Seismic recording setup for a survey in the Canadian arctic. In analyzing complex seismic records, geophysicists use methods borrowed from holography and radio astronomy.

UNITED GEOPHYSICAL

Opportunities in geophysics

Challenging jobs still exist here for physicists—exploring for oil, studying ocean-wave propagation, analyzing the behavior of water in clouds . . .

H. Richard Crane

What are the chances of a physicist finding an agreeable job in geophysics? The apparently poor prospects for jobs in academic physics led me to explore the possibilities in geophysics; this field, I guessed, is less dependent on government funds than is academic physics and should not have suffered the same kinds of cutbacks. For my survey of opportunities, I gleaned information from James T. Wilson, a seismologist, geologist and director of the University of Michigan Institute of Science and Technology; Helmut Landsberg of the University of Maryland, a past president of the American Geophysical Union; Homer Newell of the National Aeronautics and Space Administration, now the AGU president; Milton Dobrin, president of the Society of Exploration Geophysicists and Richard Geyer, head of the department of oceanography at Texas A&M University. Here is a digest of what I learned.

Exploration geophysics

Hiring of physicists in exploration geophysics does not appear to be slackening as it is in most other industries where physicists are employed. There is of course some caution because of the economic recession, but the tightening of government research funds is not a factor; the companies generally pay for their own research. Exploration geophysics is largely concerned with the search for oil, and about 500–1000 physicists (including BS's and MS's as well as PhD's) work at it. The principal oil companies and oil-company laboratories that employ physicists in research are Esso Production Research, Shell Development and Texaco in Houston; Mobil, Atlantic–Richfield, and Sun Oil in Dallas; Pan American Research Center and Cities Service in Tulsa; Gulf Research and Development in Pittsburgh; Marathon Research Center in Denver; Chevron Oil Field Research in La Habra, California and Union in Brea, California. Some of these companies, notably Shell, Texaco and Humble, have summer openings for undergraduates in physics.

In Dobrin's opinion any young person going into exploration geophysics should consider the open-air end of it, that is, literally exploration, as well as the laboratory research aspects. Many apparently routine problems encountered in the field are really research, in that each is different from every other one, and it is always challenging to outwit the earth. The decisions that hang on the scientific findings are expensive, and that fact makes the game exciting.

A nice feature of exploration research is that information is quite freely shared among companies; the advantage here is that the same geological formation may run through the domains of several companies. Exploration research includes a lot of travel and field work, and that keeps it from ever getting dull.

What are physicists currently doing in exploration geophysics? About half the research papers in the society's journal *Geophysics* are on the analysis of seismic recordings. The seismic method is an old one. In the primitive form of this method, the earth is given a shock at some point, and the vibrations reflected from underlying layers are recorded at another point. Sophistication has turned the single point energy source into an array of sources that may give single impulses, sine waves or frequency-modulated "chirps" with controlled phasing. Receiving stations are almost always multiple.

Only the advent of computers has made the analysis of the records possible, and here all the tricks of filter

H. R. Crane is physics chairman at the University of Michigan, Ann Arbor.

theory and of diffraction and refraction theory, including methods borrowed from holography, are used. There are strong suggestions of both the antenna arrays and the long-baseline interferometry of modern radio astronomy. The object is to extract from an exceedingly complex record an indication of the special kind of layer or structure that warrants sinking a multimillion-dollar hole. One of the principal research tasks is, therefore, the development of sophisticated computer programs.

Instrumentation

The sensitivities of all the principal detectors—seismic, gravity, magnetic and electric—have generally been so improved that sensitivity is not the limiting factor. The rubidium vapor optical-pumping magnetometer, for example, has more sensitivity than can be used for most exploration applications. The main problem is separating signal from noise; when geophysicists speak of noise, they do not refer to the natural (thermal) noise in the detector but to real signals from outside, either man-made or not, that are unwanted and confuse the desired signal.

Most research, now, in detectors is in their adaptation to new vehicles. Examples include the use of detectors in EROS (earth resources observation satellite) and the difficult problem of using gravimeters on board ship. A recent development in magnetic prospecting is the use of arrays of detectors. Pairs of magnetometers, for example, are towed by airplanes and read the gradient of the magnetic field directly, rather than its absolute value.

There is more need for inventiveness in sources of seismic disturbances than in detectors, believes Dobrin. The frequency-modulated ("chirp") vibrator, used singly or in arrays, the inverted bell containing an explosive gas mixture such as oxygen and propane, and the underwater explosion of a bag of gas have been significant steps forward. Continental, Sinclair and Esso have developed new sources, and have named their gadgets respectively "Vibroseis," "Dioseis" and "MSS" (Marine Seismic Source).

Measurements of temperature, radioactivity, magnetic field and seismicity can also be useful when carried out in holes already sunk. This art is an old one that computer analysis has rejuvenated. Mobil, Humble and Shell, for example, have worked on ways to measure seismic velocities in wells either as the wells are dug or afterwards.

Companies that supply equipment and services to the oil producers often have research programs of their own. Examples of such companies are GSI (Texas Instruments); Western Geophysical (Litton); Teledyne, United Geophysical (Bendix); Schlumberger, Halliburton, Dresser; E G & G. Engineers often do the research and development work in these companies, but this does not mean that physicists would not be productive. It turns out that a now-familiar phenomenon has occurred in the oil industry. Over the past 20 years or so, physics PhD's have specialized themselves out of that market. Oil companies have been glad to get physics BS's and MS's for direct exploration work but have come to be a little wary of the PhD except for basic scientific work in their research laboratories. The engineers have had the inside track.

The research to be done is really physics in many instances, and it is to be hoped (by us physicists at least) that we can get back into that market. I recall that when I was a graduate student (1930–34) there was much discussion about possible jobs in oil companies and other applied fields, and a number of my contemporaries found such jobs and became very successful. That was in the big depression. Now the physics profession is experiencing a depression. History repeats, but in different ways!

What kind of graduate preparation would be the most useful for a career in exploration geophysics? An immediate answer is more classical physics, meaning modern classical physics. Needed first is a knowledge of computers, not only programming but also a sense of what computers might do that they are not now doing. Next come filter theory, Fourier transforms, diffraction theory, correlation, information theory, statistics, holography, electronics and optics, with of course a solid foundation in mathematics, mechanics and electricity and magnetism. A student should also study as much geology as feasible, so that he can understand the significance of the data he gets. Any deficiency in geology courses can be made up on the job, but it is essential that this deficiency not be neglected.

Atmospheric physics

Atmospheric physics is at least partially dependent on government grants. But this area of research probably has, for many reasons, a better public image than does the rest of physics, and it will therefore fare better in support. It enjoys some of the reflected light from the enthusiasm over ecological conservation.

Most young people who study physics as undergraduates and do graduate work in atmospheric physics, according to Landsberg, know enough quantum mechanics and nuclear physics, but are woefully deficient in thermodynamics and fluid mechanics. Their knowledge of the classical parts of physics is generally only elementary. Although their mathematical background varies, quite a few need considerably more training in differential equations and in vector and matrix analysis. Too few are sufficiently acquainted with numerical analysis, which is needed for nearly all modern geophysics.

Often these young physicists lack experimental skills. They can perform measurements with standardized, purchasable equipment but can not build apparatus as required by the task on hand. Most of them acquire some of this ability in graduate school, but too many try to solve problems at the blackboard rather than in the laboratory.

The fields in atmospheric physics that have challenging tasks before them include cloud physics with the various transformations of water including the physico-chemical problems of nucleation; atmospheric electricity including the still unelucidated problems of lightning; atmospheric radiation and optics including the difficult problems of radiative energy transformations; scattering, polarization and absorption by particles; spectral absorption by atmospheric gases; photochemistry of atmospheric constituents and admixtures; problems of turbulence and diffusion, and fluid flow in compressible, inhomogeneous media. We must also include aeronomy (the physics of the upper atmosphere) with all the interesting phenomena of noctilucent clouds, the ionosphere and the plasmas. The upper atmosphere is also the seat of solar–terrestrial interaction and of such phenomena as the aurora.

Newell believes that in atmospheric physics, instrumentation for and training in the collection of data has outrun the ability of people to synthesize. For over a decade atmospheric physicists have been learning to make a variety of measurements in the surroundings of the earth. They have been acquiring a great deal of data on the phenomena to be found there and on their variation with time, position and solar cycle, for example. In these exploratory and survey phases of the work, the narrow specialist was in his element and was able to publish a great deal of new information on his own topic. But much of this work has now been done, and it is unlikely that questions of how and why can be answered by more data of the same type. These questions need a synthetic approach that concentrates on cause and effect. The physicist who has the background and ability necessary for transferring principles from classical physics, such as Rayleigh's theory of sound, to the solving of the new puzzles should be very helpful here.

Oceanography

Oceanography is best entered by someone who has completed an MS or even a PhD in one of the basic disciplines such as physics. Study of the ocean is not a basic science but the application of several sciences, and for this reason oceanographers do not believe in an undergraduate degree in oceanography. Some oceanographers, notes Geyer, think that personnel should not even be recruited from graduates of oceanographic institutions but should come already prepared with a PhD in a science such as physics, chemistry or biology and train as postdoctoral fellows. The major fallacy to this reasoning, up to now at least, has been that people at this point in their professional career have found little reason to look to the sea for either research problems or employment.

This situation may be changing. The Texas A&M oceanography department has in the past few years received applications from new PhD's and experienced physicists. In most cases the department has not hired these applicants because of their lack of breadth in interest and training. There has been, however, one rewarding exception that Geyer described to me. The department recently needed a marine acoustician and could not find a person with that special training. As an alternative solution, they took on a fresh PhD in physics who was particularly well grounded in classical subjects, and they "grew" a marine acoustician. The result turned out to be successful for everyone concerned.

At Texas A&M, persons enrolling for a PhD in physical oceanography generally arrive with a bachelor's degree in physics or mathematics. The department has more recently had some graduate students with the MS in physics or mathematics. At the moment, placing the better students is easy, because their thorough training equips them for the cognate sciences. This year, for example, two of the PhD geological–geophysical oceanographers were employed by an oil company not so much as oceanographers but as marine geological–geophysical explorationists. The same idea applies to a graduate in biological oceanography who could work in biological fields other than oceanography.

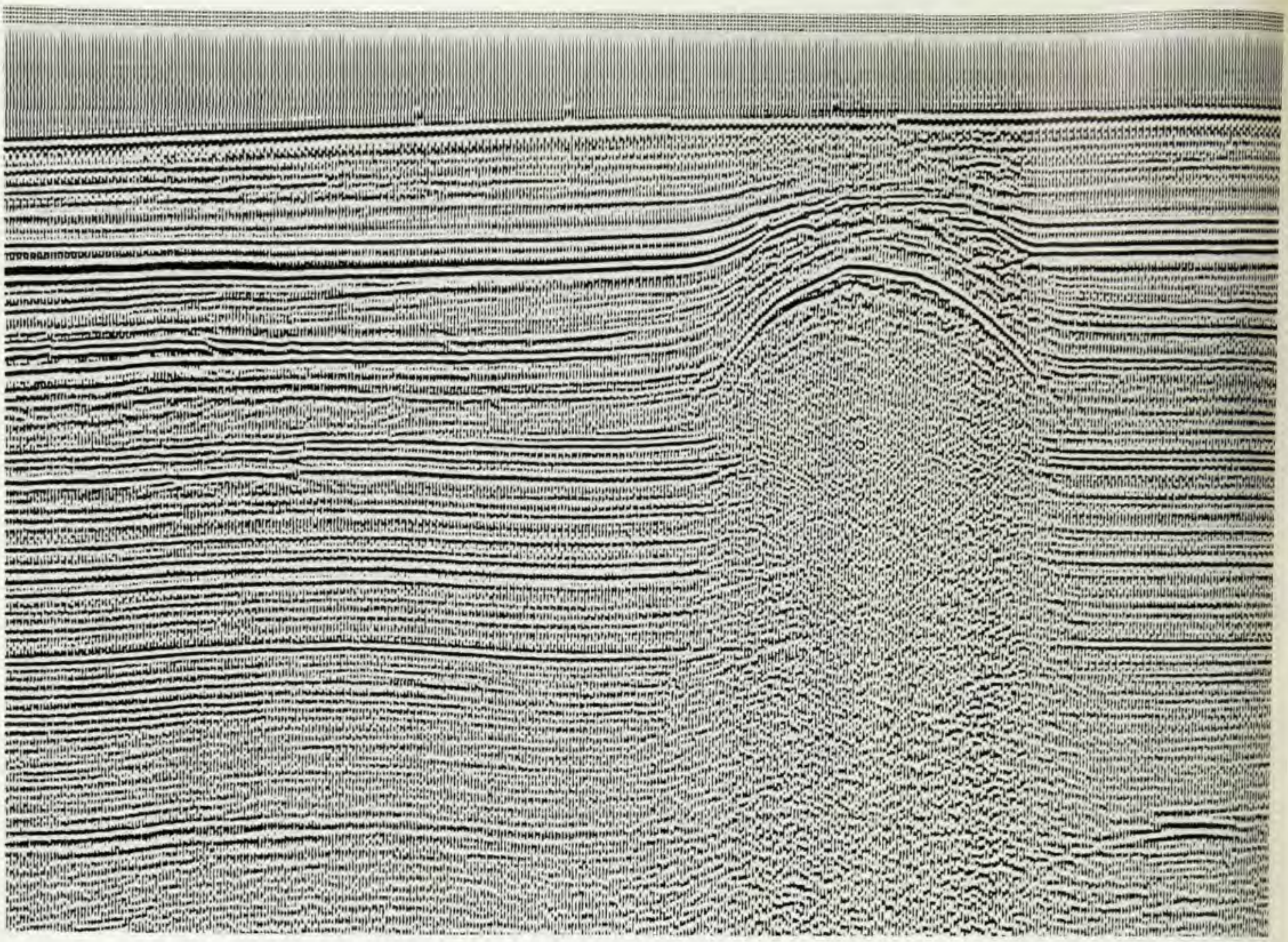
The marine acoustician we have mentioned, Jerald Caruthers, has some good things to say about present physics training: "I think that a physicist is highly theoretical but not highly specialized. An engineer, while more practical, is much more specialized. An employer is more inclined to hire a specialized engineer for a specific job than a physicist who will take time to fit in but may in the long run cover a broader area. . . I think it is most important to sell potential employers on the versatility of a physicist who has the proper attitude. I believe that it is not so

CALTEX PACIFIC INDONESIA

Portable instruments are used for this seismic survey of the Sumatran jungle. Extensive travel and field work keep exploration research from ever becoming dull.

WESTERN GEOPHYSICAL

Propane–oxygen gun ("Aquapulse," developed by Western Geophysical) is a marine seismic source. Instrumentation companies often have their own research programs.



Seismic reflection record from a deep-water survey. Feature at right of 2000-foot deep section is probably a salt dome.

much a broadening of a PhD's training that is needed as it is instilling in him a different set of attitudes." Caruthers listed some challenging problems in oceanography.

- Underwater acoustics: shallow-water propagation, sea–surface scattering, nonlinearity, phenomena associated with signal fluctuations, signal processing
- Ocean waves: generation, propagation, forecasting, better understanding of waves as stochastic processes, sea–surface scattering (acoustic and electromagnetic)
- Circulation: fluid flow problems, turbulence, real-fluid problems
- Coastal engineering
- Remote sensing, for example marine acoustics

He regrets the tendency of physics to divest itself of subjects as soon as they become practical (fluid mechanics and acoustics, for example) and cites this tendency as one of the reasons we now appear to need a smaller production of physicists. He surmises that professors find it easier to teach pure physics than applied physics, and that students more readily get wrapped up in quantum mechanics and relativity than they do in the applied areas.

The proper attitude

What have we concluded about opportunities in geophysics? A "Message to Students" from the executive director of the American Geological Institute, Linn Hoover, that was published in the November issue of *Geotimes*, indicates that I chose a good discipline to survey. Hoover, pointing out that the chances of a new geoscientist finding a job depend on his degree level and on his speciality, noted that "Geophysicists, geochemists and Earth-science teachers have better employment opportunities than geologists, oceanographers and paleontologists, and there's no evidence to suggest that this condition will soon change. Geophysicists are in great demand at all degree levels. . ."

Hopes, however, should not rise unduly. There is clearly a substantial and continuing role for physics PhD's in geophysics, but it would be naive to think that very many companies are just waiting with open arms to welcome high-energy theorists or cyclotroneurs. It will be up to physicists to recultivate geophysics and other areas of opportunity after having neglected them for a generation. Recultivation may require changes in the curriculum and research experience, perhaps reaching down into the physics-major program. But such adaptation may already be under way at a faster pace than we realize. The shocking collapse of the job market has caused many physicists to begin to reappraise applied science. They are finding that it has become a very sophisticated business, full of challenges, and that the line between pure and applied science is indeed difficult to draw. The term "modern applied science" may now be appropriate.

A physicist who has been trained in pure physics must think about his approach to applied work. Although he may be ignorant of the latest developments in the applied field, the physicist with training in pure research possesses certain potentialities that are not shared by engineers or others trained only in applied subjects. Therefore let the pure-physics PhD approach applied physics with the conviction that if the company will bear with him while he learns the lore of the trade, he will have something unique to contribute. □