Bright Spot: Better Seismological Indicators of Gas and Oil

Oil companies have long sought reliable means of detecting the presence of hydrocarbons trapped beneath the earth's surface. Direct detection, in the oilman's vision of perfection, would replace the wildcatter's hunch and even the informed guesswork of the geophysicist by something approaching certainty.

A new method of analyzing seismic data quantitatively, known as the bright spot technique, falls short of this ideal but has nonetheless revolutionized the worldwide search for gas and oil. Preliminary reports are that in regions where the technique is most applicable 60 to 80 percent of the wells drilled are successful, a considerable improvement over the 1 in 8 or 9 odds of finding hydrocarbons by traditional methods. The impact of bright spot analysis has also stimulated experiments with a host of additional techniques that together promise a more sophisticated understanding of geophysical phenomena even in applications remote from petroleum exploration.

The technique has been under development for several years, although its existence was until recently a closely held secret within the oil industry. It became evident last year, however, that some companies were willing to bid very much more for certain tracts of land in the Gulf of Mexico than were their competitors; a record $211 million was paid for rights to the gas and oil beneath one tract. The suspicion grew that the high bidders knew more than the others, and it is generally conceded that the head start of a few companies —among whom Shell and Mobil are generally credited with being in the forefront—in developing the bright spot technique was partly responsible for the erratic bidding. Within the last year the technique has been adopted throughout the industry, and it has been used extensively in exploration in the Gulf of Mexico, offshore in Nigeria and Indonesia, and in a few regions within the continental United States such as the Sacramento Valley of California.

Probing the upper layers of the earth's crust seismically, a standard technique for decades, depends on the partial transparency of the earth to sound waves at frequencies between about 15 and 100 hertz. Sound waves are generated at the surface by small explosions or pneumatic devices and penetrate into the crust. Density differences at the interfaces between different types of rock reflect part of the wave, and these reflections are monitored at the surface. Until recently only the timing of the echoes arriving at the surface was considered important. Careful analysis of arrival times yielded a picture of crustal structures from which oilmen could pick those known to be likely traps for hydrocarbons. Variations in the strength of the reflected signals were ignored, in fact were systematically eliminated in the computerized processing of the data. It turns out, however, that valuable information was being discarded. Porous rock in which natural gas is trapped reflects a much stronger seismic echo than does rock filled with water. This contrast, which shows up as a bright spot on a plot of the amplitudes of the reflected signals, is the basis of the new technique (Fig. 1).

What made it possible was the introduction in the late 1960's of equipment that records the reflected signals as digital data rather than in an analog fashion (such as the chart recorders of most seismographs). The initial acoustic signal is as much as a million times stronger than the reflected echoes, which themselves vary widely in amplitude from one data point to another. With digital amplifiers the relative strengths of the signals can be accurately recorded

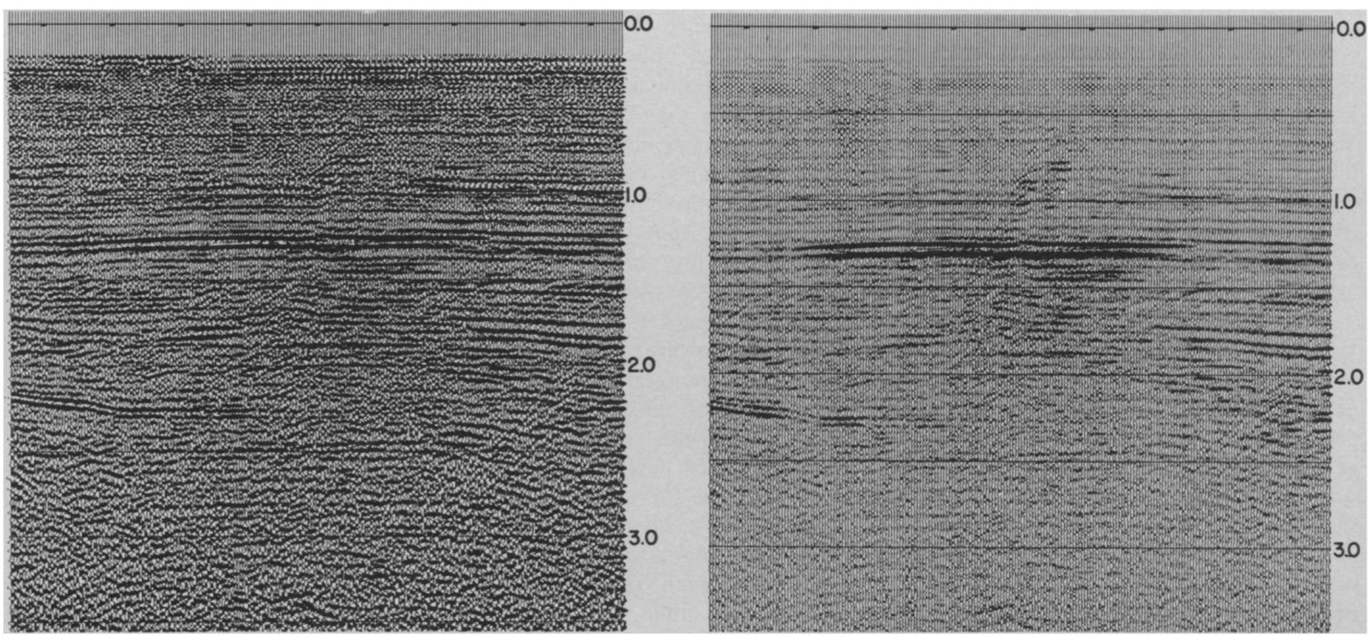

Fig. 1. Seismic profiles of a known gas field in the Gulf of Mexico. The horizontal extent in each case is 7.2 kilometers and the vertical scale is the two-way travel time of the seismic signal in seconds. At left is the profile given by standard seismic techniques, neglecting amplitudes of the reflected signals, while at right is the same profile as given by the bright spot technique. [Source: Teledyne Exploration, Houston, Texas]

over a range of about 80 to 90 decibels compared to a range of about 40 decibels for an analog system. Several indicators of the presence or absence of hydrocarbons can then be extracted from the data.

The strength of a particular signal reflected from the interface between two subsurface layers depends on both the density and the velocity of sound in each medium. The presence of natural gas in a layer can diminish the density by as much as 10 percent and the velocity by as much as 50 percent compared to the values in water-filled strata, giving rise to a reflection coefficient (the ratio of the strength of the reflected signal to that of the incident signal) two or three times larger. The presence of oil is much harder to detect, since its density is close to that of water, but wells drilled to tap a suspected gas deposit will often produce both. The strength of the echoes alone can be misleading, however, since zones where the mineral composition changes (from a sandstone to a harder carbonate rock, for example) can also give high reflection coefficients.

A second indicator, the polarity of the reflected seismic wave, can help to establish what caused a strong echo. Sound waves are transmitted as compressions and expansions (in the direction of propagation) of the medium through which they pass, and the polarity of the wave refers to the direction of the first motion. When passing from one medium into another in which the velocity of sound is higher, the reflected wave is of positive polarity (the first motion is compressive) and when passing into a region of lower velocity it is of negative polarity. Hence a low-velocity, gas-bearing layer can be distinguished from, for example, a layer of limestone by the opposite polarization of the reflected signals.

Fluid Interface a Final Clue

A third indicator of hydrocarbons, and often the confirming one for many geophysicists in the oil industry, is the presence of a reflecting interface that is perfectly horizontal. Since geologic strata are frequently twisted or tilted, such an interface is taken as evidence of contact between two fluids—gas over water or gas over oil. Where the layers of rock are flat, however, the fluid interface does not show up. Nonetheless, in a few instances it is reportedly possible to distinguish an oil-water interface as well, thus giving an indication of petroleum as well as gas. The combination of a strong reflection with negative polarity and a horizontal interface is the indicator that to many petroleum geophysicists is close to a guarantee of finding hydrocarbons.

The bright spot technique is not universally applicable. It seems to work best in young, relatively uncompacted sediments in ocean basins, such as Tertiary beds of sands and shales. One reason is undoubtedly that contrasts between the acoustic velocities in two different media are most observable where the speed of sound is itself low. The technique is more difficult to apply in sedimentary beds on the continents, where the geology is often more complex. It is not much help in looking for deep deposits, below 8,000 to 10,000 feet, because the acoustic signals attenuate too much in passing through so much earth—a limitation that is significant because deep deposits are increasingly regarded as essential if the United States is to increase its own hydrocarbon production.

False indications, such as those generated by an interface between dry sandstone and sandstone saturated with salt water or by focusing of the reflected waves, do occur. Interference patterns in the reflected waves can also cause problems because of their effects on the amplitude of the signal—multiple reflections arriving in phase can give a spuriously strong signal, and two signals that are out of phase (opposite polarity) could cancel sufficiently to disguise the presence of a bright spot. And, as indicated above, bright spot analysis is essentially a technique for finding gas rather than oil. Experience with the technique is not yet so extensive, in the judgment of one oil company's chief geophysicist, that the absence of a bright spot indicator in an otherwise promising formation would result in its being passed over.

Widespread use of the technique is relatively new, however, and improvements are still coming rapidly. One aid to interpretation of seismic exploration data now being widely used involves the construction of detailed computerized models of the subsurface layers in a region of interest. Using the approximate velocity of sound for the suspected composition of each reflecting layer, geophysicists can attempt to reproduce the observed signals with their simulated geologic section and hence to determine the thickness, fluid content, and other properties of each layer. These factors are important in estimating whether a suspected hydrocarbon deposit is large enough for commercial exploitation.

Resource estimates are easiest to make for thick layers in which a fluid interface is visible. Deconvolution, a transform technique in the computer processing of the seismic signals, allows geophysicists to effectively shorten the seismic pulses, increasing the resolution and permitting thinner layers to be examined. Another method of estimating the thickness of a formation is to study the interference pattern of the reflections. Yet another technique used for assessing the hydrocarbon resources present is to look for their horizontal extent, which is sometimes indicated by the diffraction of the signals at the edge of the gas-filled region.

Oil in Stratigraphic Traps

One significant feature of bright spot analysis—not widely exploited yet—is the potential for finding hydrocarbons in regions where there are none of the structural features commonly associated with oil and gas. Structural features such as salt domes and anticlines are perhaps the most likely place to find hydrocarbons, but oil and gas also occur in stratigraphic traps in which lateral barriers to movement of the fluid are the most important feature. These deposits, generally not detectable with traditional seismic methods, should show up when the data are analyzed with the newer techniques, and some companies report finding such deposits. More generally the bright spot technique can be described as stratigraphic rather than structural analysis because of its emphasis on the composition and fluid content of the sediments. The geophysical service companies that do much of the seismic exploration under contract for the oil companies now make two presentations of their data in reporting on their findings, a structural work-up and a bright spot or stratigraphic analysis (which includes structural information), and a few observers believe that the older structural presentation may soon be discarded as obsolete. What seems to be happening among exploration people in the industry is a new interest in squeezing all possible information out of the seismic data and a growing realization that what is needed is to understand the physics of the phenomena rather than rely on the presence or absence of various computer-generated indicators.

The impact of high-speed computers with large memories on the exploration business was substantial even before the advent of stratigraphic techniques. A typical seismic record contains about 2 million bits of information, and an exploration ship may take 60 records per mile all along a line that is part of a grid. By the time the whole grid has been covered, so that a three-dimensional picture of a region can be built up, the amount of data is truly phenomenal and its analysis would be impossible without modern computers. Interestingly enough, however, practitioners of seismic analysis report that it takes little more computer time to do a bright spot analysis than to do the cruder structural analysis. All in all, the effort amounts to the largest and perhaps the most sophisticated exploration of the earth's crust that geophysicists have yet undertaken.

Academic seismologists have for the most part had little to do with stratigraphic analysis of the bright spot type. For one thing, interest in plate tectonics has led to a focus on techniques applicable to exploration in deep water rather than the shallower offshore areas of the continental margin. For another, multichannel digital amplifiers are expensive, $160,000 for one instrument alone and more than $0.5 million to outfit a ship with all the needed gear. University research laboratories are just now beginning to put this equipment in use. But interest is growing. Some researchers have noted the potential overlap of the bright spot technique and those used in earthquake prediction despite the fact that crystalline rather than sedimentary rocks are involved. The zone of swollen, dilatant rock thought to surround a fault prior to a quake is, like a gas reservoir, characterized by an anomalously low value for the speed of sound. Others think that still more can be done to extend the bright spot technique itself. They note that so far only compressional seismic waves are used, and propose that shear waves may also find a use. It seems clear that digital data-gathering techniques and stratigraphic analysis will find uses outside the oil industry.

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Control of Protein Synthesis (I): Poly (A) in the Cytoplasm

One of the most enigmatic substances in cells of higher organisms is polyadenylate [poly(A)], a nucleotide sequence believed to play an important, but as yet unknown, role in protein synthesis. Recent experiments have provided evidence that poly(A) is associated with those intracellular events leading to protein synthesis that take place in the cytoplasm. These experiments have brought into question existing views about the role of poly(A) and have led to the advancement of several new hypotheses.

When proteins are synthesized in cells of higher organisms (eukaryotes) a portion of the cell's DNA is transcribed into a collection of RNA molecules. A sequence of poly(A) consisting of about 200 nucleotides is then added to one end of certain of those RNA molecules. Next, some of the RNA molecules that contain poly(A) are transported through the nuclear membrane to the cytoplasm. Those RNA molecules that enter the cytoplasm are called messenger RNA's (mRNA's). The mRNA molecules in the cytoplasm are translated into specific proteins. While they are in the cytoplasm, their poly(A) sequences gradually become shorter until they consist, on the average, of about 100 nucleotides.

The gradual decrease in the lengths of poly(A) sequences in mRNA's was first noticed about 2 years ago, but only recently have investigators shown that adenylate can be added to mRNA molecules in cytoplasms. This phenomenon has now been demonstrated in four kinds of cells with three different experimental techniques. Since many investigators had previously believed that adenylate is only added to RNA molecules in the nucleus of a cell and had based theories of the function of poly(A) on this belief, the details of these experiments are of more than ordinary interest.

The addition of adenylate molecules to mRNA's in sea urchin embryos was demonstrated by I. Slater and D. Slater of the National Institute of Child Health and Human Development at Baltimore City Hospital. The unfertilized sea urchin egg has in its cytoplasm both mRNA's that contain poly(A) and mRNA's that lack poly(A). The Slaters showed that, upon fertilization, the mRNA's that lack poly(A) have poly(A) added to them and are subsequently translated.

In the Slaters' experiments, sea urchin eggs were fertilized and grown in the presence of two radioactive nucleotides: namely, adenosine, which would be incorporated into newly synthesized poly(A) molecules, and uridine, which would be incorporated into newly synthesized mRNA molecules. They showed that, just after fertilization, only the poly(A) portion of mRNA's in the eggs was labeled, and, hence, poly(A) was added to preexisting, rather than newly synthesized, mRNA's. Since they believe that preexisting mRNA's are only found in the cytoplasm, they interpret their results as indicating that poly(A) was added to mRNA's in the cytoplasms of the eggs.

R. Perry of the Fox Chase Center for Cancer Research in Philadelphia used a different technique to obtain evidence that he believes is consistent with the hypothesis that poly(A) sequences are synthesized in the cytoplasms, as well as the nuclei, of cells. Perry grew mouse L cells in the presence of radioactive adenylate and measured the rate at which the labeled adenylate appears in poly(A) sequences in the nucleus and in the cytoplasm. The initial rate of synthesis of poly(A) in the nucleus was considerably less than would be predicted if all poly(A) sequences in the cytoplasm originated in the nucleus.

J. Diez of the Children's Cancer Research Foundation in Boston together with G. Brawerman of Tufts University Medical School in Boston suppressed RNA synthesis in the nuclei of Chinese hamster cells and mouse sarcoma 180 ascites cells with actinomycin D in order to observe the addition of adenylate to poly(A) sequences in the cytoplasms of these cells. Since poly(A) is normally added to RNA molecules in the nucleus after transcription, blocking transcription greatly reduces the rate at which radioactive adenylate is added to nuclear poly(A) sequences. The rate of nuclear incorporation of radioactive adenylate is slow and linear for at least an hour after actinomycin D is added, an indication that the lengths of preexisting poly(A) se-