Aid to oil hunters: ME exploration

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MAGNETOELECTRIC (ME) exploration is a remote-sensing method for detecting oil and gas accumulations, geothermal energy, and other mineral resources.

Basic principles. Oil and gas accumulations in the earth (by virtue of the hydraulic-migration process which created them) have modified the electrochemical properties of the rocks which immediately overlay such deposits.

Specifically, such rocks are more chemically reduced than the rocks outside the limits of such accumulations. Chemically reduced rocks have an excess of electrons with respect to the surrounding rocks which have been subjected to a vertical hydraulic flux lean in hydrocarbons. Such rocks are, therefore, relatively chemically less reduced, or they are oxidized, i.e., they have a deficiency of electrons. The phenomenon just described has been well studied in the laboratory.[1]

An oil and gas field may thus be visualized at the bottom of a vertical funnel of reduced rocks that extends to the surface of the earth or, as the case may be, to the bottom of the continental shelf (Fig. 1). This funnel is surrounded by relatively more-oxidized rocks. The funnel may be prevented from extending clear to the surface when it is intercepted by a permeable aquifer in which water is actively drifting laterally.

The physical conditions just described lead to the formation of giant electric fuel cells associated with oil and gas fields. Such cells are called redox fuel cells as the conventional electrotelluric (ET) currents which they generate flow from the oxidized zone to the reduced zone. The electronic current flow is in the opposite direction. Conventional ET current flow, such as measured by an industrial milliameter, will always be considered in this study.

Field evidence. Solid evidence of the reality of ET currents is best obtained from the self-potential (SP) curves of electric well logs.

The shale base line of such logs is seldom a vertical straight line; if it were, there would be no vertical ET current flow.

The normal SP gradient is one where the SP curve drifts gradually from positive at the bottom of the well toward the negative at the top. This drift is due to two main reasons: the geothermal gradient and the continued upward formation water escape as a result of compaction and evaporation. Except perhaps in geopressured formations this vertical water escape never ceases.

Other factors may affect SP curve drift, mostly the instability of metal SP electrodes when in contact with muds of varying chemical composition and temperature. Such variations may lead to erratic or even misleading maps.

As a rule, the normal SP curve drift may be eliminated by removing a drift of 0 to 0.3 mv/°F. in sand-shale sequences and 0 to 0.1 mv/°F. in carbonates-anhydrite sequences. With the introduction of new metal SP electrodes, such as oxidized iron and alloys, together with the introduction of drilling muds that are mainly chemical solutions, the mapping of SP gradients has become rather unreliable when using recent electrical logs dating from about 1960.

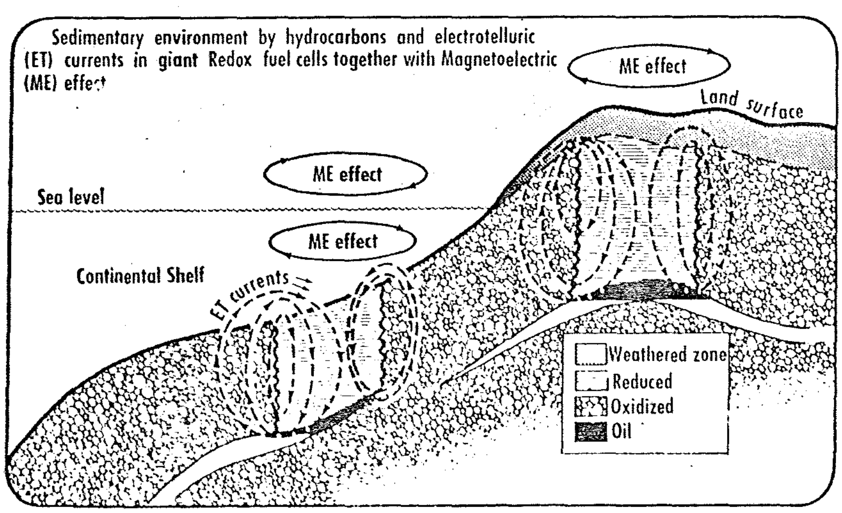
With conventional electric logs run before this date, the SP drifts' presence and significance are obvious. For mapping purposes, the SP drift read in mv/500 ft within well-defined and correlatable shale sections are measured and the readings are transferred to a map of the area. The readings are then contoured. If there are oil and gas fields in the area, an unusual correspondence between the field's limits and the positive SP gradients (read bottom up) will be observed.

A bias SP value may then be determined between the zero line and the field limits. This bias must be taken into account in delineating other prospective oil fields.

During the past 15 years, since the inception of this empirical observation, a number of SP gradient maps were made within which a good number of oil fields were subsequently

Fig. 1

Physicochemical modifications



discovered:

Survey date	Area	Field names
1961	So. Florida province	Sunoco Felda W. Sunoco Felda Lake Tafford Coral Seminole Bear Island Lehigh Acres Ted Weiner Oil Prop.-1 Oleum
1963	Upton Co., Tex.	ABM
1964	Arapahoe Co., Colo.	Peoria N. Peoria Latigo
1964-65	Clarke Co., Ala.	Womack Hill

SP gradients within massive anhydrite beds may also be used for mapping; in fact, the petroliferous trends in Florida were so derived.

A good example of an SP "oil gradient" is shown in Fig. 2 from a development well drilled in the Peoria field, Colo., within the township area that had been predicted to be petroliferous on the basis of SP gradients read from eight dry (?) holes within the area. This study was made some 5 years before the Peoria field discovery. It is estimated that the SP oil gradient on this log within the Graneros shale is 25 mv/500 ft. From experience, 10 mv/500 ft for the SP bias is allowed in this area; the true SP gradient is then 15 mv/500 ft. The resistivity of the Graneros shale in this area averages 5 Ω.m. Hence, by the application of Ohm's Law, the downward ET current flux density over the Peoria field is computed to be 87 ma/acre. This current flux density may be compared with 40 ma/acre over the N.W. Norge field, Okla., where the reservoir is considerably deeper and with 20 ma/acre over the S.W. Vici gas and distillate field, Okla. This confirms the observation already made that high-API-gravity oils and gas give rise to fuel cells of lesser ET current-flux densities.

Good examples of SP oil gradients may often be found in the literature as published geologic cross-sections: Oil and Gas Journal, Sept. 9, 1974, p. 124, and USBM Report of Investigation 3720 (1943). Both of these examples give outstanding cases of oil gradients in the Buckner anhydrite over Smackover reservoirs.

These observations establish with a high degree of certainty the existence of ET currents in association with oil and gas accumulations in the earth. Their mapping by means of SP gradient is possible mostly by means of old conventional logs that use a lead SP electrode. Even then, sufficient well control is seldom available for delineating a prospect with sufficient accuracy to warrant drilling.

At best, SP gradient mapping establishes the petroliferous nature of a prospective area. To be able to recommend drilling, it is necessary to provide additional observations by surface measurements; this is provided by ME exploration.

Hydrocarbon magnetoelectric (HME) effect. Since the downward ET currents over an oil and gas field are concentrated within a "funnel" or "chimney-like" volume of rocks and that they spread out radially near the surface of the earth to return downward in a dispersed manner to their source (the hydrocarbon accumulation), the ET currents concentrated in the funnel give rise a a magnetic vortex according to "Faraday's Law" and are governed in polarity and direction by the "right-hand" rule.

This rule states that if the thumb of the right hand is pointed in the direction of flow of an existing electric current, the magnetic field generated by such current is directed around said current in a closed circuit as pictured by the fingers of the right hand encircling the wire (or

Fig. 2

Example of "oil gradient" on SP curve

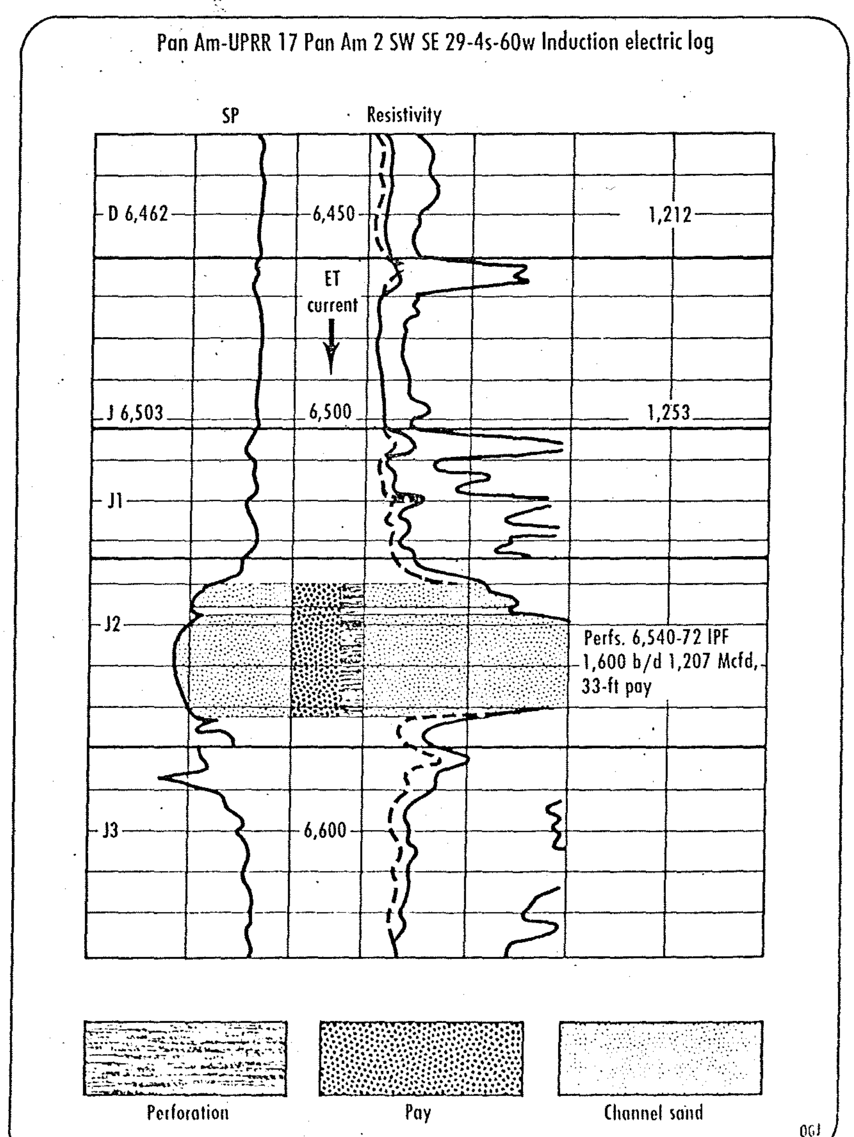


Fig. 3

Aeromagnetic survey—Oklahoma

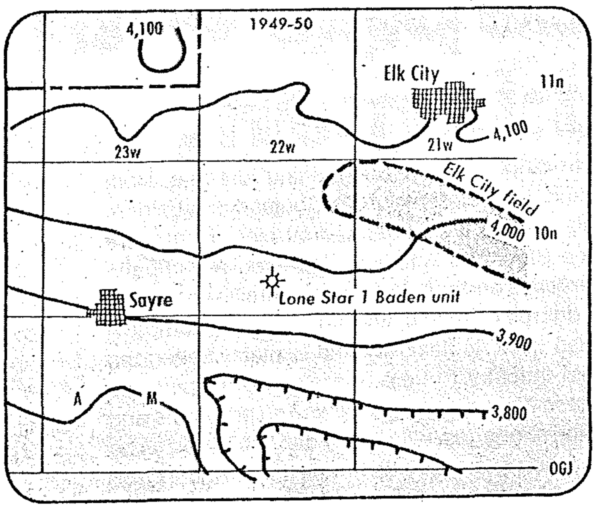


Fig. 4

Magnetoelectric interpretation

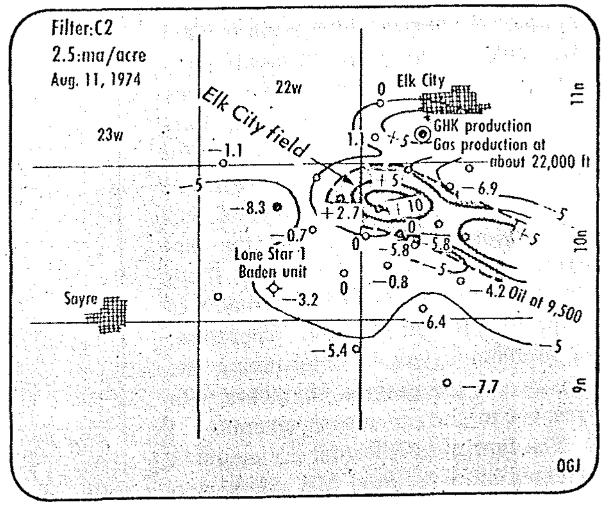


Fig. 5

Original aeromagnetic map

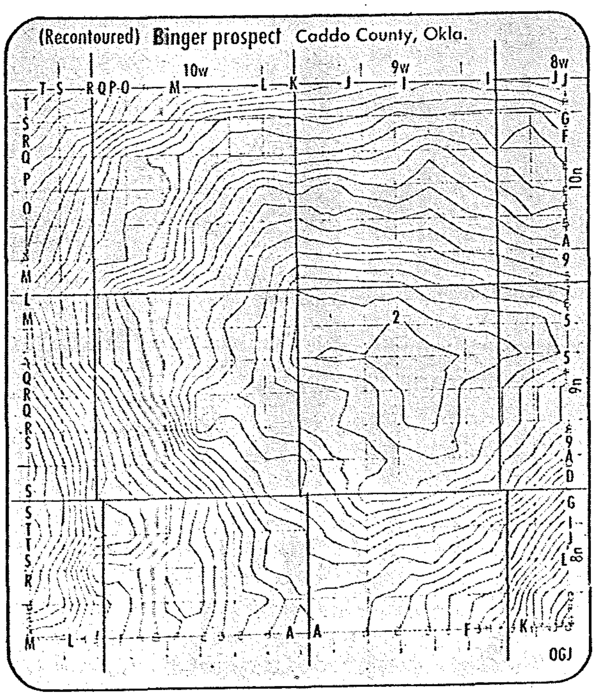
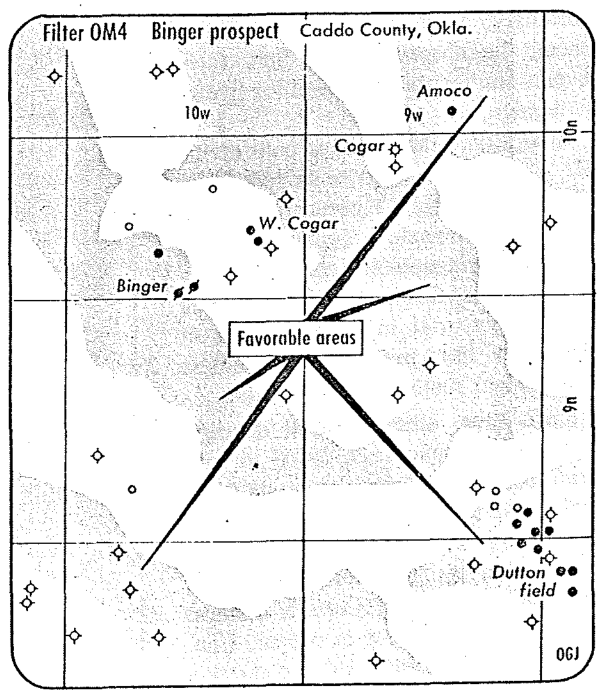


Fig. 6

Magnetoelectric survey



funnel) carrying said current.

In the case of the Peoria field, a magnetic field perturbation in the earth magnetic field of 35 gammas/mile would be observed (one gamma (γ) is about 2×10^{-5} of the total earth magnetic field intensity). Thirty-five γ is a sizable perturbation measurable by portable field magnetometers. The problem of ME exploration is to extract from magnetic field intensity measurements made over a prospective area and to map the corresponding vertical ET current densities (ma/acre) in polarity and in intensity. The "know-how" for this process is of course proprietary information.

Geothermal magnetoelectric (GME) effect. In recent years, spontaneous electric profiles have been made over geothermal energy prospects, and some of the results have been published in the literature.[2]

These results lead to the obvious conclusion that a thermal gradient within electrically conducting rocks leads to the generation of a thermal ET potential and, therefore, to the flow of thermal ET currents. The results are such that they indicate a reversal in polarity from the hydrocarbon-generated ET currents, i.e., the currents flow upward from the source of heat toward the surface of the earth from which they spread out horizontally and eventually disperse to return to the source.

An additional difference in behavior from that of the hydrocarbon fuel cells is that the vertical ET currents are probably not confined to a narrow funnel, but rather that the geothermal ET currents disperse more evenly through the overburden, perhaps selecting some conductive tortuous paths on their way to the surface.

Surface measurements, therefore, may not necessarily indicate the largest geothermal electric current anomaly exactly vertically above the deep-seated source. This is especially the case in exploring for geothermal dry-steam energy which is associated with magma chambers in highly fractured igneous and metamorphic rocks such as in Geysers, California, Larderello, Italy, etc. Such economically desirable dry-steam sources are found in fault zones at the junction of tectonic plates in motion, and the distribution of conductive paths (both to fluids and to electric currents) is expected to be erratic. Therefore, a problem exists in determining the position of the magma chambers with respect to surface measurements.

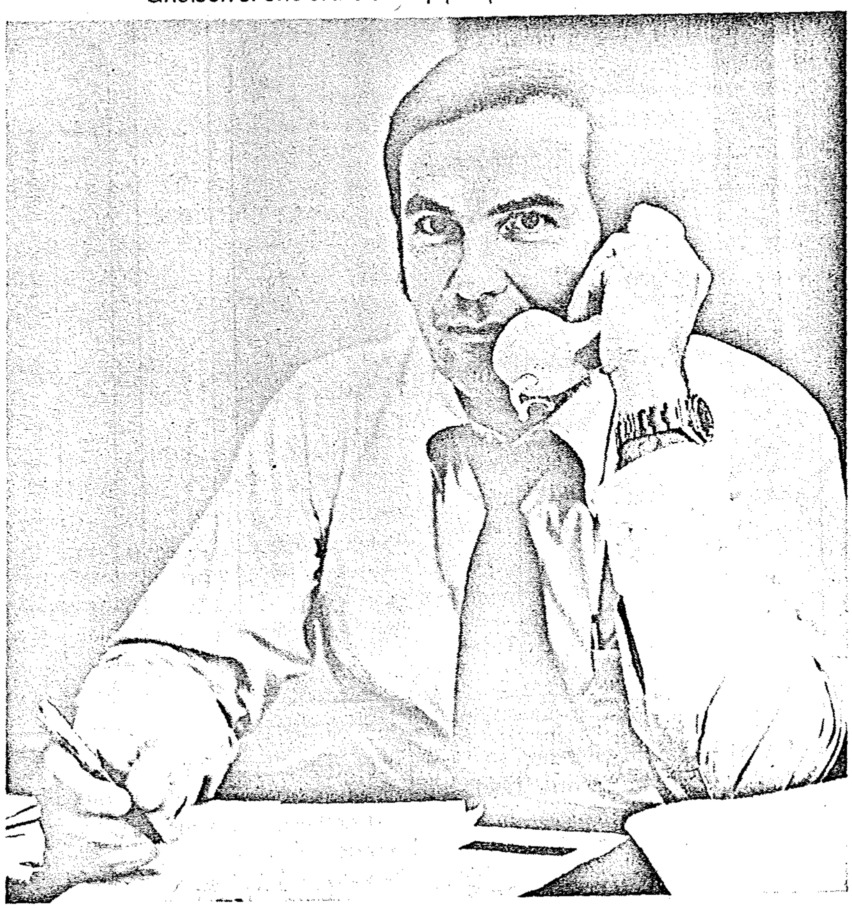
The flow of geothermal ET currents creates an associated ME effect, and judging from the magnitude of the SP anomalies (as high as 1,000 mv) at the surface of the ground, the geothermal ET current flux density must be considerable and significant. Accordingly, geothermal ME anomalies should be observable by field techniques similar to those used for hydrocarbons.

In addition, the tortuous path of the ET current flux may be traced downward by making ET current flux density maps at various depths.

Mineral magnetoelectric (MME) effect. The measurement of spontaneous electric potential in copper mines of Wales in 1830 makes it the oldest geophysical method of exploration.

Since then, other mineral deposits in the earth have been found to generate their own electric currents especially when such deposits are associated with a redox potential contrast such as is the case of sedimentary uranium and sulfur. Certain mineral deposits such as those of copper, iron, cobalt, etc., require the conductive ore body to be partially above the water table (in the zone of oxidation) and partially below the water table (in the zone of reduction). The redox fuel cells associated with such deposits give rise to vertical ET currents and, therefore, to an earth magnetic field perturbation. Without going into detail, it is obvious that these conditions favor exploration for mineral deposits by means of magnetometer surveys of proper design.

Examples of ME surveys. The types of ME surveys and interpretations are



numerous because of the wide variety of field magnetometers which may be used in the air, on land, and underwater.

In addition, the components of the earth magnetic field which may be measured and the sensitivity of such measurements is highly variable.

In effect, there are only two types of ME surveys:

1. Reinterpretation of existing magnetic maps in terms of mapping the intensity of the vertical ET currents in the earth and at variable depths of investigation.

2. Performance of ME surveys specifically for the purpose of determining the vertical ET current flux densities at desired depths with a specially designed field magnetometer.

The interpretation procedures are, of course, the same for the two methods and are proprietary information, patents having been applied for.

Elk City field example, Beckham Co., Okla. The area mapped by Fig. 3 is an airborne magnetic map surveyed around 1949-50 when the Elk City field had already been discovered.

It is located nearly over the axis of the Anadarko basin. The field produces light crude oil (API = 65°) from a depth of about 9,500 ft in the granite wash. At the time of the survey, the field was in the early stages of development. Hence, the magnetic disturbance created by steel surface and subsurface well equipment must be considered at a minimum. The contour interval is 10 γ.

The outline of the Elk City field, as it is now known, is indicated together with a one-well field; the GHK 1 Miller drilled to 26,000 ft but plugged back and producing from shallower depths. The location of the second deepest well in the world (a dry hole) is also shown: Lone Star 1 Baden drilled to 30,050 ft. At this date, there is still no other production but that shown.

The map of Fig. 4 is an ME interpratation of Fig. 3 made by data filter C2. In this procedure a filter is located on the map at selected locations so as to sift out the ME effect and convert it into vertical current flux intensities. It is observed that the Elk City field is well outlined by the Zero ET current line together with the probable extent of the gas accumulation at the GHK Miller well. The Lone Star 1 Baden well is an unfavorable location.

Binger prospect, Caddo Co., Okla. Fig. 5 is a computer-recontoured map of the prospective area which was deemed to represent accurately the features of an airborne magnetometer map of the area.

The ME interpretation was made by means of a numerical data filter OM4 which removed the ME effect from a depth of about 2 miles. The favorable areas on the interpreted map (Fig. 6) are shaded. It is observed that the Dutton field, a stratigraphic trap in the Marchand sand is well indicated. However, the ME map does not check very well the Cogar nor the W. Cogar fields.

The deep Binger well, long ago considered to be a discovery well, is on the edge of a sizable anomaly trending NW-SE, on which no deep test has been made.

Since the map was made, an Amoco well in 9-10n-9w has been drilled to 11,198 ft into the Springer sand with a potential of 20 MMcfd. Other wells, dry holes, drilled on favorable anomalies were too shallow to have tested the deep production possibilities of the area.

Track record. Experimental airborne magnetometer surveys made in Oklahoma about 1949-50 were interpreted in 1972 by various ME methods and covered a total of 1,500 sq miles.

The various surveys were located mostly in the Anadarko basin, and in the interval of time, 1950 to 1972, a large number of wells had been drilled; a total of 240 wells, both producers and dry holes.

It was impossible to break down these wells into wildcat and development wells.

The ME interpretation procedure separates the areas surveyed into favorable for hydrocarbon discovery and into unfavorable areas wherein only dry holes are expected. One hundred forty wells proved to be in the favorable areas out of which 105 were oil and gas wells or 75% of expectations. In the unfavorable area, 100 wells were drilled out of which 62 were actually dry or 62% of expectations.

Recently, in October 1974 one well was drilled in Goliad County, Tex., exclusively based on an ME interpretation of an old magnetometer map. It is the OHB Company Ltd. O'Brien-Harkins C1 drilled to 4,418 ft into the Frio sand (12 ft) where it tested 4 MMcfd with 15 bbl distillate/MMcf of 72.4° API gravity.

References

1. Pirson, S. J., and Negut, Aurelian, "Preliminary Model Experiments in Redox Well Logging," Rev. Roum. Géol. Géophys. et Géogr., Série de Géophysique 16, y-1, 145, Bucharest, 1972. Gupta, B. S., "The Electrotelluric Effect of Hydrocarbon Accumulations," PhD Dissertation, University of Texas, Austin. October 1972.

2. Anderson, L. A., and Johnson, G. R., "A Self Potential Survey of Long Valley Caldera," USGS Open-file Report, 1974. Yamashita, S., "The Electromotive Force Generated Within the Ore Body by the Temperature Difference," J. Min. Coll., Akita University, Serie A, Vol. 1—No. 1, pp. 69-72, September 1961.

MAPS

1975 OKLAHOMA State Pool Map. Published by Oklahoma Oil Maps, 1100 Classen Dr., Suite 222, Plaza Court Bldg., Oklahoma City 73103.

This excellent wall map of the state of Oklahoma and its many oil and gas fields has been updated to March 1975. Every section, township, and range in Oklahoma is shown. All wells are noted as are field delineations, county seats, and other important data. With the increase in drilling activity noted throughout the state in recent months, this map is a must for those watching or drilling in Oklahoma.

A MAJOR, nonexclusive mapping of Alaska is now more than 60% complete.

Wilde Inc., a Denver consulting firm, is doing the work. The area being mapped includes that part of Alaska south of Brooks Range. Total area covers 447,000 sq miles and will be the largest mapping job ever done by one firm. A uniform scale of 1:96,000 or 1 in.=8,000 ft, allows for the delineation of all major structural and stratigraphic features. For progress information and other data, contact Edward J. Kelty at Wilde Inc., 1660 S. Albion St., Writers' Tower, Suite 414, Denver 80222.

SILURIAN AND DEEPER WELL LOCATION MAP OF EASTERN MICHIGAN. Published by W. E. Bulmer, Box 596, Chatham, Ontario, Canada. 1974. $35 plus 10% for handling and postage. This map provides an overall view of the Niagaran Reef trend of southeastern Michigan and southwestern Ontario.

GEOLOGIC MAP ATLAS OF CAMPBELL COUNTY, WYOMING. Published by Geological Society of Wyoming, by Roy M. Breckenridge et al. 1974. Box 3008, University Station, Laramie. 82071. $3.

This is a geologic map atlas and summary of land, water, and mineral resources of Campbell County in northeastern Wyoming.

THE Alaska Map Service, Anchorage, has issued its 1974-75 Oil & Gas Well Atlas for Alaska. The Atlas, a composite of the company's wildcat maps covering 10 basins and regions of Alaska, has been updated and will be published annually. The price is $25.

RELIEF map of Missouri, ERTS Orthophotomosaic map of Missouri, 1974. Published by Missouri Geological Survey and Water Resources, Rolla, Mo. 65401. 25¢ each.

BOOKS

TWO CHEERS FOR THE AFFLUENT SOCIETY. By Wilfred Beckerman. Published by St. Martin's Press, 175 Fifth Ave., New York 10010. 1975. 238 pp. $7.95.

The case against economic growth has become one of the most widely publicized of all indictments of modern society. This book is not an attempt to present a survey of all the pros and cons of economic growth. The author notes that the prosecution case has been put to the public over and over again in numerous forms. He wants to put the case for the defense as he sees it.

INSTRUMENTATION IN THE PROCESS INDUSTRIES. Published in three parts by U. G. Andrew. $24.95/vol. Published by Gulf Publishing Co., 3301 Allen Parkway, Houston 77001. 1974.

This is the most comprehensive work yet produced in the field. Instrumentation is partly art and partly science. Vol. 1 is "A survey," Vol. 2 is "Practical guidelines," and Vol. 3 is "Engineering data and resource material." These volumes are directed at hastening the development of instrument trainees, at bridging the gap between instrument people and engineers and designers in other engineering disciplines, and in aiding experienced instrument engineers.

PORT PLANNING AND DEVELOPMENT. Edited by Eric Schenker and Harry C. Brockel. Published by Cornell Maritime Press Inc., Cambridge, Md. 21613. 1975. 325 pp. $12.50.

This is a collection of the papers presented at the conference of port planning and development and the U.S. coastal environment jointly sponsored by the University of Wisconsin and the Transportation Dept. in 1973.