OREGON GEOLOGY

published by the

Oregon Department of Geology and Mineral Industries

VOLUME 47, NUMBER 5 MAY 1985

THIS MONTH:
THE 1984 LANDSLIDE ON THE POWDER RIVER

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 47, NUMBER 5 MAY 1985

Published monthly by the Oregon Department of Geology and Mineral Industries (Volumes 1 through 40 were entitled *The Ore Bin*).

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of their bibliographic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Oblique aerial photo of the Hole-in-the-Wall landslide in the Powder River Basin east of Baker, eastern Oregon. Photo was taken September 24, 1984. View is to the northeast. Article beginning on next page discusses this landslide, which blocked traffic on Oregon Highway 86 for three months.

OIL AND GAS NEWS

Columbia County — Mist Gas Field

ARCO has spudded its second well in the field, Banzer 34-16, in sec. 16, T. 6 N., R. 5 W. The proposed depth is 3,500 ft, and Taylor Drilling is the contractor.

The company's first well, Columbia County 44-21, is awaiting a pipeline connection.

Clatsop County

Nehama and Weagant Energy Company is drilling Jewell 1-23 in sec. 23, T. 5 N., R. 7 W. This is the company's first effort in Oregon since drilling Klohs 1 in Yamhill County in 1982. Taylor Drilling is the contractor for this well, proposed to 3,600 ft.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
292	Reichhold Energy Columbia County 33-8 009-00141	SE¼ sec. 8 T. 6 N., R. 5 W. Columbia County	Application; 3,300.
293	Hutchins and Marrs Great Discovery 2A 019-00032	NW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	Application; 6,000.
294	Oregon Nat. Gas Dev. Tesch 44-21 047-00018	SE¼ sec. 21 T. 5 S., R. 2 W. Marion County	Application; 3,000.

□

New biostratigraphy study available

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released the results of a study of nine exploratory wells in the southern Willamette Basin, mostly Linn County. Data for eight of the wells are published here for the first time.

Biostratigraphy of Exploratory Wells, Southern Willamette Basin, Oregon, by D.R. McKeel, has been released as DOGAMI Oil and Gas Investigation 13. The 17-page report presents correlations of fossils and lithology and is based on the analysis of 987 samples from nine wells, one of them drilled in Marion County, the others in Linn County. Five of the wells were drilled in 1980 and 1981 and reached almost 5,000 feet and three, older deep test wells, between 9,000 and 10,000 feet.

The new report is the fourth in a series of biostratigraphic studies published by DOGAMI. Earlier reports analyzed wells in northwestern Oregon (Oil and Gas Investigation 9), southwestern Oregon (Oil and Gas Investigation 11), and the northern Willamette Basin (Oil and gas Investigation 12).

Section I of the report contains a summarizing overview, including a composite chart for subsurface stratigraphy and a paleobathymetric curve. Section II presents sample-by-sample descriptions of rock types and marine fossils for each well. These identifications are used to determine the age, water depth, and paleonenvironment for each distinctive well interval. Included with the report is a separate illustration sheet containing a surface location map for the wells and selected subsurface correlations for eight of them in the form of a generally north-south oriented cross section.

The new Oil and Gas Investigation 13 is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201. The purchase price is $6. Orders under $50 require prepayment. □

The 1984 landslide and earthquake activity on the Baker-Homestead highway near Halfway, Oregon

by R. Jacobson, College of Oceanography, Oregon State University; W. Milne, Geotechnical Group, Oregon Highway Department; H.C. Brooks, Oregon Department of Geology and Mineral Industries; J. Zollweg, Geophysics Program, University of Washington; and B. Brandsdottir, College of Oceanography, Oregon State University.

One of the authors, Bob Milne, passed away suddenly on March 26, 1985. This paper is dedicated to his memory.

INTRODUCTION

The recent landslide on the north side of the Powder River between the Hole-in-the-Wall and Maiden Gulches closed Oregon Highway 86 at a point 31 mi east of Baker, Oregon, and caused a major inconvenience to the communities of Richland, Halfway, Oxbow, and Homestead. A 21-mi detour through Sparta was used temporarily but was considered unsafe for traffic during the winter months because of the severe gradients, switchbacks, and the dirt surface. What caused the landslide? Could it have been prevented, or, failing this, foreseen earlier so that preparations for more adequate detours could have been undertaken ahead of time? Two moderate earthquakes occurred in the general area at about the time the slide began to move. Were the earthquakes the cause of the Hole-in-the-Wall landslide, or was there another cause? To answer these questions, we undertook an investigation to determine the likely causes of this landslide. Our preliminary determinations indicate that three factors were primarily responsible: Incompetent geological formations, the low angle of stability of these formations, and increased ground-water flow due to recent heavy rains.

CHRONOLOGY OF EVENTS RELATING TO THE LANDSLIDE

On or about August 1, 1984, Steven Shold, a rancher living close to the slide, noticed some fissures high up on the slope from the Powder River to the Sparta Plateau. On August 10, 1984, at 0726 Greenwich Mean Time (GMT) (12:26 a.m. PDT), a magnitude-3.5 earthquake occurred at lat. 44°59′ N., long. 116°58′W., about 17 mi north-northeast of Richland, Oregon (Figure 1). The location of this earthquake was not well constrained, however, and could vary in any direction by at least 10 mi, possibly placing the earthquake close to the landslide. On Friday, August 31, 1984, a heavy rainfall occurred over much of eastern Oregon, with reports of 3 in. or more of precipitation within 24 hours.

On September 13, 1984, the cracking of the slope increased dramatically, producing significant earth movement. A second large fissure began to open on September 17, 1984, and the Oregon Highway Department was notified at this time. The landslide continued to move, now at an accelerated pace, finally closing Oregon Highway 86 on September 18, 1984, due to falling rocks and minor avalanches. Another moderate earthquake, magnitude 3.5, occurred at 0132 GMT on September 19 (6:32 p.m. PDT on September 18), at approximately the same location as the earlier shock and was felt at Richland and Halfway. During the next week, geophysical and geological investigations were begun to determine the primary causes of the landslide. These investigations included a seismic-refraction survey, the drilling of a 200-ft deep hole for core samples, and a microseismicity survey. The road was completely covered by slide material by October 4, 1984, when underground telephone lines were severed between Baker and Richland. Temporary cables were laid across the Powder River, bypassing the slide. By late October, the landslide had crept across the river, partially damming it and creating a 20-ft-deep reservoir behind it.

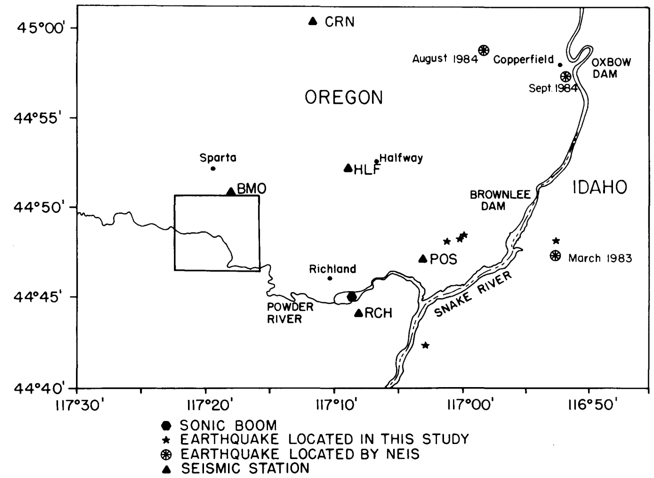


Figure 1. Location map of eastern Oregon, showing the locations of the seismic stations, earthquake locations, and the position of the Hole-in-the-Wall landslide. The outlined box delineates the location of Figure 2.

The Highway Department decided to install a temporary graded detour on the south side of the Powder River, effectively bypassing the landslide. Construction officially began on November 4, 1984, and this detour was officially opened on December 14, 1984.

GEOLOGY NEAR THE HOLE-IN-THE-WALL LANDSLIDE

The immediate geology surrounding the Hole-in-the-Wall landslide area has been mapped by Prostka (1962) and is reproduced in Figure 2.

The basement rocks of the Sparta Complex lie under the landslide and consist of three units, presumably of Permian to early Triassic age: albite granite, hornblende quartz diorite, and severely sheared and weathered gabbro. Several outcrops of the gabbro (identified by Taubeneck, 1985) were noted on the southeastern edge of the slide along the highway cut and 200-400 ft southwest from the slide across the Powder River. The contacts between these units have been observed in the field and are gradational. Aerial photography (Figure 3) indicates long, linear features that are unrelated to the rock contacts. One interpretation of these lineations is that they may be pre-Miocene faults that are no longer active. Circumstantial evidence supporting this interpretation is that the Powder River aligns itself a mile downstream along one of these southeasterly trending lineations. The observations suggest that the slide may be located over a zone of intersecting pre-Miocene fault traces.

Following the emplacement of the basement complex in early Triassic time, there was apparently a sustained hiatus in deposition and intrusion until the middle of the Miocene.

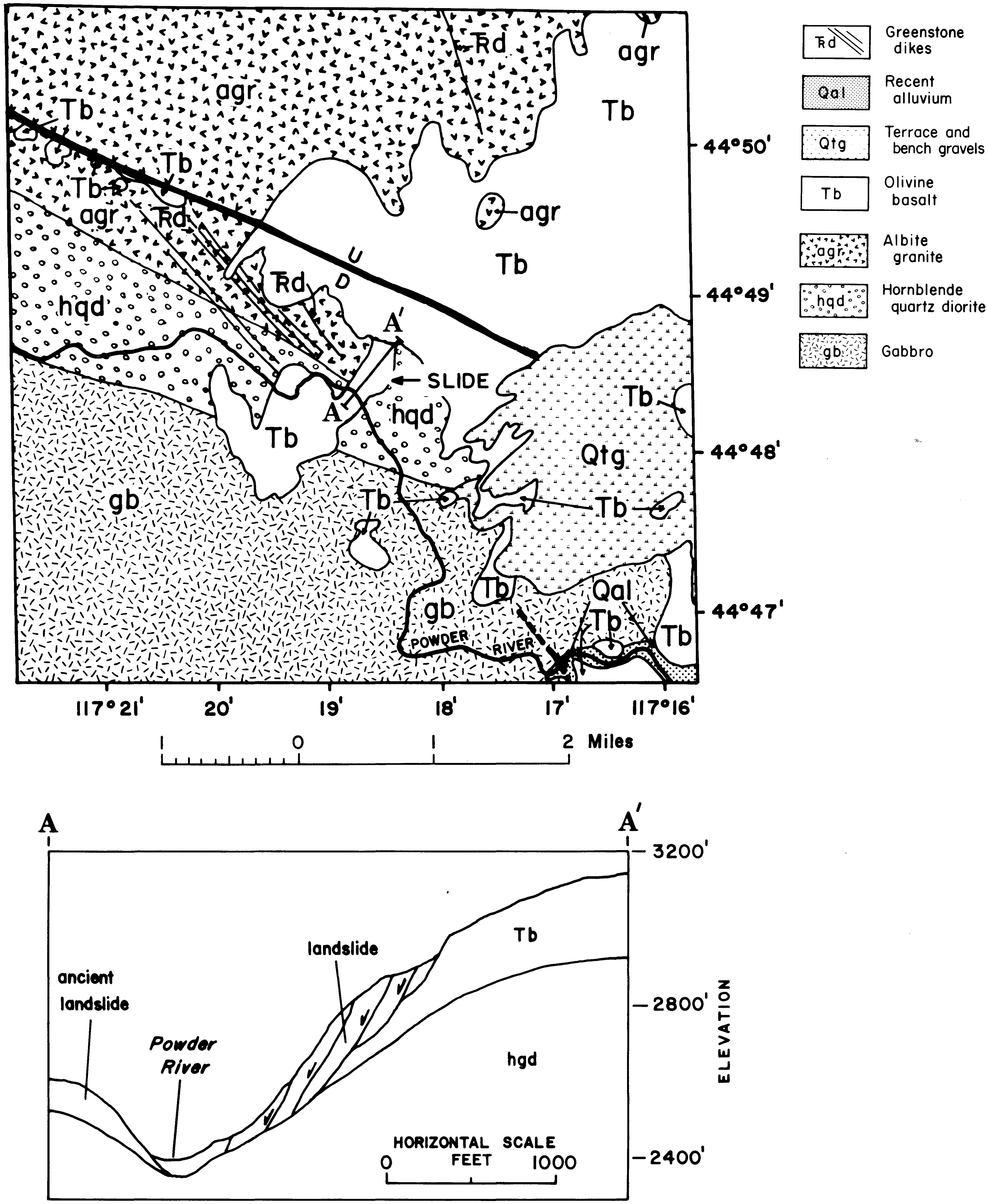


Figure 2. Geologic map of the area surrounding the landslide (adapted from Prostka, 1962). The landslide itself consists of Miocene basalt interspersed with numerous ash and tuff beds filling a pre-Miocene channel that cuts across the present-day location of the Powder River. Schematic cross section (A-A') of the landslide is larger scale than the geologic map and was prepared for this paper by Howard C. Brooks, Oregon Department of Geology and Mineral Industries.

Extensive erosion probably took place, with the development of a canyon trending northeast-southwest at the present-day location of the landslide. In the mid-Miocene, Imnaha and Grande Ronde Basalt flows of the Columbia River Basalt Group covered portions of the intrusive complex and filled the canyon. This ancient canyon extends downward to at least 50 ft above the present-day road, as evidenced by outcrops of basalt and a basalt quarry near the slide. Tuff, ash beds, and baked soil horizons may be seen at the exposure of the basaltic cap, or rimrock, and were identified within the core that was drilled above the slide (Table 1). Finally terrace and bench gravels were deposited, followed by the development of the Powder River. The landslide itself has involved only the Miocene basalts and associated interbeds of tuffs and breccias and has moved over the underlying basement complex.

There is evidence for previous landslides in the immediate area. There is a prehistoric landslide associated with the hummocky topography across and just upriver from the present slide in the aerial photographs (Figure 3). The toe of this prehistoric slide crosses the Powder River and has been undercut by the highway. Maintenance of this section of the road has presented problems over the past twenty years, suggesting that the toe is now moving backwards towards the Powder River. Other signs of previous landslides are barely visible ancient pressure ridges around the pressure ridges of the present-day slide. The oblique aerial photograph (Figure 4) shows that the basaltic rimrock is offset in places, suggesting movement by slumps or fissuring. Alternatively, these may be separate flow sequences, of which five were cored.

Local slopes near the landslide are quite high, averaging 30° and occasionally reaching 45° in isolated locations. The landslide begins at an elevation of 3,000 ft and toes out at an elevation of 2,400 ft, over a horizontal distance of 1,300 ft. Two distinct slides are evident. The major portion of the slide is the upper section, which appears to be sliding over a southerly dipping (<4°) bench at an inferred elevation of 2,600 ft. This portion of the landslide is moving to the south. The lower section is sliding more to the southwest at elevations of generally less than 2,600 ft. This lower slide has covered the highway, has crossed the Powder River, and is now ramping up onto the south wall of the Powder River basin. A moderate reservoir that formed behind the slide is about 30 ft deep (as of March, 1985) and covers part of the highway. The lower slide has also raised parts of the draw located immediately to the southwest of the slide some 40 or 50 ft up onto the western bank without obliterating the original features. This upraised block has now been disrupted and covered with rubble.

A series of engineering studies were performed near the slide. First, a series of shallow seismic refraction studies on the south side of the river indicated a 20-ft-thick weathered layer overlying a 50-ft-thick, more competent layer with a velocity of 2,000-5,000 ft/sec (0.6-1.5 km/sec). Basement rock with seismic velocities of about 10,000 ft/sec (3 km/sec) was detected in isolated locations. True basement would normally have velocities of 20,000 ft/sec (6 km/sec), which would indicate highly competent, unweathered igneous rocks. The low velocities found at the site indicate a high degree of weathering. This is not surprising, considering the age of the rocks (Triassic) and their proximity to the Powder River. These profiles were conducted on what we interpreted as the ancient landslide. The velocities found are certainly consistent with this hypothesis.

A 200-ft-deep borehole was drilled immediately above the slide to determine the lithology at the top of the landslide (Table 1). The recovered core indicates four separate Grande Ronde

Table 1. *Lithology of core located above the landslide*

Depth (ft)	Unit	Description
0-5	Grande Ronde Basalt flow #4	Red, pink, gray volcanic breccia. Brown and green clay-filled fractures. Moderate to slight weathering.
5-21		Red, pink vesicular basalt. Brown and green clay-filled fractures. Slight weathering. Fewer vesicles and less fracturing below 5 ft.
21-25.5		Pink, gray dense basalt. Highly fractured with brown and green clay filling the fractures. Less fracturing below 22.5 ft.
25.5-39		Gray blocky basalt. Highly fractured below 30.5 ft.
39-67		Gray dense basalt with brown and green clay-filled fractures. Slight weathering. Moderately weathered from 66-67 ft.
67-72	Tuff interbed	Red volcanic tuff.
72-75	Tuff interbed	Red and purple tuff breccia.
75-80.5	Grande Ronde Basalt flow #3	Gray vesicular basalt with brown and green clay-filled fractures. Slight weathering above 78.5 feet; severely weathered below.
80.5-83	Tuff interbed	Red and gray tuff breccia.
83-112.5	Grande Ronde Basalt flow #2	Gray dense vesicular basalt with brown clay-filled fractures. Slightly weathered. Well fractured from 104 to 105 ft and 111 to 112.5 ft.
112.5-116.5	Tuff interbed	Red volcanic tuff.
116.5-121	Grande Ronde Basalt flow #1	Gray vesicular basalt with brown clay-filled fractures. Slightly weathered above 120.5 ft; highly weathered below.
121-196.5	Imnaha Basalt flow	Green-gray coarse-grained vesicular basalt. Slight weathering and brown or green-brown clay in fractures. Few vesicles below 126 ft.

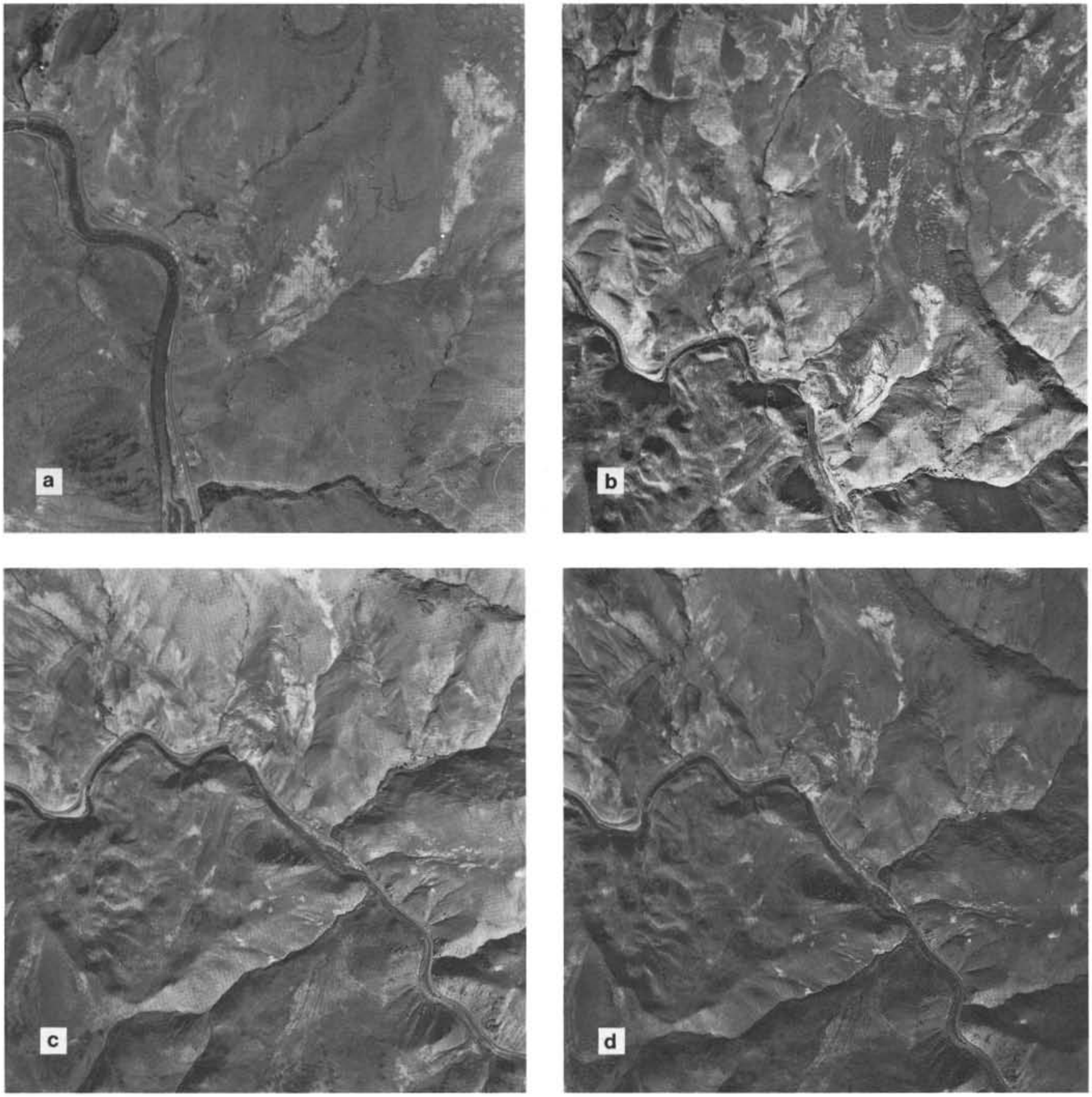


Figure 3. Aerial photographs of the landslide, taken on (a) September 25, 1984; (b) October 7, 1984; (c) October 21, 1984; and (d) November 4, 1984. Photo (a) is larger scale than the rest of the photographs. The orientation varies slightly with each photo, but north is toward the top of the page in each photo. The ancient landslide southwest of the present landslide is indicated by hummocky topography and is especially prominent in photo (d). The ancient landslide noses out across the Powder River west of the present-day slide.

Columbia River Basalt Group flows interspersed with tuff horizons, all overlying an Imnaha Basalt flow. The core did not penetrate through the basaltic rimrock into the slide itself.

Ground water can move through the fractures in the basalt and can saturate the interflow beds of volcanic tuff as well as the weathered soil horizon that is presumed to exist at the top of the basement complex. Before the slide developed, ground water infiltrated the basalt in the slide area, as indicated by caliche formations within the fractures of the uppermost portions of the slide. These fissures, which formed as tensional cracks, are typically 5 ft wide and 400 to 600 ft long and are estimated to extend up to 100 ft in depth. Local ranchers have noticed a rejuvenation of springs within the slide complex over the past two years, indicating an increase in ground-water flow due to the higher than normal precipitation during this time. The severely weathered tuffs and ashes that comprise part of the slide have been devitrified to form bentonite clays which can act as glide planes in the presence of significant amounts of ground water.

Landslides occur when the strength of a mass of rock and soil supporting a slope is exceeded by the forces of gravity. The strength of the material in a slope can be gradually reduced by weathering, which softens the rock and soil and forms clay minerals. Some clay minerals swell and shrink with changes in moisture content and thereby help break up the rock. Certain clay minerals tend to become plastic and slippery when wet, and some lose cohesion when saturated. Water can dissolve the cementing agents that exist in some soil and rock, and the alternating freezing and thawing of the water promote fracturing and down-hill creep.

The effect of gravity is increased by increasing the angle of a slope either by erosion or by excavations. Water adds materially both to the weight and ease of movement of the mass. By filling pore spaces, cracks, and other openings, water reduces the internal cohesion of the rock and soil particles, making it easier for them to move. If only natural processes are involved, the conditions that result in a landslide generally take a long time to develop.

SEISMIC MONITORING OF THE RICHLAND AREA

Two poorly located earthquakes on August 10, 1984, and September 19, 1984, occurring contemporaneously with movement of the landslide, prompted concern from everyone involved with monitoring the slide. Earthquakes from eastern Oregon are generally not strong enough to be recorded on enough instruments to determine adequate locations by the National Earthquake Information Service (NEIS). Many events go unreported, except for those felt by persons located in isolated towns. All events with magnitudes less than 4.5 may have locational errors up to 20 mi. A quick check of historical seismicity near the landslide (Table 2) and inspection of earthquakes recorded during these two months on the University of Washington network revealed some interesting data. First, a magnitude-3.5 earthquake that occurred on March 29, 1983, in the general area may have been related to the later earthquakes. Second, a series of three earthquakes occurred on August 10, 1984; only the one occurring at 0726 GMT (12:26 a.m. PDT) with a magnitude of 3.5, as reported by NEIS, could be located. The other two events, both of magnitude 2.8, were precursors to the 0726 GMT event, but were not strong enough to be recorded on enough stations to be located.

Did the landslide cause the earthquakes, or did the earthquakes cause the landslides? The available seismic data could not answer these questions, as the locations of the earthquakes were poorly constrained. One way of locating these earthquakes is by monitoring aftershocks and assuming that the aftershocks occur at the same location as the main earthquake. Thus, it was imperative that seismic monitoring be initiated, so that these aftershocks could be recorded and located.

Five portable microearthquake seismographs were deployed in the area (Figure 1): at Richland (RCH), Halfway (HLW), Posey Valley (POS), Cornucopia (CRN), and the abandoned Blue Mountain Seismic Observatory (BMO) located about 2 mi directly north of the slide. Based upon the local structure (Basin and Range?) and historical seismicity, we felt that the seismic activity would be clustered around the community of Halfway, as this was where the September 19, 1984, earthquake was felt the strongest. The locations and durations of operation of each station are listed in Table 3.

Seismic activity was monitored continuously for four days. The two most active stations were BMO and RCH, each recording an average of one event/hour. Activity at the other stations ranged from 0.68 events/hour at POS to 0.23 events/hour at CRN. A histogram of seismic activity versus

Table 2. *Historical seismicity*

Year	Date	Origin time (GMT)	Latitude	Longitude	Depth (km)	Magnitude[1]
1915	10/20	0730	45.330°N	116.750°W	--	--
1916	5/13	0230	44.750°N	117.000°W.	--	VII
1927	4/9	0500	44.880°N.	117.200°W.	--	V
1927	4/9	0700	44.830°N.	117.320°W.	--	IV
1927	4/9	0930	44.820°N.	117.080°W.	--	IV
1927	4/9	1400	44.750°N.	117.230°W.	--	IV
1941	12/23	1748	44.750°N.	117.000°W.	--	IV
1942	6/12	0930	44.920°N.	117.000°W.	--	V
1942	6/12	0935	44.920°N.	116.870°W.	--	III
1942	6/14	0600	44.830°N.	116.920°W.	--	III
1963	9/6	1923 55.7	44.800°N.	117.100°W.	33[2]	--
1965	11/7	1641 47.4	44.900°N.	117.000°W.	5[2]	4.3
1966	12/30	0351 40.3	44.900°N.	117.000°W.	10[2]	4.2
1983	3/29	0136 59.4	44.790°N.	116.881°W.	5[2]	3.5
1984	8/10	0726 38.3	44.981°N.	116.970°W.	5[2]	3.5
1984	9/18	0132 06.1	44.958°N.	116.861°W.[3]	5[2]	3.5

[1]Roman numbers indicate the use of the modified Mercalli intensity scale, related to the visible and felt effects of earthquakes.

III: Felt by several people at rest.

IV: Felt by people in motion, disturbance of movable objects, cracking of ceiling.

V: Felt generally by everyone, disturbance of furniture, ringing of bells.

VI: Felt by people asleep, stopping of clocks, movement of trees.

VII: Overthrow of movable objects, fall of plaster, general panic.

Arabic numbers refer to the Richter scale. Each increase by one indicates a factor of about thirty increase in seismic energy.

[2]Depths of 5, 10, 33 km are commonly assumed when the depth cannot be determined.

[3]Location adjusted by using additional data from University of Washington.

time (Figure 5) confirms this activity rate and indicates a diurnal variation, especially prominent at BMO. A peak of seismicity occurs daily from 1800 to 0600 GMT (11:00 a.m. to 11:00 p.m. PDT). Most of these events are extremely small and are not recorded on the other stations, suggesting a source close by. Since BMO is within 2 mi of the landslide, we conclude that most of these small events are either rockslides or cracking associated with the landslide. The temporal variations suggest that most of the movement of the landslide occurs during the afternoon and evening, possibly related to cooling as the sun sets.

We attempted to locate all events that were recorded by at least four instruments. Of the eight events that fit this criterion, only two could not be located accurately with our network of seismic stations. Table 4 summarizes these results.

The event at 2247 GMT (3:47 p.m. PDT) on October 3, 1984, was determined to be a sonic boom located close to the south end of Richland. Two of us (RJ, JZ) heard the event as we were examining the records at BMO, and we were unsure of the cause at that time. Two distinct events were heard from the general direction of the Powder River Canyon. Upon reflection, however, we realized that the sound came more from the southeast, from the general area of Richland, in agreement with our later determination of its location based on our seismic recordings. It is rare to hear an earthquake, as most seismic energies are at frequencies just at and below those detectable by ear. Further, we experienced no shaking or vibration, which surely would accompany an earthquake large enough to be heard. If the waves had traveled through the air, as they would have done with a sonic boom, they would have traveled with a velocity of approximately 1,100 ft/sec (352 m/sec). In fact, this velocity was required to adequately locate the event, proving to us that it was a sonic boom.

The second event at 0838 GMT (1:38 a.m. PDT), October 4, 1984, is a moderate event with magnitude 2.1, as measured from the signal duration recorded on the seismograms of the earthquake. This event was located 5 mi east-southeast from RCH near the Snake River, at a depth of about 7 km. The crustal model used to determine its location is described in Table 5.

The four remaining events that could be located are in a narrow zone northeast of POS and 15 mi from the landslide. Given the uncertainty of our locations, we feel that all of these events could have come from the same location at a depth of about 9 km. The magnitudes were quite small, ranging from -0.2 to 1.0. The number and magnitude of these events were not unreasonable if they are considered to be an aftershock sequence of the August 10 and September 18, 1984, multiple-shock sequence. We surmise, then, that these moderate earthquakes occurred within this seismic zone at a depth of 9 km. If true, the error of the original location is on the order of 13 mi, well within the probable error of its determination. What is unusual, however, is that the seismicity rates indicate most activity would be located nearer the west end of Richland, rather than east of Halfway. The high level of seismic activity of one event/hour may be due to the landslide.

HISTORICAL SEISMICITY

The historical seismicity in the Halfway-Richland area is poorly documented. Most events prior to 1962 were located by reports of people who felt them, and thus the events tend to cluster around centers of population. A search of our archives yielded a sizable number of moderate events (Table 2) from 1915 to the present. Curiously, a periodicity of about 12 to 20 years appears. These events could very well be associated with a single seismic zone, the one we have located. If true, we could expect continued seismic activity east of Richland in the years ahead. Even more interestingly, the historical record suggests that a moderate earthquake is often followed by at least one other within 6 to 18 months. This pattern is most unusual and may possibly be useful as a predictive tool for earthquakes in this area.

CONCLUSIONS AND SUMMARY

We have ascertained that the landslide is largely or completely unconnected with the recent seismicity in eastern

Table 3. *Seismic station operation times*

Station	Latitude	Longitude	Time of operation (GMT)
Blue Mountain (BMO)	44° 51.07′N.	117° 18.25′W.	1746 3 Oct. — 1358 7 Oct.
Richland (RCH)	44° 44.30′N.	117° 08.75′W.	1920 3 Oct. — 0330 6 Oct.
Posey Valley (POS)	44° 47.82′N.	117° 01.95′W.	0100 4 Oct. — 1330 4 Oct. 1806 5 Oct. — 1633 7 Oct.
Halfway (HLW)	44° 52.30′N.	117° 08.26′W.	2035 3 Oct. — 1602 7 Oct.
Cornucopia (CRN)	45° 00.74′N.	117° 11.79′W.	2043 2 Oct. — 1111 3 Oct. 2052 3 Oct. — 1844 6 Oct.

Table 4. *Summary of earthquake activity*

Date	Origin time (GMT)	Latitude	Longitude	Depth (km)	Magnitude
10/3/84	2247 49.08	44° 45.15′N.	117° 08.62′W.	0.00	Sonic boom
10/4/84	0838 21.80	44° 42.37′N.	117° 02.95′W.	6.68	2.1
10/4/84	1046 48.09	44° 48.14′N.	117° 01.44′W.	6.90	-0.2
10/4/84	1315 42.67	44° 48.16′N.	116° 52.74′W.	9.57	1.0
10/4/84	1703	Borah Peak, Idaho, aftershock(?)		(?)	4.0
10/4/84	2201	Cannot locate, SE of array(?)		(?)	2.7
10/5/84	2139 27.94	44° 48.36′N.	117° 00.27′W.	9.00	0.9
10/5/84	2228 18.17	44° 48.61′N.	116° 59.57′W.	9.09	0.3

Figure 4. Oblique view looking northeast at the landslide on September 24, 1984.

Oregon. The slide area first fissured well before the first earthquake and moved significantly before the second earthquake. Further, we have located an active, narrow zone of seismic activity east-northeast of Richland and far enough away from the slide to preclude its being the direct cause of the landslide. The activity of this seismic zone, along with its historical record, deserves further investigation, particularly if it can be associated with a surface fault of any kind. The proximity of the seismic zone to various dams on the Snake River also warrants further investigations. These dams, however, are designed to withstand much more severe earthquakes.

What then caused the landslide? Certainly, the geological formations — incompetent ash and tuff beds that are heavily altered and weathered — are conducive to landslides. Landslides are not uncommon in that part of eastern Oregon: several slides of various scales were observed in the area. In fact, a landslide had previously occurred on the south side of the Powder River. We believe that the immediate cause of the present landslide was the increase of ground water, due to the recent heavy winters in the area. Steven Shold, the rancher near the slide, mentioned that several springs had been rejuvenated on the hillside in the past couple of years. If the ground water infiltrated an ash zone, a glide plane may have formed. If the canyon walls are steep enough, a landslide is likely to occur. Our observations of the slide indicated a high amount of water under the toe of the slide. The heavy rain of August 31, 1984, may have been the final factor in promoting the movement of the landslide.

We have already determined that the landslide began to move before any of the 1984 earthquakes occurred. In general, significant earth motion due to large earthquakes can help liquify the soil and may cause landslides. Usually, such landslides are in very close proximity to the epicenter and are sometimes used to help locate earthquakes when adequate instrumental coverage is unavailable. The local earthquakes were too far away to be the direct cause of the landslide, even if the above-mentioned timing of the events is in error. Could these earthquakes promote the movement of the landslide itself? We have calculated the expected ground motion from a magnitude-3.5 earthquake at a distance 15 mi away. The ground motion is insufficient to cause any significant liquefaction of the soil. We are certain that the dominant cause of the landslide was the incompetent material and the increased flow of the ground water.

Table 5. *Crustal model used for earthquake hypocenter determination*

Layer	Velocity (km/sec)	Depth (km)
1	6.10	0.0
2	6.90	9.0
3	7.97	43.0

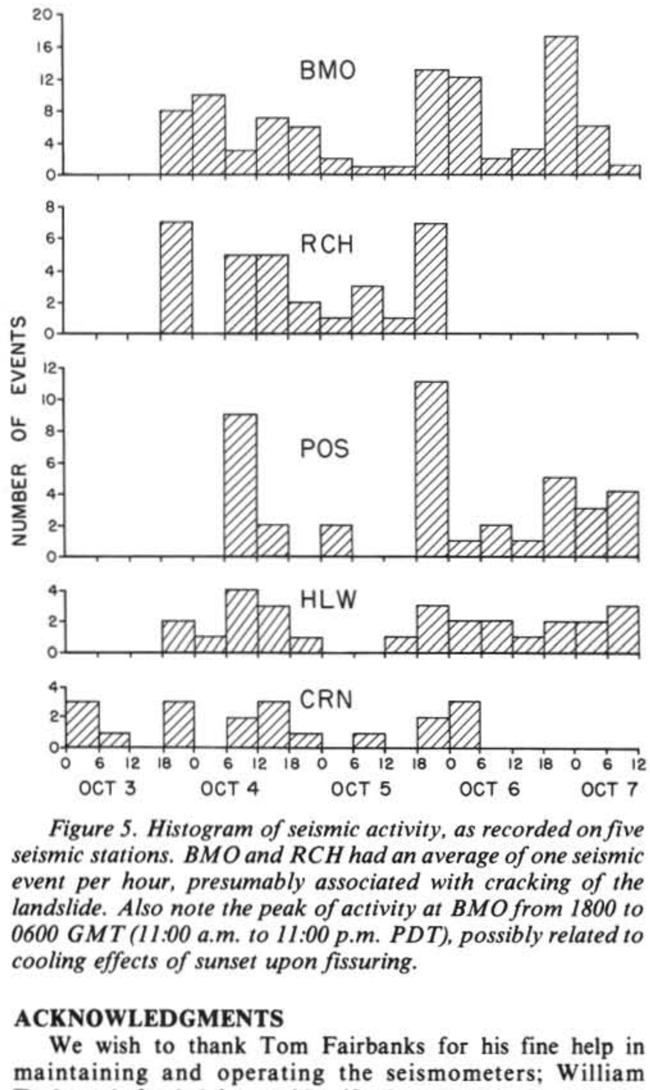


Figure 5. Histogram of seismic activity, as recorded on five seismic stations. BMO and RCH had an average of one seismic event per hour, presumably associated with cracking of the landslide. Also note the peak of activity at BMO from 1800 to 0600 GMT (11:00 a.m. to 11:00 p.m. PDT), possibly related to cooling effects of sunset upon fissuring.

ACKNOWLEDGMENTS

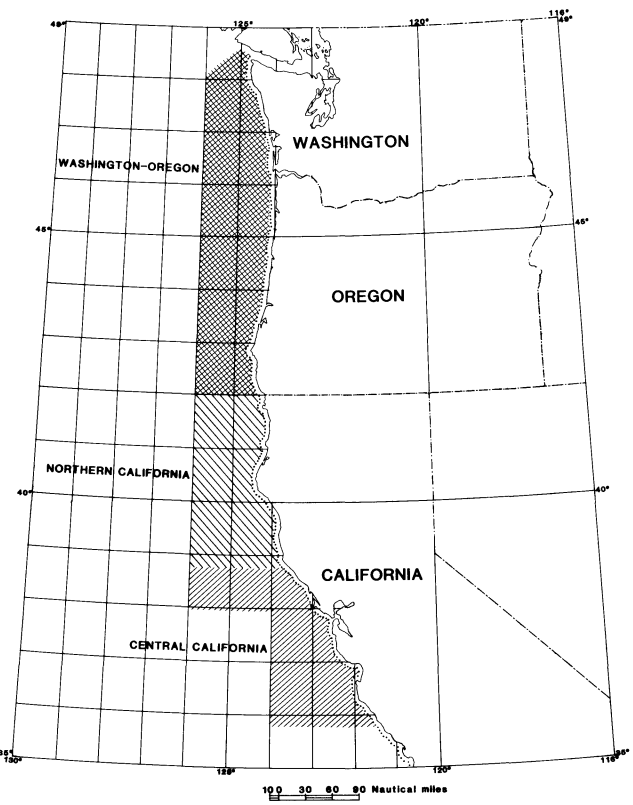
We wish to thank Tom Fairbanks for his fine help in maintaining and operating the seismometers; William Taubeneck for helping to identify the core samples and the gabbro at the edges of the slide; Vern Moore, George Machan, Gordon Cochran, and Bob Matheson of the Oregon Highway Division for bringing the slide and earthquake activity to our attention; and Steve and Grant Should for their outstanding documentation on the landslide. We would also like to acknowledge the generosity of Larry Bush of UNC Mining and Milling for allowing us to put a seismometer on their property at Cornucopia. Finally, we wish to thank the citizenry of eastern Oregon for their cooperation, friendliness, and interest in our project.

REFERENCE

Prostka, H.J., 1962, Geology of the Sparta quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-1, scale 1:62,500. □

Oregon-Washington OCS named on five-year MMS proposed oil and gas program

The Minerals Management Service (MMS) announced in the *Federal Register* on March 22, 1985, that the Oregon-Washington outer continental shelf was included along with 24 other areas in its draft proposed five-year oil and gas leasing program. The area, shown in the accompanying map, would be leased during 1991 if the program is approved. Comments are requested on specific topics listed in the announcement and are due by May 20, 1985. The comments should be marked "Comments on the Draft Proposed Five-Year OCS Leasing Program" and should be submitted to: Deputy Associate Director for Offshore Leasing, Minerals Management Service, Mail Stop 641, 12203 Sunrise Valley Drive, Reston, VA 22091.



Outer Continental Shelf (OCS) oil and gas planning areas.

MMS also announced its intent to prepare an environmental impact statement for the proposed leasing program. Scoping comments are due by May 20, 1985. They should be marked "Scoping Comments on the Proposed Five-Year Leasing Program EIS" and should be submitted to: Daniel Henry, Minerals Management Service, Mail Stop 644, 12203 Sunrise Valley Drive, Reston, VA 22091. □

Geology career information available

The American Association of Petroleum Geologists (AAPG) and the American Geological Institute (AGI) have jointly produced a new leaflet, *Careers in Geology*. The leaflet describes briefly what geology is, what geologists do, where they work, what the job outlook is, and where sources of additional information can be found. Single copies are free upon request; additional copies cost $20 per hundred. Copies are available from Andrew J. Verdon, Director of Education, AGI, 4220 King Street, Alexandria, VA 22302; and also AAPG, Box 979, Tulsa, OK 74101. □

Arthur G. Heizenrader dies in Portland

A prominent figure in Oregon's mineral industry, Arthur G. Heizenrader, died April 13 in Portland. He was 61 years old.

Heizenrader was managing director of the Oregon Concrete and Aggregate Producers' Association, Inc., and secretary-treasurer of the Oregon Chapter of the American Concrete Institute.

In the course of his long association with the aggregate industry in Oregon, Heizenrader was instrumental in the coordination of the activities of the mining industry with the regulatory functions of the Oregon Department of Geology and Mineral Industries. □

New collection shown at State Capitol mineral display

The Portland Earth Science Organization (PESO) has installed an extensive display of Oregon materials in the State Capitol display case of the Oregon Council of Rock and Mineral Clubs. The exhibit was arranged by Evelyn Davis, PESO president, Fred and Alyce Meikle, and Don Serafin.

The new display, which will remain until May 31, features more than 90 separate items in 29 groups. The specimens were collected in 10 different counties of the State. The colorful variety includes spheres, cabochons, slices, rough rock, thunderegg halves, bookends, rough and faceted sunstones, petrified wood, and many different kinds of agates.

In June of this year, the PESO display will be followed by an exhibit provided by the Roxy Ann Mineral Club of Medford. □

GSOC meetings announced

The Geological Society of the Oregon Country (GSOC) holds noon luncheon meetings in the Standard Plaza Building, 1100 SW Sixth Ave., Portland, Oregon, in Room A adjacent to the third floor cafeteria, and evening lectures (8 p.m.) at Portland State University, Room 371, Cramer Hall. Upcoming meetings, topics, and speakers are:

May 17 (luncheon) — *Haleakala Volcano on Maui*, by Robert L. Gamer, senior geologist, Foundation Sciences.

May 24 (lecture) — *Yugoslavia's Karst Topography*, by Thomas M. Paulsen, Head, PSU Geography Department. Dr. Paulsen was in Yugoslavia in 1966-1967 under a Fulbright Research grant. Since then he as been there many times, most recently in 1983.

June 7 (luncheon) — *Another Look at the Arches National Monument*, by Lloyd A. Wilcox, Honorary Life recipient and former GSOC president.

June 14 (lecture) — *Springtime in the Mojave*, by Donald D. Barr, naturalist and GSOC past president.

June 21 (luncheon) — *A Visit to the George C. Page Museum of La Brea Discoveries*, by Frank and Frances Rusche, members of Oregon Agate and Mineral Society and GSOC.

June 28 (lecture) — *Anza Borrego Desert*, by Lloyd A. Wilcox, GSOC past president.

July 5 (luncheon) — *GSOC President's Campout in the John Day Area*, by GSOC President Donald B. Parks.

For additional information about the lectures or luncheons, contact Viola L. Oberson, GSOC 50th President, phone (503) 282-3685. □

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