Some unconventional geophysical methods: A review

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The dramatic decrease in oil and gas exploration in the United States since 1986 has renewed the interest of small independent operators in less costly, unconventional techniques. Among these are near-surface soil gas analysis, radiometric investigations, and magnetometry surveys of shallow Precambrian topography. The purpose of this article is to review the results of original research that I conducted in these areas in the period 1962-80 and to assess the possible value of these methods in modem exploration.

Near-surface soil gas analysis. One fundamental assumption in soil sampling and soil-gas sampling is that the lighter hydrocarbons in an oil or gas reservoir migrate vertically to the surface of the earth. Oxidation and subsequent polymerization of these migratory hydrocarbons may form waxy or liquid materials in the near-surface zone of the earth. Some techniques investigate the association of hydrocarbon migration with the accumulation of inorganic compounds in the immediate subsurface.

Investigation into the relationship of near-surface hydrocarbons to oil-and-gas producing areas started during the pioneering era of geophysical exploration (e.g., 1929 in Germany and 1932 in Russia). These early efforts measured the enriched soil gas over producing reservoirs. US explorationists became interested in 1936.

One of the early investigators, Leo Horvitz, analyzed soil samples collected at depths of 8-12 ft, for methane, ethane, and heavier hydrocarbons. He concluded that "every good oil accumulation produces a hydrocarbon anomaly near the surface."

In 1961, I learned that Rayflex Exploration had formed an Experimental Methane Count Exploration Crew to develop a tool for exploration in shallow and stratigraphic producing areas. This crew (six men in the field plus one in the Winnfield, Louisiana office) covered about four miles a day. Basic field procedure was to drill a hole with a depth of 2-3 ft, seal the hole as soon as the auger came out, and take a sample of the soil gas. Interpretation consisted of converting readings to methane values and contouring those values on a map.

The crew first worked over a shallow oil field and generally recorded higher methane readings over the producing area. Problems encountered were the presence of "marsh gas" at the surface in some locales and faulting which could detour the methane's path to the surface.

Subsequent work at Goodpine, Louisiana (which resulted in an oil discovery) used a new field procedure involving a pattern of 20 holes at each station. Statistical analysis determined which values were high enough to be significant. *The percentage* of significant values, not the absolute values, were contoured. The discovery well had 14 ft of pay at the top of the Wilcox Formation (depth about 1900 ft). The crew was able to work 6-10 stations per day in this area. Spacing was 1320 ft for reconnaissance work and 660 ft in a zone of interest. Seven producing wells had been drilled in this new field by January 1962.

At about this same time, I was working with the late Horace Ridge11 in the investigation of ethane anomalies. Ridgell's procedure of ethane intensity exploration involved correlation of the geology of a producing area with an empirically determined diffusion factor; i.e., in an area of equal geologic reference, ethane intensity readings in shale mantle were half those in sandstone mantle, and the readings in limestone mantle were a third of those in sandstone mantle.

During the summer of 1962, while working as a seismic consultant to the late W.T. Graham, I collaborated with geologist Roy Short in a research program concerning methane intensity measurements in areas where seismic surveys had revealed the geologic structure. We also conducted exploratory methane surveys over known hydrocarbon producing areas, stratigraphic as well as structural. Our "Graham procedure" was based on what had been learned from Ridge11 and from the Rayflex crew (which I had observed).

Field experiments began in the fall and continued for three years. During that period, I also corresponded with Lajos Stegena of the Roland Eötvös Geophysical Institute in Budapest, Hungary, who was conducting similar research. Stegena had published results of his initial work in GEOPHYSICS in 196 1 and I was impressed by the similarity in our conclusions.

By April 1964, Stegena and I had agreed on several fundamentals in methane intensity exploration. The most important was our conviction (which Ridge11 also shared) that methane is much slower to migrate than other gases; therefore, methane will be retained longer and will comprise the greater quantity of residual gas in any given reservoir.

Methane intensity research under Graham's auspices came to an end in September 1965 because of the initiation of an accelerated seismic exploration program. Conventional single-fold seismic reconnaissance had defined 13 major prospects at depths of 5000-9000 ft. Based on our comparison of the shallow production of Goodpine, Louisiana and the deeper nonproducing area of the Munster Arch in north central Texas, these prospects were considered too deep for accurate near-surface soil gas analysis.

Radiometric investigations. In the early 1960s, radiometry was considered a possible method of direct detection of hydrocarbon accumulation. This was based, as was methane analysis, on the upward migration principle.

In that time, most research concluded that the ability of rock formations to trap hydrocarbons is continuously exceeded over the life of a producing field so that there is an almost continuous stream of upward seepage.

A common denominator was observed for most of the various seepage phenomena-the anomalous radioactivity of the producing areas. Hydrocarbon molecules have an affinity for radioactive minerals, precipitating and uniting with them. As components of a hydrocarbon reservoir migrate toward the surface, they absorb and transform the radioactive minerals in each layer, resulting in a reduced radioactive measurement at the surface. These "negative" areas are often marked by a surrounding halo of higher radioactive readings. Several such anomalies found over producing fields led to the conclusion that a new oil exploration tool had been found.

In 1964-65, I conducted several radiometric research projects for Graham. Scintillator surveys were conducted across shallow producing areas near Bartlesville, Oklahoma, and over the Mobeetie Field in Wheeler County, Texas. The Oklahoma work led to no useful conclusions. However, the Mobeetie Field project revealed a *positive* radioactive area over the producing field. This agreed with surveys conducted by Stegena in Hungarian fields.

Correlation of seismic and geologic data for Mobeetie with the radiometric data led to the conclusion that numerous factors tended to interrupt and alter the surface manifestation of the radioactive "lows"-fracture systems, faults, and permeability minima.

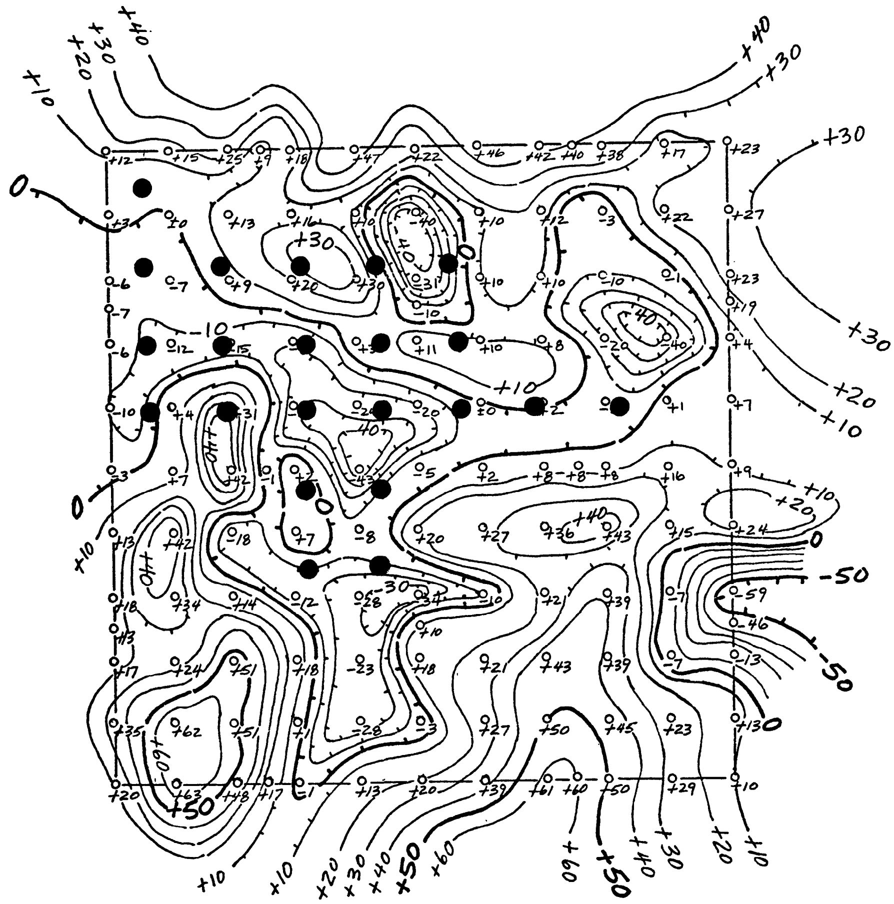

Figure 1. Original "pothole" discovery.

In 1965, I became acquainted with the work of Delbert Long and his Empire Surveys of Moab, Utah. He utilized an ionization chamber which had a minimum of drift due to temperature and other causes, made it easy to integrate the values to a minimum of variation and a maximum of repeatability, and was light and rugged enough for easy portability and to survive rough handling.

Empire made parallel traverses at 0.5- or 1.0-mile spacing, taking an observation every 330 ft. The normal regional gradient had to be determined for each area. The field crew tabulated base and traverse data, diurnal information, weathering and rock type data, along with topographic descriptions.

Interpretation and mapping included corrections for the mass effect of topography, weathering, and formation changes. Regional gradient corrections were made if the traverses were sufficiently long. After these corrections, the surface radioactivity readings were converted to "intensity values" as related to an averaged background value. The intensity values were plotted in profile with respect to their location on the traverse. After processing the profiles, a map of the area was made with potential anomalies indicated.

The disparity of results and lack of definition led to the conclusion that radiometric investigation did not warrant the time and expense involved. Low instrumentation sensitivity and uncertain correction factors added to the lack of confidence in this method.

Magnetometry investigation of shallow Precambrian topography. While conducting geologic and geophysical surveys in the Panhandle Field of Texas and the shallow oil fields of southwestern Oklahoma, I became aware of oil and gas production associated with granite wash and fractured granite formations which were situated in Precambrian lows.

An observer standing atop Mt. Scott, northwest of Lawton, Oklahoma, will see a general lineament of granite peaks to the northwest and surmise that same trend exists toward the vicinity of Amarillo, Texas, where the granite is over 3000 ft beneath the earth's surface. Looking down from Mt. Scott, the observer could imagine Lake Thomas and the topographic valley in which it is situated to be filled with granite wash and contain hydrocarbons, the topographic low (commonly known as a "pothole") trapping the hydrocarbons against the granite. The numerous faults and associated fracturing would provide the access mechanism for hydrocarbons to migrate into the pothole.

The opportunity to develop the pothole theory appeared during the Arab Embargo of 1973, when US oil and gas exploration accelerated. Field experiments showed that aerial magnetometers, proton precession magnetometers, and gravity surveys were not sufficiently accurate to map the small topographic lows of the Precambrian granite. Our conclusion was that only the field balance, a mechanical device comprised of a pivoted magnet measuring vertical magnetic intensity, could acquire the necessary data.

The actual instrument used was an Askania Gf6, consisting of a horizontal magnet supported on a quartz knife edge. The torque produced by the reaction of the magnetic poles with the vertical component of the earth's magnetic field is balanced by the weight of the moving system with its center of gravity being adjusted at the correct distance from the knife edge support. The position of the moving system is indicated by a scale in the eyepiece which is reflected from a mirror mounted on the moving magnet. Accuracy of l-3 gammas was obtained when proper care was practiced.

Field procedure consisted of observation stations located at 0.5mile intervals for reconnaissance surveys and 0.25mile intervals for detail surveys. A 0. l-mile station spacing was used on two large prospects in Carson County, Texas, but the Precambrian potholes which resulted in new oil discoveries were quite discernible on maps based on the original 0.25mile intervals.

Computation of the observed data involved application of diurnal corrections based on the periodic reading of the magnetic intensity at an area base station.

The corrected magnetic intensity readings for each station were placed on a map and contoured with a lo-gamma interval. Any contoured pothole of 30 gammas or more was recommended for exploratory drilling.

The original pothole discovery was in the northwestern quarter of Section 86, I&GN Survey, Block 5 in Carson County, Texas (Figure 1). The first wells potentialled 100- 150 b/d from depths averaging 2800 ft. The oil had a distinctive reddish-brown color (as compared to the greenish-brown oil of the Brown Dolomite Formation), indicating a virgin reservoir. The rock pressures were approximately 400 psi (15-50 psi was usual for this area) and the wells maintained this pressure throughout at least the first three years of production.

Subsequent pothole discoveries were made in similar or smaller anomalies. The better producing wells were generally found in the deepest part of the potholes because they usually possessed the greater amount of porous granite wash or highly-fractured granite. Wells located on the rims of the potholes had marginal economic value due to the increasing shale facies which thereby reduced the total amount of porous reservoir capability.

Detailed magnetic intensity surveys in southwest Oklahoma did succeed in finding shallow gas reserves in a granite wash formation draped over a basement "peak", but they did not find profitable pothole oil discoveries.

Magnetometry investigation of shallow Precambrian topography was a successful hydrocarbon-finding tool in geologic provinces where basement rocks were generally less than 5000 ft deep. However, the magnetic field balance, which can provide the necessary definition of small Precambrian negative anomalies, is a time-consuming method. Thus, although I think it is a viable exploration technique, it may not be cost-effective in times of low oil prices.

Conclusion. Many of the major oil companies and large independents have shifted the majority of their exploration efforts out of the United States. The smaller independents, who are working the area, often cannot afford 3-D seismic and thus are seeking less expensive exploration methods.

The current emphasis among this group seems to be on aerial magnetometry and radiometric investigations. My personal experience is that they should consider greater investment in the utilization of the magnetic field balance in shallow producing areas. LE