location, Hanford Site, Washington (December 1984)
- Mission Plan for Civilian Radioactive Waste Management Program (June 1985)
- Draft Environmental Impact Statement Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (March 1986)
- Environmental Assessment, Reference Repository Location, Hanford Washington (May 1986)

These documents are available for inspection at the Divison's office on Sixth Avenue in Lacey, the Office of Nuclear Waste Management on Pacific Avenue in Lacey, and in major public and university libraries.

To get on the mailing list for more information from Washington State write or call:

The Office of Nuclear Waste Management
Department of Ecology, PV-11
Olympia, WA 98504
(206) 459-6670

To obtain copies of the final "Environmental Assessment, Reference Repository Location, Hanford, Washington, May 1986" (3 volumes), write to:

U.S. Department of Energy
Attention: EA
1000 Independence Ave., SW
Washington, D.C. 20585

To obtain copies of the "Draft Environmental Impact Statement, Disposal of Hanford Defense High Level, Transuranic and Tank Wastes, Hanford site, Richland, Washington, March 1986" (3 volumes), write or call:

Steve H. Leroy, Director,
Communications Div.
U.S. Department of Energy
Richland Operations Office
Richland, WA 99352
(509) 376-7378

GET INVOLVED!

Four public hearings on the Department of Energy's Defense Waste Draft Environmental Impact Statement were held during July in Washington cities and Portland, Oregon. Information on future hearings can be obtained from Marta Wilder, Washington Department of Ecology, MS: PV-11, Olympia, WA 98504.

The public is welcome to attend the Washington State Nuclear Waste Board meetings. They are held at 1:30 p.m., the third Friday of each month at:

Energy Facility Site
Evaluation Council
EFSEC Hearings Room
4224 Sixth Ave., SE
Building 1
Lacey, Washington

ISSUES RELATING TO PETROLEUM DRILLING NEAR THE PROPOSED HIGH-LEVEL NUCLEAR WASTE REPOSITORY AT HANFORD

by

William S. Lingley, Jr.
and Timothy J. Walsh

In February 1986, the Office of Nuclear Waste Management of the Washington State Department of Ecology requested that the Division of Geology and Earth Resources assist in a study of future petroleum activities in the vicinity of the proposed high-level nuclear waste repository at Hanford. The objective of this study is to determine the probability that the repository could be accidentally breached as the result of drilling for oil or gas. If significant probability for such an accident exists, then Hanford will not meet the U.S. minimum qualifying conditions for nuclear waste repository siting (10 CFR 960-4-8-1a). Our preliminary findings suggest that the probability of such an accident is low. These findings were presented to the Northwest Petroleum Association during their 1986 annual meeting (Lingley and Walsh, 1986). This article discusses the issues and describes some ongoing studies designed to reach a more conclusive decision on the breaching issue.

The U.S. Nuclear Regulatory Commission is concerned that, in the distant future, accidental breaching may occur at the repository despite prohibition of access to the Hanford Reservation and despite the elaborate hazard warning system planned for the repository. The minimum effective life span of the repository must exceed the 10,000 years necessary for the waste to decay to minimum acceptable radiation levels (Brewer and Lasmanis, 1986). Consequently, it is probable that the repository will outlast present political institutions, and it might also outlast written record of the presence and dangers of the radioactive nuclides stored in the repository chambers.

Accidental breaching could result from drilling directly into the repository or from drilling nearby and, as a result, exposing rocks contiguous with the repository to formation fluids or drilling fluids capable of leaching fracture-filling minerals in the chamber walls. The **apparent** probability of either type of breach is low, given that the Columbia Basin, in which Hanford is located, is covered with a thick section of Columbia River basalt which is relatively unprospective for oil and gas and given that petroleum is not presently produced in Washington State. ("Prospective" is used as in the industry idiom to indicate favorable possibilities for oil or gas accumulation(s) at a given location. "Petroleum" is used here in the legal sense and includes oil, gas, and gas condensate).

However, Shell Western Exploration and Production, Inc., and others have undertaken a relatively aggressive exploration program in the basin. During 1986 alone, the Division of Geology and Earth Resources has received permit applications for acquisition of more than 250 line miles of seismic data and for drilling a 15,000-foot wildcat well, the Boylston Mountains Unit No. 2-1. This well will be located 40 miles northwest of the proposed waste repository site (Fig. 1). This exploration program, undertaken during a severe recession for the petroleum industry, suggests that this part of the Columbia Basin is prospective.

A central question is whether the proposed repository site is sufficiently prospective to attract drillers to those areas having hydrologic continuity with the repository. In order to answer this question, we have commenced studies of the petroleum potential of the repository proper and of the northwestern Columbia Basin. Previous work by Leaming and Davis (1983) dealt only with the petroleum potential of the basalt, and work by Campbell and Banning (1985) concentrated on regional stratigraphy.

Petroleum Potential at the Proposed Repository Site

The first step in assessing the probability of accidental penetration of the repository is to find obvious prospects for petroleum accumulations at or near the proposed repository site. Prospects are usually delineated by mapping anticlines or faulted anticlines having potential to trap oil and/or gas migrating out

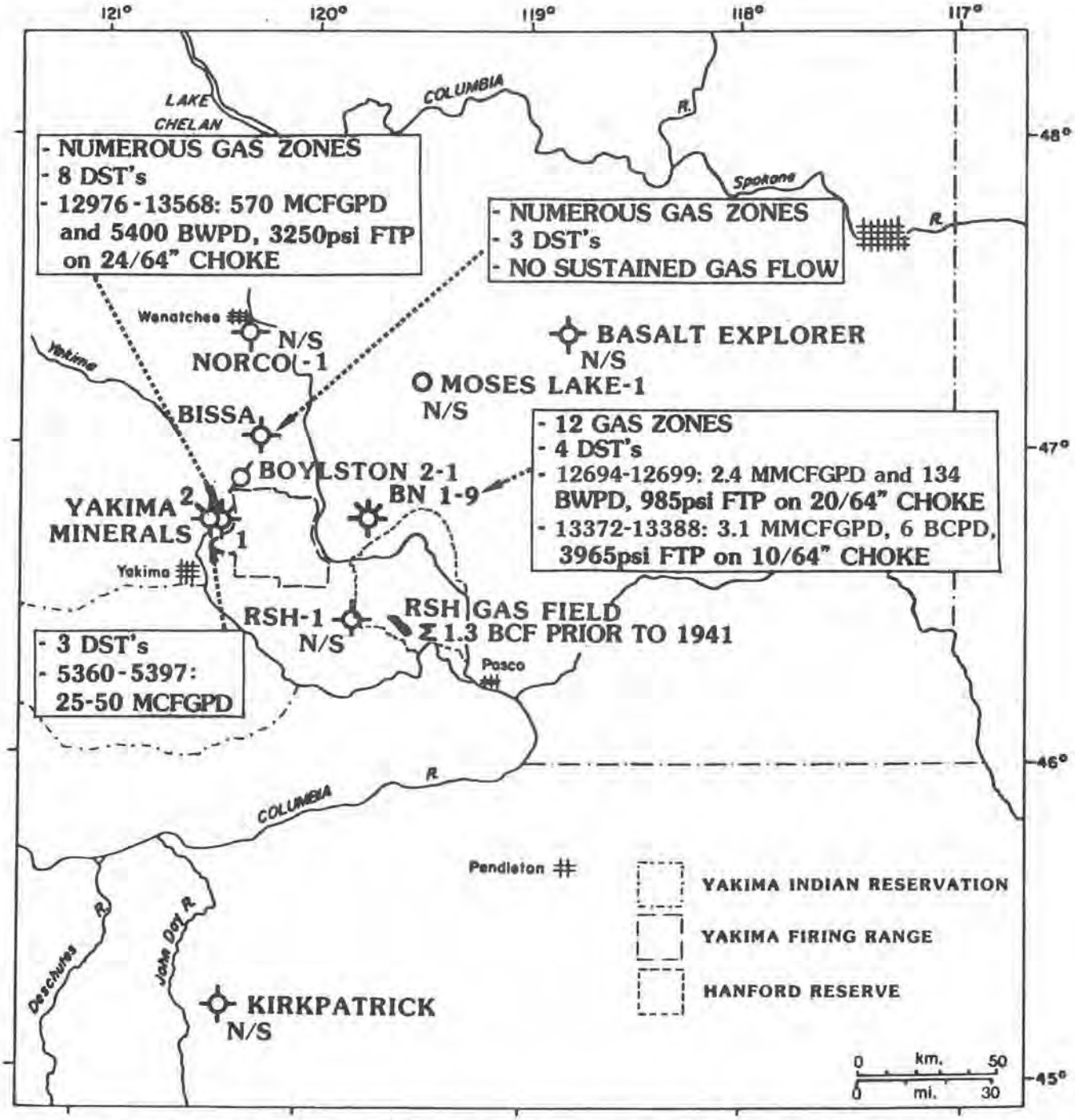

Figure 1. Index map showing locations of important northern Columbia Basin wildcat wells with data on relevant petroleum shows and drillstem tests (DST's). BWPD, barrels of water per day; BCPD, barrels of condensate per day; FTP, flowing tube pressure; N/S, no shows; BCF, billion cubic feet; MCFGPD, thousand cubic feet of gas per day. All depths in feet referenced to the kelly bushing.

of petroleum source rocks. In some parts of the Columbia Basin, structural geometry at depth can be deduced by extrapolation of structure as mapped at the surface downward to the most prospective horizons. These horizons comprise Paleogene sandstones, which generally lie at depths of 5,000 to 14,000 feet. However, it is likely that some Columbia Basin anticlines fold only Paleogene strata and have no manifestation in the basalt or at the surface. There is no definitive, yet inexpensive means of mapping these deeper structures in the Columbia Basin with present technology. Relatively inexpensive prospecting techniques, including interpretation of gravity, magnetic, and electromag-

netic data, have failed to yield prospect-scale information owing to limited resolution.

In order to locate possible prospects, we recommend that mapping of surface structure be augmented with state-of-the-art, regional reflection seismograph traverses across the site. These new traverses should be included in the ongoing petroleum assessment that is part of the Hanford site characterization study. The traverses should be planned so as to avoid interference from known faults and so as to decrease accoustical noise by having the line laid out on alluvium rather than on basalt. We believe that a meaningful assessment cannot be accomplished without acquisition of these seismic data.

An alternative to seismic traverses being considered by the U.S. Department of Energy (USDOE) and the Nuclear Regulatory Commission is drilling a well at the repository site through the basalt and into the more prospective Paleogene rocks to a total depth of approximately 15,000 feet. The estimated cost of this drilling program exceeds $10 million. We oppose this proposal because the results of such drilling may be equivocal, providing information for only one point, and therefore may not justify the high cost to utility ratepayers. Shell's experience gained by drilling and testing three sub-commercial discoveries in the vicinity of Hanford indicates that numerous gas zones are likely to be penetrated if a well is drilled at Hanford. In order to determine the magnitude of gas reserves in these zones, many will have to be stimulated and tested at additional expense. The probable result of this testing program will be that none of these zones is commercial under present-day economic constraints. However, it is not difficult to envision a wellhead gas price many times greater than the present $1.50 per thousand cubic feet, considering the non-renewable nature of petroleum resources and the likely demand for natural gas to be used as a petrochemical feedstock in the future. It is likely that a future wildcatter would find a greatly increased gas price to be a strong incentive for re-entering a well already drilled and cased through the basalt. Hundreds of wells originally abandoned as dry holes were re-entered for just this reason during the 1970s. If public records should cease to exist, the plugged well could be located because of the magnetic signature of the casing. Under this unpleasant but possible scenario, the well drilled for the very purpose of deciding if it is necessary to keep future explorers out of the repository area would have precisely the opposite effect (unless a carefully reasoned plugging program for this 15,000-foot test and for the numerous shallower wells already drilled by USDOE is developed).

Regional Petroleum Potential of the Columbia Basin

It is reasonable to assume that some form of direct petroleum detection technology may be developed during the life span of the repository and that use of this technology may result in successful exploration in areas such as Hanford where no obvious manifestations of petroleum potential exist today. Direct detection or other new exploration technology could be applied to the greatest advantage in unexplored basins that have significant theoretical but untested potential to produce hydrocarbons. Historically, petroleum has been discovered by drilling at locations proven by mapping to be analogous to existing oil or gas fields. Some small accumulations, trapped by structure, hydrodynamics, or stratigraphic pinchouts too subtle to map using existing technology, have been discovered accidentally by drilling in thoroughly explored basins. However, closely spaced drilling in almost all onshore basins in the United States diminishes the probability of large new oil or gas discoveries from anticlinal or subtler types of traps because the remaining unexplored area is insufficient for typical large petroleum fields. For example, the Powder River Basin, a productive basin in northeastern Wyoming roughly equal in size to the Columbia Basin, has had more than 27,000 wells drilled for oil and gas. On the other hand, the Columbia Basin, where only nine wells have been drilled to date, is the least explored, large onshore basin in the United States. Consequently, it is likely to have more intensive exploration in the future if reasonable hope for a commercial discovery exists.

The basic ingredients of a petroleum-generative province are present in the Columbia Basin. For example, sedimentary rocks in excess of 10,000 feet thick were penetrated in the Yakima Minerals 1-29 well (Figs. 1 and 2). Gas shows were logged in

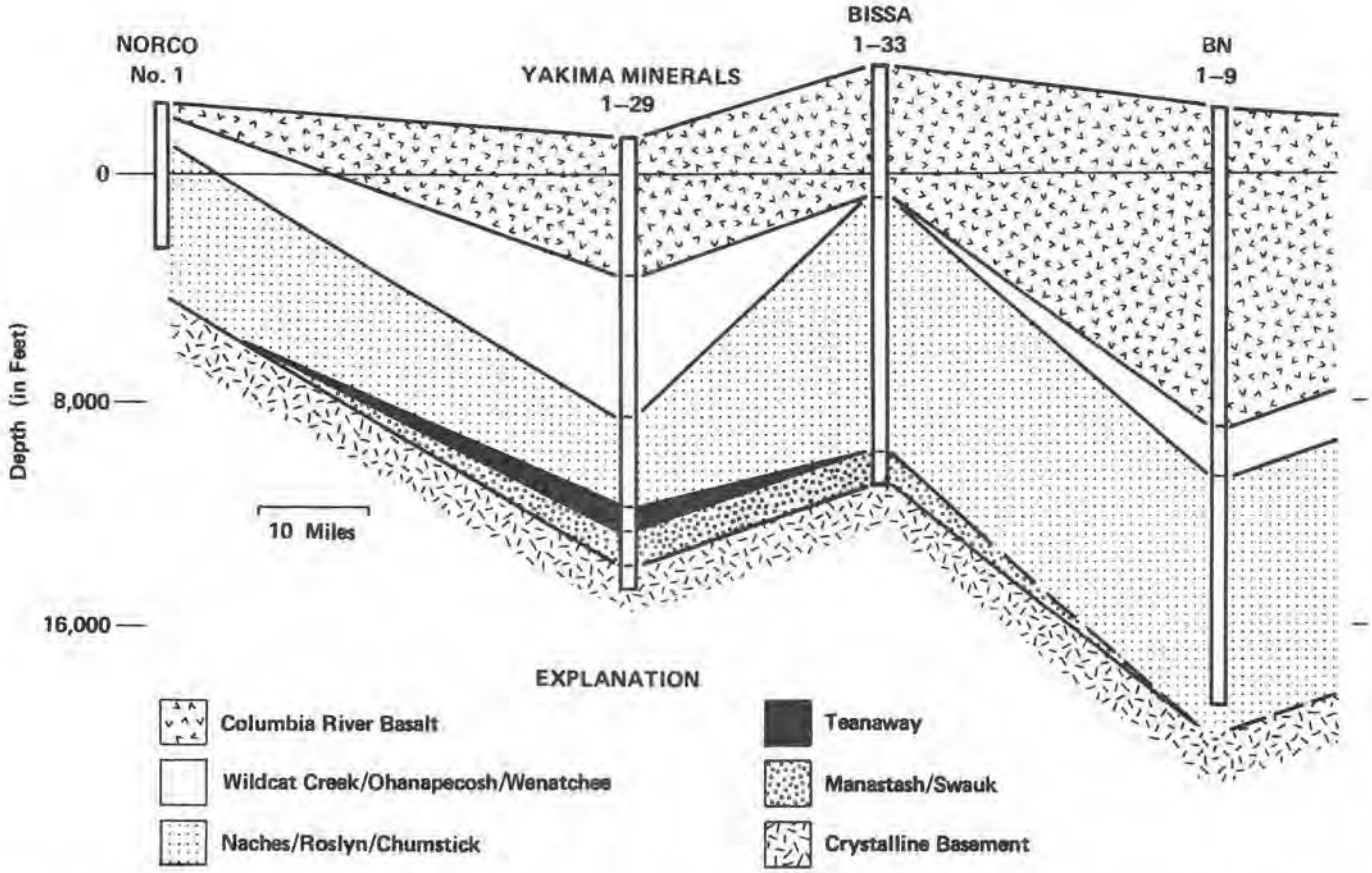

Figure 2. Correlation diagram for selected Columbia Basin wells. Interpretation is from Campbell and Banning, 1985; N. E. Campbell, personal communication, 1986; and J. E. Evans, University of Washington, written communication, 1985.

all wildcat wells drilled into the sedimentary section and in numerous water wells drilled into the Columbia River basalt. We calculate moderately high geothermal gradients (+/- 40°C/kilometer), which are optimally conducive to generation and preservation of petroleum. The reflectance of vitrinite, a coal maceral, is considered to be a maximum-reading paleo-thermometer. We have measured vitrinite reflectance values between 0.5 and 1.0 which also demonstrate that much of the sedimentary section is thermally mature for petroleum generation (Fig. 3, Table 1). Large, doubly-plunging or faulted anticlines are common (Fig. 4) and provide abundant traps. Furthermore, 1.3 billion cubic feet of natural gas were produced from the Rattlesnake Hills gas field prior to its abandonment in 1941 (McFarland, 1983). This field, located in a subsidiary fold on the north flank of the Rattlesnake Hills anticline, lies within the Hanford Reservation a few miles from the proposed repository (Fig. 1).

The obvious questions many laypersons ask when presented with this information are, "Why aren't hydrocarbons being produced at present, and why haven't more exploratory wells been drilled if the Columbia Basin is such a good place to search for petroleum?" Three obstacles have impeded successful exploration in the Columbia Basin: (1) the difficulty in drilling through the basalt (2) the difficulty of obtaining seismic data, and (3) the gas-generative nature of the source rocks.

Basalt is difficult to drill because of its hardness and because of the problems of maintaining drilling-mud circulation while penetrating numerous, highly permeable fracture zones that characterize these rocks. The Shell BN 1-9 well located directly north of the repository and the Standard Oil of California Rattlesnake Hills No. 1 well located within the Hanford Reservation both drilled through more than 10,000 feet of basalt (Figs. 1 and 2); these were unusually expensive projects, and neither penetrated commercial gas zones.

It is particularly difficult to acquire high-quality seismic data in basalt because of

low signal-to-noise ratios and because of poor coupling between the seismic signal receivers and basalt outcrops. Complex faulting, which is common in the vicinity of the proposed repository, also diminishes the quality of seismic records and hinders interpretation. However, a future explorationist may regard this complexity as an advantage because complex faulting generally results in numerous potential petroleum traps.

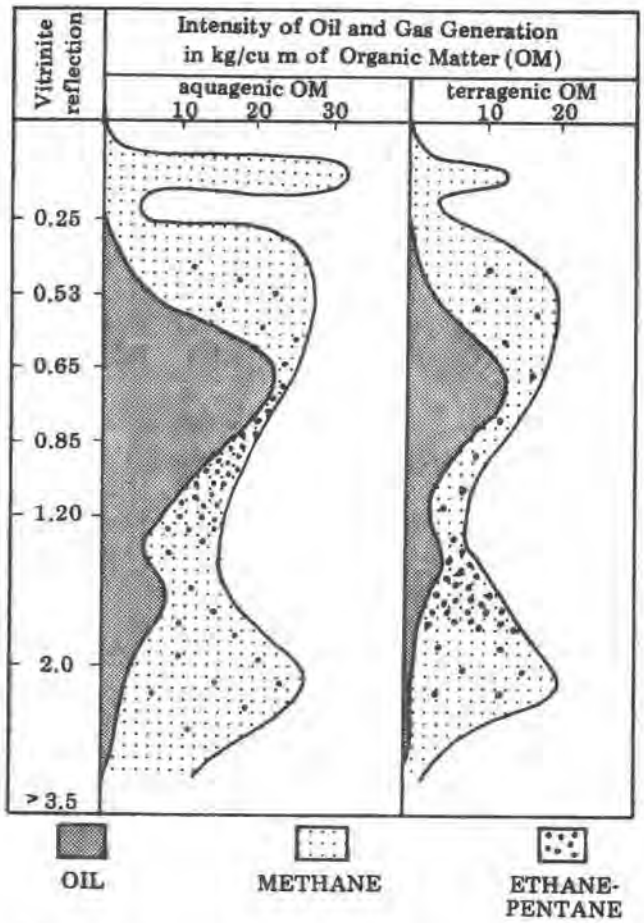

Figure 3. Suggested correlation between vitrinite reflectance and hydrocarbon generative potential (from Kontorovich, 1984.)

No public data, except those herein and in Lingley and Walsh (1986), are available to characterize the quality of the petroleum source-rocks. The USDOE and the Washington State Office of Nuclear Waste Management plan to evaluate the source potential and maturation levels of selected intervals in the Shell wells and in the Norco well (Fig. 1) during the site characterization study.

Despite the paucity of data, petroleum shows logged to date give an indication of the general nature of the source potential of the northern part of the basin. These shows suggest that the source rocks in this part of the basin will probably generate natural gas only. Gas or gas-condensate shows have been recorded throughout the sedimentary section of the northwestern part of the basin, but no oil shows have been logged to date. Much of the sedimentary section in the basin lies within the oil-generative thermal window (Fig. 3), and therefore, we infer that if areally extensive oil-prone source rocks were present in the basin, oil shows should have been observed. Although we expect most future wildcats will penetrate some gas zones, the possibility for an oil discovery cannot be ruled out because few holes have been drilled through the basalt. On the other hand, gas source-rocks are evidently present in abundance in the basin. Gas shows are so ubiquitous that few 100 percent water-bearing reservoirs are present in the Paleogene section. Water-bearing zones are critical for normalizing the responses of sondes used to determine such petrophysical characteristics as porosity and water saturation (the percentage of water that partially fills most pore space below the water table). Nevertheless, natural gas is a less attractive product than oil because of traditionally soft markets and because of high transportation costs. Gas pipeline construction can cost $40 per linear foot, and gas gathering and compression generally cost in excess of a million dollars per field. Because only small markets exist nearby, gas would have to be transported large distances to users.

Even if these three technological problems related to exploring this basalt-covered basin are solved, there remains a question as to whether the potential petroleum reserves in the basin are sufficient to encourage further exploration. In order to answer this question, it is necessary to determine why tests drilled through the basalt into prospective rocks have been sub-commercial discoveries at best. The Yakima Minerals 1-29, located 45 miles west-northwest of the proposed repository, tested 500 thousand cubic feet of gas per day (MCFGPD), and the BN 1-9 tested 3,100 MCFGPD. These rates are commercial for typical wells, but not for wells in the Columbia Basin where the development wells

Table 1. Mean random vitrinite reflectance measurements on coals from selected wells in the Columbia Basin

Well name	Depth interval (feet)	R_o (mean)	Standard deviation	Number of Measurements
Shell BN 1-9	11280-11290	0.54	0.02	50
Grant County	11990-12000	0.63	0.03	50
965' FWL, 1869' FNL	15110-15120	1.13	0.09	50
sec. 9, T. 15 N., R. 25 E.	15160-15170	1.15	0.11	31
	15810-15820	1.32	0.12	50
Shell Bissa 1-29	4620- 4630	0.43	0.05	50
Kittitas County	5150- 5160	0.39	0.04	38
1318' FEL, 1928' FSL	5820- 5830	0.45	0.05	75
sec. 29, T. 18, R. 21 E.	6480- 6490	0.51	0.05	77
T.D. = 14,965 ft.	6890- 6900	0.50	0.05	75
	7600- 7610	0.53	0.06	75
	8560- 8570	0.57	0.06	100
	9210- 9220	0.53	0.06	79
	9590- 9600	0.47	0.08	41
	10070-10080	0.57	0.05	53
Shell Yakima Minerals 1-33	9840- 9850	0.86	0.11	76
Kittitas County	10070-10080	0.91	0.07	74
925.5' FNL, 1445.6' FWL	10370-10380	1.08	0.08	75
sec. 33, T. 15 N., R. 19 E.	10805-10810	1.11	0.09	61
T.D. = 16,199 ft.	11010-11020	1.20	0.13	75
	11860-11870	1.38	0.12	75
Norco No. 1	1751- 1760	0.39	0.03	54
Chelan County	1920- 1930	0.39	0.03	7
NW1/4 NW1/4 SW1/4 sec. 26,	2253- 2260	0.51	0.05	51
T. 22 N., R. 20 E.	2400- 2410	0.49	0.08	53
	2535- 2540	0.48	0.06	24
	2690- 2700	0.32	0.02	45
	2785- 2790	0.42	0.17	4
	2885- 2890	0.28	0.03	25
	3144- 3150	0.35	0.03	51
	3305- 3310	0.47	0.04	48
	3444- 3450	0.42	0.06	26
	3692- 3700	0.51	0.05	50
	3972- 3980	0.50	0.06	24
	4208- 4220	0.77	0.07	11
	4671- 4680	0.66	0.07	57
	4840- 4850	0.51	0.06	69

necessary to establish commercial production may cost $8 to 14 million each. Flow-test data indicate that the reservoir sandstones penetrated by the Yakima Minerals 1-29 and the BN 1-9 wells are not sufficiently extensive to sustain production. Furthermore, many of the sandstones are composed mostly of volcanogenic detritus. This detritus tends to break down to form clays or other minerals that reduce porosity and/or permeability within the reservoir. The alteration appears to be a function of depth of burial.

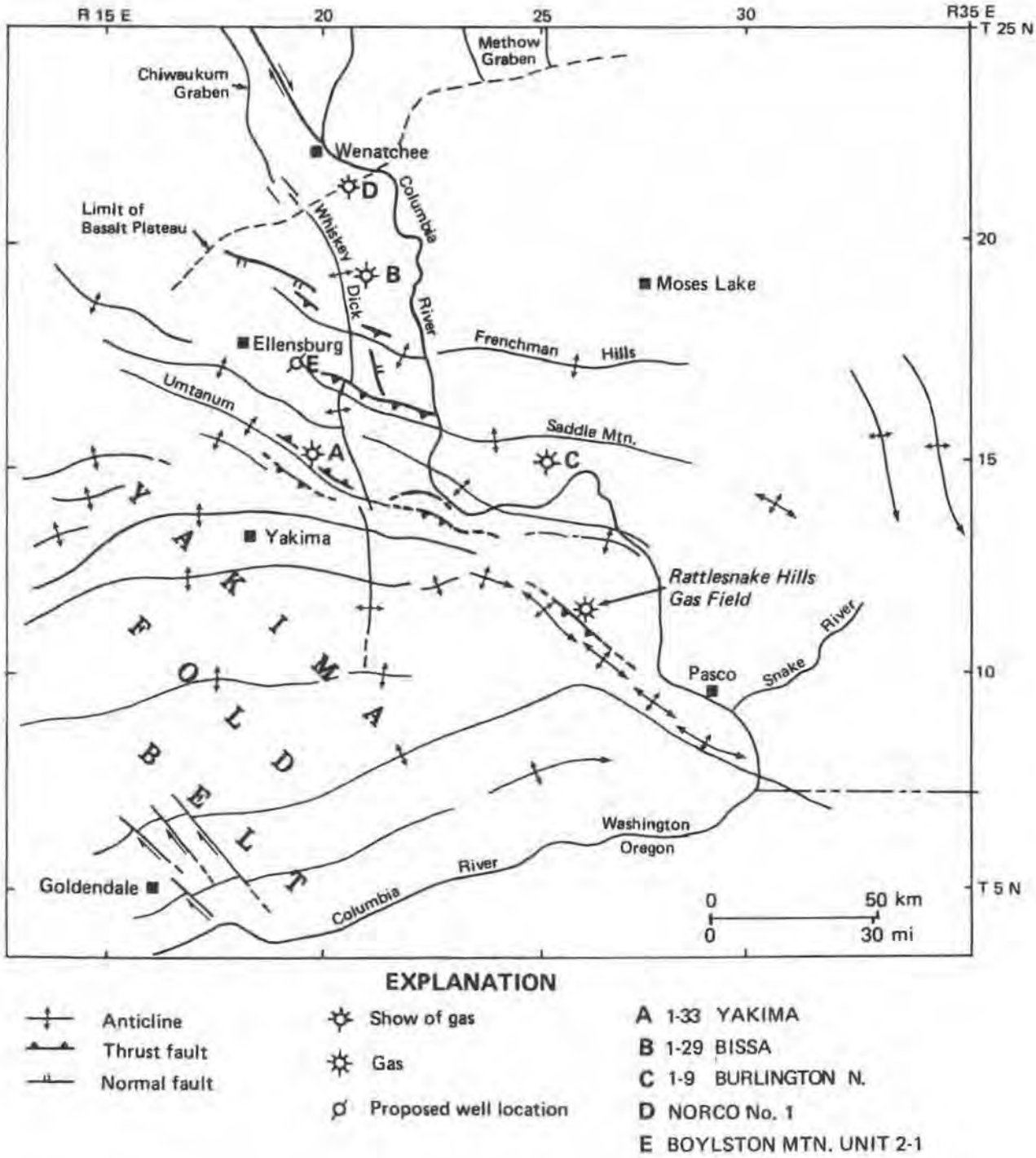

Figure 4. Structure map of the Yakima fold belt and adjacent basins to the north (from Montgomery, 1985).

We determined that mean sandstone porosity, expressed as a percentage of the bulk volume of the rock, is 18 percent at 6,000 feet drilled-depth. Mean sandstone porosity is reduced to only 8 percent at 14,000 feet, regardless of the age or composition of the sandstone present at this depth (Fig. 5). Generally, petroleum cannot flow at high rates through rocks having 8-percent porosity unless expensive and risky mechanical fracturing of the strata is performed to artificially increase permeability.

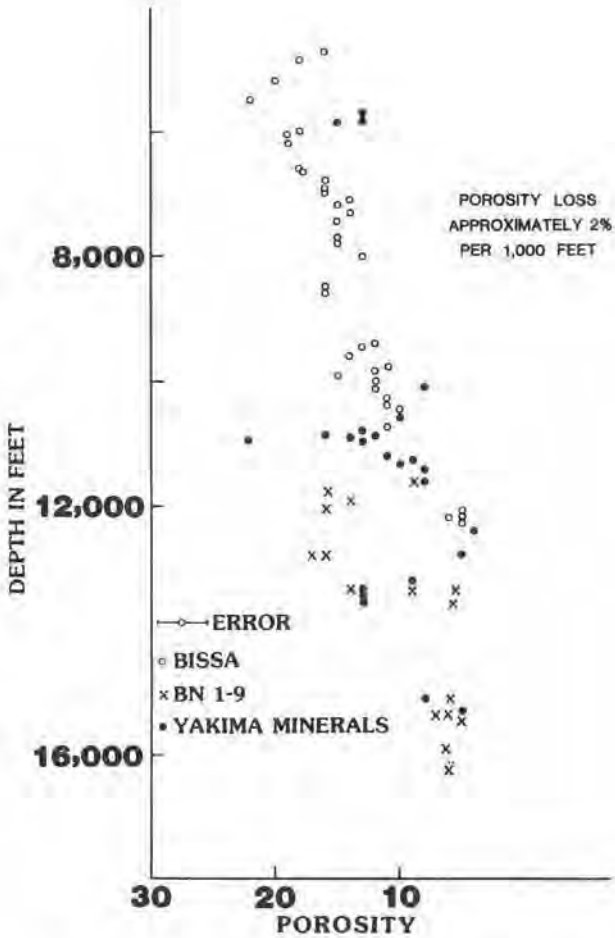

Figure 5. Interpreted porosity versus drilled depth referenced to the kelly bushing for three Columbia Basin wells. Schlumberger (1984) charts Por-14b and Por-15 were used to determine the bore hole environmental corrections and chart CP-1d was used to calculate porosity. The error bar shows the uncertainty in each porosity interpretation.

These problems relating to the porosity and permeability may not exist elsewhere in the Columbia Basin, where the reservoir sandstones may have been derived from a less volcanogenic and more quartz-rich source and where prospective Paleogene rocks lie at a shallower depth. One area having potential for better porosity is located in the east-central part of the basin, directly east of Hanford. Shell is presently concentrating their seismic acquisition program in this area.

If future explorationists wish to undertake further investigations in the basin, they may have to convince management that major reserves are present in order to justify expenditure of considerable amounts of risk capital. To simulate the arguments that these explorationists might invoke, we have estimated the range of possible reserves in the event of a commercial discovery. To make these estimates, the potential range of reservoir volumes and the amount of petroleum that can be squeezed into a unit volume of reservoir rock must be determined. Reservoir volume is a function of porosity of the rock, thickness of the reservoir, areal extent of the trap, and percentage of the reservoir that is actually filled with petroleum. The amount of petroleum that can be held in a unit volume of pore space within a reservoir rock is a function of pressure, temperature, petroleum composition, and water saturation.

Normally, the most significant variable is the size of the petroleum trap. The proposed nuclear waste repository lies within the Yakima fold belt where large anticlines, including the Rattlesnake Hills, the Yakima Ridge, and Umtanum anticlines, impinge on the Hanford Reservation (Fig. 4). These complex folds are mostly asymmetric, commonly verge to the north, range from 3 to 6 miles across strike, and are from 75 to more than 100 miles long as measured along trend. The surface expression of these folds is similar in size and morphology to folds that entrap the giant oil and gas fields of Iran, Rumania, western Alberta, and western Wyoming. Our analysis of mapping by Bentley (1980) and Swanson and others (1979) suggests that trap areas within the fold belt could range from 3,000 to 25,000 acres. The average area of potential anticlinal petroleum traps at the Paleogene sandstone horizons, as interpreted herein, is significantly less than the area of these same anticlines as mapped at the surface. This is because the anticlines are thought to plunge more steeply towards the center of the basin at depth owing to basinward thickening of the basalt. The thickness of the basalt cannot be determined with precision, but interpretation of well and geophysical data suggests that the basalt thickens toward a depocenter in the Pasco subbasin directly north of the repository. However, no data are available to indicate whether the Yakima fold belt anticlines maintain anticlinal morphology within the sedimentary rocks underlying the basalt at the repository.

We predict that fault traps are more likely than anticlinal traps at depth in the basin.

The average porosity of the Paleogene sandstones known to contain gas in the Columbia Basin ranges from less than 6 to approximately 18 percent (Fig. 5). Our work shows that the average thickness of sandstone reservoirs logged in the BN 1-9, Yakima Minerals 1-33, and Bissa 1-29 wells that have greater than 6 percent porosity is approximately 26 feet (Fig. 6). We calculate that the volume of typical Columbia Basin natural gas that can be contained in one cubic foot of pore space at the predicted reservoir pressure and temperature at 5,000 feet drilled-depth is approximately 150 standard cubic feet of gas. At 14,000 feet drilled-depth, approximately 350 standard cubic feet of gas can be contained in one cubic foot of pore space because gas is highly compressible.

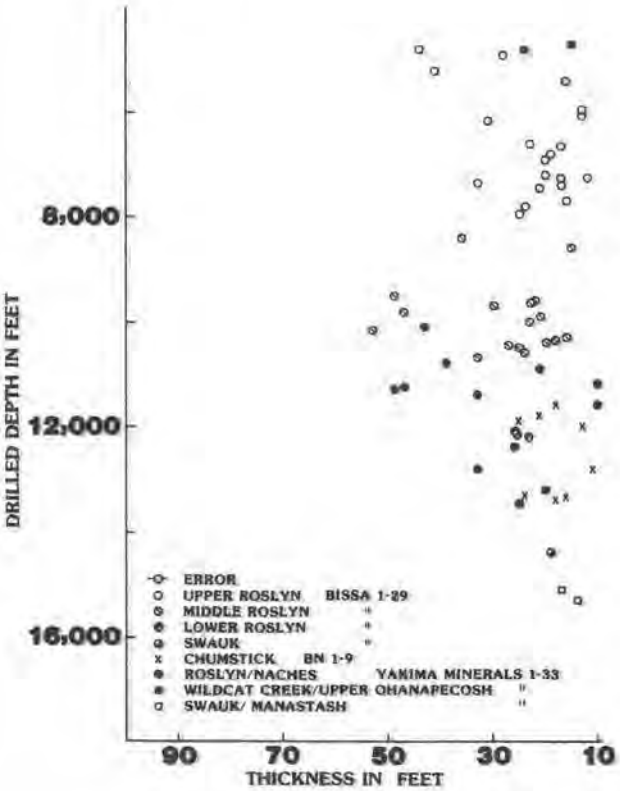

Figure 6. Thicknesses of sandstone having greater than six percent porosity versus drilled depth referenced to the kelly bushing for three Columbia Basin wells. Porosity was determined using the technique given in Figure 5. The thicknesses given represent only those sandstones having relatively uniform porosity; thick siltstone or claystone interbeds are considered to segregate a unit into two or more sandstones for the purposes of this figure. Error bar indicates the uncertainty for each thickness measurement.

These data and interpretations suggest to us that possible petroleum reserves in the vicinity of the proposed repository site range from 40 billion to 1 trillion cubic feet of gas initially in place per trap. The larger volume estimate is based on assumptions of good reservoir characteristics and three stacked pay zones; less conservative gas reserve estimates determined by using these same data will be much greater. Typical recovery currently achieved from gas reservoirs is 60 percent of the gas initially in place in the trap. A giant gas field, that is, a field with sufficient reserves to have major favorable economic impact, is defined as one in which 1 trillion cubic feet of gas can be produced. The potential for reserves of this magnitude is the reason why Shell and others persist with difficult and expensive exploration in the Columbia Basin. It is also the reason why the potential for accidental breaching of a high-level nuclear waste repository, if sited at Hanford, requires thorough investigation before it will be known whether this site will meet the minimum Federal guidelines. More detailed study of the petroleum geology of the greater Columbia Basin is now in progress.

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INDOOR RADON AND ITS SOURCES IN THE GROUND

by
Allan B. Tanner

(This article is taken verbatim from U.S. Geological Survey Open-File Report 86-222)

Introduction

Radon is a radioactive element that is produced by the radioactive decay of radium, which itself is derived indirectly from uranium. When radon disintegrates, it produces radioactive decay products that are now recognized as an important cause of lung cancer. Uranium, radium, and radon are naturally present in very small concentrations in nearly all soils and rocks. There are typically only a few radon atoms among the 10,000,000,000,000,000 molecules of air in a pore space in the soil. The radon atoms do not combine with other elements but can diffuse or can be carried along with air from the soil into a house through openings such as cracks, joints, sumps, and utility penetrations in basement foundations and walls or through floor openings from crawl spaces above the soil.

What causes soil air to move into a house?

Soil air moves into a house when the air pressure inside the house is lower--even if only a hundredth of a percent lower--than the atmospheric (barometric) pressure outdoors. Wind blowing by the house can reduce the air pressure in the house, depending upon the positions of open windows and other openings. If the air in the house is warmer than the outdoor air, it is more buoyant, can leak out at the upper levels of the house, and "draw" cooler air in from below, just as a fireplace does. In effect, lowered air pressure makes the house a large vacuum cleaner, sucking some air from the soil and some air from the outdoors near ground level.

If an ice or clay apron, or concrete deck outside offers resistance to the movement of air from the soil to the atmosphere,

and the pathway through the house offers less resistance, then falling barometric pressure can cause soil air to move into the house. Heavy rainfall also can increase the movement of soil air into the house.

What determines how much radon can get into the house?

First there has to be radium in the soil. Some radium is almost always present in soil, but its concentration ranges over about a factor of ten. Other things being equal, soils with higher concentrations of radium are potentially more hazardous.

Second, the radon, which is constantly being created by disintegration of radium, has to be able to get into the soil pores and move fairly quickly into the house. Ninety percent of a given amount of radon will decay in 13 days enroute. If the soil "breathes" easily, the radon can move; conversely, if the soil does not "breathe", the radon decays before it can move more than a foot or so.

Third, there must be porous building material or openings below ground level to permit radon or radon-bearing soil air to move into the house. If a house is well sealed below ground level, much of the radon decays before it can pass through most building materials.

Fourth, it is likely that reduced air pressure indoors, which forces air to flow into the house, is needed to produce a serious indoor radon problem. Some radon may enter without movement of air by a process known as diffusion, but it is thought to be less important for entry of radon into a building than air flow driven by pressure difference.

Are there maps showing radon distribution in the soil?

Direct measurements of radon in soil are not often made. However, radiations from one of the radon decay products can be measured from aircraft and provide an approximate measurement of the radon in the top foot of an area of the ground below. Such measurements were made in strips covering much of the area of the 48 States and some of Alaska as part of the National Uranium Resource Evaluation (NURE) program. Complex processing of the measurements is required to make accurate maps, and only the radiometric maps of Ohio are currently available. Because the flight strips of the NURE program left gaps in the coverage, the information is not satisfactory for detail in areas smaller than about six miles in diameter. No matter how accurate and detailed a radon map may be, it represents only one of the four major factors that determine whether an indoor radon hazard exists in a house. At present, we expect that some localities having potential for excessive indoor radon exposure exist in all the States.

What controls radon movement in the ground?

Radium in rock and soil contributes radon to the soil air only if the radium is very close to the surfaces of the rock and soil grains. In many rocks, only a few percent of the radium disintegrations produce radon that can get into the pore spaces. In most soils, a fifth to half of the radon can get into pore spaces. In extremely dry soil, however, most radon stays in the solid material.

Once radon is in the rock or soil pores, the amount of water in the ground is very important. If the pores are filled with water, radon can move only a few inches before it decays. If only a small amount of water is present, radon may move a hundred times further. The distance the radon can move tends to be greater in fractured rocks and coarse soils and gravels, and much less in fine-grained soils like silt and clay, which also tend to hold water. Air and water carry radon by flow much more easily through coarse and fractured material than through fine-grained soil.

What types of ground favor indoor radon problems?

Remember that it takes a combination of factors to cause an indoor radon problem: (1) radium in the ground, (2) ease of radon movement in the ground, (3) porous building materials or openings below grade, and generally (4) lowered atmospheric pressure in the building. Few of the measurements of indoor radon made to date have been carefully related to the soil and underlying rock types on which the houses are sited. The criteria given below are based on scientific prin-

ciples, rather than on proven correlations between certain rock and soil types and radon concentrations in houses built on them.

Rock types to suspect: Granites, many gneisses, phosphatic rocks, and dark marine shales typically contain higher than normal levels of radium; if these rocks are fractured, they can be important sources of radon. When limestones and dolomites recrystallize, they exclude uranium and radium from the new crystals and concentrate them in the pores and along surfaces that fracture easily, so that radon can be picked up and carried by air or water moving along the fractures. Sandstone is not usually enriched in radium, but it is the host rock for uranium deposits in some areas of the West. Well water derived from the above rock types may contain such high concentrations of radon that a significant amount of radon is liberated from the water in showers and other domestic uses, in addition to radon entering from the soil.

Soils to suspect: Some residual soils, particularly those known as terra rossas (reddish-brown soils sometimes found over limestone bedrock), have become enriched in radium as other parts of the soil have been leached away. Coarse, well-drained soils allow radon-bearing air to move easily and may make radon available to a building even if the soil itself does not contain much radium. Gravels and coarse sands are possible troublemakers. At the other extreme, clays and muds, particularly if they are usually wet and extend to the lowest foundation level, should not permit much radon movement into a building even if their radium concentration is greater than normal. Ground that does not pass the percolation test (of the suitability of the ground for a septic drain field) should not pass dangerous amounts of radon.

Topographic effects: Houses built on hillsides and ridges are apt to be located on soils that are coarser and better drained than soils in adjacent valleys. They are also apt to be closer to bedrock which, if fractured, may yield more radon than the soil.

What can be done to prevent radon entry into buildings?

The U.S. Environmental Protection Agency advises that measures currently being investigated in State or Federal projects include:

- Sealing foundation cracks and openings around basement drains and utility pipes or cables with caulking compounds or epoxy sealants.
- Ventilating crawl spaces or underfloor areas such as sumps or other drain systems.
- Ventilating the inner hollow spaces of concrete blocks in basement walls.
- Covering earth inside or under the building by using concrete or a tightly sealed polymeric vapor barrier.
- Ventilating the area around entrances to the basement (such as where pipes come in or cracks in the wall or floor) and then exhausting this air to the outdoors.
- Controlling the building ventilation rate through the use of air-to-air heat exchangers.

How can the radon level be tested?

Radon measurements require special instruments or detectors. Radiation protection bureaus of some States, some local health departments, and some utility companies have facilities or arrangements for making indoor radon measurements. The references cite some sources of detectors. The U.S. Environmental Protection Agency has established a "hot line", 1-800-334-8571, extension 7131, from which general information can be obtained; effective in late May 1986, lists will be available of detector vendors participating in a voluntary quality control program.

References for further reading:

"Indoor Air Pollution", in Consumer Reports, October, 1985, includes information about indoor radon and one type of detector that can be obtained.

"Radon Exclusive", in Popular Science, November, 1985, features a lengthy article on indoor radon and cites two sources of radon detectors for homeowner use.

"The Radon Report", in Rodale's New Shelter magazine, January, 1986, is a feature article. Contrary to statements in the article, slab-on-grade houses are less

likely to collect radon than houses with basements. The article's map should be used with great caution, because it is based on regional occurrences of bedrock that tend to contain greater-than-average radium concentration, which is only one of the factors that create indoor radon problems. Parts of the shaded areas should not have been shaded because the bedrock is not exposed near the surface. Many localities not shaded on the map may have high potential for indoor radon exposure because of local enrichment of rock or soil by radium or because of particularly low resistance of the rock or soil to movement of radon-bearing air.

"The Indoor Radon Story", in Technology Review, January, 1986, was written by Anthony V. Nero, Jr., leader of the extensive program of indoor radon investigations conducted by the Lawrence Berkeley Laboratory, and is the most authoritative of the popular publications so far.

Indoor Air and Human Health, edited by R. B. Gammage and S. V. Kaye and published by Lewis Publishers, Inc., 121 S. Main Street, P.O. Drawer 519, Chelsea, MI 48118 (ISBN 0-87371-006-1), is a 1985 book that contains technical articles on radon sources, radon dosimetric and risk models, epidemiology of radon decay products as a cause of lung cancer, and European radon surveys and risk assessment.

Guidance and information about remedial action may become available from the U.S. Environmental Protection Agency, Radon Program, 401 M Street, S.W., Washington, D.C. 20460.

LANDSLIDE DAMS
A Potential Geologic Hazard

by
Gerald W. Thorsen

Landslides present a wide spectrum of potential problems when they block streams. If the stream and the slide are large enough and the valley is narrow, subsequent events can happen very fast. Areas upstream of the dam can be flooded in minutes. Usually more serious, however, is the potential for extensive property damage and loss of life downstream if the dam breaks or is overtopped and then quickly eroded. Thousands of lives have been lost in such events.

The subject of landslide dams was deemed important enough to warrant a special session at the April 7, 1986, convention of the American Society of Civil Engineers (ASCE) in Seattle. The proceedings have just been published as Landslide Dams: Processes, Risk, and Mitigation (Schuster, 1986; available from ASCE, 345 East 47th St., New York, NY 10017-2398, for $17). In addition to papers on slide dams in China, Japan, Pakistan, and Utah, three papers discuss conditions in the Pacific Northwest. Two papers deal with the dams formed as a result of the avalanche from Mount St. Helens in 1980; the other treats slide dams in British Columbia.

The situation in British Columbia is of particular interest not only because of its proximity to Washington State, but also because of the many geologic and topographic similarities of that area to the Cascades. The paper, by S. G. Evans, reviews 18 historic landslide dams. One that breached suddenly resulted in a flood that devastated the mining village of Brittania Beach just north of Vancouver, killing 37 people. Evans concludes (p. 128) that "Quaternary volcanic centres exhibit the highest potential" for large-scale catastrophic outburst floods. He also points out (p. 128) that "a large-volume damming event and a large impoundment volume are not necessarily related to the magnitude of a potential disaster," because other factors come into play.

The avoidance of what are termed outburst floods is precisely the reason for the emergency responses to damming events such as occurred at Thistle, Utah (1983), Spirit Lake, Washington (1980), and Hebgen Lake, Montana (1959). In the last instance, a massive slide dammed the Madison River, and the water rose so rapidly that some campers in the area had to climb trees to escape (Witkind, 1964). Prompt action by the U.S. Army Corps of Engineers in cutting a spillway probably prevented catastrophic failure of the dam.

In their introductory chapter to the volume of papers from the ASCE meeting, Schuster and Costa (1986) report that of the 135 slide dams they studied, 84 of the slides were triggered by rainstorms and snowmelt or by earthquakes. They further report that half of the slide dams failed within 10 days and that overtopping was the commonest mode of failure. They also stress (p. 17) the need for more systematic study because "mitigation must be accomplished quickly" when needed.

Other than those dams mentioned that accompanied the eruption of Mount St. Helens, Washington State appears to have had no life-threatening slide dams in historic times. The slide triggered by the 1872 earthquake that temporarily blocked the Columbia River occurred in a section of valley too broad for significant impoundment. Similarly, the slide shown in Figure 1 essentially diverted rather than dammed the Stillaguamish River; even then, it caused considerable damage. Probably our most recent significant landslide dam occurred as a result of unusually heavy rains in 1983 in a small remote bedrock canyon in Whatcom County. The site was examined in June 1986 by Thorsen and R. L. Schuster. The dam appears to be made up largely of sandstone boulders, and thus it is leaking too rapidly to impound much water and appears to be very stable.

There are many prehistoric slides in the state, some much larger than the one shown in Figure 2. Some undoubtedly created significant impoundments, but most of these have long ago been drained by downcutting

Figure 1.--This slide, about 1,500 feet across, blocked and diverted the North Fork Stillaguamish River through a recreational subdivision (note cabins, lower center). A slide of this size in the canyon cut in sandstone and situated downstream would have blocked the river, possibly for days. (From Pacific Aerial Surveys photo, 1967, for U.S. Army Corps of Engineers)

Figure 2.--Some slides, such as this prehistoric one along the White Pass Highway (on left), may have been triggered by an earthquake. The distance from the head scarp to the "landslide lake" (lower left) is about 3,500 feet. Bottom sediments from such lakes can sometimes be used to determine roughly when the slide occurred. (Department photo, 1973, view from above the pass to west)

through their slide dams. For example, the 6-mile-wide Cleman Mountain slide probably blocked the Naches River for some time, but no reservoir remains today. The ancient slide shown in Figure 2 is near the head of a basin, and the valley walls have relatively gentle slopes. Its initial impoundment was probably not much greater than what exists today.

In summary, Washington State has many steep-sided narrow valleys, and much of the region is subject to heavy rains and earthquakes. One of our five Quaternary volcanic centers has recently confirmed Evans' concern for a particular source of slide hazard. Washington State has the ingredients for slide dam hazards discussed in this timely ASCE publication, and the Division can only support Schuster's and Costa's plea for systematic data-gathering and research. The results of such studies will aid authorities in deciding what to do when our next potentially life-threatening slide dam occurs. In addition, the factors that contribute to landslides will be of concern to land-use planners working in slide-prone areas.

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TWIN RIVER OIL AND GAS, INC. DRILLING NEAR PORT ANGELES

by
William S. Lingley, Jr.

Twin River Oil and Gas Inc., spudded a new-field wildcat, the State No. 1-30 on August 10, 1986, and the well is presently drilling below 500 feet. It is located in section 30, T. 31 N., R. 9 W., W.M., about 20 miles west of Port Angeles in Clallam County (Fig. 1). The State Oil and Gas Drilling Permit for this test is No. 410. The drillsite lies approximately 1,700 feet south of and 150 feet above the Strait of Juan de Fuca on State land administered by the Department of Natural Resources, Division of Land Leasing and Recreation. Because of the site's proximity to the strait, the Division of Geology and Earth Resources, which administers the Oil and Gas Conservation Act (RCW Chapter 78.52) has required the operator to take special precautions in order to protect the adjacent waters.

This well will be a test of the upper Eocene to lower Miocene Twin River Group on the north flank of the Tofino-Fuca Basin. Eleven dry holes have been drilled in the onshore part of this northwest-trending basin, which lies mostly offshore between Vancouver Island and the Olympic Peninsula (McFarland, 1983). These wells penetrated a stratigraphic section comprising claystone and

siltstone with a few thin sandstone interbeds. The operator anticipates that the State No. 1-30 will penetrate better reservoir strata consisting of thicker sandstones in the middle Twin River Group. Middle Twin River Group turbidite sandstones are as much as 400 feet thick near Neah Bay but thin eastward toward the drillsite (Snavely and others, 1980). Only one well, the Standard Oil of California, Dungeness Unit 1-54, located 37 miles to the east, is known to have drilled through the middle Twin River Group.

The prospect was initially located during 1983 by Craig Gagnon, president of Twin River Oil and Gas, Inc., who observed several significant gas seeps while scuba diving directly north of the proposed drillsite. One seep was crudely gauged at a flow rate in excess of 20,000 cubic feet of methane per day. Analyses by Twin River Oil and Gas, Inc. indicate the petroleum gas is 95 percent methane, with 2.4 percent ethane and heavier hydrocarbons; the remainder is nitrogen and carbon dioxide. Geothermal gradients calculated from two wells near the State No. 1-30 location range from approximately 1.5 to 2.0°F/100 ft. The relatively low gradient coupled with shallow depths to crystalline basement near the prospect (Craig Gagnon, personal commun., 1986) suggests that, while potential for a natural gas accumulation exists, oil is less likely to be present. However, the geothermal gradient in this area may have been higher in the past.

Structures cropping out near the prospect consist of a local southwest-dipping homocline that is part of the north limb of a major syncline (Fig. 1). A marked gradient observed on Bouguer gravity mapping acquired and interpreted by Twin River personnel, suggests that the faulted hinge of the major syncline lies directly south of the prospect (Ken Koenen, Twin River Oil and Gas, Inc., personal commun., 1986). Several geomorphic anomalies suggest to the operator that a complex fault trap could be present at the prospect.

This well is a remote wildcat and therefore one must assume a relatively low probability of a commercial discovery. However, a significant percentage of oil and gas fields have been discovered by drilling adjacent to petroleum seeps.

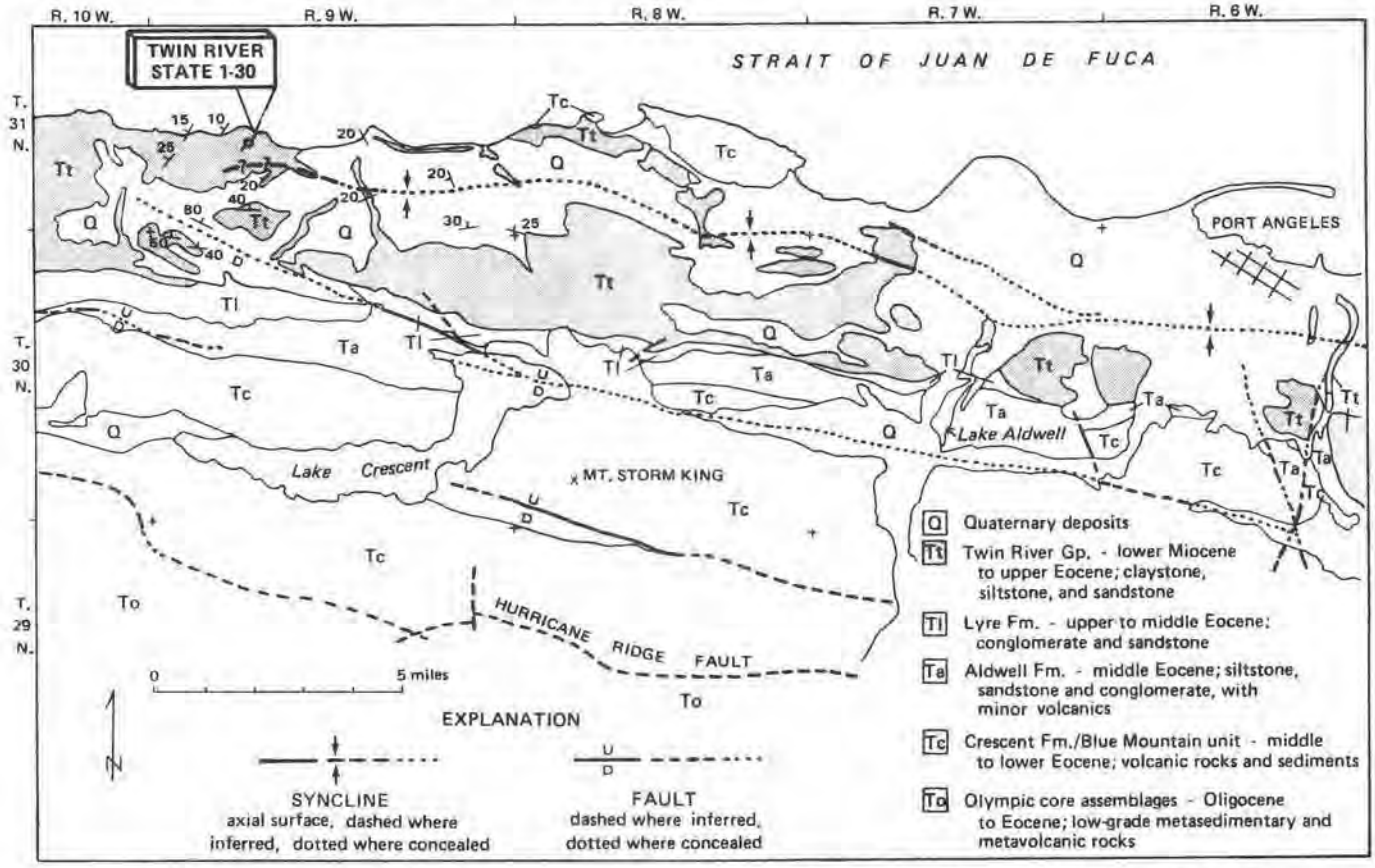

Figure 1. Simplified geologic map of part of the northern Olympic Peninsula near Port Angeles showing the Twin River Oil and Gas, State No. 1-30 location. (Geology after Tabor and Cady, 1978).

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Snavely, P. D., Jr.; Niem, A. R.; Macleod, N. S.; Pearl, J. E.; Rau, W. W., 1980, Makah Formation--A deep-marginal-basin sedimentary sequence of late Eocene and Oligocene age in the northwestern Olympic Peninsula, Washington: U.S. Geology Survey Professional Paper 1162-B, 28 p.

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GEOLOGIC MAP OF WASHINGTON
A Progress Report

by
J. Eric Schuster

Geologic maps of Washington were published in 1936 and 1961 by predecessors to the present Divison of Geology and Earth Resources. Both maps were at 1:500,000 scale. Additional mapping in Washington and significant changes in concepts of tectonics make this an opportune time to be revising this map. The new state geologic map will be published in four quadrants at a scale of 1:250,000. A common color and pattern scheme will be used on all four quadrants.

Preparation of the southwest quadrant will be completed this year. The quadrant's north and east boundaries are 47°15' north latitude and 120°30' west longitude. The Division's schedule calls for publication of the northeast quadrant in 1988, the southeast in 1990, and the northwest in 1992.

Division cartographers are preparing a new base map for the state geologic map, using U.S. Geological Survey (USGS) 1:100,000-scale topographic maps as sources of data. We plan to print the base map for each quadrant as a separate topographic map.

Five Division geologists began geologic compilation at 1:100,000 scale in the southwest quadrant more than two years ago. Significant reconnaissance mapping, field checking, and some detailed mapping were done as part of compiling the maps at that scale. These compilations have been drafted, sent out for peer review, and revised as necessary. The 1:100,000-scale geologic maps will be either open-filed or published beginning in late 1986 or early 1987.

The 1:100,000-scale geology has been reduced to 1:250,000 scale and somewhat simplified for the state map. The map of the southwest quadrant is now in peer review.

Geologists in the Division's Spokane office, meanwhile, have completed geologic compilations for four 1:100,000-scale quadrangles (Robinson Mountain, Oroville, Colville, and Chewelah) in the northeast quadrant and are working on several more. Fieldwork this summer in the northeast quadrant is concentrating on areas in which little mapping has been done and where there are significant geologic problems. Division geologists from the Olympia office are assisting. Additional geologic mapping is being done by graduate students with Division support.

The Division is investigating a possible cooperative effort with the USGS, through their COGEOMAP program, to complete 1:100,000-scale geologic maps in the north Cascades (Concrete 1:250,000 sheet).

NEW MINERAL INVENTORY IN PROGRESS

by
Bonnie B. Bunning

The Washington Division of Geology and Earth Resources has begun a revision of its Bulletin 37, "Inventory of Washington Minerals, Parts I and II", which was published in 1960. The new bulletin will be compiled from unpublished data in the Division's files and field notes, published maps and reports and non-confidential exploration or mine data from private sources.

Property descriptions in the new inventory will emphasize geology, tectonic setting, and deposit type and will include basic prospect identification data such as name(s), location, commodity, and past production. The properties will be plotted on 1:250,000-scale maps included in the report.

Data will be completely referenced and extensively indexed.

As presently planned, the data will be compiled on an IBM PC XT computer, using the REVELATION data base manager program to implement GS-MODS, a Mineral Occurrence Data System written by Bruce Johnson of the U.S. Geological Survey. GS-MODS consists of four interrelated data bases: user data, text data, bibliographic data, and location data--linked with a digitizer and plotter capable of producing map overlays to accompany a report. Data entry will begin in the fall of 1986.

In advance of the bulletin's publication, it will be possible to request a search of the data by any of the 30 fields in the system. The inventory can easily be kept up to date, and the Division will be able to provide the most recent data to the public.

The Division of Geology and Earth Resources requests your suggestions for improving the inventory as it currently exists in Bulletin 37, as well as corrections to the information there. If you can contribute non-confidential exploration data for prospects to be included in the revised bulletin, please contact Bonnie Bunning of the Division office at PY-12, Olympia, WA 98504, or telephone (206) 459-6372.

CLARIFICATIONS

In the January/April 1986 issue of this newsletter, the article "High-calcium limestones tested for brightness" listed sample L-81-15B as being from the J+E Sherve Property in eastern Washington. This property is also known as the Janni Blue limestone quarry. Surface rights are held by the Sherve family, while the Janni family owns the minerals.

In the lead article of the same issue, "Washington's Mineral Industry, 1985", prospect 37 in Table 1 is owned by Columbia River Carbonates, a joint venture of Bleeck Management, Inc., and Genstar Stone Products Co.

DEPARTMENT OF NATURAL RESOURCES SUSPENDS MINERAL LEASING

On April 14, 1986, Commissioner of Public Lands Brian Boyle issued an order to suspend issuance of all new state mining contracts and prospecting leases for about 3.6 million acres of state-managed land.

The order affects about 180 prospecting leases and about 20 mineral contracts. Most of the contracts and leases involve state-managed lands in northeast and northwest Washington.

The purpose of the suspension is to allow the Department of Natural Resources to clarify its authority regarding the issuance of prospecting leases and to better protect the interests of state trust land beneficiaries. The Commissioner's order followed an audit of existing state mining leases and a review of the state's 1965 mining law and 1968 royalty regulations.

Provisions of the order are as follows:

- Applications received prior to April 14, 1986, for new mining contracts and for conversions of existing prospecting leases to mining contracts will be processed under new regulations. The new regulations change the royalty provisions to read "royalties shall be payable to the department upon production from lands held under any lease or mining contract on the basis of 3% of the gross value."
- Applications for new prospecting leases or mining contracts on state lands will not be processed until after the 1987 Legislature has considered revisions to the state's mining laws.
- Applications for new prospecting leases or mining contracts sent to the DNR after April 14 will receive a "first in time" right for issuance when the Department again grants new permits.

The department's proposal for revisions to the state's mining laws is available for public review and comment. If you are interested in reviewing the proposed changes, please contact the Department of Natural Resources, Land Leasing and Recreation Division, John A. Cherberg Building, Room 202, Olympia, WA 98504; or telephone (206) 753-2989.

FEDERAL MAPPERS AT WORK IN WASHINGTON

Field mapping crews from the U.S. Geological Survey are working in Okanogan County, Washington, this summer gathering and field-checking data that will be used in producing 12 new topographic maps covering about 600 square miles of the state.

Two crews of cartographers and field assistants from the USGS Mid-Continent Mapping Center in Rolla, Mo., are working to locate USGS benchmarks, determine elevations, measure distances, and verify occupied and abandoned structures and civil boundaries. Mapping is being conducted on federal, state, and state-leased land, but private property is also included and is being traversed when necessary, according to USGS District Cartographer Dave Bennett of Rolla.

The surveyors are using modern electronic distance-measuring instruments and theodolites, as well as the traditional surveyor's alidade and stadia rod to measure horizontal distances and determine elevations. The distance-measuring instruments use microwaves to determine distances, making it possible to obtain fast, accurate measurements in areas where it would take days or weeks to obtain such measurements on foot with transit, rod, and chain.

This will be the first time this area of Washington has been mapped at a scale of 1:24,000 (that is, one inch on a map represents 2,000 feet on the ground), although it was mapped at a less-detailed scale in the 1950s and 1960s. Each of the new maps will cover an area of 7.5 minutes of latitude by 7.5 minutes of longitude, or about 50 square miles. The new maps will be available in about three years.

ROCKHOUNDS: A REMINDER

A regulation put out by the Washington State Game Department in 1981 makes it unlawful to remove any materials from lands administered by that department without a permit issued by its director. Please be careful not to trespass on lands under the department's management while collecting minerals, fossils, or petrified wood. And please respect private property during your excursions.

MEETING ANNOUNCEMENTS

The following meetings will be held in the Pacific Northwest in September:

American Geophysical Union, 33rd Pacific Northwest Regional Meeting, September 4-5, University of Washington, Seattle

> **Field trip:** Mount St. Helens, September 5-6, 1986
> **Registration information:** PNAGU, University of Washington, GH-25, Seattle, WA 98195 (206) 543-2300.

Friends of Mineralogy, 12th annual symposium, Pacific Northwest Chapter, September 26-28, Doric Tacoma Motor Hotel, Tacoma

> **Topic:** Minerals of Mexico; speakers: Bill Panczer, Miguel Romero.
> **Information:** Mike Groben, 1590 Olive Barber Road, Coos Bay, OR 97402.
> **Registration:** Robert Smith, Box 197, Mail Room, Seattle University, Seattle, WA 98122.

INJUNCTION HALTS BLM LAND ACTIONS

More than 100 pending land actions in Oregon and Washington, ranging from legitimizing home site sales to providing land for a high school football field are indefinitely halted by an injunction placed against the Bureau of Land Management as a result of a lawsuit by the National Wildlife Federation.

The injunction, which became effective nationally last February 15, has varying degrees of effect on approximately 10 million acres of federal land in Oregon and Washington, and it prevents opening other federal lands currently closed by formal withdrawals or classifications.

All new mining claim filings must be checked to determine if they are in conflict with the injunction. Some filed since February 15 on areas that were closed to mining and on the lands subject to the lawsuit could be declared null and void, according to Bill Luscher, BLM Oregon-Washington state director.

The status of approximately 160 mining claims filed prior to the injunction may also be encumbered. Miners whose claims might

be nullified will be contacted by BLM to determine the types of minerals being mined and other facts required for a decision.

Luscher said that title conveyances completed before the injunction are not affected. However, many pending land exchanges and land sales, including land transfers involving schools and land fill sites, wildlife projects, and other activities are stopped.

The legal controversy stems from a lawsuit filed in July, 1985 by the National Wildlife Foundation concerning public lands that have been opened by the Secretary of the Interior for sale, transfer to other governmental units, mining, and other uses. BLM opened these "withdrawn" and classified lands because it was determined that restrictive closures were outdated, no longer appropriate, and the lands were needed for other important public purposes.

The injunction has slowed BLM's program to streamline its land management through exchange and sale of lands uneconomic to manage. BLM had planned to sell 2,228 acres of land this year, but was able to offer only 415 acres. Several land exchanges with the State of Washington that would have facilitated land management for both parties have been stopped.

Several actions to solve problems of a mistaken private land survey which would have provided titles to buyers of homesites are halted, although BLM had already accepted money for down payments on the property.

Another action was a proposal to furnish five acres of land for a football field and parking lot for a high school in south central Oregon. The sale had been scheduled for last March but has been suspended pending the outcome of the suit.

(Reprinted from a Bureau of Land Management news release of August 13, 1986. For more information contact Bill Keil, BLM, Oregon State office, 825 N.E. Multnomah St., P.O. Box 2965, Portland, OR 97208; phone number (503) 231-6276)

RECENTLY RELEASED PUBLICATIONS OF THE DIVISION OF GEOLOGY AND EARTH RESOURCES

Publications listed below can be ordered from the Division, PY-12, Olympia, WA 98504. All orders must be prepaid; add $1 to each order for postage and handling. Checks must be payable to the Department of Natural Resources.

Barnett, Brent, 1986, The 1985 geothermal gradient drilling project for the State of Washington: Washington Division of Geology and Earth Resources Open-File Report 86-2, 34 p. Price $1.00.

Rau, W. W., 1986, Geologic map of the Humptulips quadrangle and adjacent areas, Grays Harbor County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-33, 1 sheet, scale 1:62,500. Price $3.00.

Wagner, H. C.; Batatian, L. D.; Lambert, T. M.; Tomson, J. H., 1986, Preliminary geologic framework studies showing bathymetry, locations of geophysical tracklines and exploratory wells, sea floor geology and deeper geologic structures, magnetic contours, and inferred thickness of Tertiary rocks on the continental shelf and upper continental slope off southwestern Washington between latitudes 46°N. and 48°30'N. and from the Washington coast to 125°20'W: Washington Division of Geology and Earth Resources Open-File Report 86-1, 8 p., 6 pl. Price $4.00.

SELECTED REPORTS ADDED TO THE WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES LIBRARY

February – July 1986

THESES

Grady, Michael, 1985, Stratigraphy, sedimentology, and hydrocarbon potential of the Hoh turbidite sequence (Miocene) western Olympic Peninsula, Washington: University of Idaho Master of Science thesis, 226 p.

Gray, John E., 1982, Petrology and geochemistry of the eastern portion of the Ingalls Complex, central Washington

Cascades: University of Kansas Master of Science thesis, 63 p.

Holder, Grace A. McCarley, 1985, Geology and petrology of the intrusive rocks east of the Republic graben in the Republic quadrangle, Ferry County, Washington: Washington State University Master of Science thesis, 87 p.

Jett, Guy A., 1986, Sedimentary petrology of the western melange belt, north Cascade Range, Washington: University of Wyoming Master of Science thesis, 85 p.

Koesters, Donna Baird, 1984, A structural and hydrocarbon analysis of the central Cascade Range, Washington: Texas Christian University Master of Science thesis, 120 p., 4 pl.

Krafft, Alison Davison, 1984, Mineral and chemical composition of suspended and bottom sediments, Quinault submarine canyon: Lehigh University Master of Science thesis, 62 p.

Mohl, Gregory Blaine, 1985, Bouguer gravity investigation of the cratonic margin--southeastern Washington: Washington State University Master of Science thesis, 67 p.

Orr, Kristin Elizabeth, 1985, Structural features along the margins of Okanogan and Kettle domes, northeastern Washington and southern British Columbia: University of Washington Doctor of Philosophy thesis, 109 p., 4 pl.

Parsons, Michael Raymond, 1985, Spatial and temporal changes in stream topology--Post-eruption drainage, Mount St. Helens: Oregon State University Doctor of Philosophy thesis, 179 p.

Pine, Keith A., 1985, Glacial geology of the Tonasket-Spectacle Lake area, Okanogan County, Washington: Western Washington University Master of Science thesis, 130 p., 1 pl.

Quintana, Carlos Wesson, 1983, Ice structure in a vertical core at the margin of South Cascade Glacier, Washington: University of Washington Master of Science thesis, 120 p., 1 pl.

Rauch, William E., 1985, Sedimentary petrology, depositional environment and tectonic implications of the upper Eocene Quimper Sandstone and Marrowstone Shale, northeastern Olympic Peninsula, Washington: Western Washington University Master of Science thesis, 102 p.

Ridgway, Eric Robert, 1986, Mineralogy of the Steel Creek manganese deposit, Olympic Peninsula, Washington: Eastern Washington University Master of Science thesis, 70 p.

Roberts, James Warren, 1985, Stratigraphy, sedimentology, and structure of the Swauk Formation along Tronsen Ridge, central Cascades, Washington: Washington State University Master of Science thesis, 188 p., 2 pl.

Ritger, Scott D., 1985, Methane-derived authigenic carbonates formed in subduction induced pore water expulsion along the Oregon-Washington margin: Lehigh University Master of Science thesis, 66 p.

Silverberg, David Scott, 1985, Structure and petrology of the Whitchuck Mountain-Mount Pugh area, north Cascade Range, Washington: Western Washington University Master of Science thesis, 173 p., 3 pl.

Smith, Moira T., 1986, Structure and petrology of the Grandy ridge-Lake Shannon area, north Cascades, Washington: Western Washington University Master of Science thesis, 156 p., 2 pl.

Snyder, Geoffrey William, 1984, Size distributions of suspended and bottom sediments in and around Quinault submarine canyon--Implications for modern sediment transport and accumulation off the Washington coast: Lehigh University Master of Science thesis, 90 p.

Vanderwal, Kathy Sue, 1985, Compositional and textural variations in the Vashon Till and underlying drifts in the northern and central Puget Lowland, Washington: University of Washington Master of Science thesis, 110 p.

White, Patricia J., 1986, Geology of the Island Mountain area, Okanogan County, Washington: University of Washington Master of Science thesis, 80 p., 1 pl.

Ziegler, Charles B., 1985, The structure and petrology of the Swift Creek area, western north Cascades, Washington: Western Washington University Master of Science thesis, 191 p., 5 pl.

GEOLOGY AND RELATED TOPICS
FEDERAL AGENCIES

Publications of the U.S. Geological Survey

Atwater, B. F., 1986, Pleistocene glacial-lake deposits of the Sanpoil River Valley, northeastern Washington: U.S. Geological Survey Bulletin 1661, 39 p., 3 pl.

Gough, L. P.; Shacklette, H. T.; Peard, J. L.; Papp, C. S. E., 1986, The chemistry of fruits and vegetables, Yakima River Valley, Washington, and the influence of the 1980 Mount St. Helens ash-fall episodes: U.S. Geological Survey Bulletin 1640, 13 p.

Bauer, H. H.; Vaccaro, J. J.; Lane, R.C., 1985, Maps showing groundwater levels in the Columbia River basalt and overlying materials, spring 1983, southeastern Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4360, 4 pl., scale 1:500,000.

Hearn, P. P.; Steinkampf, W. S.; Bortleson, G. C.; Drost, B. W., 1985, Geochemical controls on dissolved sodium in basalt aquifers of the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4304, 38 p.

Jones, M. A., 1985, Occurrence of groundwater and potential of seawater intrusion, Island County, Washington: U.S. Geological Survey Water-Resources Investigations Report 85-4046, 6 sheets, scale 1:31,680.

Turney, G. L., 1986, Quality of groundwater in the Puget Sound region, Washington, 1981: U.S. Geological Survey Water-Resources Investigations Report 84-4258, 170 p., 2 pl.

Vaccaro, J. J., 1986, Plan of study for the regional aquifer-system analysis, Columbia Plateau, Washington, northern Oregon, and northwestern Idaho: U.S. Geological Survey Water-Resources Investigations Report 85-4151, 24 p.

Church, S. E.; Frisken, J. G.; Mosier, E. L.; Willson, W. R., 1985, Geochemical maps of the Eagle Rock and Glacier Peak roadless areas, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1380-D, 2 sheets, scale 1:100,000.

Miller, R. D.; Safioles, S. A.; Pessl, Fred, Jr., 1985, Map showing relative slope stability in the Port Townsend 30' x 60' quadrangle, Puget Sound region, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map 1-1198-C, 1 sheet, scale 1:100,000.

Jacobson, M. L.; Rodriguez, T. R., compilers, 1985, National Earthquake Hazards Reduction Program, summaries of technical reports Volume XXI, prepared by participants in National Earthquake Hazards Reduction Program: U.S. Geological Survey Open-File Report 86-31, 653 p.

Baker, G. E., 1986, Three component long-period data for the 1949 South Puget Sound, Washington earthquake: U.S. Geological Survey Open-File Report 85-613, 8 p.

Laird, L. B.; Taylor, H. E.; Lombard, R. E., 1986, Data on snow chemistry of the Cascade-Sierra Nevada Mountains: U.S. Geological Survey Open-File Report 86-61, 25 p.

Hays, W. W.; Gori, P. L., editors, 1986, Proceedings of Conference XXXIII, a workshop on "Earthquake hazards in the Puget Sound, Washington area," October 29-31, 1985: U.S. Geological Survey Open-File Report 86-253, 261 p.

U.S. Geological Survey, 1986, Washington--Geographic Names Information System alphabetical finding list: U.S. Geological Survey, 469 p.

Publications of the U.S Bureau of Mines

Chaney, R. E., 1985, Strategic and critical materials program annual report: U.S. Bureau of Mines Minerals and Materials Research Contract Report, 125 p.

Rice, W. L.; Bunning, B. B., 1986, The mineral industry of Washington; preprint from the 1984 Bureau of Mines Minerals Yearbook: U.S. Bureau of Mines, 11 p.

Publications of Other Federal Agencies

Hagmod, M. C., 1986, Structure and evolution of the Horse Heaven Hills in south-central Washington: Rockwell Hanford Operations RHO-BWSA-344 P, 190 p., 1 pl.

U.S. Department of Energy, 1985, Draft environmental impact statement, disposal of Hanford defense high-level, transuranic and tank wastes, Hanford site, Richland, Washington: U.S. National Technical Information Service, 3 v.

U.S. Department of Energy, 1986, Environmental assessment--Reference repository location, Hanford site, Washington: U.S. Department of Energy, 3 v.

Skelly and Loy, 1986, Coal Creek abandoned coal mine reclamation, King County, Washington, final specifications: Skelly and Loy under contract to U.S. Office of Surface Mining, 1 v., 6 pl.

U.S. Federal Energy Management Agency, 1985, Guidebook for developing a school earthquake safety program: U.S. Government Printing Office, 184 p.

Potyondy, J. P.; Megaham, W. F.; Bengeyfield, Pete, 1979, rev. 1981, Technical guide for erosion prevention and control on timber sale areas: U.S. Forest Service [Ogden], 1 v.

Webster, F. L., 1985, Pacific OCS lease sale, October 1, 1964, Oregon and Washington: U.S. Minerals Management Service Report 85-101, 36 p.

Lenfesty, C. D.; Reedy, T. E., 1985, Soil survey of Yakima County area, Washington: U.S. Soil Conservation Service, 345 p., 15 pl.

GEOLOGY AND RELATED TOPICS NONFEDERAL ORGANIZATIONS

Biography of General Interest

Rosen, Shirley, 1981, Truman of St. Helens-The man and his mountain: Madrona Publishers [Seattle], 163 p.

Environmental Radiation

Peterson, D. S.; Mooney, R. R., 1984, State of Washington environmental radiation program, 22nd annual report, July 1982-December 1983: Washington Department of Social and Health Services, 1 v.

Geographic Names

Hitman, Robert, 1985, Place names of Washington: Washington State Historical Society, 340 p.

Phillips, J. W., 1971, Washington State place names: University of Washington Press, 167 p.

Geology Departments

American Geological Institute, 1985, Directory of geoscience departments, United States and Canada, fall 1985; 24th ed.: American Geological Institute, 221 p.

Mining law

Maley, T. S., 1984, Mineral title examination: Mineral Land Publications, 396 p. (includes 1986 cumulated supplement).

Maley, T. S., 1985, Mining law from location to patent: Mineral Land Publications, 597 p. (Includes 1986 cumulated supplement).

Petroleum

Montgomery, S. L., editor, 1985, Investigating the potential of the Pacific Northwest: Petroleum Information Corporation Petroleum Frontiers, v. 2, no. 4, 83 p.

Northwest Petroleum Association, 1986, NWPA Symposium, May 16, 1986 [Program and Abstracts]: Northwest Petroleum Association, 10 p.

Petroleum Publishers, Inc., 1986, Pacific coast oil directory 1986: Petroleum Publishers, Inc., 384 p.

Seismology

Ihnen, S. M.; Hadley, D. M., 1986, Seismic risk maps for Puget Sound, Washington: Sierra Geophysics, Inc. [Redmond], 37 p.

Structural Geology

Drummond, K. J., Chairman; and others, 1984, Geodynamic map of the circum-Pacific region, northeast quadrant: American Association of Petroleum Geologists Northeast Quadrant Panel, 1 pl., scale 1:10,000,000, with 12-p. text.

GEOLOGIC RESEARCH PROJECTS ACTIVE IN 1986

Student and faculty research projects at colleges and universities in Washington State under way in 1986 are listed below. (Not all institutions responded in time to meet this newsletter's deadline.)

CENTRAL WASHINGTON UNIVERSITY

Faculty Research Projects

Yakima Firing Range--Geologic map, Black Rock Springs quadrangle (R. D. Bentley)

Structural analysis of Leavenworth fault zone (R. D. Bentley)

Evolution of the Hog Ranch anticline and the Yakima River in Neogene time (R. D. Bentley)

Stratigraphy of Frenchman Springs Basalt (R. D. Bentley)

Correlation of deep wells in Yakima fold belt (R. D. Bentley)

Major and trace elements in Wanapum Basalt by microprobe methods (J. R. Hinthorne)

Hardware and software modification to Geographic Information Computer System at CWU (J. R. Hinthorne)

Analysis of Li, B, Be, and F in coexisting metamorphic minerals (J. R. Hinthorne)

EASTERN WASHINGTON UNIVERSITY

Faculty Research Projects

Geochemistry of granitic rocks of northeastern Washington (M. Ikramuddin)

Geochemistry of volcanic rocks and its relationship to gold-silver mineralization (M. Ikramuddin)

Hydrogeochemical methods of exploration for gold and silver (M. Ikramuddin)

Thallium--A potential guide to mineral deposits (M. Ikramuddin)

Geochemistry of platinum-group elements (M. Ikramuddin)

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington (E. H. Gilmour)

Biostratigraphic studies of Pennsylvanian and Permian bryozoans in North America and Pakistan (E. H. Gilmour)

Fumarole and geothermal ice cave monitoring, Mounts Rainier and Baker (E. P. Kiver)

Glacial and catastrophic flood history of eastern Washington (E. P. Kiver)

Geology of the national parks (E. P. Kiver)

Quaternary map of northeastern Washington east of the Okanogan River (E. P. Kiver)

Major and trace element chemistry of "porphyry" molybdenum, tin-tungsten, and copper systems (F. E. Mutschler)

Compilation of computer data base of whole-rock chemical analyses of igneous rocks (F. E. Mutschler)

Styolites in ore deposits (J. R. Snook)

Thrust faulting in northeastern Washington (J. R. Snook)

Petrology of the Quartz Hill molybdenum deposit, Alaska (J. R. Snook)

Paleomagnetic investigations of glacial Lake Missoula flood deposits (W. K. Steele)

Use of remanent magnetization direction to correlate air-fall ash deposits from Cascade volcanoes (W. K. Steele)

Stratigraphy, sedimentology, and paleontology of the Cambrian System of the Great Basin (L. B. McCollum)

Paleozoic paleoecology and the Lower to Middle Cambrian extinctional event (L. B. McCollum)

Paleozoic continental margin sedimentation (L. B. McCollum)

Mesozoic transcurrent faulting and suspect terranes in the Great Basin (L. B. McCollum)

Mineralogy of the Golden Horn batholith, North Cascades, Washington (R. C. Boggs)

Mineralogy of the Wind Mountain laccolith, New Mexico (R. C. Boggs)

Nitrate contamination of groundwater in Deer Park vicinity, northeastern Washington (J. P. Buchanan)

Sedimentation in sand-bed braided rivers (J. P. Buchanan)

Sedimentology of Cretaceous-age coarse-clastic deposits in Washington and Nevada (J. P. Buchanan)

Geochemistry of sediment-hosted precious metals deposits (M. Ikramuddin)

Development of new analytical methods by inductively coupled argon plasma and electrothermal atomic absorption (M. Ikramuddin)

Rare earth elements geochemistry of gold deposits (M. Ikramuddin)

Geochemistry of gallium (M. Ikramuddin)

Alkaline igneous rocks and related precious metal deposits (F. E. Mutschler)

Mineralogy of the Sawtooth batholith, Idaho (R. C. Boggs)

Epithermal precious metal deposits (F. E. Mutschler)

Student Research Projects

A mineralogical and chemical study of manganese-bearing and associated rocks of the Crescent Formation, Olympic Peninsula, Washington (Eric R. Ridgway)

Geology of the Clayton silver mine, Custer County, Idaho (Robert L. Hillman)

Hydrogeochemistry of platinum and palladium in southwestern Oregon (Daniel W. Fears)

Geology of the southwest 1/4 of the Aeneas Valley 15' quadrangle, Okanogan County, Washington (Charles W. Gulick)

Geology of the southeast 1/4 of the Twin Lakes quadrangle, Washington (Corey Y. Fullmer)

Study of the metallic mineral deposits of the Shawangunk and Kittatiny Mountains, New York-New Jersey (J. Scott Wilber)

Thallium compared to As and Sb as pathfinders for Au in soil and rock surveys at the Mayflower mine, Howard Mining District, Crook County, Oregon (Thomas J. Cammarata)

Ferros--A computerized database for Precambrian auriferous banded iron formations and related rocks (Glen R. Carter)

Geochemical characteristics of tin-bearing granites (Fred T. Langston)

Gold deposits associated with alkaline plutons and volcanics--Selected trace element geochemistry (Robbin W. Finch)

Reconnaissance trace element geochemistry of the Loon Lake batholith, northeastern Washington (Adolphus A. Afemari)

Vertical geochemical variations in granodiorite associated with the molybdenum-copper porphyry deposit at Mount Tolman, Ferry County, Washington (Danelle D. Elder)

Granite molybdenite systems--North American Cordillera (Curtis A. Hughes)

Petrography of Carboniferous dolomites, Springdale area, Washington (Mehemed S. Gheddida)

Contact aureole geochemistry of the Bayview granodiorite, northern Idaho (Clarence E. Chase)

Economic geology and production cost analysis of the Golden Sceptre mine, Boundary County, Idaho (T. Michael Sweeney)

Geology of the Gold Hill-Mica Mountain area, Latah County, Idaho (Gary D. Walker)

Sedimentology of the Harts Pass Formation, north-central Washington (Robert L. Rau)

Sedimentology of the Puget Group, western Washington (Charles C. Cacek)

Paleomagnetism of Lake Missoula flood deposits in the Sanpoil River valley of northeastern Washington (Russell G. Mitchell)

Biogeochemical methods of exploration for base-metal sulfides (Richard B. Lestina)

The geochemistry of precious metal mineralization in post-emplacement ophiolitic terrains, Ingalls ophiolite complex, Washington (Phillip C. Nisbet)

Pegmatites in northeastern Washington (John W. Aiken)

Paleoecology of the Ferdelferd fossils beds, Diamond Peak Formation (Mississippian), Elko County, Nevada (W. Gregory Goodwin)

Geologic map of the Boulder Mountain 7-1/2' quadrangle, northeastern Utah (Andrew R. Mork)

Biostratigraphy of the Peronopsis bonnerensis zone fauna (Middle Cambrian), Horse Thief Canyon region, California (Mark W. Ansell)

Carbonate petrography of the Garden Valley Formation in north-central Nevada (Scott E. Morrison)

Depositional processes in the magnetization of air-fall ash (James E. Garman)

Clay formation of rocks under humid tropical climatic conditions in east Jiwo Hills, Java (Aryono S. Salehdanu)

Depositional model of catastrophic flood bars in the Pine Creek channel, eastern Washington (Robert A. Pinotti)

The geochemical characterization of a part of the Stillwater Complex, Montana, with particular reference to the platinum-group elements (Michael W. Knoper)

Geochemistry and petrography of veins and wall rocks associated with gold-silver mineralization in the Republic district, Ferry County, Washington (Walter M. Martin)

Geology of the McCullough Creek area, Douglas County, Oregon (Allen V. Ambrose)

Geochemistry of granitic rocks from Newport quadrangle, northeastern Washington (Abebe Kassaye)

Geochemistry and petrology of the San Poil volcanics and associated granitic rocks of

a part of the Colville Indian Reservation, Washington (Sharon J. M. Digby)

Bryozoan biostratigraphy of the Phosphoria Formation, southeastern Idaho (Robert C. Walker)

Induced polarization-direct current resistivity methods in the exploration for paleodrainage channels (John S. McBeth)

Petrology and mineralization of the William Henry Bay zinc prospect (Stanley A. Ellison)

Economic geology of the Sherman molybdenum prospect, Okanogan County, Washington (Grant R. Newport)

Geochemistry of alaskite and quartz monzonite of Mount Spokane, northeastern Washington, and its relation to uranium mineralization (Roy Bongiovanni)

Stratigraphy and sedimentology of the Cretaceous Newark Canyon Formation in the Cortez Mountains area, north-central Nevada (Crague C. Biglow)

The sedimentology and stratigraphy of the glaciogenic deposits near Kettle Falls, Washington (Roger W. Doak)

Nitrate contamination of the Deer Park aquifer (Randall L. Anderson)

Biostratigraphy and lithostratigraphy of the Late Devonian-Early Mississippian Pilot Shale of eastern Nevada and western Utah (Mark E. Jones)

Geochemistry of the Eureka-Excelsior gold-lode deposit and associated metasediments and greenstones, Cracker Creek District, Baker County, Oregon (Craig P. Calder)

Sedimentation and mineralogical composition of the Latah Formation (Miocene), eastern Washington (John D. Robinson)

UNIVERSITY OF WASHINGTON

Faculty Research Projects

Geomagnetic induction in the Earth revealed by a study of deep electrical structure of the Juan de Fuca plate and adjacent continent (John R. Booker)

Reconciliation of geoidal maps supplied by NASA with large-scale tectonic features (Robert C. Bostrom)

Mineral physics at elevated pressure and temperature (J. Michael Brown)

Modeling drainage trees found during desalination of sea ice (William O. Criminale, Jr.)

Crust and upper mantle structure from broadband and short-period network measurements (Robert S. Crosson)

Inversion of seismic data (Robert S. Crosson)

Source mechanisms of volcanic earthquakes (Robert S. Crosson)

Earthquake hazards of the Pacific Northwest (Robert S. Crosson)

Geophysical aspects of cosmic radiation; cosmic radiation at Earth (John T. A. Ely)

Experimental investigation of electrical parameters in the Earth's environment (Robert H. Holzworth, II)

Marine seismology using deep-towed reflection and ocean bottom refraction methods and the study of seismicity at ocean ridges and transforms (Brian T. R. Lewis)

Cooling processes in the Earth (and other rocky planets): convection processes, conduction processes, thermodynamics, volcanic processes (Clive R. B. Lister)

Geophysical investigations of Mount St. Helens (Stephen D. Malone)

Geomagnetism, paleomagnetism, and rock magnetism (Ronald T. Merrill)

Characteristics of earthquakes produced by the Mount St. Helens volcano (Anthony Qamar)

Research in sliding of glaciers, water behavior in and at the bed of glaciers, and surge behavior of glaciers (Charles F. Raymond)

Mineralogy of the Earth's mantle (Yosiko Sato Sorenson)

Study of density-stratified turbulent flows: mixing of momentum, heat, and salt across sharp density interfaces and related topics (J. Dungan Smith)

New methods of utilizing seismic first-motion data to infer tectonic stress orientation from both compressional and shear waves at the tectonic plate boundary between the Juan de Fuca plate and the North American plate (Stewart W. Smith)

Application of finite element and finite difference models to understand the flow and thermal history in regions of ice sheets and glaciers (Edwin D. Waddington)

Radiation processes in climate and the role of snow and ice in climate (Stephen G. Warren)

WASHINGTON STATE UNIVERSITY

Faculty Research Projects

Remote sensing and geologic spatial analysis of satellite images, digital terrain models, earthquake foci, and other data bases--In conjunction with Batelle PNL (Richard L. Thiessen)

Refold analysis of the Balmat #2 zinc mine in northern New York State (Richard L. Thiessen)

Geophysical studies of southeastern Washington and adjacent Oregon and Idaho (Richard L. Thiessen)

Refold study of the Loch Monar, Scotland, area (Richard L. Thiessen)

Remote sensing studies of a portion of the Nevada test site (Richard L. Thiessen)

Structural and tectonic models of northeast Washington (A. J. Watkinson, with Mike Ellis)

Illite--Composition, stability, and relationship to muscovite and phengite (Philip E. Rosenberg and J. A. Kittrick, Professor, Dept. of Agronomy and Soils)

Sedimentology, stratigraphy, and tectonic evolution of the Republic graben, north-central Washington (David R. Gaylord)

Quaternary airflow-terrain interactions in Wyoming (David R. Gaylord)

Determination of the free energy of formation of searlesite, $NaBSi_2O_5(OH)_2$, and its implications regarding other borosilicates (Philip E. Rosenberg and J. A. Kittrick, Professor, Dept. of Agronomy and Soils)

Occurrence of precious metals in skarn deposits (Lawrence D. Meinert)

7th quadrangle mapping of CRB--Alpowa Ridge quadrangle (Peter R. Hooper)

Magnetic orientation of CRB and tectonic rotation (Peter R. Hooper)

Isotopic analysis of CRB feeder dikes (Peter R. Hooper)

Geochemistry of the Pomona Flow (Peter R. Hooper)

Geology of the Pullman, Clarkston, and Anatone 15' quadrangles, southeast Washington (Gary D. Webster and Peter R. Hooper)

Student Research Projects

Thrust geometries in the footwall of the Diversion thrust, Teton County, Montana (Diane Johnson)

Fission track age of tephras in the Palouse Loess (Kevin Nelstead)

Petrogenesis of the Picture Gorge Basalt (Michael M. Bailey)

Geology, geochemistry, and hydrology of the thermal springs areas west of Lowman, Idaho (John Reed)

Structural analysis and kinematic interpretation of rocks in the southern portion of the Okanogan gneiss dome, north-central Washington (Jeffrey Volk)

Crystal chemistry of alkaline-defective tourmaline (Prawit Towatana)

Estimating groundwater travel times in heterogeneous media--A study of the effects of using average hydraulic properties in calculating groundwater travel times and flow paths for heterogeneous media (Sharon Hunt)

Carbonate petrology and conodont biostratigraphy of the West Canyon Limestone and equivalents, southeastern Idaho and northern Utah (Larry E. Davis)

Re-evaluation of the Lodgepole Formation (Lower Mississippian), southeastern Idaho and northern Utah (Larry E. Davis)

On the occurrence of Nautilus scrobiculatus in Papua, New Guinea (Larry E. Davis)

Post-mortem distribution of Nautilus in the southwestern Pacific Ocean (Larry E. Davis)

Petrology and geochemistry of gold-bearing skarns in southern British Columbia, Canada (Art Ettlinger)

Alteration and mineralization at the Chilco Mountain molybdenum-tungsten deposit, Bonner and Kootenai Counties, north Idaho (Dean B. Ingemansen)

Structural geology in parts of the Metaline District, northeast Washington (Glenn Wiedenhoeft)

Solubility and stability relationships of muscovite and phengite (Douglas M. Yates)

Detailed foraminiferal biostratigraphy, depositional environment, trace element analysis, and hydrocarbon source rock assessment of five wells from the northwest part of the Niger Delta, Nigeria (Adedotun A. Adekoya)

Illite stability relationships (Stephen U. Aja)

Petrogenesis of volcanic rocks in the Baker area, northeast Oregon (David G. Bailey)

Flow stratigraphy, chemical variation and petrogenesis of Deccan flood basalts from the western Ghats, India (John E. Beane)

Geology and genesis of the Mizpah deposit, Latah County, Idaho (Kenneth A. Beidler)

Slope stability analysis (David R. Black)

Geology and geochemistry of the precious and base metal quartz veins in the Mineral Point District, San Juan County, Colorado (John G. Bloom)

Geology, mineralogy, and geochemistry of the Iron Crown calcic iron skarn deposit, Vancouver Island, British Columbia (Gail E. Bloomer)

Gold mineralization in low-angle faults, Cargo Muchacho Mountains, California (Alan D. Branham)

A mineralogical, fluid inclusion, and oxygen isotope study of the Mammoth Revenue vein, Platoro Caldera, San Juan Mountains, Colorado (Jeffrey W. Brooks)

A comparative study of high Cascade volcanism, with emphasis on the Mt. Jefferson, Oregon, area (Richard M. Conrey)

Geology, hydrology, and geochemistry of the geothermal area east of Lowman, Idaho (Brad E. Dingee)

Stratigraphy, sedimentology, and structure of the Upper Proterozoic Three Sisters Formation and the Lower Cambrian Gypsy Quartzite, northeast Washington (Louis H. Groffman)

Magmatic sulfide minerals in the Ferrar Dolerite, south Victoria Land, Antarctica (Kathryn H. Bailey)

Computer analysis of remote sensing and geologic data sets (Lisa K. Johnson)

Hydrogeologic investigation of the upper Long Valley, Idaho (George L. Landle)

Paleomagnetic trend of the Pomona basalt flow from central Washington to west-central Idaho (Jose B. Lim)

Stratigraphy, sedimentology, and petrology of the Lower Cambrian Addy and Gypsy Quartzites, Stevens and Pend Oreille Counties, northeastern Washington (Kevin A. Lindsey)

Stratigraphy, petrology, and depositional environment of the Middle Canyon Formation (Late Mississippian), south-central Idaho (Kate Lofland)

Origin, provenance, and sedimentary environments of the basalt interbeds exposed near Lewiston, Idaho, and Clarkston, Washington (John H. Lundquist)

Gravity definition of the cratonic margin in west-central Idaho and adjacent Washington (Gregory B. Mohl)

Structural control of mineralizing fluids in a portion of the Chloride Mining District, New Mexico (William S. Neal)

Burial diagenesis of the Mission Canyon Limestone (Mississippian) of south-central Montana (Daniel C. Quigley)

The hydrology and hydrochemistry of the Pahasapa (Madison) Limestone in Wind Cave National Park, South Dakota (John A. Rohde)

Alkaline rocks in northern Idaho (Diane K. Schalck)

Carbonate petrology and sedimentology of an undifferentiated limestone unit, southern Pahranagat Range, Lincoln County, Nevada (Caroline S. Singler)

Sedimentology and diagenetic history of the Jefferson Formation, southwest Montana (Tad M. Smith)

Refolds in ductile deformation zones (Bart A. Stryhas)

Geology, mineralization, and sedimentary environments of the Atlas Mine area, Coeur d'Alene Mining District, Shoshone County, Idaho (Brion D. Theriault)

Sun River Canyon, northwest Montana, structural mapping (Erik D. Weberg)

The geochemical cycle of boron--An experimental study (Wen Yang)

Controls on gold mineralization in the epithermal environment (Brian S. Zimmerman)

Emplacement and geochemical evolution of Eocene plutonic rocks in the Colville batholith (R. Wade Holder)

CLARK COLLEGE

Faculty Research Project

Evolution of Mount St. Helens dome with emphasis on flow morphology: development of 17 geologic maps of the dome from October 1980 to present at a scale of 1:2,000 (Wayne Colony)

GRAYS HARBOR

Faculty Research Project

Holocene history of the Grays Harbor estuary (James Phipps)

PACIFIC LUTHERAN UNIVERSITY

Faculty Research Project

Origin of vivianite in Pleistocene outwash deposits (Steve Benham)

TACOMA COMMUNITY COLLEGE

Faculty Research Project

Field trip guide, Mount Rainier (Jack Hyde)

WHITMAN COLLEGE

Faculty Research Projects

Textural and grain-size characteristics of sand from coastal and inland dune fields in the Pacific Northwest (Patrick Spencer and David Rossman [student])

Occurrence and origin of Washington coprolites (Patrick Spencer)

Foraminiferal paleoecology and biostratigraphy, northeastern Olympic Peninsula (Patrick Spencer)

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