See pocket 1 for 1987 for enclosure

United States Department of the Interior

BUREAU OF MINES

WESTERN FIELD OPERATIONS CENTER
EAST 360 3RD AVENUE
SPOKANE, WASHINGTON 99202

December 4, 1987

Memorandum

To: Charlotte Abrams, Project Officer, Geotechnical Branch, Division of Waste Management, U.S. Nuclear Regulatory Commission, Washington, DC

From: Chief, Branch of Engineering and Economic Analysis

Subj: Letter report pertaining to the Workshop on the Structural Geology and Petroleum Potential of the Central Columbia Plateau, October 28-29, 1987, Richland, Washington (Interagency Agreement NRC-02-85-004)

FIN D1018

In response to your request, Russell G. Raney of the Bureau's Western Field Operations Center attended the subject workshop. Enclosed are six copies of Mr. Raney's letter report.

/S/
Bert Crosling
for Robert D. Weldin

Enclosure

enclosure to 12/4/87 ltr. to CABrams from Chief, Branch of Engineering & Economic Analysis

TRIP REPORT

SUBJECT: Workshop on Structural Geology and Petroleum Potential of the Hanford Reservation and Central Columbia Plateau, sponsored by the Council of Energy Recource Tribes (CERT), Denver, CO, October 28-29, 1987, Richland, WA

BY: Russell G. Raney, Physical Scientist
Western Field Operations Center
Bureau of Mines
Spokane, Washington

The purpose of the subject workshop, as stated by Mr. Steve Hart, workshop moderator, was to ". . . get the Department of Energy (DOE) and others together to discuss the geology and resource potential of Central Washington." However, no representative of the DOE was present.

AGENDA

October 28, 1987

Topic: Structural Geology of the Central Columbia Plateau

Steve Hart, Moderator

Presentations

1. Columbia Plateau Structural Evolution: John Bond, Geoscience Research.
2. Tectonic Development, Central Columbia Plateau: Karl Fecht, Westinghouse.
3. Tribal Cross-Section, Central Columbia Plateau: Curtis Canard, CERT Consultant.
4. Columbia Plateau Microseismicity: Alan Rohay, Westinghouse.

Panel Discussions

1. Are current structural models of the Columbia Plateau adequate?
2. Are major seismic events possible in the Central Plateau in the next 100 years?
3. What specific research in neotectonics of the Plateau is needed?

October 29, 1987

Topic: Petroleum Potential of the Central Columbia Plateau

John Bond, Moderator

Presentations

1. Oil and Gas Leases in the Central Plateau: David Faley, W. E. Mays and Associates.

2. Oil and Gas Exploration in the Central Plateau: Richard Bowen, Northwest Oil and Gas Report.

3. Hanford Petroleum Resource Potential--Plans: Lynn Moses, Westinghouse.

4. High-Resolution, Full-Wavefield Seismic Profile: Rufus Catchings, Research Geophysicist, U.S. Geological Survey.

5. Tribal Borehole Study: Curtis Canard, CERT Consultant.

Panel Discussions

1. Is the Central Plateau the next "Overthrust Belt?"

2. Could economic oil and gas resources be located at Hanford?

3. What specific research is needed to determine the oil and gas potential of the Central Plateau?

STRUCTURAL GEOLOGY OF THE CENTRAL COLUMBIA PLATEAU

OCTOBER 28, 1987

SYNOPSES OF PRESENTATIONS

Columbia Plateau Structural Evolution
by
John Bond, Geoscience Research
October 28, 1987

Note: The presentation by Dr. Bond was not based on original work. It is a compilation of recent studies designed to provide background material and orientation for those members of the audience unfamiliar with the geologic history of the Columbia Plateau.

Background

The Columbia Intermontane Province is subdivided into three subprovinces: the Palouse, Yakima Foldbelt, and the Blue Mountains. Within these subprovinces, five general formations have been identified; each is widespread spatially and temporally and consists of many individual flows. These formations are listed below in order of decreasing age:

1. Imnaha. Imnaha is the oldest formation in the region; it was extruded 17 to 16 million years before the present (mybp). Imnaha units are primarily located along the Idaho-Oregon border and extend into southern Washington. The Imnaha is not encountered in local (Pasco Basin) studies.

2. Picture Gorge. The Picture Gorge is located mostly south of the Blue Mountains and is generally comparable to the Grand Ronde Formation.

3. Grand Ronde. Grand Ronde is the most widespread unit of the Columbia River Basalts (CRB). Its many flows extend from the Clearwater Embayment, across most of the Columbia Plateau, to the Pacific Ocean.

4. Wanapum. This unit is more constrained (in distribution) than the foregoing, generally not extending south of the Blue Mountains but does, however, extend into Idaho. Distribution patterns suggest some type of weak structural control. Wanapum flows are generally concentrated in the interior of the plateau.

5. Saddle Mountains. Saddle Mountain flows were extruded 14 to 10 (perhaps as little as 8) mybp and tended to concentrate in the interior of the plateau. Some flows, however, followed existing channels to the Pacific Ocean.

As the source areas were, in most cases, far to the east, flows were generally westward.

General Structure of the Columbia Plateau
(based on Dickerson, 1979)

Evolution of the Pacific Coast

The evolution of the Pacific Coast (and its effects on the structural evolution of the Columbia Plateau) proceeded through four basic stages:

1. 80 mybp. The western coast of North America consisted then of three tectonic plates in relative motion; the Kula, Farallon, and North American plates. Both the Kula and Farallon plates were actively subducting beneath the North American plate.

This plate activity was responsible for producing such features as the Alberta and Sevier thrust belts (early Laramide). At this time, both Washington and Oregon were beneath the ocean; subduction may have occured in what is now the Pasco Basin.

2. 40 mybp. Pattern changed slightly in which the Pacific plate was developed. The Kula was totally subducted or had merged with the Farallon plate. The relative motion of the Farallon plate was to the north-northeast, sliding beneath the North American plate. This is the pattern that controlled the eventual structural development of the west coast and the Columbia Plateau.

3. 20 mybp (just prior to extrusion of the Columbia River Basalt (CRB). The remaining (unsubducted) portion of the Farallon plate divided into two parts, now known as the Juan de Fuca plate (on the north) and the Cocos plate (on the south). The Juan de Fuca, Pacific, and North American plates came into contact forming a triple junction; the Cocos plate's relative motion was to the south. Effects of subduction of the Juan de Fuca plate include volcanic activity behind the Cascades (to the east of the present day Cascades) and volcanoes in the south. Separation of the Pacific plate resulted in the incipient development of the San Andreas rift zone. As the Pacific plate pulled away from the continent along the incipient San Andreas Fault, tensional features were produced in the Basin and Range Province.

4. 15 mybp. Subduction continued along the Pacific coast, the spreading zone moved beneath the North American plate, and the San Andreas Fault system developed. The time was characterized by typical arc volcanism and inland extension of volcanic activity.

Structural Evolution of the Columbia Plateau

Structural features such as the Olympia-Walla Lineament (OWL) and the Cle Elum Wallula Lineament (CLEW) are basement manifestations attributed to onshore remnants of transform faulting.

The Columbia Plateau evolved in three basic stages:

1. 17 to 10 mybp. North-northwest compressional stress produced dike swarms that fed the CRB extrusions. This interpretation agrees with the trend of the Basin and Range Province. Upwarp at this time in the Blue Mountains prevented the spread of Grand Ronde and younger flows to the south. Subsidence in the Columbia Basin continued.

2. 10 mybp. The regional stress field shifted from north-northwest compression to north-south compression that led to the development of the east-west trending Yakima Folds. The general sense of movement was to the north as evidenced by overturning, faulting, and thrusting on the north side of the folds.

3. 4 mybp. North-south compression continued, but with lesser intensity, and involved younger sediments (such as the Ringold) and basalts. Deformation is still in progress as evidenced by regional seismicity.

Tectonic Development of the
Central Columbia Plateau
by
Karl Fecht, Westinghouse
October 28, 1987

Note: Mr. Fecht's discussion centered on recent advancements in stratigraphy, geometry, and structural style of the Central Columbia Plateau and the timing and rate of deformation, structural analysis, and constraints on current structural models. Mr. Fecht responded to two questions following his presentation.

Stratigraphy of Central Columbia Plateau

In the central plateau, only the Yakima Basalt subgroup, the Grand Ronde, Wanapum, and Saddle Mountains units are present. Recently, Westinghouse has identified many new units within the Yakima Basalts that include refining of Frenchman Springs stratigraphy and breaking up the Grand Ronde into regional units beyond the magnetostratigraphic units described by Swanson (1979). The newly defined units, present throughout the Plateau, are found in the lower Wanapum and Grand Ronde and are important in understanding the structural evolution of the Plateau.

Refinements to Frenchman Springs stratigraphy were based on more than 200 surface sections and borehole data. Also, over 200 surface sections and deep borehole data from the Shell wells were used to break out the Grand Ronde regional units. Further, workers traced out a flow in the Grand Ronde (Untanum) and were able to isopach and show distribution and limits of many other units. The new stratigraphic data aided in interpreting some of the features found in deep boreholes.

The Central Plateau is characterized by three structural subprovinces:

1. Yakima Foldbelt--generally east-west trending folds that are between 11,000 and 15,000 feet thick. Sub-basalt sediments are the thickest beneath this subprovince.

2. Palouse--the least deformed of the subprovinces, about 5,000 feet thick, that hosts a few very low amplitude features and gentle northwest trending folds. The Palouse gently slopes westward toward the Central Plateau area, and;

3. Blue Mountains at the southern margin of the Plateau.

Yakima Fold structures include the Saddle Mountains, Untanum Ridge, Yakima Ridge, Manastash Ridge, Rattlesnake Hills, Horse Heaven Hills, Toppenish Ridge, and others. These structures tend to be relatively long (some greater than 100 kilometers) and trend from N 20° E to N 50° W. Generally, the structures are characterized by long, gentle slopes (about 5°) on the south, and steeply dipping slopes, often folded, faulted, and thrusted on the north. Many folds are broken by north-south trending cross faults that die out quickly to the south.

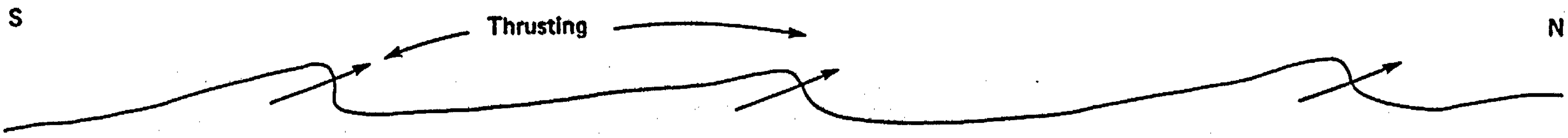
A diagrammatic cross section of the Yakima Foldbelt is presented in figure 1. The diagram is intended solely to demonstrate the gross style of folding within the foldbelt. Figure 2 presents a diagrammatic cross section of the Saddle Mountains showing folding, "rollover," thrusting, and zone of intense brecciation.

The area of Untanum Ridge near Priest Rapids Dam is characterized by a relatively complex structure that includes imbricate thrust sheets and overturned folds. Asymmetrical anticlines and thrust faulting are found to the east, most of which run through to the margin of the Palouse. In the areas of the Rattlesnake and Horse Heaven Hills, however, the folds tend to be terminated by the Cle Elum-Wallula (CLEW) structure.

Information pertaining to faulting at depth and the gross substructure was obtained from Shell's Saddle Mountain well. A zone of low resistivity was encountered at depths of 6,000 to 8,000 feet and was initially interpreted to be the Saddle Mountains Fault. If so, this would effectively constrain the fault plane to about 35°, imply 2,000 feet or more of uplift, and provide for possible repetition of sequence. However, chemical analyses of drill chips indicated no repetition. The latest interpretation is that the fault is not intersected by this borebole.

Similar results were gained from the Shell well on Rattlesnake Mountain, in that the Saddle Mountain Fault did not penetrate the well nor were there chemical data to evidence repetition. This information and that collected at Saddle Mountain strongly suggest the Saddle Mountain Fault plane is constrained to an angle equal to or greater than 45°. Other work in the Rattlesnake Hills included magnetotelluric surveys and cross sections done on closely-spaced intervals.

Isopachs developed for the Columbia Plateau indicate about 15,000 feet of basalt overlie the Pasco Basin and the Lower Yakima Valley. However, geophysical studies indicate a thickness of 11,000 feet over Rattlesnake Mountain. Although some uncertainties exist, evidence would support thinning of the units over Rattlesnake Mountain.



Not to scale

FIGURE 1.– Generalized cross-section, Yakima Fold Belt

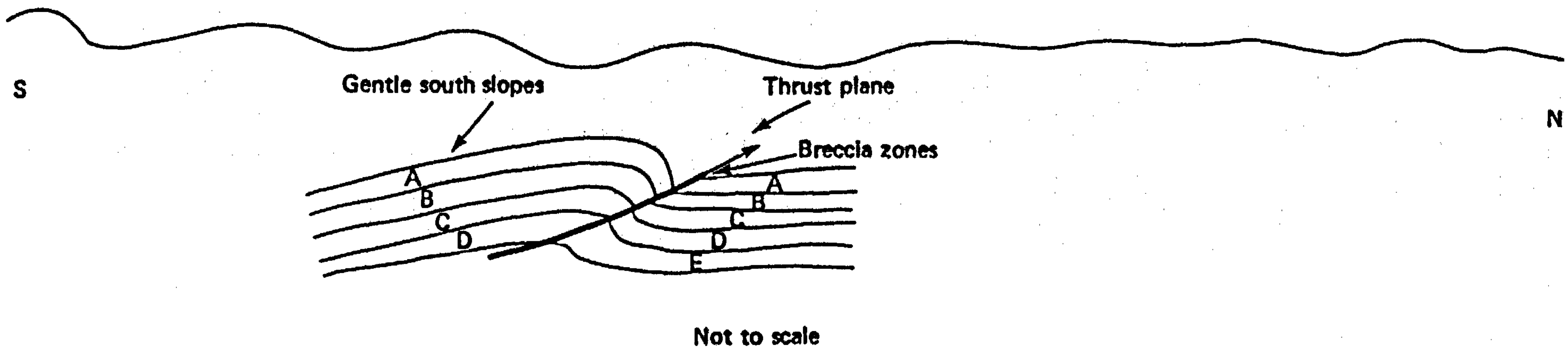


FIGURE 2.— Generalized cross-section of typical Yakima Fold

Rattlesnake Mountain is one of few features of the Columbia Plateau thought to be basement-controlled; another is the Hog Ranch structural high west of Rattlesnake. Some of the Grand Ronde flows that crossed the Hog Ranch structure seem to thin; many of the high mag (magnetic? magnesium? magnetotelluric?) sequences did not make it over the structure. In the Frenchman Hills, fault planes at depth are thought to be 45° or greater; along the Columbia River at Columbia Hills, fault plane angles equal or exceed 70°. The consensus is that fault planes in the Columbia Plateau are relatively steep. What happens to the faults in the sub-basalt sediments is not known.

Timing of Deformation

Isopach maps have been developed to determine where the basalt flows occur within the Plateau and the nature of the controlling mechanism. Reidel and others at Westinghouse have extended the breadth of their studies beyond the Central Plateau and have found that thinning of flows is a common occurrence on the west. Anderson reports the same in southern Washington and in northern Oregon; this view is not necessarily shared by (Dr. Robert) Bentley. According to Reidel, evidence of thinning of the Pomona flow has been demonstrated in the Saddle Mountains, Untanum Ridge, and over Rattlesnake Mountain. Long periods of time between flows have allowed the structures to grow, resulting in crestal thinning of the flows. The structures (generally) have grown for the past few millions of years at a reasonably constant rate of about 40 meters per million years; combined subsidence and uplift amount to approximately 70 meters per million years. Lines of evidence indicate that the deformation rate may be <u>increasing</u> (emphasis added).

Summary

1. Most deformation, i.e. faulting, folding, thrusting, and brecciation, has occurred on the northern sides of the Yakima Folds with only minor deformation on the southern sides.

2. Fault planes apparently steepen at depth.

3. Rotation of blocks on the north side of some ridges suggest right lateral motion. This is based on paleomagnetic data from the Pomona flow.

4. Rotation is confined to anticlines; there is no known evidence of rotation in synclines.

5. The amount of rotation changes along the structural trend.

6. Paleomagnetic data from older flows indicate rotation was greater than in Pomona time.

7. There is an apparent relationship between Yakima Foldbelt growth rates in the Central Plateau and basalt extrusion rates.

8. Structural rotation and folding was due to north-south compression resulting from oblique subduction of two convergent plates.

9. The Columbia River Basalt is a function of plate margin motion rather than of hot-spot activity.

Questions

Q: What is the source of the data points used for determining thinning and/or thickening?

A: The data was provided by the DOE through its consultants and contractors. Most other data are felt by the DOE to be unreliable . . . the DOE has no confidence in data from other sources.

Q: Are the slides, charts, and maps you presented available . . . have they been published?

A: The study concerning rotation within the Pomona has been published. Thickness data were presented at the Hilo, HI meeting (Spring, 1987) . . . the magnetic data may be published in the future by the GSA.

Tribal Cross-Section, Central Columbia Plateau
by
Curtis Canard, CERT Consultant
October 28, 1987

Note: Mr. Canard was commissioned by the Council of Energy Resource Tribes, Denver, CO, to develop a geologic cross section of the central Columbia Plateau. According to Canard, the cross section is designated as a "diagrammatic cross section," which is to say that the section is largely conceptual. At best, the section should be considered as a preliminary working hypothesis and subject to change as more comprehensive data are studied. It was constructed based on a series of oil and gas company exploratory well data supplemented by borehole data from BWIP.

The line of section extends from Shell's BISSA 1-29 on the north, southerly through the reference repository location and Nuclear Reservation, and terminates at the Rattlesnake Hills No. 1 well, a distance of about 70 miles.

Shell's BISSA 1-29 Well, Kittitas County

The well was drilled on the apex of a pre-Miocene structural high known as the Naneum Ridge and Hog Ranch Cross Fold. Oligocene-Lower Miocene sediments were encountered after penetration of about 4,000 feet of Columbia River Basalt (CRB). The sediments include sandstone, siltstone, and a number of coal measures. Eocene sediments, primarily sandstone, shale, and siltstone, were encountered at about 7,300 feet. These units exhibited several gas shows.

Underlying the Eocene is a sequence of what is interpreted as Cretaceous marine sediments that include shale, sandstone, siltstone, and limestone.

The hole bottomed at 14,965 feet in granite or possibly gneiss.

To the southeast of BISSA 1-29, the Leavenworth Fault was included by Canard to illustrate the possibility of the existence of a structural graben between this fault and the Entiat Fault that underlies the Columbia River at this point.

Shell's BN 1-9 Well, Grant County

The well was air-drilled to a depth of 1,759 feet; cement for the casing was lost, presumably in fractures or interbeds. Circulation was lost, on many occasions, between 1,800 and 3,300 feet. Also, a large water flow was encountered at 2,600 feet. It is at this depth Canard postulates the Saddle Mountain thrust is intersected by the borehole. Drilling difficulties, including setting casings several times, cost Shell an estimated $20 million for this well. Sandstone, siltstone, tuff, and shale were found below the basalt beginning at about 9,350 feet.

Below 11,500 feet, coal was encountered as well as high pressure gas flares. At 13,372 to 13,388 feet, gas was found in a section of volcaniclastic sands. Testing of the zone indicated flows of about 3.1 million cubic feet per day; in less remote areas or in areas with sufficient infrastructure, this well might be considered economic.

The gas zone is underlain by more coal measures and another volcaniclasticsand unit; a fault zone was noted at about 15,000 feet. The hole bottomed at 17,518 feet.

Drill Hole D-18

When the cross section was in preparation, the D-18 was in the process of being re-drilled. Well data indicated good water flows and good gas shows. Canard has projected the Untanum Thrust beneath this well.

RRL-2 Well

RRL-2 was drilled to a depth of 3,900 feet; the Cohassett flow was encountered between 2,993 and 3,266 feet. No coal was noted either above or below the Cohassett.

DC-24 Well (proposed)

The proposed well site is about 4 miles from RRL-2. Canard feels the well should be drilled to 15,000 feet instead of the proposed depth of about 4,000 feet.

Walla Walla No. 6 (in Rattlesnake Hills gas field)

The borehole encountered gas zones between 791 and 800 feet and between 992 and 1,039 feet; both zones are overlain by 73 feet of shale. A 39-foot section of sandstone was penetrated at about 1,200 feet and "tar-like" oil was encountered at 3,150 feet. The hole bottomed in basalt at 3,600 feet.

Standard's Rattlesnake Hills No. 1

The general stratigraphy revealed by this well is as follows:

- Four thrusts were encountered between about 1,660 and 4,500 feet.
- 1,660 to 1,680 feet--siltstone with abundant coal.
- 1,966 to 2,188 feet--Cohassett flow.
- 2,100 to 2,300 feet--coal samples taken.
- 2,400 to 2,420 feet--coal.
- 3,000 to 3,100 feet--coal.
- 3,210 to 3,420 feet--25 percent coal and carbonaceous material.
- 3,500 to 3,540 feet--coal.
- 4,660 to 4,700 feet--coal.
- 4,700 to 4,800 feet--coal.
- Numerous fault zones below 6,100 feet.

The well was originally drilled to a depth of 8,418 feet, then later rentered and drilled to 10,655 feet; the basalt was not penetrated.

Columbia Plateau Microseismicity
by
Alan Rohay, Westinghouse
October 28, 1987

Note: Mr. Rohay's talk consisted of an oral presentation accompanied by a series of maps, charts, and graphs, none of which, to my knowledge, were available to the participants as handout material. Without this material, much of the information presented suffers a loss of meaning. However, important points of the presentation that do not depend on visual aids for understanding are summarized below in bullet form.

- A major portion of the work pertaining to microseismicity of the Columbia Plateau was done in conjunction with licensing of the Washington Public Power System (WPPS) nuclear power plant No. 2 at Hanford. Workers on this project reviewed press accounts, various journals, catalogs, and other publications to produce an authoritative listing of historic earthquakes in the Pacific Northwest.

- Some of the larger seismic events to occur in the Columbia Plateau include the 1872 earthquake near Lake Chelan (some workers place the epicenter in British Columbia) and later events with a magnitude of 6.0 or greater at Walla Walla, WA; Umatilla, OR; and Milton-Freewater, OR. There appears to be somewhat of a northeast-southwest pattern to a plot of earthquake epicenters in this area.

- An arbitrary upper magnitude limit for microseismic events was set at M=3.

- Earthquake patterns and local concentrations of seismic activity have been noted around Lake Chelan and in the areas of Ellensburg, Saddle Mountains, and Walla Walla.

- A plot of earthquake epicenters seems to have an east-west pattern in the vicinity of Saddle Mountain. Further, the events occur mostly north of the south-dipping Saddle Mountains Fault, not to the south as one might expect.

- In many cases, seismic activity is not necessarily associated with known structural features or faults. Presently, there is no solid basis for predicting where the events will occur.

- Microseismic activity often displays distinct patterns in some areas and is not confined solely to anticlines; many occur in synclinal structures.

- There is no apparent concentration of seismic activity at Rattlesnake Mountain.

- Some workers contend that microseismic events may be peculiar to the modern age and attribute such activity to increased pore pressure in the subsurface as the result of agricultural irrigation. This line of reasoning may account for the singular lack of seismic activity on the Hanford Reservation which has been withdrawn from the public domain for more than 40 years. Most workers, however, feel this is not important as many microquakes have occurred in other areas unaffected by irrigation.

- There may be some correlation of seismic patterns to basalt thickness and basement depth. However, there has been no one-to-one correlation of microquakes to the growth of structures.

- Microquake epicenters are all quite shallow. Since 1969, more than 600 events have occurred at depths of 0 to 1 kilometer; the vast majority occur at depths of 0 to 3 kilometers. Most activity is confined, it seems, within basalt and tend to taper off in sub-basalt sediments; basement rocks are relatively aseismic. Future earthquakes, even major events, will quite probably be associated with faults in the basalt.

- Deeper earthquakes do not display "clustering" as do shallow events.

- At least one earthquake of a magnitude of 6.0 or greater can be expected in the Columbia Plateau every 100 to 1,000 years. Fairly large events might be expected on Saddle Mountain, in the Horse Heaven Hills, and on Toppenish and Untanum Ridges.

Panel Discussions

"Are structural models of the Central Plateau adequate?

Panel members:
John Bond, Moderator
Michael West
Karl Fecht

The discussion included several structural and tectonic models of the Columbia Plateau presented by the panel members and the audience. Most models were in general agreement. Differences were based mainly on degree or rates; however, some models were quite divergent. The consensus was, while an enormous amount of data has been acquired to develop structural and tectonic models of the Columbia Plateau, much more work is needed; the present models are not fully adequate.

"Are major seismic events possible in the Central Plateau in the next 100 years?"

Panel Members:
Michael West, moderator
Stephen Malone
Alan Rohay

Consensus: Yes, a major event with a magnitude of 6.0 or greater is not only possible, but probable, in the Columbia Plateau within the next 100 years.

"What specific research in neotectonics of the Plateau is needed?"

Consensus: Additional trenching and more dating of sediments and organic material is needed in the areas of Smyrna Bench (ongoing), Toppenish Ridge, east of Ellensburg, Filey Road area, and other areas that demonstrate a potential for neotectonism. Geophysical studies and perhaps shallow drilling are also needed.

PETROLEUM POTENTIAL OF THE CENTRAL COLUMBIA PLATEAU

OCTOBER 29, 1987

SYNOPSES OF PRESENTATIONS

Oil and Gas Leases in the Central Plateau
by
David Faley, Vice President,
W. E. Mays and Associates
October 29, 1987

Note: W. E. Mays and Associates, Ellensburg, WA, gathers information pertaining to oil and gas leases in the Columbia Plateau and northern Oregon. The information is analyzed, compiled, and published as a series of maps that show leaseholdings, ownership, and other information not readily available from other sources.

Oil and gas exploration activity is not new to the Columbia Basin; it has been ongoing, in fits and spurts, since 1901. The history of oil and gas exploration in the Plateau can be divided into five periods or eras: 1) The pre-modern, 1901-1956; 2) the beginning of the modern, 1957-1958; 3) the modern era, 1973-1980; 4) the "great land rush" of 1981-1985; and 5) present day leasing.

The pre-modern leasing era (1901-1956) is characterized by small plays that were limited to a single structure or objective, and generally limited in size to one or two townships. Most companies were attracted to these prospects by physical evidence of hydrocarbon occurrences such as methane seeps or its presence in water wells and surface anticline structures like the Rattlesnake Hills, Manastash Ridge, Snipes Mountain and others. Many stock companies were organized to explore areas of Yakima, Kittitas, Klickitat, Walla Walla, Stevens, Adams, Benton, Garfield, and Spokane counties. It was pretty much a widespread effort with little continuity between plays.

During this time, more than 50 wells were drilled in Eastern Washington. The Rattlesnake field was discovered and produced 1.3 billion cubic feet of gas between 1929 and 1941 from 17 shallow wells. During the 1940's, the emphasis shifted from small exploration and production companies to large, well financed corporations.

The beginning of the modern era commenced in 1957 and continued through 1958. Standard Oil Company of California brought to bear advanced techniques of exploration and established a trend of scientific data acquisition. Further, the company set a precedent for large-scale land leasing. Together with Shell Oil Company, Standard drilled the Rattlesnake Unit Number 1 to a depth of 10,655 feet in 1957. Prior to drilling, the companies put together a large Federal unit of 105,000 acres that stretched across 14 townships; it was the largest lease block to date. After this acquisition, other major and independent companies developed an interest in the Plateau and commenced putting together their own large lease blocks, thereby setting a trend.

Between 1958 and the early 1970's things were relatively quiet in the Washington oil patch due to the downturn in domestic exploration; activity virtually ceased until 1973.

The modern era (could be called the "Shell" era) began in 1973. After being out of the Plateau since the late 1950's, Shell Oil Company commenced a large land acquisition program in Kittitas, Grant, and Yakima Counties. The leases, which encompassed more than 500,000 acres, were generally located on or in proximity to anticlinal structures such as Rattlesnake Mountain, Boylston Mountain, Saddle Mountain, and Ahtanum Ridge. By late 1980, Shell had collected enough geological, geochemical, and geophysical data to warrant drilling of the Yakima Minerals 1-33 wildcat well near Roza Dam in Kittitas County.

The "great land rush" of 1981-1985 was precipitated by the release of data pertaining to the Yakima Minerals wildcat. Shell quickly acted to extend its holdings, especially to the north, south, and east, and it spudded the BISSA 1-29 on Whiskey Dick Mountain. The company also drilled an offset to the Yakima Minerals 1-33 (YM 2-33). During this period, over 100 small operators, independents, and majors came into the play within 9 months. This was unprecedented in the Plateau.

Three significant regional exploration efforts were mounted during this period that included 1) the Burlington Northern-Delaware Coastal lease; 2) ARCO's purchase of 50 percent of Shell's program; and 3) Texaco-Boise Cascade Exploration agreement. An arrangement between Burlington Northern and Shell resulted in drilling of the BN 1-9 well. The Texaco-Boise Cascade agreement involved some 500,000 acres in southern Washington and northern Oregon. Texaco performed an magnetotelluric survey in the Cleman Mountains and on Manastash Ridge in 1982.

The "great land rush" began to wane in 1985 largely because of the intense competition for acreage. Many lease bonuses were in excess of $120 per acre; this effectively drove out many small operators and independents. The abandonment by Shell of the Yakima Minerals 1-33 and the BISSA well further acted to dampen the drive of the remaining players.

The remainder of the era primarily involved consolidating holdings and purchasing of smaller operations by the major companies. Exploration moved into the eastern portion of the basin that had, heretofore, no previous exploration or drilling history.

The present era, 1986 to date, is marked by the continuation of selective in-field leasing and further land consolidation. State lease results are a very accurate indicator of what was happening in the oil patch. No one is currently willing to pay the high bonuses paid in the past. For example, in 1984, the state lease bonus high was $280; in 1986, the high bonus was $28. In the latest state lease auction (Spring, 1987), the high bonus was $67; many leases were let with no bonus whatsoever. "The halcyon days are over," stated J. D. Mason, president of Globe Oil Company, "a semblance of sanity has returned to the oil patch."

In the past 2 years, Shell, AMOCO, and ARCO have continued to acquire acreage and established several exploration, if not drilling targets. Shell applied for a drilling permit in 1986 for a prospect on Boylston Mountain in Kittitas County. Litigation with Burlington Northern and an effort by the U.S. Army to increase the area of the Yakima Firing Range to include Shell's Boylston Mountain leases, however, has forced the company to put drilling plans on hold.

Several independents have been actively securing small leases primarily for eventual sale to the majors; others have been filling in acreage positions acquired in the "boom days."

Exploration activity has been very lively, including hundreds of miles of seismic lines. Estimates of Shell's seismic efforts alone total between 150 and 170 miles. Shell has also re-shot areas on Saddle and Boylston Mountains originally surveyed in 1984 . AMOCO also ran a seismic line across Saddle Mountain this summer and Chevron has purchased some 90,000 acres in the Benton City area from City Services.

Perhaps the most important exploration effort in the past 2 years is the drilling of the Darcell-Western Explorer No. 1 by Shell in Walla Walla County. This is the first wildcat drilled in the Plateau based solely on seismic evidence. As of October 15, 1987, the drilling had proceeded to 3,800 feet.

The State of Washington plans to hold another oil and gas lease auction in December of this year, but very few state acres are available for lease.

Two large, important areas in the Plateau, the Hanford Nuclear Reservation and the Army's Yakima Firing Range, remain closed for mineral or energy exploration. Since 1980-1981, over 145 applications for exploration at Hanford have either been denied or are pending. Surface management agencies, the Department of Energy at Hanford and the Department of Defense at the firing range, have declared that oil and gas leasing and exploration activites are incompatible with their use of the properties.

Oil and Gas Exploration in the Central Plateau
by
Richard Bowen,
Northwest Oil and Gas Report
October 29, 1987

Note: Mr. Bowen publishes the Northwest Oil and Gas Report in Portland, OR. His firm collects exploration, lease, borehole, and other germane data for publication or for sale to interested parties in the petroleum industry.

Serious hydrocarbon exploration in the Columbia Basin began with the 1913 discovery of gas in the Rattlesnake Hills. In 1929, several more wells were drilled and a gas line was installed from the field to the town of Prosser, WA. All production (1929-1941) was from breccia zones and interbeds within basalt at relatively shallow depths. Most wells produced about 100,000 cubic feet per day; the maximum flow was about 3 million cubic feet per day.

From 1913 to 1929 the wells were shut in and there was a tremendous loss of gas to the atmosphere. It has been estimated that at least 1.3 billion cubic feet were lost, this equals or exceeds the total gas produced during the years 1929-1941.

The next exploration surge occurred in the mid 1950's, triggered by the Suez Canal crisis of 1956. At that time, two significant wells, Standard's Rattlesnake Hills Unit and Kirkpatrick No. 1 in Morrow County, OR, were drilled. The Rattlesnake well was drilled to a depth of 10,600 feet but did not penetrate the basalt.

Standard's Kirkpatrick was drilled through about 4,000 feet of basalt then another 4,000 feet of sediments. The first 2,000 feet of sedimentary rock included the Tertiary John Day and Clarno formations; the subsequent 2,000 feet penetrated Mesozoic marine sediments.

Kirkpatrick No. 1 is still generating interest. The Oregon Division of Geology and Mineral Industries recently released a report funded in part by ARCO and the Basalt Waste Isolation Project (BWIP). The report, authored by Steve Reidel and Tom Fox, presented detailed information pertaining to the potential (hydrocarbon) source and maturation of the underlying sediments.

The next period of activity was in response to the 1973 Arab oil embargo. This activity resulted in regional large-scale leasing and drilling of Shell's wells in Kittitas County and Snowbird Resources' Moses Lake 1A well near Moses Lake in Grant County. The Moses Lake 1A was drilled to about 6,980 feet and did not penetrate the basalt.

Shell's Yakima Minerals 1-33 well, north of Yakima in Yakima Canyon, went to 16,199 feet and penetrated about 11,000 feet of pre-basalt rock. As the result of a series of flow tests which included acidizing and fracturing, the well was deemed non-commercial notwithstanding a combined flow of 1.5 million cubic feet per day.

A companion well (Yakima Minerals 2-33) drilled about 200 feet from 1-33, only reached the first sand (Wenatchee Sand ?) immediately beneath the basalt. The well produced an insignificant amount of gas. Both wells were drilled based on structural and other geological information; apparently no seismic data were available or, if available, were not used. The wells have subsequently been abandoned.

After abandonment of the Yakima Minerals wells, Shell moved its drilling operations to Whiskey Dick Mountain, where it drilled the BISSA 1-29 to a depth of 14,965 feet. The well penetrated about 5,000 feet of basalt and about 10,000 feet of pre-basalt sediments. It was tested in several zones; only a very minor amount of gas was present. While unproductive, it provided a great amount of structural, stratigraphic, and lithologic data. During this period of time, Shell was busy to the south and east conducting a large seismic program.

Shell's next well, the BN 1-9, was not sited based on geophysical data, although some MT work was done; siting was primarily based on surface anticlinal features. Over 11,400 feet of basalt and 4,000 feet of sediments were penetrated. Two zones, one at 12,000 feet and the other at 15,000 feet, gave the best flows after acidization and fracturing. The well flowed at a rate of greater than 5 million cubic feet per day but was not considered economic due to the relatively small reservoir underlying the site. Flow volumes in this range could be economical if the reservoir were larger. Like the Yakima Minerals wells, the BN 1-9 was abandoned.

In the past few years, Shell has made a tremendous effort to collect and interpret seismic data. Since abandonment of the BN 1-9 in 1984, however, exploration activity has decreased somewhat.

The Darcell-Western Explorer No. 1, spudded in August 1987, is Shell's latest drilling venture. Unlike most wells drilled in the Columbia Plateau, the Darcell was sited solely on the basis of geophysical data.

Other companies, primarily major operators, are continuing exploration in Whitman County, WA, and in northern Oregon. Such work includes seismic, geological, and MT studies.

Exploration is ongoing in the Blue Mountains anticlinorium. Several sandstone units underlying basalt in the region have been tested and may have the necessary permeability and porosity to act as reservoirs.

Hanford Petroleum Resource Potential--Plans:
by
Lynn Moses, Westinghouse
October 29, 1987

Note: Ms. Moses and co-workers are charged with the responsibility of assessing the hydrocarbon and mineral resource potential of the proposed repository site. In her presentation, she outlines Westinghouse Hanford's plans and methodology to be employed in conducting the assessment.

Plans for estimating the hydrocarbon resource potential of the Hanford Reservation will employ a typical exploration approach. It is anticipated that the level of effort will be about four man-years. The exploration plan includes:

° Compilation of information. A literature research program will be conducted to amass relevant geological, geophysical, geologic, and historical information pertaining to hydrocarbon exploration and production in the Columbia Plateau in general and the Hanford area in particular.

° Monitoring of industry activities. Industry activities such as leasing, geological and geophysical work, drilling, etc., will be closely watched and noted. Information sources will include professional journals, newsletters, press accounts, published and unpublished industry data, and personal communications. Information so acquired will be compiled and become a part of the record.

° Determination of stratigraphy and structure. Existing stratigraphic and structural information will be collected and used, along with any additional information acquired during site characterization, to determine regional and site-specific stratigraphy and structure.

° Analysis of potential source and reservoir rocks. Source rocks will be analyzed for total organic content (TOC), pyrolysis, kerogen type, and vitrinite reflectance, among others. Analyses of reservoir rocks will be conducted to determine rock porosity and permeability. Thin section studies will be conducted for both rock groups.

° Down-hole geophysical studies. Well log studies will be conducted, the number and types of which will be dependent upon time and funding constraints and overall site characterization plans.

° Burial and thermal history. A detailed study pertaining to the burial and thermal history of local and regional rocks will be conducted.

° Production history. A study of the exploration and production history of the Rattlesnake Hills gas field is planned. Redrilling and resampling of some of the wells in the field may be done if time and funds permit.

° Analog areas. Areas within the Plateau analogous to the proposed repository site will be identified and comparison studies conducted. The study may provide needed insights.

° Present-day value. Analyses will be conducted to determine the present-day value of any actual or hypothetical resources.

High-Resolution, Full-Wavefield Seismic Profile
by
Rufus Catching, U.S. Geological Survey
October 29, 1987

Note: Dr. Catchings' excellent presentation was delivered in two parts; in one part, he described the crustal structure of the Columbia Plateau and presented evidence for continental rifting based on his 1984 seismic study. In the second part, he examined the advantages of explosion-source, high-resolution, full-wavefield seismic ("full-wavefield") profiling. His presentation, out of necessity, was heavily dependent on graphics such as charts, maps, velocity spectra, seismic reflection data, and others resulting in some loss of detail in the synopsis.

Part 1. Crustal structure of the Columbia Plateau; evidence for continental rifting.

The area of the Columbia Plateau is structurally complex and the crustal structure and associated tectonics are not fully understood. Data from a 260 km long seismic profile conducted in 1984, however, revealed for the first time some of the more important aspects of the crustal structure beneath the Plateau. The profile, centered on the Hanford Nuclear Reservation, trends approximately N 50° E from Wasco, OR to Warden, WA.

The analysis of the profiles revealed Eocene (and possibly later) continental rifting that has greatly altered the continental crust within the central Plateau. Crustal thickness and velocity structure, however, suggest the entire central Plateau is underlain by continental crust.

The crust and upper mantle consist of at least 8 primary units (refer to figure 3):

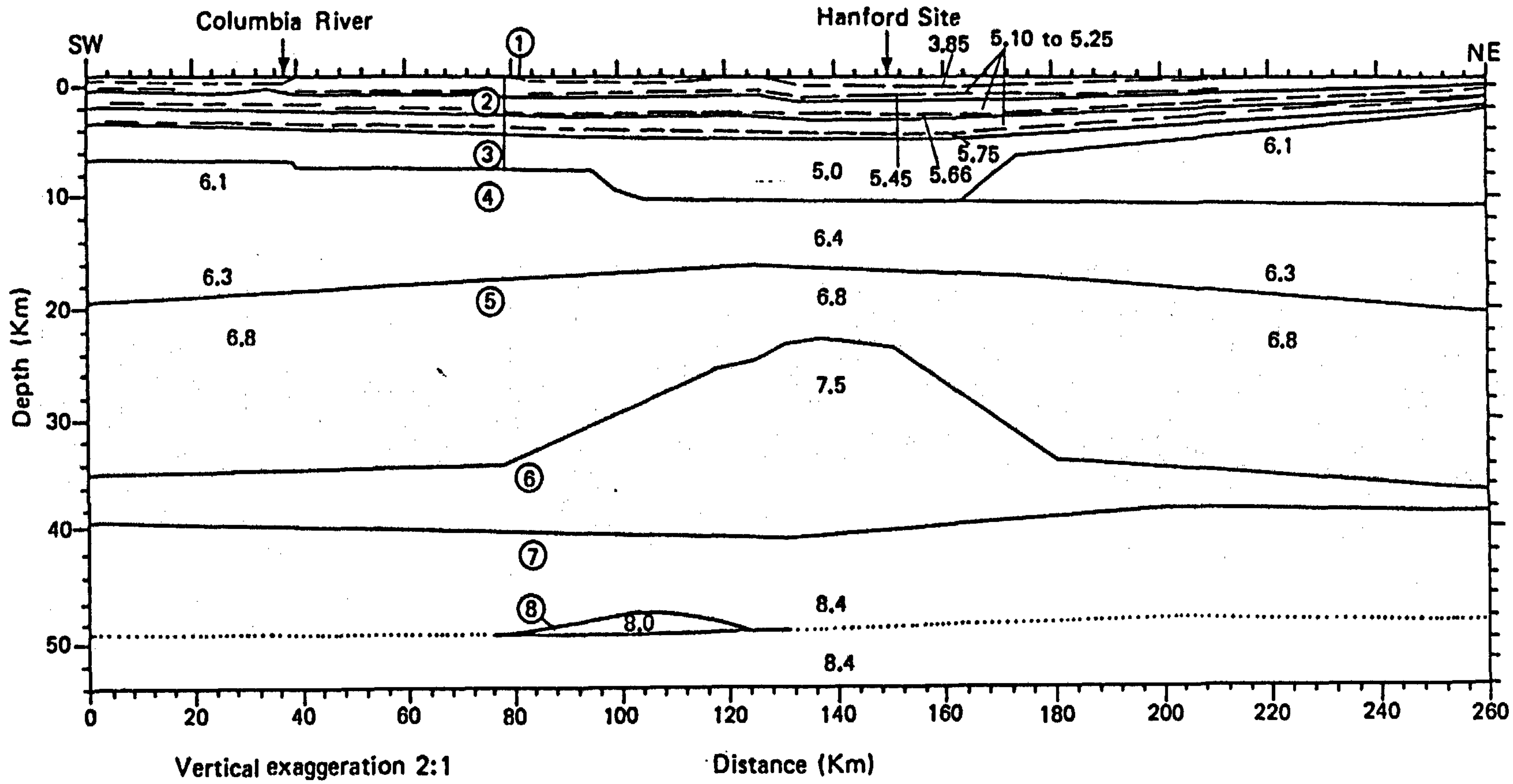
1. A thin surficial sediment layer present only within the modern topographic basins;

2. A 3- to 6-kilometer-thick basalt (Columbia River Basalt--CRB) pile with alternating high and low velocity layers;

3. A 2- to 5-kilometer-thick sub-basalt sedimentary rock unit;

4. A complex basement structure with a sub-basalt graben that may be an extention of one or more of the northern surficial grabens (Methow, Republic, or Chiwaukum grabens);

5. A relatively shallow (18 kilometer) 6.8 kilometers per second layer beneath the graben;



Redrawn from Catchings, 1985

FIGURE 3.– Seismically derived crustal structure model

6. A 7.5 kilometer per second layer located at a minimum depth of 25 kilometers.

7. An atypically-high-velocity upper mantle zone (8.4 kilometers per second) located at about 40 kilometers and;

8. A laterally discontinuous upper mantle low velocity layer at a depth of about 50 kilometers.

Continental rifting beneath the Columbia Plateau is consistent with other geophysical and geological data. Paleomagnetically determined positions of surrounding geologic provinces suggest rifting beneath the Plateau took place during the Eocene. Gravity data suggests that the crust is intruded by or contains high density rock at a relatively shallow depth. Geologic evidence of rifting includes the existence of surficial Eocene grabens which trend southward beneath the basalt and the existence of the highly extended metamorphic core complexes east and north of the Plateau.

Comparison of the Columbia Plateau with other continental rifts shows many similarities in crustal structure. Specifically, a central graben, high velocity crust, and rift pillows appear to be features common to all rifts. Comparison of the Columbia Plateau rift with the Mississippi Embaymant rift could be useful for seismic risk and hydrocarbon resource assessment.

Part 2. High-resolution, explosive-source, full-wavefield seismic profiling

Past attempts to characterize the CRB and sub-basalt sediments have been only partially successful using traditional multichannel seismic reflection techniques to obtain clear subsurface images. This may be attributed to strong attenuation in near-surface sedimentary layers and to scattering in the basalt-interbed sequence. These problems, along with other data acquisition and processing problems in basalt-covered terranes, continue to plague conventional multichannel seismic reflection techniques.

These problems, however, can be overcome by using high-resolution, explosive-source, full-wavefield seismic techniques ("full-wavefield"). The techniques involve the use of deeply buried chemical explosive sources that produce excellent signal-to-noise ratios and utilize both the wide-angle and near-vertical-incidence portion of the seismic wavefield.

Unlike traditional seismic reflection or refraction data, full-wavefield seismic data provide high-resolution structural and compositional information as well as accurate depth control. Further, full-wavefield methods utilize a greater portion of the wavefield, including the wide-angle portion where the deeper "target" events increase dramatically in amplitude, and shallow reverberations die out due to attenuation. Lower resolution versions of this technique have been successfully employed in northwestern Nevada and west-central Arizona.

Tribal Borehole Study
by
Curtis Canard, CERT Consultant
October 29, 1987

Note: Mr. Canard's presentation was based on geological, geophysical, and borehole data available (to the public, presumably) at the Hanford Reservation. Canard and others spent three working days in reviewing the data. Although a large number of boreholes have been drilled on the reservation, only a small number were selected for review (due mostly to time constraints). Boreholes on the reservation range in depth between less than 200 feet to more than 5,660 feet (DC-1).

The Tribal Borehole Study focused on drilling records to find any indications of faulting, water flow, or oil and/or gas shows. Canard was surprised at the large number of the wells that contained methane dissolved in water; some of the hydrologic test wells (reportedly) actively evolved gas from flow-top water. Gas shows have been noted both above and below the Cohassett flow.

In coal mining, dewatering of coal zones often results in significant increases in methane. Two examples of this phenomenon in the San Juan Basin, NM, were cited by Canard in which commercial volumes of gas were recovered as the result of dewatering coal zones. Canard speculated on the possibility of increased gas flow in the Hanford area if the zones above and below the Cohassett (and others) were dewatered.

The DOE has an internal plan to review well data from the Rattlesnake Hills gas field to better understand the zones that were gas productive, the water contacts, and the oil shows, as well as to examine wells that may be re-drilled to collect additional samples and information.

The Walla Walla No. 6 (in the Rattlesnake field) was drilled to a depth of 3,660 feet. Gas was encountered from 900 to 1,000 feet and an oil show at 3,400 feet. The Benson Ranch well had two oil shows, probably the best shows in the entire area. Water samples taken, according to State records, contained fluid oil.

Another well, about 4 miles north of the Rattlesnake No. 1, at the 1,003 foot level, encountered a 400-foot interval of water (presumably water-saturated flow-tops or interbeds) that evolved gas. After the casing was pulled, a show of gummy oil was found at 800 feet. Although it is well known that gas is present, little work has concentrated on the oil shows.

Two large gas shows were encountered at well DC-19; both had good flows.

Cores from RRL-16 indicate (flow-top ?) dips of 50 to 60°. This may have significance with respect to trapping mechanisms.

Gas shows were reported in well RRL-2. The gas zones were tested and their volumes incorporated into the record.

Well DH-24, about a mile north of RRL-2, has indications of subsurface faulting. Faulting is noted in the sediments overlying the basalt; sheared boulders were found at 300 feet and indications of open and closed fractures, breccia, slickensides, and fault gouge were also noted. Many questions remain unanswered concerning this well.

Two indications of faulting were noted at DC-18. Upon completion, this well flowed gas for a period of about 5 days. Drilling was difficult and circulation was lost a number of times.

DC-6, on the eastern margin of the reservation, exhibited steep dips, coal, and low resistivity presumably due to faulting; indications of open and closed fractures and slickensides were noted.

Canard was impressed by the large areal expanse of active gas shows on the reservation. Even though gas has escaped from the subsurface over geologic time, a great amount of gas remains. In some core descriptions it was stated that the cores, at the time of removal, were actively evolving gas.

Summary

There are many documented oil and gas shows on the Hanford Reservation; Canard believed that these should be thoroughly and expeditiously investigated. He suggested that several specific wells on the reservation should be re-drilled, sampled, and reevaluated. In addition, he recommended deep drilling (on the order of 15,000 feet) at Hanford. Probably the best site, according to the author, for deep drilling is adjacent to the DC-24 location. This site is on the down-thrown side of a projected anticline (Yakima Ridge ?) that runs beneath the DC-24 well.

Panel Discussions

Is the Central Plateau the next "Overthrust Belt?"

Panel Members
Curtis Canard, Moderator
Tim Walsh
Karl Fecht
Rufus Catchings
Lynn Moses

Consensus: While the Central Plateau may not be another "Overthrust Belt," the panel felt there is a real potential for the discovery of a major oil or gas field. Major oil companies have invested and continue to invest large sums of money on land acquisition and exploration. Traditionally, the major companies have explored for giant fields ("hunted elephants") which, by definition, host 100 million or greater barrels of oil.

Large structures on the Plateau rival those of Iran and Rumania and may provide the structure required for hydrocarbon accumulation. A conservative estimate of more than 1 trillion cubic feet of gas (or oil equivalent) may underlie the Plateau. Further, if the postulated rift zone exists beneath the Plateau, this would provide the type of environment in which a major oil/gas field could be expected.

Could economic oil and gas resources be located at Hanford?

Panel Members
Curtis Canard, Moderator
Tim Walsh
Lynn Moses
Rufus Catchings
Karl Fecht

Consensus: Quite possibly. Drilling on the reservation has demonstrated the presence of both oil and gas, although quantities have yet to be defined. Further, seismic work by the Geological Survey suggests the reservation may be underlain by a rift zone with attendant graben that may provide the basin for sediment accumulation and hydrocarbon generation. Without further studies, however, it is difficult at best to determine whether Columbia Plateau oil and gas would be economical at current prices, given the cost of the infrastructure required to produce and transport the product.

What specific research is needed to determine the
oil and gas potential of the Central Plateau?

Panel Members
John Bond, Moderator
Curtis Canard
Tim Walsh
Lynn Moses
Karl Fecht
Rufus Catchings
Audience

Consensus: Much more seismic work and borehole drilling must be done, especially on the Hanford Nuclear Reservation, Yakima Firing Range, the Yakima Indian Reservation, and along the trend of the postulated rift zone. Boreholes must be of sufficient depth to penetrate the CRB to assess the underlying sediments. When released, data from Shell's wildcat Darcell-Western Explorer No. 1 may supply much needed information to support (or deter) further exploration in these areas.

APPENDIX

Workshop Attendees

Name	Affiliation	City
Steve Hart	CERT 1/	Denver, CO
Stephen Malone	Univ. of WA	Seattle, WA
Richard Galster	Consultant	Seattle, WA
Floyd Kugzruk	Nez Perce Tribe	Lapwai, ID
Ellen Caywood	WA State Inst. for Public Policy	Olympia, WA
Mihai Rupeza	Umatilla Tribe	Pendleton, OR
Edward Levine	Weston Geophysical	Westboro, MA
Abdul Alkezweeny	Nez Perce Tribe	Lapwai, ID
James Springer	Matec/Woodward-Clyde	Richland, WA
Richard Wallace	Battelle	Richland, WA
John Bond	Geoscience Research	Moscow, ID
Patricia McGee	Yakima Tribe	Minneapolis, MN
Timothy Walsh	WA Div. Nat. Res.	Olympia, WA
Curtis Canard	CERT Consultant	Tulsa, OK
Harold Lafevre	U.S. NRC	Silver Spring, MD
Karl Fecht	Westinghouse	Richland, WA
Michael West	Consultant	Denver, CO
Russell Raney	U.S. Bureau of Mines	Spokane, WA
Richard Bowen	NW Oil & Gas Rep.	Portland, OR
Grant Valentine	Consultant	Olympia, WA
Steve Armstrong	Yakima Tribe	Toppenish, WA
David Faley	W. E. Mays and Assoc.	Ellensburg, WA
Larry Calkins	Umatilla Tribe	Pendleton, OR
James Consort	Woodward-Clyde	Richland, WA
Brian Dick	Matec/Woodward-Clyde	Richland, WA
Phil Spencer	Mobil Oil Corp.	Denver, CO
Rufus Catching	U.S. Geological Survey	Menlo Park, CA
Alan Rohay	Westinghouse	Richland, WA

1/Council of Energy Resource Tribes

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