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AUGUST 1986



THIS MONTH:
OIL AND GAS EXPLORATION
FOR THE NONGEOLOGIST

OREGON GEOLOGY

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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 the 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

Southeast Oregon country typical of the area covered by a study of geochemical data that was recently released by the U.S. Bureau of Land Management. See announcement and discussion on page 98. Photo courtesy Oregon State Highway Division.

OIL AND GAS NEWS

State Land Board adopts offshore rules

On June 27, the State Land Board, consisting of the Governor, Secretary of State, and State Treasurer, adopted new Oregon Administrative Rules governing offshore geological, geophysical, and seismic surveys in State waters. The rules, which had been in preparation for a year, will apply to oil, gas, and sulfur exploration under State-owned waters. This includes tidal submerged lands and extends to the 3-mi line offshore. No drilling or explosive techniques will be allowed under these rules.

The Land Board and Division of State Lands anticipates offshore surveys by the oil industry leading to eventual leasing in State waters. The rules, codified as OAR 141-10-201 through -290, will govern such surveys. In the near future, similar rules will be written for offshore exploration for metallic and industrial minerals, such as those found in placer deposits.

The newly adopted rules set forth a permitting process and a fee and bond structure for geological and geophysical surveys. The opportunity for a public hearing is provided, as well as public notice of impending surveys. Results are to be reported to the State if specified by the Division and are treated as confidential.

Copies of the new rules can be obtained from the Division of State Lands, 1600 State St., Salem, OR 97310, phone (503) 378-3805.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft), use
368	ARCO CFI 41-4 009-00205	NE¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Application; 2,400.
369	ARCO CFI 31-22 009-00206	NE¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Application; 2,400.
370	ARCO CFI 12-5 009-00207	NW¼ sec. 5 T. 5 N., R. 4 W. Columbia County	Application; 4,850.
371	ARCO CFI 12-12 009-00208	NW¼ sec. 12 T. 5 N., R. 5 W. Columbia County	Application; 2,400.
372	Oregon Natural Gas Dev. OM 32a-11 009-00209	NE¼ sec. 11 T. 6 N., R. 5 W. Columbia County	Application; 3,000; gas storage.
373	Oregon Natural Gas Dev. IW 34d-3 009-00210	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 2,800; gas storage.
374	Oregon Natural Gas Dev. OM 43c-3 009-00211	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 3,000; gas storage. □

Correction

In last month's issue (v. 48, no. 7, July 1986), two errors occurred in the article on the Willamette meteorite: On p. 79, the weight of the meteorite is, of course, "31,107 lbs. or slightly over 15½ tons." And on p. 80, the name of the mineral that is one of the meteorite's components is, of course, "troilite."

Oil and gas exploration (for the nongeologist)

by Wesley G. Bruer, Consulting Geologist, St. Helens, Oregon 97051

This is the first in a series of articles on the oil and gas industry that have been written for *Oregon Geology* by people who work in various occupations within the industry itself. This particular article tells in nontechnical terms how oil and gas form and why they are found where they are. Future articles, which will appear at irregular intervals in upcoming issues of *Oregon Geology*, will discuss such topics as leasing and geophysical exploration.

— Editor

INTRODUCTION

If you have ever passed by an oil drilling rig, a well producing oil or natural gas, or an abandoned drill site and wondered how it was decided to drill in that particular place, then this article may be for you.

Exploratory wells are drilled with the hope of finding an underground accumulation of oil or natural gas, collectively known as hydrocarbons, big enough to be worth developing commercially. Before such an accumulation, or pool, can form, certain conditions must be met in the area. First, there must be or have been source rocks, that is, rocks containing enough organic material to have served as a source for the hydrocarbons. Second, there must be rocks, called reservoir rocks, that are porous enough to have space available to be occupied by the hydrocarbons and permeable enough to allow fluids to move in and out of the rocks. Third, there must be a layer of cap rock that is not readily permeable to oil or gas and that is in a position to hold the hydrocarbons in the reservoir. Fourth, there must be a trap, that is, the rock units in and near the pool must be shaped in three dimensions in such a way as to cause the hydrocarbons to migrate into, accumulate in, and stay trapped in the pool. And fifth, all of these necessary rocks and relationships must have come into being and have been properly shaped in the right sequence over sufficient geologic time. Together, we will consider each of these factors in more detail below. Since all of them must exist at the same place and time, you may already have an inkling as to why oil and gas fields occur under such a tiny fraction of the earth's surface.

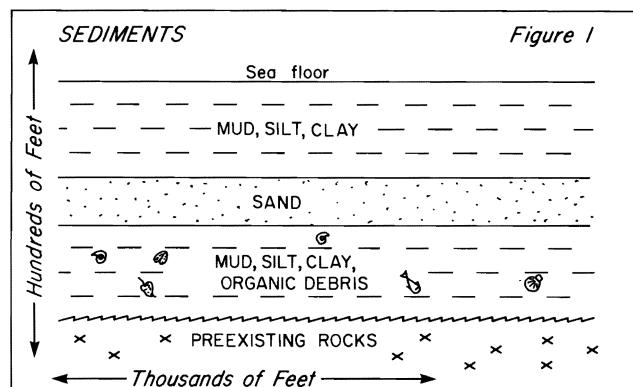
SOURCE ROCKS

In addition to water, streams carry a fluctuating load of sediment to the sea or to lakes. For our purposes, the term "sea" will also include "large lake." Rock and mineral particles make up most of this load. Depending on the climate, the volume, velocity, and gradient of the stream, and the nature of the countryside drained by the stream, these particles can range in size from boulders down through gravel, sand, silt, and clay.

Organic debris is also part of the sediment load. This may include everything from uprooted trees and large animal remains down through sticks, leaves, dead fish, insects, peat dust, algae, pollen, spores, and other microscopic plant and animal remains.

On reaching the sea, stream currents dissipate, their velocity decreases, and the sediment load tends to settle out. Sometimes this happens in the lower reaches of the stream itself. Other agents, such as ice and wind, can also carry material to the sea. Sediments derived from land are joined in the sea itself by organic remains, especially of plankton, and by rock and mineral particles originating within or at the margins of the sea. Waves, tides, and currents may continue to transport all or part of the sediments, but eventually they are deposited on the bottom.

Swift currents or vigorous wave action can carry heavy particles. Where a current begins to slow, it drops the heaviest part of its sediment load, such as boulders and cobbles. As it continues to slow, it will drop the pebbles, then the sand-size grains, then silt, and finally clay particles. Thus, sediments tend to



get segregated by size as they are deposited. Organic material, being of lower density than most inorganic particles, commonly ends up with the fine-grained sediments, that is, silt and clay (Figure 1).

The organic part of the sediments that is not destroyed by living organisms or by chemical reaction (mostly oxidation), during transport is, of course, deposited along with the inorganic particles. With continued deposition, the organic material is eventually buried deeply enough to preserve it from living organisms, especially bacteria. Preservation is usually best in the finer grained sediments.

Bacterial destruction of organic material can itself result in the generation of methane, the principal constituent of natural gas. Present-day examples are "marsh gas," "sewer gas," and "landfill gas." Some gas generated by bacterial action in the geologic past has been trapped in underground reservoir rocks and is commercially produced from wells drilled into such pools. However, it has been estimated that only about 5 percent of all natural gas produced originated in this way; the remaining 95 percent is the result of deep burial (see below). In recent years, there have been successful efforts to use sewer gas and landfill gas directly, including two landfill gas recovery projects operating in the Portland, Oregon, area.

Areas in which sediments have accumulated over long periods of time, usually measured in millions of years, are known as "sedimentary basins." In some basins, sediments (and the sedimentary rocks that they become) are tens of thousands of feet thick. As sediments accumulate, the original floor of the basin typically continues to warp downward so that the surface remains a basin and sediments continue to be deposited there. Even relatively slow rates of deposition can add up to a thick section of sediments over geologic time. For example, the accumulation of sediments at a rate of 1 inch (in.) per 100 years would result in a thickness of 1 foot (ft) in 1,200 years and 10,000 ft in 12 million years.

With the increased pressure of burial, the sediments are compressed and become sedimentary rocks. Gravel, cobbles, and boulders become "conglomerate," sand becomes "sandstone," silt becomes "siltstone," and clay becomes "claystone" or

"shale." The term "shale" is sometimes used in the oil and gas industry to include all the fine-grained sedimentary rocks, that is, everything finer grained than sandstone. That's the way we will use it here.

Temperatures within the earth's crust increase with depth. Usually this increase is 1 or 2 degrees Fahrenheit (F) for each 100-ft increase in depth, although it can be much higher in some places such as young volcanic areas. Thus, in an area with an average surface temperature of 50° F and a temperature gradient of 1.5° F per 100 ft, the temperature at a depth of 10,000 ft would be 200° F.

As organic material in the sediments is progressively buried and heated, it slowly changes form. Finally, when a critical temperature is reached and held or exceeded over a sufficient period of time, part of the organic material is converted to droplets of oil or bubbles of gas. The longer the organic material is exposed to elevated temperature, the lower that temperature needs to be to cause the conversion. For example, it has been estimated that for burial of longer than 75 million years, a temperature of only about 150° F is required to begin the conversion to hydrocarbons; to begin conversion in less than about 20 million years, the temperature must be on the order of 200° F or more.

There is almost always some natural gas associated with underground oil accumulations, with the gas being either in a free state or dissolved in the oil or both. However, there are many "dry gas" accumulations, that is, pools containing gas only, with no liquid hydrocarbons present. This is sometimes due to the type of organic material originally preserved in the source rock. Woody plant remains tend to be converted to natural gas, while waxy plant material and fatty animal remains tend to become both oil and gas. Other dry gas accumulations are the result of another process (see below).

With continued increase of temperature or length of burial time beyond that necessary to begin conversion of source material to hydrocarbons, the conversion will continue within certain limits. Depending on the length of burial, as we discussed above, after the temperature increases beyond a range of 275° to 375° F, no more oil will be generated, but only gas; in fact, any oil still within the source rock will begin to break down into gas at and above these temperatures. This process explains the occurrence of many dry gas fields. Finally, and again varying with the length of burial, above temperatures ranging from 350° to 450° F, even natural gas generation will cease, and any remaining organic material will eventually become solid carbon.

All of the above assumes that the sedimentary rock contains enough organic material to generate significant amounts of hydrocarbons. This is not always the case. Some rocks are so barren of organic material that they can never become source rocks, regardless of their burial history.

Now that we have discussed the generation of oil and gas, we need to consider what happens to it.

RESERVOIR ROCKS

Under certain conditions, many kinds of rock can be both porous (having pore spaces available to contain fluids) and permeable (having pore spaces connected so that fluids can move through the rock) and can therefore be capable of serving as reservoir rock. These include any hard, brittle rock such as granite, limestone, basalt, chert, or hard shale that is extensively jointed or fractured. Limestone fossil reefs can be very porous and permeable because they may contain now-empty living spaces once occupied by the reef-building organisms. Other kinds of limestone (and its close cousin, dolomite) may be suitable reservoir rocks because of selective partial solution by water. However, on the West Coast, sandstone is by far the most common reservoir rock for oil and gas. The only commercial hydrocarbon production in the Northwest (at the Mist gas field in

Oregon) is from sandstone reservoirs. Therefore, our further discussion of reservoir rocks will center on sandstone, but much of it will also apply to other porous and permeable rocks.

It is easy to imagine oil or gas wells as producing from underground caves or rivers or lakes full of the stuff. However, that is not the way it works. It is harder to visualize the little pores in the rocks underground that actually contain oil or gas. Let's try it this way. Imagine a 10-gallon (gal) bucket filled level full of marbles all of the same size. You can pour a little more than 2½ gal of water into that bucket full of marbles before the water spills over. Furthermore, you can put a screen or grate over the bucket and pour all the water out, except for a thin film around each marble. More than a quarter of the marble-filled bucket "reservoir" is pore space (porosity), and the water goes in and out readily, demonstrating that it is permeable (permeability).

In the above example, the size of the marbles, within certain limits, doesn't matter, as long as they are round and of the same size (well-sorted). Rounded sand grains, even as small as 0.1 millimeter (mm) or a little less in diameter, will give a similar result, except that there will be a greater amount of water retained as a film around the grains. The same sort of thing would result using gas or very "thin" (low viscosity) oil instead of water; with thicker (higher viscosity) oil, the effectiveness of the permeability will be reduced.

If the size of the marbles or sand grains varies greatly (poorly sorted), then the smaller ones will fill part of the voids (pores) between the larger ones, thereby reducing the porosity. If enough clay or silt particles are mixed with the sand grains ("dirty" sand), they can completely choke the pores and greatly reduce the effective porosity and permeability. Also, in nature, certain minerals such as calcium carbonate or silica can solidify in the pore spaces of sandstones, thereby partly or completely closing (cementing) them. Finally, if the grains are angular rather than round, the sharp corners will tend to project into what would otherwise be pore space if the grains were round, thereby reducing porosity.

Our ideal sandstone reservoir rock then consists of well-sorted, well-rounded, clean, and uncemented sand grains. And while we are wishing, we would also like the sandstone to be nice and thick and to extend over many square miles. In real life, we seldom get ideal and gladly settle for adequate, if we can get it.

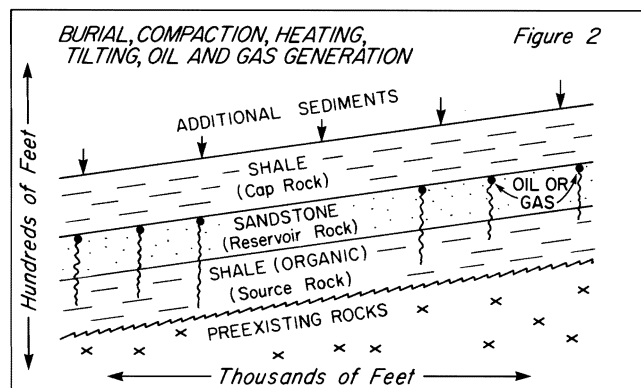
Suitable reservoir sandstones did not all originate as sand deposited in the sea. Sands deposited in such features as dunes, river bars, stream-channel fills, deltas, or alluvial fans can become reservoir rocks if the resulting sandstones are porous and permeable.

We left our source-rock discussion with oil and gas neatly generated into droplets or small bubbles but still within the source rock, mostly likely a shale. How does it get from there into the reservoir rock?

When sediments, including those that eventually become source rock, are deposited in an aqueous environment, they are completely saturated with water. With the pressure of burial, the sediments are progressively compressed, and water is squeezed from them. While sands typically lose only about 5 percent of their thickness this way, shales may be compressed as much as 40 percent. In addition to free water within the mass of sediments, some clays also contain chemically combined water. After gas and oil have been generated, it is thought that additional compression expels the finely divided hydrocarbon from the source rock along with some of the remaining water. In this way, oil and gas are slowly flushed into adjacent reservoir rock. The source rock can be below, above, or alongside the reservoir rock, just so long as the two are adjacent.

Reservoir sandstone is also saturated with water unless and until the water is displaced by something else. Because they are lighter than water, oil droplets or gas bubbles entering the water-filled pore spaces will work their way vertically upward through

the permeable rock. If the reservoir rock is thick enough to extend up to the surface of the land or the floor of the sea, the oil and/or gas will escape there as a "seep." If the reservoir rock is covered by a layer of rock that is not permeable, the vertically buoyant movement of the hydrocarbons will stop at the boundary (Figure 2).



CAP ROCKS

Any rock layer that is not readily permeable to oil or gas can stop the vertical migration of hydrocarbons. In most sedimentary basins around the world, the most common effective seals, or cap rocks, for reservoir rocks are salt, anhydrite (calcium sulfate), and unfractured shale. Beds of salt and anhydrite usually result from long periods of evaporation; these are not important as cap rocks in West Coast oil and gas fields, so we shall limit our discussion to shale cap rock, including siltstone, claystone, and mudstone.

To be effective, cap rock must extend unbroken over the areas of hydrocarbon generation and of eventual accumulation, as well as any area between. Otherwise the hydrocarbons will work around the shale body and resume their vertical migration. Other things being equal, the thicker the shale body, the more likely it will be to continuously cover a large area.

In order to be sufficiently impermeable to act as a seal, especially for natural gas, shale must have been compressed enough for most of the interconnected water-filled pore spaces to have been eliminated from the original sediments. Otherwise gas will rapidly diffuse and escape upward through such pores. On the other hand, the shale must not have become brittle enough to fracture readily under stresses and strains within the earth's crust.

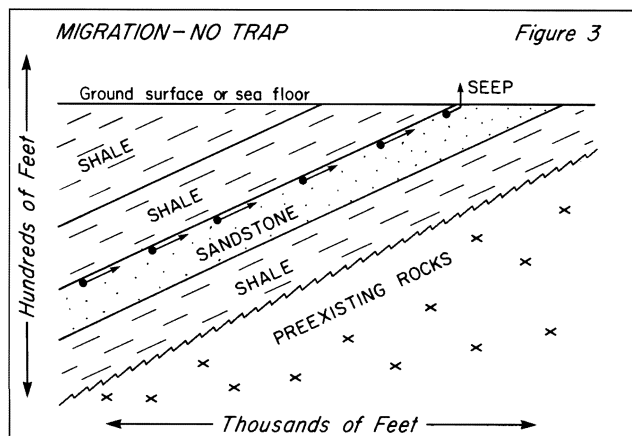
We have talked about cap rocks in their capacity as a top seal on the reservoir rocks. However, for a thickness of hydrocarbons to accumulate, a seal (cap rock) must be present to prevent lateral movement also.

TRAPS

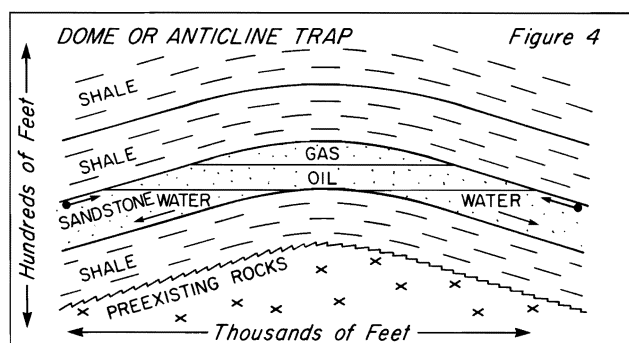
We think of the earth's crust as being more or less stable, at least between earthquakes and volcanic eruptions. In fact, over geologic time, Mother Earth has been very active in terms of movement. Consider, for instance, that sedimentary rocks containing the fossilized remains of sea creatures are present at or near the top of many peaks in the Rocky Mountains. As well as having been uplifted, parts of the crust have been shoved together, spread apart, downwarped, tilted, folded, and broken and offset along the breaks (faults). Almost all areas of the globe have been or currently are being subjected to one or more of these dynamic processes. Consequently, nearly all rock layers are tilted or otherwise deformed to some degree. Fortunately, in most cases, these movements take place so slowly that they are unnoticed by human beings.

We left our migrating oil droplets and gas bubbles stopped (momentarily) in the upper part of the reservoir rock at its contact

with overlying cap rock. They cannot penetrate the cap rock vertically, but their buoyancy will continue to carry them laterally and upward at a slant under the contact. The hydrocarbons may continue their upward inclined migration to the surface of the ground or to the sea floor, where they will leak out as a seep (Figure 3). Or their upward migration may be stopped at some point by the configuration of the reservoir and cap rocks, and the hydrocarbons will accumulate in this trap.



There are many kinds of hydrocarbon traps. The easiest to visualize is a dome-shape trap, in which the underground reservoir rock and its overlying cap rock are arched up from all directions to an apex (or, as the geologist says, it dips in all directions down from the apex) (Figure 4). Hydrocarbons migrating upward in the reservoir rock just under its contact with the cap rock can go no higher than the top of the reservoir rock at the apex of the dome. Here, the hydrocarbons begin to collect. As they do so, the water previously in the pore space is displaced downward.



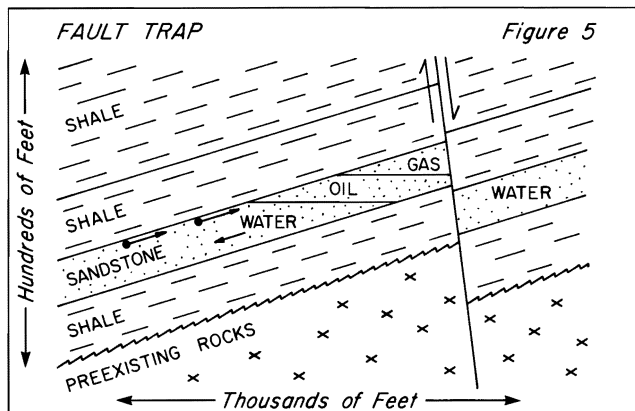
If both oil and gas are trapped, they will begin to segregate in the reservoir, with the lighter gas above the oil, which in turn will stay above the still heavier water. The quantity of hydrocarbons in the trap will increase as long as migration into it continues, until it is full and further additions spill out, or until it is ruptured or otherwise destroyed.

In a dome-type trap, the same cap rock that serves as the top seal over the apex dips down to or below the base of the hydrocarbon accumulation and therefore also serves as the lateral seal for the trap.

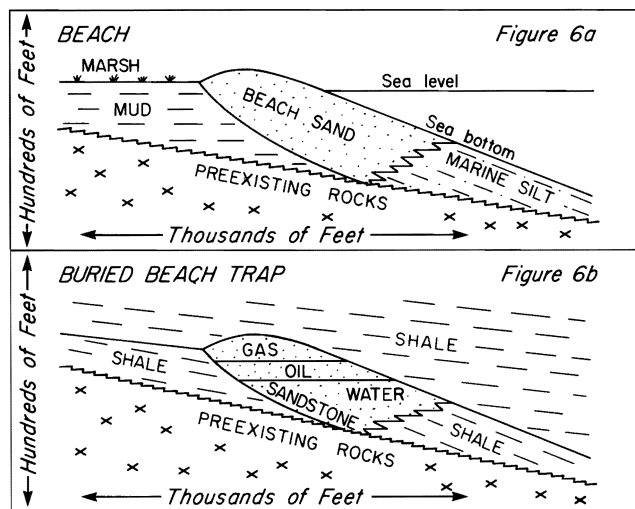
Folds in the rock layers that are convex upward (called anticlines) occur more commonly than domes, but the trapping process is similar (Figure 4).

Where the rock layers are broken along a plane and the rock on one side of the break is displaced relative to the other side, a fault trap can result (Figure 5). If the reservoir rock at the up-tilted (updip) edge on one side is offset against cap rock on the other side

of the fault, then hydrocarbons migrating up to the fault cannot cross it. (Except at very shallow depths, faults do not normally stand open but are self-sealing because of the pressures at depth.) Hydrocarbons will then begin to accumulate at the highest part of the reservoir against the cap rock above the reservoir and laterally against the cap rock across the fault.



The segregation of different sediments during their deposition can later result in traps. For example, sand bars, sand beaches, sand-filled stream or tidal channels, and sand dunes may develop while mud (or silt or clay) is being deposited on one or more sides of them and, later, over their tops as well. After millions of years, those sands may have become potential underground sandstone reservoirs, with their updip edges sealed in the shale that the fine-grained sediments have become (Figures 6a and b).

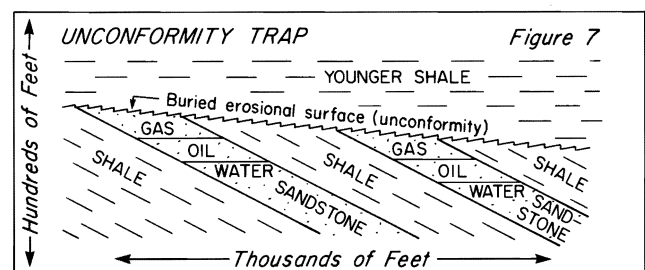


Some kinds of erosion followed by selective deposition and subsequent burial can also create traps. One example would be a stream valley that has been cut into shale bed rock, later filled with sand from the stream, then submerged along with the surrounding area, and finally covered by a thick layer of mud. The sand-filled channel could eventually become a potential underground sandstone reservoir with lateral seals of older shale on at least two sides and a top seal of younger shale. Another example would be tilted beds of alternating sandstone and shale eroded to a near-horizontal surface (an unconformity), with that surface later being covered with silt, clay, or mud (Figure 7). After further burial and compaction, the younger blanket shale could serve as a top seal, and the older shale beds could serve as lateral seals to the reservoir sandstones.

There are many other kinds of traps, including those caused by differential cementing of reservoir rocks or by differential fracturing of otherwise nonreservoir rocks. And, of course, there

are combination traps resulting from the interaction between two or more trapping mechanisms.

On occasion, an unsuccessful exploratory well, known in the industry as a "dry hole," is drilled into a theoretically good trap containing adequate reservoir and cap rocks in a basin containing rocks that obviously generated hydrocarbons.



SEQUENCE

Even if all the right physical features necessary for an oil or gas accumulation are present, it comes to naught if they did not develop in the right sequence. For example, when hydrocarbons are first generated, if there is no reservoir rock nearby, they may remain dispersed in impermeable source rock. When hydrocarbons migrate into reservoir rocks, if there is no cap rock already in place, they may be lost to the surface. This would also be true if no trap exists along the route at the time of migration, or if a preexisting trap has been breached by erosion, faulting, or adverse tilting of the rocks. And, of course, even if all of the parameters otherwise necessary for hydrocarbon accumulation are present, if the potential source rocks have not been buried deeply enough or long enough, the trap is likely to be barren.

So in exploring for oil and gas accumulations, as in cake making, just having all the ingredients does not assure success. In either case, if they are not combined and baked properly, the result will be less than desirable.

EXPLORATION METHODS

How do we go about determining if a given unexplored or relatively unexplored area has oil or gas potential? Fortunately, much can be learned from the surface.

First, we must determine if the area is in a sedimentary basin. Typically, at least some of the sedimentary rock layers of a basin are tilted up and exposed around the edges. In arid climates, bed rock may be exposed and accessible for inspection over broad areas. In wet climates such as that of western Oregon, the bed rock is usually deeply weathered and covered with soil and dense vegetation, and outcrops of bed rock are often limited to stream cuts and road cuts. Inspection of even small, scattered outcrops will usually tell us quickly whether or not they are part of a sedimentary basin.

At least some of the rocks buried thousands of feet below the surface in the deeper parts of the sedimentary basin may be represented in basin-edge surface outcrops. Close examination of these outcrops in the field can give the experienced geologist a fair idea as to whether the basin possibly contains hydrocarbons. Later, physical and chemical laboratory tests of rock samples taken from the outcrops can quantitatively determine such things as porosity and permeability and the type, quantity, and stage of transformation of contained organic matter.

The ages of rock layers may be determined if fossils are present. The relationship of rocks in different areas can often be determined on the basis of their ages. Especially important are small fossils called microfossils, which are fossil shells of tiny aquatic animals and some fossil plant remains, such as pollen, that generally require a microscope for identification. These can sometimes be matched directly with microfossils taken from well-bore drill cuttings, since many of them survive the drilling

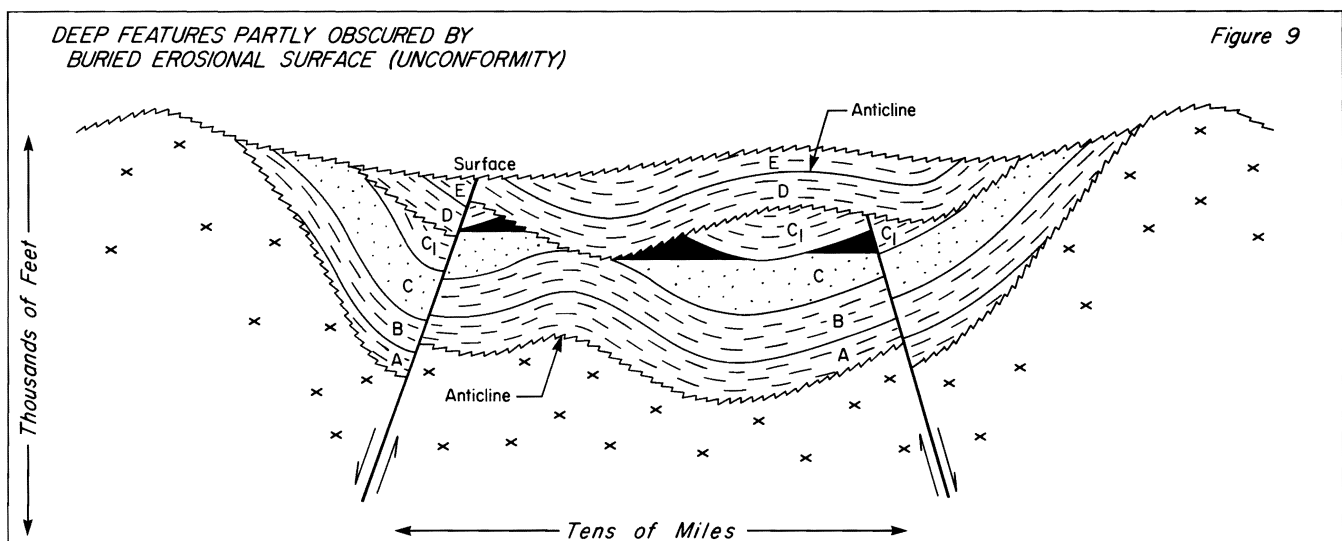
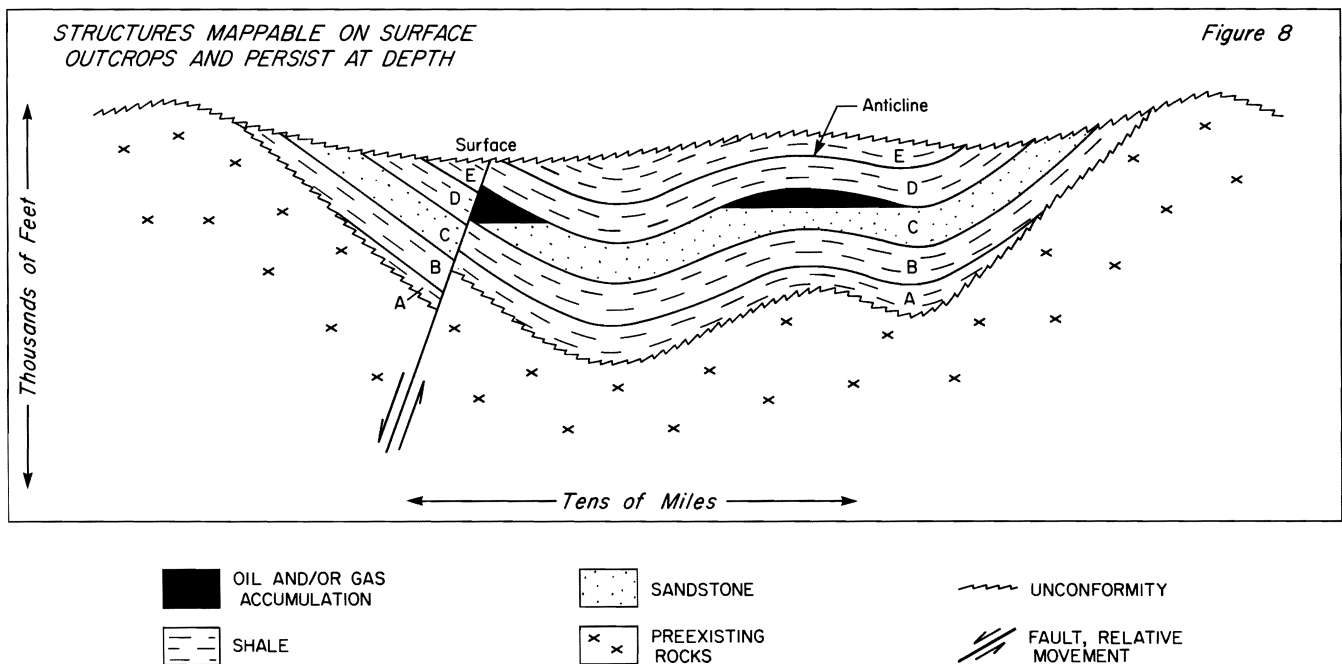
action that usually destroys larger fossils. Sometimes the age of a rock can be determined from the relative abundance of certain radioactive elements and their isotopes or from the degree of chemical alteration of some minerals.

Basin-edge sedimentary rock outcrops are not necessarily representative of all of the rocks concealed in the subsurface in the central part of the basin. Some of the sediments deposited deeper in the basin may not have been deposited around the edges; periods of uplift and subsequent erosion may have taken place, resulting in the removal of relatively more rock near the edges. Furthermore, it often happens that one kind of sediment was deposited near the edge at the same time that another kind of sediment was deposited in the central part of the basin.

Nevertheless, rock outcrops generally provide good clues as to whether (1) potential source rocks are present in the basin and whether they have at some time been buried deeply enough and long enough to have generated hydrocarbons, (2) potential reservoir rocks are likely to be present, and (3) potential cap rocks exist.

Surface-rock outcrops are not necessarily limited to the edges of sedimentary basins. However, outcrops in the central part of a basin, if they occur, are usually of rocks younger than those exposed around the basin edges. Because they are at the surface, these rocks are probably not objectives for drilling. However, the direction and angle of tilt of these exposed rock layers can be measured from place to place, and the presence of faults and folds can often be detected. In this way, the overall geometric shape or structure of the rock layers can be constructed. Folds, tilted fault blocks, and other potential hydrocarbon trap shapes mappable in outcrops can be the surface expression of those kinds of traps in older, favorable rocks at depth (Figure 8). In such case, all we have to do is drill into it and — bingo! — we're in business. Sometimes it even happens that way!

More often, it does not work that way. The folding or faulting mappable at the surface may have taken place so recently that the hydrocarbons migrated before the trap formed. Or, the favorable characteristics we saw in the older rocks in outcrop at the edge of the basin do not extend as far as our drill site area. Or, the



older rocks may have been folded or faulted and then uplifted and beveled off by erosion prior to deposition of younger sediments now exposed on the surface, so that surface structures do not coincide with deep subsurface structures (Figure 9).

We may have outcrops between the central basin and the basin edge in which the relationships between various rock units can be partially seen, but even this is not likely to pinpoint a subsurface trap.

Oil or gas pools, especially those full to overflowing, may leak a little. This may result in an oil or gas seep at the surface, which can be a very good sign. On the other hand, a seep may be an indication of no trap at all, as we discussed earlier.

In surface geologic mapping, or field geology, topographic maps are a necessity. Aerial photographs, especially in stereoscopic pairs (for a three-dimensional effect), and remote-sensing imagery from satellites can be very useful. If available for the area of interest, regional geologic maps and reports such as those published by the Oregon Department of Geology and Mineral Industries and the U.S. Geological Survey can provide a great head start toward understanding the geologic history of the area and in detailed mapping.

In addition to careful geologic surface mapping, what can we do to increase our chances of finding a commercial hydrocarbon accumulation in the subsurface when we drill our exploratory well, called a wildcat?

Surface and near-surface physical and chemical measurements can be made of phenomena that are affected by subsurface conditions. Measurement of such things as differences in gravity, magnetic field, heat flow, radioactivity, natural or induced electrical currents, and response to induced seismic waves is called geophysical surveying. Measurement of variations in the concentration of chemical elements or hydrocarbons in surface or near-surface materials or organisms is called geochemical surveying.

Favorable results from geophysical or geochemical surveys can certainly enhance our chances of success in drilling. Sometimes our drilling site may be picked primarily from such results. However, these surface measurements of subsurface conditions are indirect and are without exception dispersed and distorted to some degree by the intervening rock. The costs of such surveys range widely; for example, a magnetic survey of an entire basin may cost no more than a seismic survey of a few square miles. Geophysics and geochemistry should be considered in every exploration program but must be planned carefully; the costs can quickly add up to more than the cost of drilling the ensuing wildcat.

When an exploratory hole has been drilled into the older rocks in the basin, we get some direct information on the subsurface, assuming we have access to the well records. If the well was completed as an oil or gas producer, it is likely that other hydrocarbon accumulations will be found in the basin. If the well was a dry hole, that is, if it was not successful in finding commercial quantities of hydrocarbons, it does not necessarily mean that the entire basin is barren. At least 10 dry holes were drilled in Saudi Arabia before a commercial oil field was found; more than 200 dry holes were drilled in Oregon before the Mist gas field was discovered. A field, incidentally, consists of one or more pools in the same general area.

In either case, descriptions or our own examination of rock samples taken from the well will be very useful. In addition, graphic representations called logs, of downhole measurements of electrical, radioactivity, sonic or acoustic velocity, drilling rate, and other characteristics of the rocks penetrated by the well should be available. Electric logs, sonic logs, and gamma-ray logs are just a few of the types of logs generated during a drilling program.

From the borehole samples and logs, the depths, thicknesses, and types of rocks can be determined, as can the kind of fluid

contained in reservoir rocks (salt water, fresh water, oil, or gas). From a dip log, or dipmeter, the angle and direction of tilt of the rock layers can be calculated.

With information from the hole, events on nearby geophysical surveys can be better calibrated to subsurface features, and rocks in the subsurface can be better related to rocks in outcrops elsewhere. If a number of wells have been drilled, and if the information from these wells is available, maps and cross-sections showing the shape or geologic structure of various layers of rock in the subsurface can be constructed from the wells. Geophysics can be very useful in the interpretation of the structure between and beyond wells, and the surface geology can also be helpful. From such subsurface depictions, possible hydrocarbon traps may be identified.

When we think that all of our information indicating a trap is conclusive enough, then we may recommend that a wildcat well should be drilled to test the prospect. But first we need to talk about money.

ECONOMICS

My education on the economics of oil and gas exploration began when I was an eager young geologist for a sizable oil company. After a long session with the Chief Geologist, when I was pushing hard to get my favorite prospects drilled, he said, "Bruer, you have the mistaken idea that this company is in business to find oil and gas. It is not. It's in business to make money." Doubtlessly, the stockholders heartily agreed.

The economics of oil and gas exploration is a very complex subject. I intend to point out just a few of the more obvious considerations.

We will drill the wildcat well on our prospective underground trap (our "prospect") only if we think it is good business to do so — that is, if by drilling this prospect and others like it, we can pay the costs of all our operations and still make a profit (and thereby stay in business). We need to make a careful evaluation of these costs and of how much oil or natural gas may be recovered from our prospect if it should prove to be productive.

In addition to the potential quantity of oil or gas, we need to consider quality. Natural gas may contain more or less inert contaminants such as nitrogen or carbon dioxide that reduce its heating value and therefore its price. Or, it may contain noxious contaminants such as hydrogen sulfide (rotten egg gas), which require expensive treatment to remove. Thick, heavy, low-gravity crude oil can be difficult to produce and transport, and it will yield a higher percentage of lower priced refined products, such as residual fuel oil, than products from lighter, high-gravity crudes. Contaminants in crude oil, such as sulfur and sulfur compounds, can be removed by more expensive refining processes; if they are not removed, the resulting refined products will be less desirable and lower in price.

The revenue from the saleable products of an oil field must pay for (1) the cost of exploration, possibly including many dry holes prior to discovery; (2) the cost of lease acquisition, lease rentals, and royalty payments; (3) the cost of drilling, testing, completing, and equipping the discovery well and the other producing wells necessary to drain the field; (4) the cost of pumping or otherwise lifting and gauging the oil; (5) the cost of gathering the oil from all the wells to a shipping point; (6) the cost of disposing of waste water produced with the oil; (7) the cost of shipping the oil to a refinery, whether by pipeline, tanker, barge, rail, or truck; (8) the cost of refining; (9) the cost of distributing the refined products; (10) the cost of retailing the products; and (11) taxes and the cost of accounting, management, depreciation, maintenance, repair, and other overhead.

For natural gas, steps 7 and 8 above do not apply, but at that point in handling gas, it will probably have to be treated to remove excess water vapor and any liquid hydrocarbons. It will

be odorized for safety purposes (most natural gas is odorless as well as colorless and tasteless), and it will probably have to be compressed at least once to push it through the pipeline to market. As you can see, it takes more than a few thousand barrels of oil or a few million cubic feet of natural gas to constitute a commercial hydrocarbon accumulation, even under the best of circumstances.

Obviously, we don't want to drill a wildcat well that costs \$2 million in order to possibly find \$1 million worth of oil or gas. It is not even good economics to drill a \$1 million wildcat to possibly find \$2 million worth of oil or gas. Now that is not a "put on"; because of that word, "possibly," the risk has to be factored in.

Statistically, one wildcat in six drilled in an attempt to find a new field in the United States will find some commercially producible oil or gas. However, the odds are about 1 in 150 that a large field of more than 10 million barrels of recoverable oil or 57 billion cubic feet of recoverable natural gas will be found.

Now, back to our \$1 million wildcat to possibly find \$2 million worth of hydrocarbons: Statistically, we will have to drill six similar wildcats, five of which will be dry holes, for a total drilling cost of \$6 million to find our \$2 million field.

Let us consider very expensive wildcats, such as those drilled offshore in the Arctic Ocean or in any very deep or very difficult drilling area. If we assume the wildcat will cost \$5 million just to drill, then we already know our potential field had better be a large one. Statistically, it will take 150 wildcats to find one large field at a drilling cost alone of 150 multiplied by \$5 million, or \$750 million! For all practical purposes, in such areas it does not make economic sense to drill a wildcat to try to discover a field containing less than about \$1 billion worth of oil and/or gas. Fortunately, there are many less difficult and less costly areas in which to explore.

Other parts of the economic mosaic above can render our prospect noncommercial. We may estimate that the prospect contains \$30 million worth of natural gas. Great! But, it may be so far out in the boondocks that it would cost \$40 million to build a pipeline to get the gas to market.

Or the mineral owners may ask for exorbitant lease bonus or

rental payments. The cost of leasing on exploratory prospects, like the cost of wildcat drilling, also has to be factored for risk. That is, when evaluating a prospect, lease costs should be multiplied by the statistical number of prospects that must be leased as well as drilled before one is successful (six or 150 or whatever). For example, in a 10,000-acre lease block on a potential large field prospect, an additional cost of \$1 per acre factored for risk (times 150) would require that the potential field contain a value of \$1.5 million more in recoverable oil or gas than otherwise to warrant going ahead with leasing and drilling the prospect. Many a drilling plan has been canceled because of leasing problems.

We may evaluate our prospect, including weighting it for risk, and conclude that we can make a profit by drilling it and others like it. In fact, we may calculate that the profit left over after paying local, State, and Federal taxes on our gross revenue will about equal the amount of those taxes. But then, perhaps, the Feds may eliminate our tax deduction for intangible drilling costs, and/or the state doubles its severance tax, and/or the county raises its mineral tax, so that the net effect is to double our taxes. Goodbye profit, so long prospect. Of course, a reduction in the price of crude oil or natural gas can have a similar effect. On the other hand, increased prices for oil or gas can make economically marginal prospects profitable.

And that's enough about economics to give you a general idea.

CONCLUSION

We have covered the broad question of "Why is an oil or gas field" with some very general answers. If you want to get deeper into the subject, you should probably start with any good beginning general geology textbook, preferably an edition no older than 10 or 12 years. Then, if you're still interested, you can delve into one or more of the many books on petroleum geology.

More fields will be discovered in the Northwest in coming years. I hope that this article has dispelled the mystery of oil and gas exploration and that it will help you to enjoy following the action. □

Gorda Ridge reports released

Six reports on the geology and biology of the Gorda Ridge have been prepared by the Oregon State University (OSU) College of Oceanography and released as open-file reports by the Oregon Department Geology and Mineral Industries (DOGAMI). The Gorda ridge is a sea-floor spreading center off the coast of southern Oregon and northern California that lies within the U.S. Exclusive Economic Zone (EEZ). The six newly released documents report the results of research on the benthic (ocean-bottom) ecology, heat flow, trace-metal chemistry, radon gas concentration, seismic activity, and mineralogy of the ridge area.

The reports were commissioned by the joint Federal-State Gorda Ridge Task Force in March 1985. The Task Force, which was formed in 1984, was charged with conducting a technical analysis of the economic and environmental implications of leasing the Gorda Ridge for the mining of polymetallic sulfide minerals. Funding was provided by the U.S. Minerals Management Service.

Analysis of Benthic Epifaunal and Infaunal Community Structure at the Gorda Ridge (Open-File Report O-86-11) was written by Andrew G. Carey, Jr., David L. Stein, and Gary L. Taghon. The 34-page report discusses the invertebrate and fish fauna observed on film shot in the vicinity of the ridge during 1984 and 1985.

Heat-Flow Results from the Gorda Ridge (O-86-12), by Dallas

Abbott, describes on 10 pages the results of heat-flow measurements made in the sediment-filled southern third of the ridge, the Escanaba Trough.

Studies of Trace Metals and Active Hydrothermal Venting on the Gorda Ridge (O-86-13), 36 pages long and written by Robert W. Collier, Scott H. Holbrook, and James M. Robbins, discusses the use of trace-metal concentrations in conjunction with hydrography and turbidity to identify hydrothermal vent plumes on the Gorda Ridge.

Radon-222 as a Real-Time Tracer of Hydrothermal Activity on the Gorda Ridge (O-86-14) is 19 pages long. In it, author David Kadko documents the radon concentrations in hydrothermal plumes located over the Gorda Ridge during the summer of 1985.

Ocean-Bottom Seismometer Measurements on the Gorda Ridge (O-86-15), by L. Dale Bibee, is a 25-page report discussing seismic activity observed on the southern Gorda Ridge and comparing the seismicity to results obtained on the southern Juan de Fuca Ridge.

Hydrothermal Sulfides, Breccias, and Greenstones from the Gorda Depression (O-86-16) describes the mineralogy and chemical composition of samples dredged from a fault scarp along the Blanco Fracture Zone. Authors of the 31-page report are Roger Hart, Douglas Pyle, and James Robbins.

All reports are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The price for each report is \$5. Orders under \$50 require prepayment. □

In Memoriam: S. Kyle Huber

S. Kyle Huber, a member of the Portland law firm of Weiss, DesCamp, Botteri, and Huber, died at his home on June 6, 1986. Born on May 24, 1948, in Port Arthur, Texas, Huber received his bachelor's degree in economics from Tulane University in 1970 and his law degree from South Texas College of Law in 1975. Throughout his professional career, Huber worked in and was closely associated with the oil and gas industry. He worked with Texas Eastern Corporation of Houston, concentrating in natural gas regulatory matters from 1973 through 1976. In 1976 he and his family moved to Portland, where he became Assistant General Counsel to Northwest Natural Gas Company. He remained in that position until 1979, during which time he also acted as General Counsel to the gas company's geothermal resources subsidiary, Northwest Geothermal Corporation. In 1979 Huber left the gas company for the private practice of law in which he concentrated almost exclusively in natural resources law, particularly concerning oil and gas, geothermal, coal, and other minerals, including lode and placer mining.

In addition to being a member of the Oregon, Texas, and American Bar Associations, Huber was a founding member and first president of the Northwest Petroleum Association and was a member of the Northwest Mining Association, the American Association of Petroleum Landmen, the Pacific Coast Gas Association, the Geothermal Resources Council, the Western Oil and Gas Association, and the Minerals Committee of the Portland Chamber of Commerce.

Huber was an adjunct professor of law at the Northwestern School of Law, Lewis and Clark College, in 1983, where he taught oil and gas law. He also authored an article in "Landman," published by the American Association of Petroleum Landmen, entitled "Pacific Northwest: Recent Legal Developments," as well as authoring "Legislative Developments in Energy and Environmental Law" in 1983 for the Oregon State Bar Continuing Legal Education series.

Kyle will be missed by his friends and colleagues. Those of us who had the pleasure of knowing and working with him will remember his integrity, warmth, enthusiasm, and professional competence which he brought to his interactions with others. He is survived by his wife, Betsy, and his three children, Dallas, Kellan, and Will.

— James P. Draudt,
Weiss, DesCamp, Botteri and Huber,
Attorneys at Law,
Portland, Oregon

Luscher appointed new BLM state director

Charles W. (Bill) Luscher has been appointed to succeed retiring William G. Leavell as State Director for the Oregon/Washington office of the U.S. Bureau of Land Management (BLM). Leavell had served in that capacity for the last six of his 34 years in Federal service.

Luscher, a native of Libby, Montana, was graduated from the University of Idaho College of Forestry in 1954 and received a Master of Natural Resources Administration degree from the University of Michigan in 1967. He has held positions in BLM offices in Washington, D.C., Colorado, and Nevada; most recently, as State Director in New Mexico.

He has also served with the BLM Resource Management Team under the U.S. AID Program in Nigeria and participated as a BLM range specialist in a cultural exchange with the Soviet Union. In 1976, the Department of the Interior honored Luscher with its Honor Award for Meritorious Service. □

BLM releases geochemical data on southeast Oregon

A report on geochemical data from parts of southeastern Oregon's Harney and Malheur Counties and southwest Idaho's Owyhee County is available in several offices of the U.S. Bureau of Land Management (BLM).

The report includes analyses of 376 sediment and 65 rock-chip samples collected in an area totaling 220,000 acres. The samples were analyzed for 30 metals. The study was conducted by BLM's Oregon State Office in Portland and the Western Field Operations Center of the U.S. Bureau of Mines (USBM) in Spokane, Washington. BLM will use the data to assess the mineral resource potential of the survey areas as part of the studies leading to recommendations for wilderness suitability.

The report is available for examination in the following BLM offices: BLM Public Room, 14th floor, 825 NE Multnomah St., Portland, Oregon; BLM Vale District Office, 100 Oregon St., Vale, Oregon; BLM Boise District Office, 3948 Development Ave., Boise, Idaho. It is also on file at the USBM Western Field Operations Center, 360 E. Third Ave., Spokane, Washington. □

Geologist Nolf honored in Bend

Bruce O. Nolf, geology instructor at the Central Oregon Community College in Bend, has become the second recipient of the college's Distinguished Professor award.

In his recommendation to the college's Governing Board, President Fred Boyle praised Nolf for his community service, his geologic research in central Oregon, and his efforts toward keeping his instruction "on the cutting edge of geology."

Nolf is a graduate of the University of Iowa (B.S.), the California Institute of Technology (M.S.), and Princeton University (Ph.D.). □

Northwest miners honored

Three Pacific Northwest mining firms were honored by Federal agencies recently for their environmentally sensitive, safe, and efficient operations on Federally administered mineral lands.

Philip J. Sali, president of Columbia Asphalt and Gravel, Inc., Parker, Washington, and John Wisch of the Washington Irrigation and Development Company, Centralia, Washington, accepted awards from the U.S. Bureau of Land Management. The USDA Forest Service presented a similar award to Max Buckner and Irv Lamb of the Black Raven Placer Group located in northeastern Oregon.

The awards were presented in recognition of the willingness and cooperation of the operators to go beyond government requirements and for demonstrating a high level of concern for environmental and public values. □

Notice of change

During the next one month or two the mailing of *Oregon Geology* will undergo some significant — and we hope beneficial — changes. The mailing itself will be taken over by a mailing service outside the Department, and the maintenance of the mailing list will be handled with the help of a computer.

Please bear with us, if some problems occur during the transition. Let us know soon if you do not receive your magazine or if your address should not be quite correct. That address, by the way, will include a code number whose last four digits will tell you the expiration month and year of your subscription. Please take note of it as a timely reminder to renew!

— The editors

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-4: Oregon gravity maps, onshore and offshore. 1967	\$ 3.00		
GMS-5: Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
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