Magneto-electric exploration: development of a statistical track record

R. M. Herzfeld
Independex Inc.
Dallas

During a 1 year term beginning Aug. 16, 1982, Independex conducted ground magnetic surveys under a U.S. Department of Energy award grant to evaluate the process of magneto-electric exploration.

The process was developed by the late Dr. S. J. Pirson and his son, Jacques E. Pirson. The procedures are discribed in detail in "Line Integral Method of Magnetic-electric Exploration", U.S. Patent 3,943,436, Mar. 9, 1976. The basic theory involved in magneto-electric exploration is that the vertical electric currents generated in the earth by the electrotelluric effect of oil and gas accumulations give rise to anomalies in the static earth magnetic field.

Through proper data processing, it is possible to deduce the direction and magnitude of vertical electrotelluric currents from anomalies represented by maps of the earth's magnetic field, by virtue of Maxwell's equations of electromagnetism and other accepted fundamental theorems and laws of theoretical physics. During the grant program, Independex completed 19 ground magnetic survey projects with

Fig. 1

Ropes project

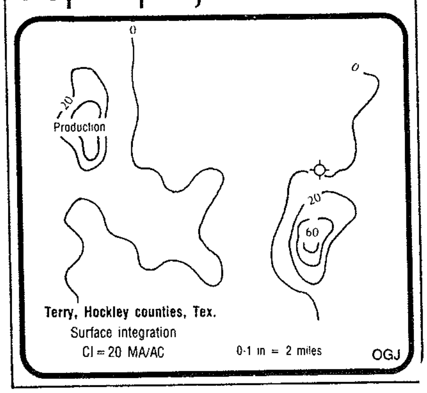


Fig. 2

Moore's Station project

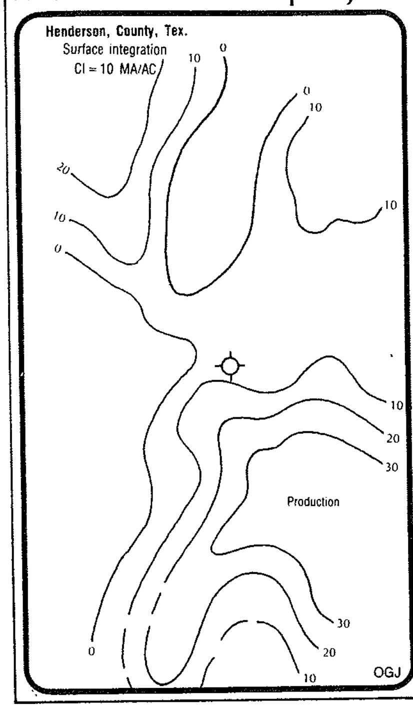


Fig. 3

Blanchard project

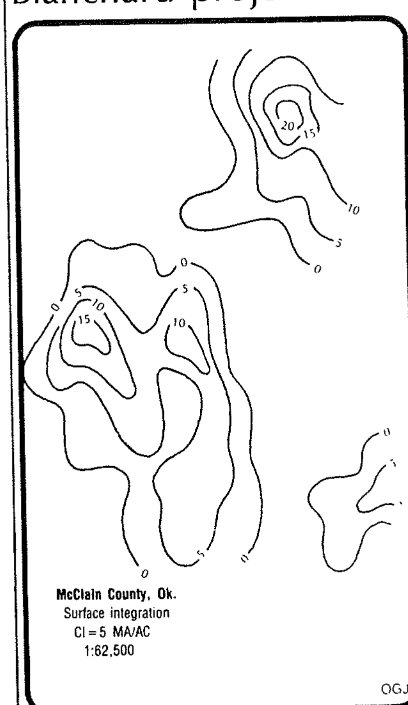


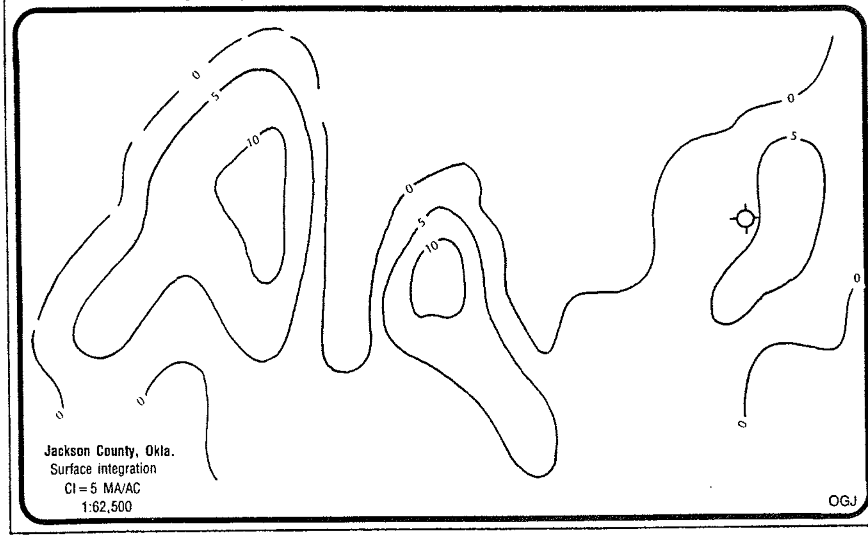
Table 1

Recap of time and mileage

Project	Field hr.	Travel hr.	Mileage	Days per diem.
Ropes	33.21	13.00	1,425	4
Moore's Station	33.92	2.40	992	4
Blanchard	21.78	9.09	689	3
Quanah 5	14.73	9.67	1,062	3
Vitoskey	10.88	3.80	413	1
Cook Ranch	9.41	3.80	413	1
Chalakee	9.18	3.80	414	2
S.E. Miles	17.90	8.92	901	3
Calvary Creek	11.15	9.25	773	2
N.E. Ashland	9.23	9.25	773	2
Cummins Creek	18.69	0.82	342	2
Kubela	18.54	10.58	795	3
Bellevue Scaling	22.65	7.07	695	3
Willow West	14.98	11.00	987	3
Herr-King	19.91	6.34	713	3
Pace	15.67	4.42	442	2
Little Rush Creek	33.15	0.50	295	4
N.W. Powell	11.05	0.50	142	2
Arbuckle	17.62	8.50	847	3
Totals	**343.65**	**122.70**	**13.113**	**50**

Fig. 4

Quanahs project



magneto-electric interpretation over an area of about 523,555 acres, spending 343.65 man hr in the field and traveling 13,113 miles, as shown on Tables 1 and 2.

The primary purpose of this program was to develop a statistical track record for the process of magneto-electric exploration, with a secondary purpose of evaluating the acquired data and utilizing that data for any refinements necessary to the improvement of the process, adjustments to the procedure, determination of criteria of the value intensities as they apply to hydrocarbon productive and nonproductive areas, and in essence, provide controlled data to evaluate the present state of the interpretative procedure of magneto-electrics.

To develop a statistical record, Independex contracted numerous oil and gas exploration companies and requested that they submit an area where they were drilling or about to commence a wildcat well, so that a ground magnetic survey could be conducted and results could be processed prior to the actual results of the drilling and completion operations. Table 3 reflects those results, which are based on the processed surface intergration maps that were derived from total intensity magnetic field maps acquired from field surveying. The surface integrations maps were compared with the results of the drilling operation of the initial well on each anomaly defined, evaluating only whether the well was completed as a producer or plugged as a dry hole. Low level intensity values, for this evaluation, were considered as an area where noncommercial reserves would be located and only a show of hydrocarbons would be encountered.

The sampling of the projects was purposefully conducted by Independex over a variety of objectives in different geologic and depositional environments. To date, there has been 20 wells reported to have been drilled on projects conducted under the DOE grant. Independex has developed a preliminary track record, based on the 20 wells sampling and has reported the following results: six oil and gas producers predicted (results—five producers, one dry hole, 83.3% correct); 14 dry holes predicted (results—13 dry holes, 1 producer, 92.9% correct).

Of the 20 wells drilled, the oil and gas companies involved in this program reported six wells as producers, which is a 30% confidence ratio and which corresponds with the oil and gas industry's recent years track record for exploratory wells. The controlled sampling under this program demonstrated a 83.3% confidence ratio in predicting producing wells but represents only the initial well drilled on each project anomaly. Even though the predictive capability of

Fig. 5

Vitoskey project

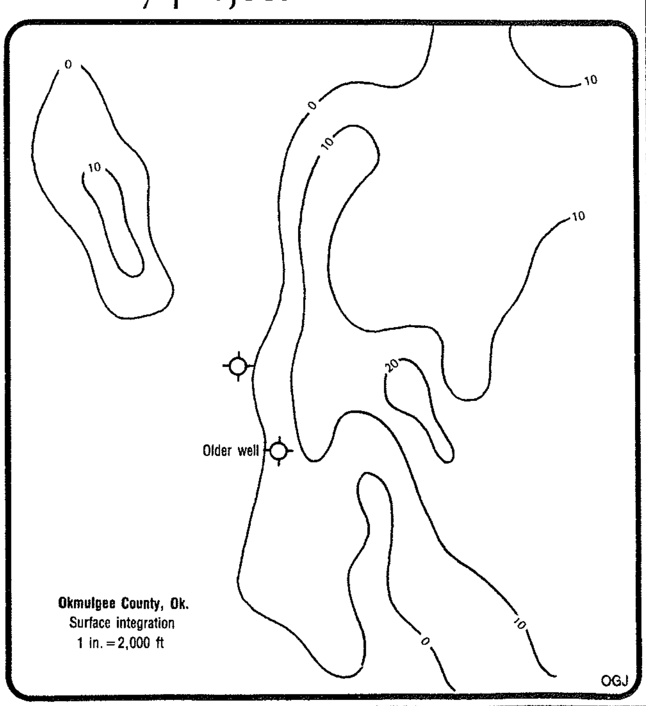


Fig. 6

Cook Ranch project

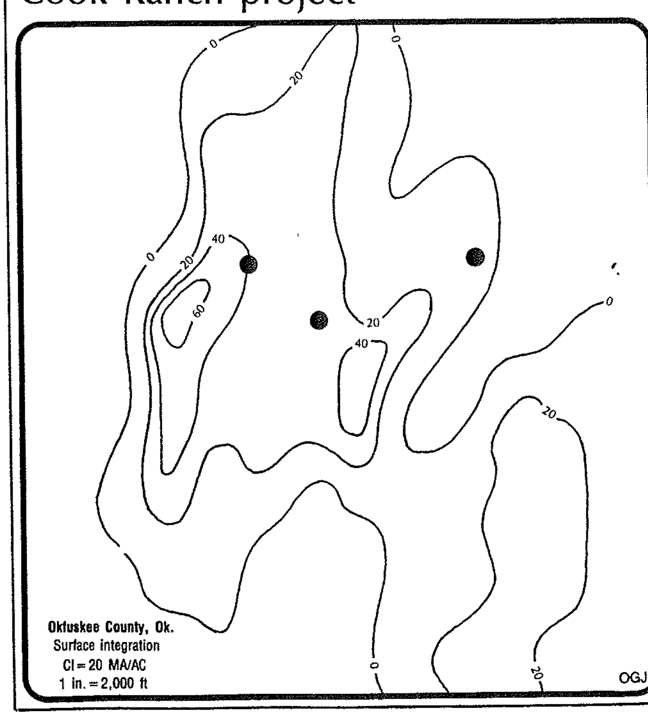


Table 2

Data sheet project evaluation

Project	County	State	Acres	Cum. Base	Cum. sta.	Cum. Hr.	Sta./hr.	Min./Sta.	Acres/hr.
Ropes	Terry	Texas	125,440	23	219	33.21	6.6	9.1	3,777
Moore's Sta.	Henderson	Texas	72,000	25	171	33.92	5.0	12.0	2,123
Blanchard	McClain	Oklahoma	72,000	14	150	21.78	6.9	817	3,300
Quanah 5	Jackson	Oklahoma	40,500	11	105	14.73	7.1	8.5	2,750
Vitoskey	Okmulgee	Oklahoma	4,500	8	57	10.88	5.2	11.5	414
Cook Ranch	Okfuskee	Oklahoma	4,500	6	58	9.41	6.2	9.7	478
Chalakee	Okmulgee	Oklahoma	4,500	5	61	9.18	6.6	9.1	490
S.E. Miles	Tom Green	Texas	18,000	12	112	17.90	6.3	9.6	1,006
Calvary Ck.	Clark	Kansas	18,000	8	80	11.15	7.2	8.3	1,614
N.E. Ash	Clark	Kansas	18,000	7	74	9.23	8.0	7.5	1,950
Cummins Ck.	Ellis	Texas	18,000	14	96	18.69	5.1	11.8	963
Kubela	Wharton	Texas	18,000	12	116	18.54	6.3	9.5	971
Bellevue	Clay	Texas	18,000	16	128	22.65	5.7	10.5	795
Willow West	Chambers	Texas	41,000	11	90	14.98	6.0	10.0	2,737
Herr-King	Challahan	Texas	10,125	15	130	19.91	6.5	9.2	510
Pace	Throckmorton	Texas	18,000	10	105	15.67	6.7	9.0	1,150
L. Rush Ck.	Navarro	Texas	490	20	225	33.15	6.8	8.8	15
N.W. Powell	Navarro	Texas	4,500	8	70	11.05	6.3	9.5	407
Arbuckle	Murray	Oklahoma	18,000	12	113	17.62	6.4	9.4	1,020
Totals			**523,555**	**237**	**2,160**	**343.65**	**6.3**	**9.5**	**1,524**

magneto-electric interpretation appears to be very high, future results from drilling activity through further exploration, development, and well production history will ultimately place the statistical work conducted into a proper perspective. From the initial evaluation, however, it can be concluded, that the correlation between oil and gas accumulations and magneto-electric exploration is relatively close and that magneto-electrics can become an important exploration technique to determine areas favorable for oil and gas accumulation, reduce risk in wildcat exploration, and provide an intergral part to a combined exploration program.

The following is a brief description of each drilled projects:

Ropes Project (Ex. 1)
Terry and Hockley counties, Texas.

A dry Fusselman test was drilled to a depth of 11,598 ft. The well was drilled on a northeast-southwest nose geologically and had only 3 ft of dolomite remaining and came in low subsurface to the nearest control well. The well was situated on the zero contour line of the ME surface integration map and was predicted as being a dry hole.

Moore's Station Project (Ex. 2)
Henderson Co., Tex.

A dry James Lime test was drilled to a depth of 11,354 ft. The well was situated in a low intensity area and was predicted to be a dry hole. The well was low structurally but did have a slight show.

Blanchard Project (Ex. 3)
McClain Co., Okla.

A Bromide test was drilled to a depth of 11,480 ft. The primary objective, the Bromide sandtone was dry, being too tight to produce. There were good shows at shallower depths. The well was drilled in a relatively low intensity area and was predicted to be a dry hole. The well was plugged back

Fig. 7

Chalakee project

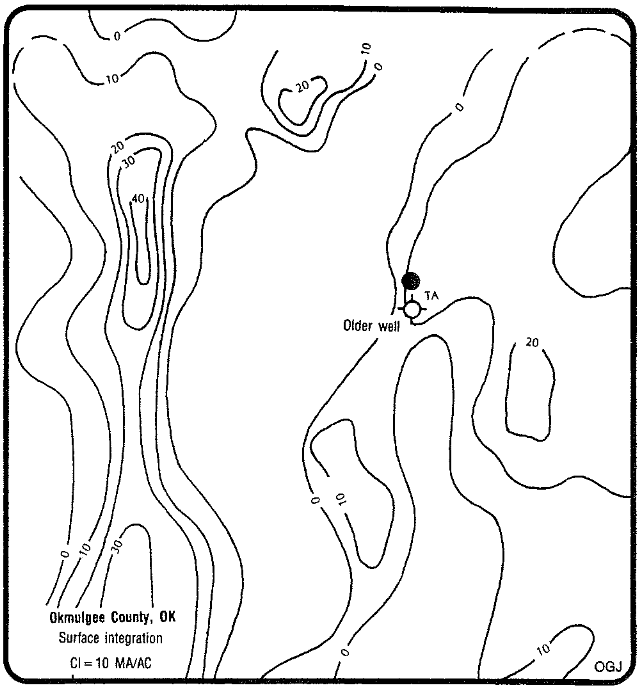


Fig. 8

NE Ashland project

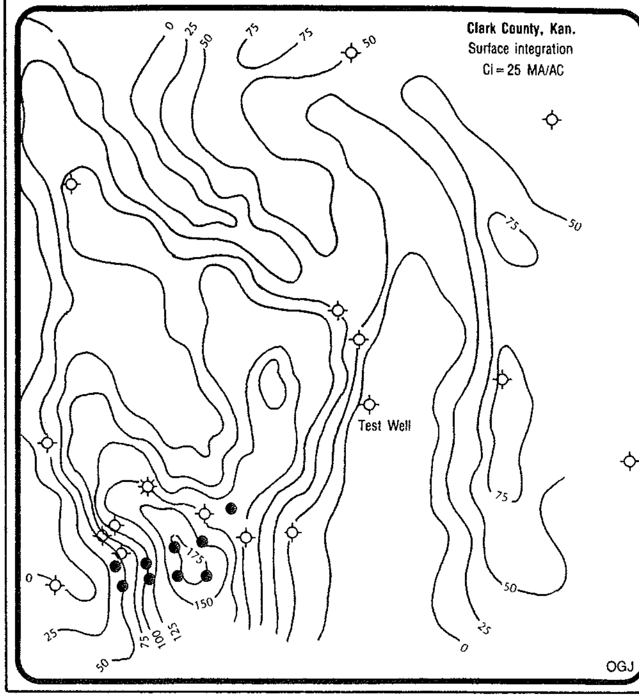


Fig. 9

Kubela project

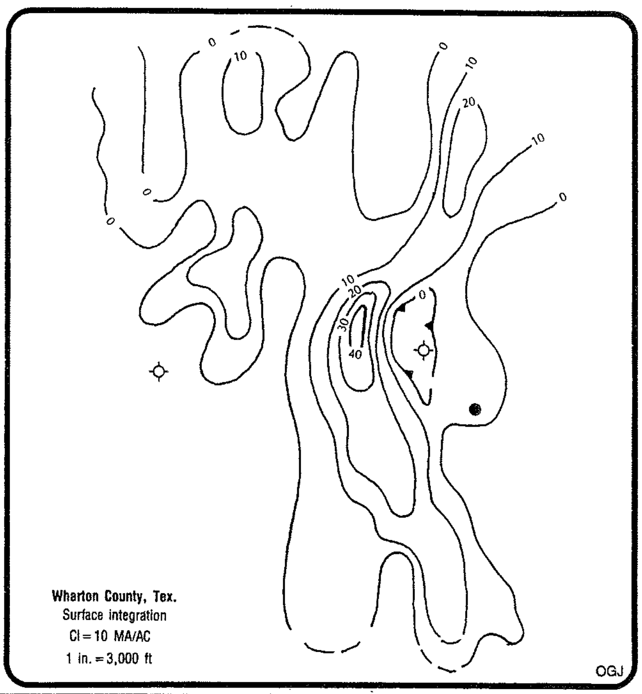
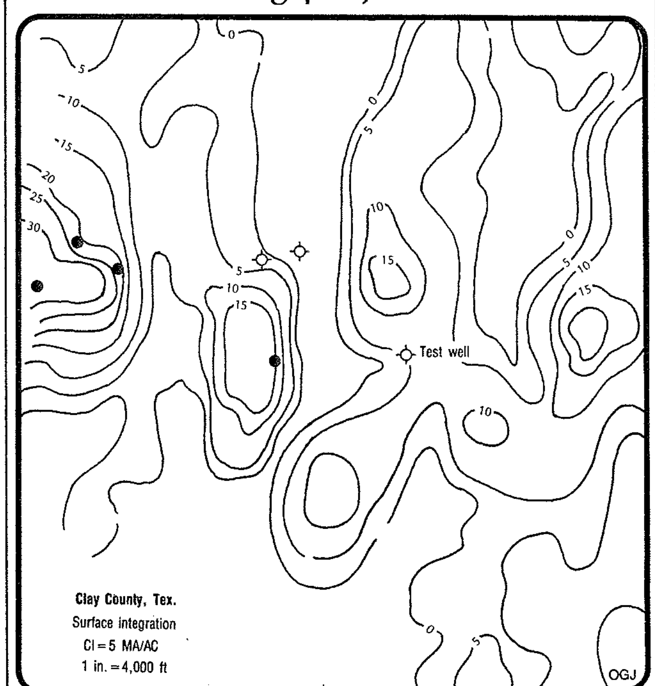


Fig. 10

Bellevue-Scaung project



to a shallower zone and potentialed initially at 60 b/d. Another well, recently drilled and completed in the same producing horizon, situated on a much higher value intensity, potentialed 191 b/d.

Quanah 5 Project (Ex. 4)
Jackson Co., Okla.

A dry Mississippian Chappel Lime test was drilled to a depth of 8,843 ft. The well was situated in a low intensity area and was predicted to be a dry hole.

Vitoskey Project (Ex. 5)
Okmulgee Co., Okla.

A dry test was drilled to a depth of 2,815 ft. The well was situated in a negative area on the surface intergration map. An older well was situated in a low intensity area. On a drillstem test, the older well recovered shows of oil and gas.

Cook Ranch Project (Ex. 6)
Okfuskee Co., Okla.

The initial well was drilled to a depth of 2,825 ft in a good intensity area. The well potentialed 53 b/d, OBWPD, 89 Mcfd. The development wells, also on anomalous area, resulted in good commercial producers.

Fig. 11

Herr-King project

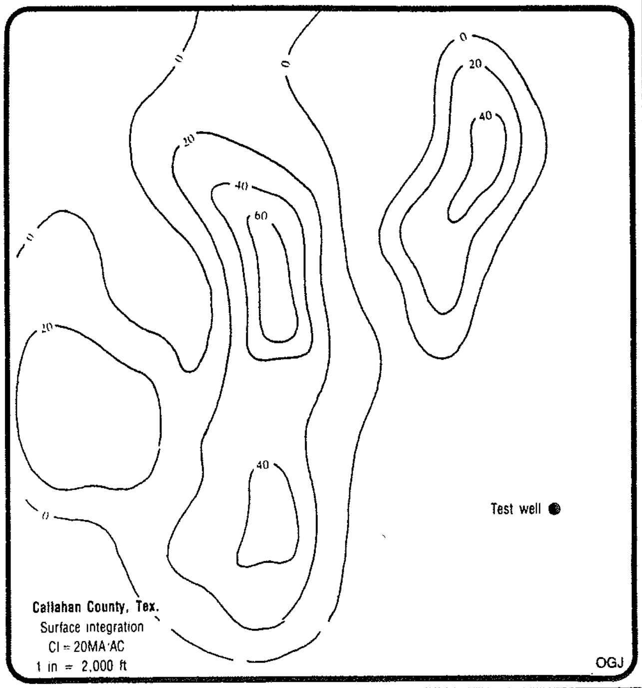


Fig. 12

Pace project

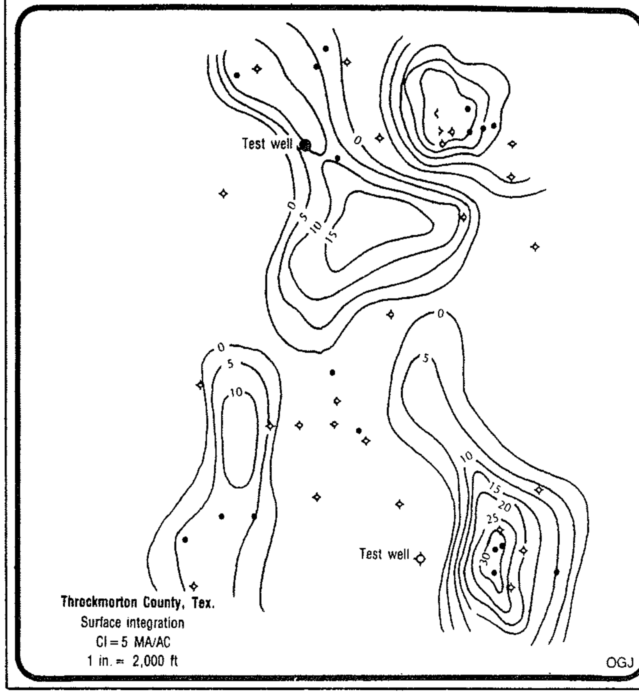


Fig. 13

Little Rush Creek project

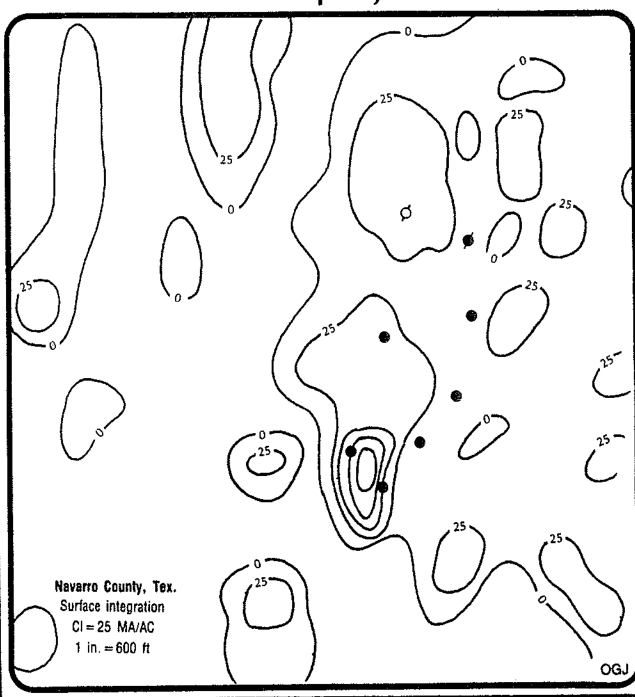
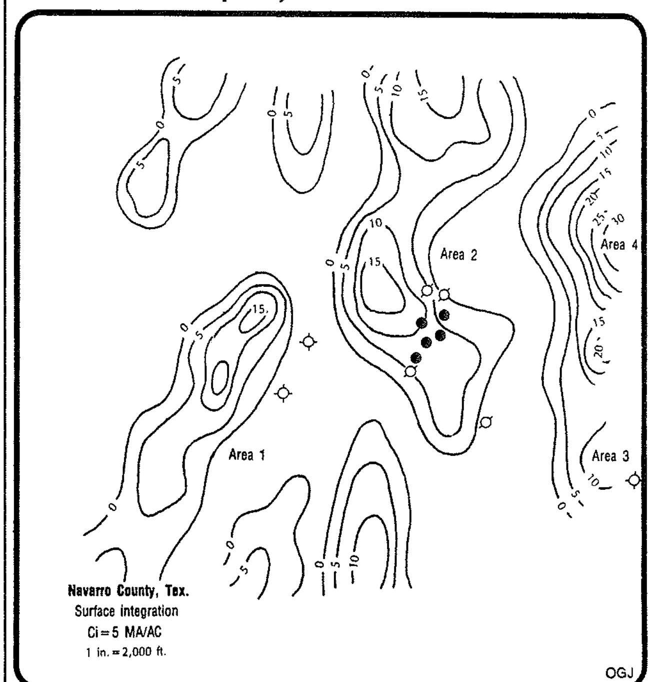


Fig. 14

NW Powell project



Chalakee Project (Ex. 7)
Okmulgee Co., Okla.

A well was drilled to a depth of 2,420 ft and was initially plugged and soon after reentered. The well was situated in a positive area and had a potential of 20 b/d, 24 bw/d, 50 cfd of gas.

An older well was previously abandoned, although a drillstem test indicated shows.

N.E. Ashland Project (Ex. 8)
Clark Co., Kan.

A well was drilled to a depth of 6,917 ft. The well was situated in a negative area. There were good shows in a secondary objective.

Prior drilling indicates a strong correlation with the surface integration interpretation.

Kubela Project (Ex. 9)
Wharton, Co., Tex.

There were three prospects drilled in this project area. The results are from verbal communication. The two dry holes are situated in negative areas; the producer is near an old field in a positive area.

Bellevue-Scaling Project (Ex. 10)
Clay Co., Tex.

A dry hole was drilled on this pro-

Fig. 15

Arbuckle project

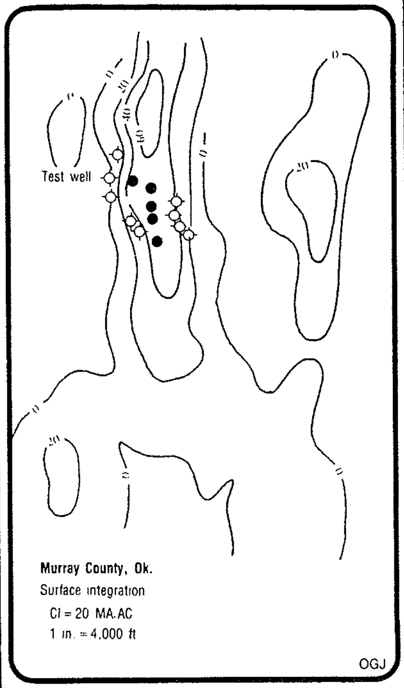


Table 3

Prediction vs. results

Project	Prediction		Results	
Ropes	Dry Hole		Dry Hole	
Moore's Station	Dry Hole		Dry Hole	
Blanchard	Dry Hole		Dry Hole	
Quanah 5	Dry Hole		Dry Hole	
Vitoskey	Dry Hole		Dry Hole	
Cook Ranch	Producer		Producer	+4 development wells
Chalakee	Producer		Producer	
S.E. Miles		Not Drilled		
Calvary Creek		Not Drilled		
N.E. Ashland	Dry Hole		Dry Hole	
Cummins Creek		Not Drilled		
Kubela	Dry Hole		Dry Hole	Lakeview Prospects
	Producer		Producer	Hutchins Redevelopment
	Dry Hole		Dry Hole	Northwest Hutchins
Bellevue Scaling	Dry Hole		Dry Hole	
Willow West		Not Drilled		
Herr-King	Dry Hole		Producer	
Pace	Producer		Producer	
	Dry Hole		Dry Hole	
Little Rusk Ck.	Producer		Producer	+5 development wells
N.W. Powell	Dry Hole		Dry Hole	Area 1A
	Dry Hole		Dry Hole	Area 1B
	Producer		Dry Hole	Area 3
Arbuckle	Dry Hole		Dry Hole	

ject. There was good show of oil in the Strawn sand but could not be commercially completed. The primary objective, Caddo lime, was not developed. The producing wells shown are Caddo producers, discovered prior to the project.

Herr-King Project (Ex. 11)
Callahan Co., Tex.

A recent test has been drilled on this project and has been anticipated to be completed as a producer. The well was predicted to be a dry hole. The positive anomalous areas correspond somewhat to existing field production.

Pace Project (Ex. 12)
Throckmorton Co., Tex.

There were two wells drilled on this project during the program. A Mississippian producr tested 60 b/d, 11 bw/d, 43 Mcfd of gas. The well was situated in a positive area. The other well drilled resulted in a dry hole and was drilled to a depth of 4,735 ft in a negative area of the surface integration map.

Little Rush Creek Project (Ex. 13)
Navarro Co., Tex.

There were recently six producing wells drilled on this project. There were two wells drilled prior to this project but were produced and then plugged. The wells are producing from the shallow, Nacatoch formation at a depth range of 750-1,050 ft.

N.W. Powell Project (Ex. 14)
Navarro Co., Tex.

There were four areas in this project. The first area, a negative area, resulted in two dry holes. The second area is the same as the Little Rush Creek Project discribed above but surveyed at different station spacing intervals. The anomalous area did not change materially between the two independent surveys. The third area resulted in a noncommercial gas area, and the fourth area has not been recently drilled but had produced previously.

Arbuckle Project (Ex. 15)
Murray Co., Okla.

A dry hole recently drilled in a negative area was situated downthrown and low on a north-south fault trend. Newly established producing wells are situated in the positive anomalous area of the surface integration map. There are two fields that are producing in other positive anomalous area. ▪

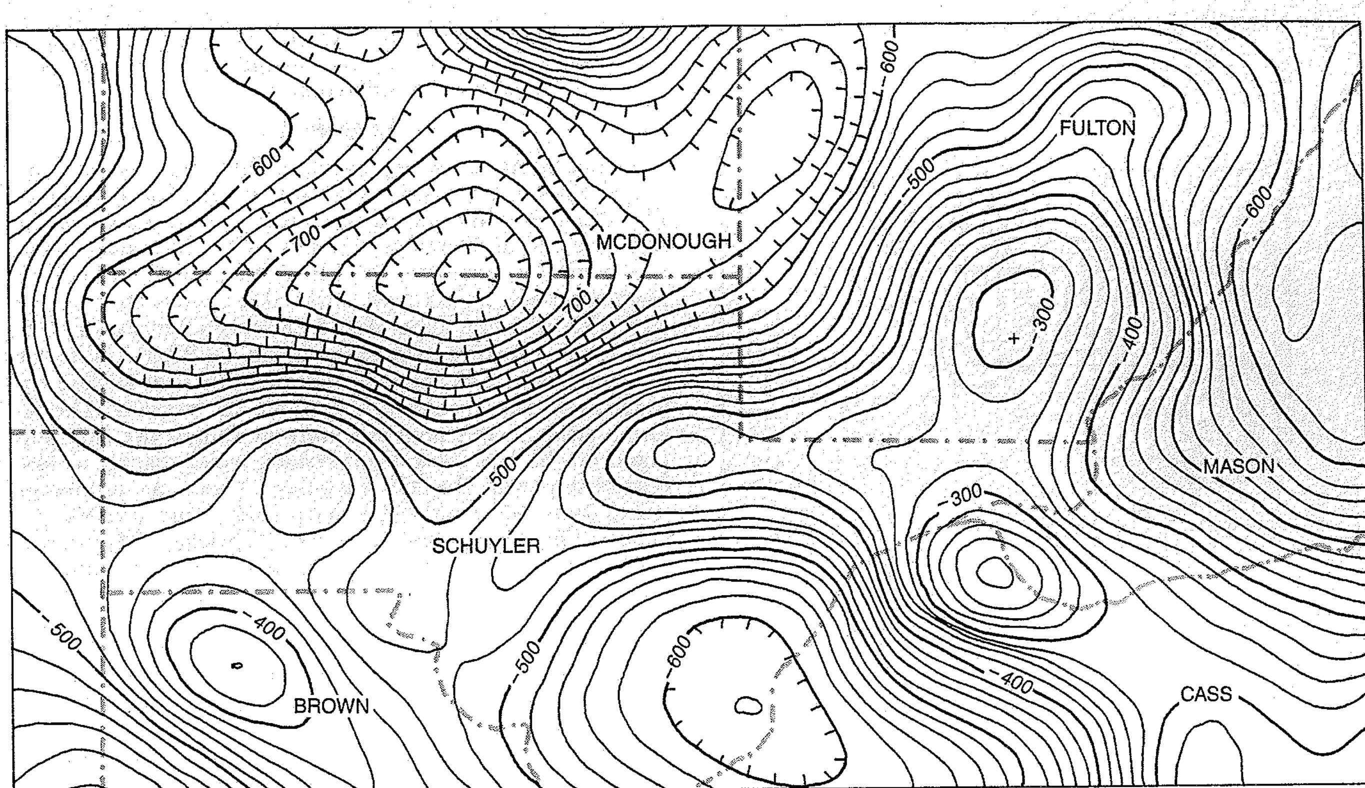


Fig. 1—In this NURE aeromagnetic survey, a portion of the Burlington Quadrangle of southwest Illinois is displayed. The flux density of the total intensity of the earth's magnetic field in this area is shown by the contours. This is the base data to which ME processing is applied.

Oil and gas exploration: A good place to start

Ron Herzfeld, Independex, Inc., Dallas, Texas

10-second summary

In choosing a site for an oil and/or gas prospect, the most difficult decision is often in what geographic area to begin. Though seldom utilized, publically available aeromagnetic surveys taken under the National Uranium Resource Evaluation program of the '70s, when coupled with magneto-electric exploration methods, have proven to be a valuable tool for prospect selection. The following text will review the application and usefulness of this exploration approach.

THERE ARE TIMES when it seems that the most difficult step in generating exploratory prospects is finding a good place to start. Even though there are tremendous volumes of information available for today's explorationist, many sources of data are relatively obscure by not being generally publicized. One such storehouse of data can be found in the NURE (National Uranium Resource Evaluation) program, which was begun in 1974 by the U.S. Department of Energy to provide a comprehensive assessment of the nation's uranium resources for use in government energy program-planning and decision-making activities.

In conjunction with the NURE program, total intensity aeromagnetic data were collected. Some 464 of the 468 National Topographic Map Series (NTMS) quadrangles in the conterminous U.S. and 98 of the 153 quadrangles in Alaska have been surveyed. The surveys were flown from an altitude of about 400 ft, with flight-line spacings of from 1 to 12 miles, though usually the standard procedure was 4 to 5-mile flight-line spacing.

The airborne magnetic data only provide a broad approach to regional studies, but can be of great assistance in delineating favorable areas or trends for oil and gas exploration when combined with interpretive procedures that are designed to filter out derivatives from the total intensity measurements of the earth's magnetic field. The process of magneto-electric (ME) exploration can provide such an interpretation. The following data briefly describe the ME process and illustrate its application to a region in southwest Illinois.

Continued

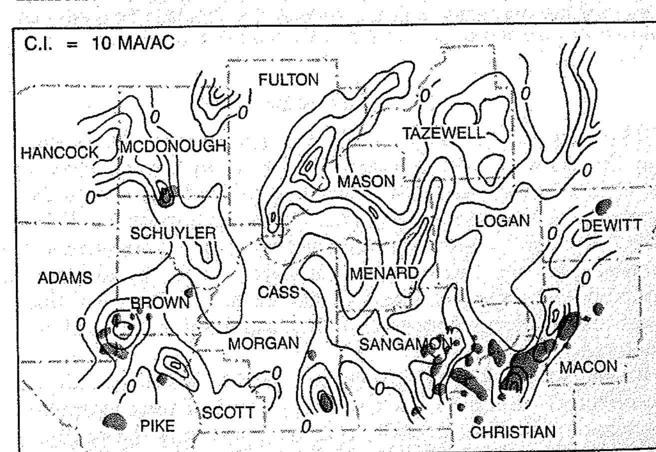


Fig. 2—Magneto-electric anomalous trends are computed from NURE aeromagnetic surveys (Fig. 1), and the ME Surface Integration map shown results. Also shown are producing Silurian fields. Note the close correlation between the indicated ME anomalies and the indicated production to date.

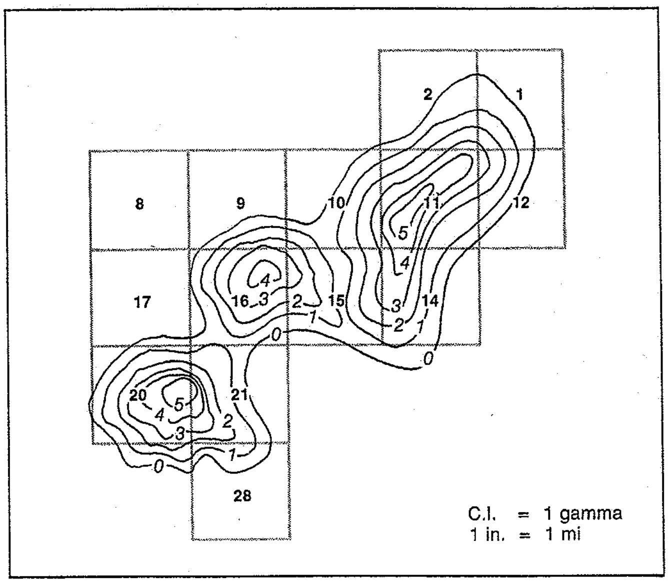


Fig. 3—ME anomaly areas indicated from airborne surveys (Fig. 2) are then subjected to more detailed ground magnetic surveys. A resulting ground survey for the Brooklyn field area is shown (see field located on the county line shared by McDonough and Schuyler counties, Fig. 2). Specific location is Schuyler Co., Illinois, T3N R3W.

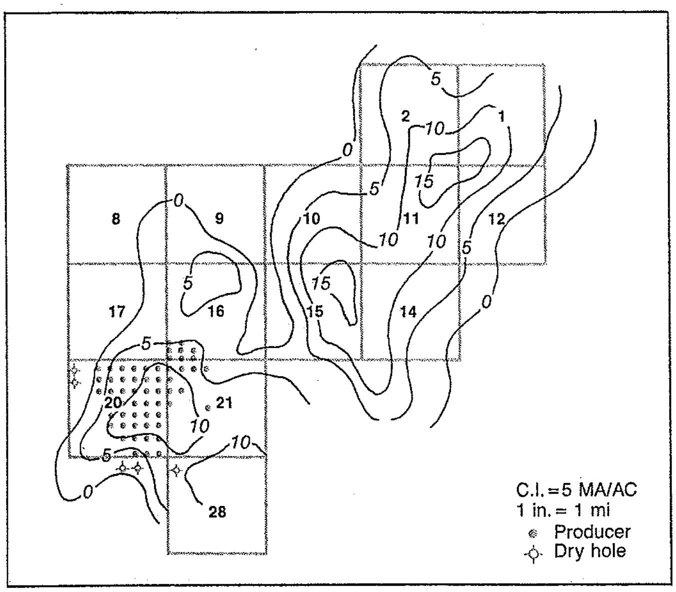


Fig. 4—ME processing was applied to the ground magnetic survey results (Fig. 3) and the ME Surface Integration map shown resulted. Note how the dry holes drilled to date in the Brooklyn field area lie outside, or near the edges, of the indicated ME anomaly.

ME PROCESS

The concept of magneto-electric exploration establishes that the vertical electro-telluric (ET) currents generated in the earth by the "fuel cell" effects of oil and gas accumulations give rise to anomalies in the static earth magnetic field. This "fuel cell" effect is manifested by: (1) an oxidation-reduction potential formed at the interface of an oil-saturated environment, being reduced by the excess of electrons, and (2) an oxidized environment, being water-saturated and deficient in electrons.

In the data-processing procedure used in ME exploration, the effect of basement rock structure and of rock magnetic polarization are theoretically removed and only the residual magnetic part related to vertical electric currents remains. The mapping and contouring of the polarity and of the intensity of such currents therefore depict the subsurface "fuel cell" anomalies, and thereby delineate the favorable areal extent of potential oil and gas accumulations. This process is basically attempting to identify favorable areas in which to concentrate oil and gas exploration endeavors and, likewise, to denote areas that are unfavorable.

EXAMPLE

To demonstrate the application of ME exploration to regional studies, an area in southwest Illinois was evaluated. Fig. 1 shows a portion of the study area, situated in the Schuyler and McDonough counties area. The contours represent the flux density of the total intensity of the earth's magnetic field in this area. From this contoured map, an ME effect was computed. Fig. 2 presents a Surface Integration map constructed from processing the NURE airborne magnetic data. The contours represent the near-surface expression of electric current flow of the ET currents. The Silurian fields in this area of southwest Illinois are superimposed on the ME integration results, which display a close relationship with the ME mapping. There are numerous trend areas, some of which have been more actively explored. The area around Sangamon, Christian, Macon and DeWitt counties shows a trend of east-west production through Sangamon and Christian counties, turning to the northeast through Macon and DeWitt counties. The Wapella East field in DeWitt County is on the eastern limit of the survey area, and on the western limit, in the Brown and Adams counties area, the ME anomaly is encircled with producing fields.

To provide greater detail to the study, numerous airborne ME anomalies were surveyed on the ground. Fig. 3 is a ground magnetic map from a survey located in T3N R3W of Schuyler Co., which is situated in and around the environs of the Silurian age, Brooklyn field. This area may also be located on the airborne ME map in Fig. 2, on the common county line of McDonough and Schuyler counties at the field (Brooklyn) shown. A general NE-SW trend of magnetic highs, though very subtle, was observed. The ground magnetic survey was conducted with a station-density pattern of about one-half mile along existing county roads, using a portable proton precession magnetometer. The data were processed using ME procedures, and an ME Surface Integration map (Fig. 4) was created.

There appears to be a similarity between the total intensity of Fig. 3 and that of the ME Surface Integration of Fig. 4. Throughout the study area, this similarity was at times noted, but was certainly not the rule. An ME anomaly did not always follow well-defined boundaries controlled by magnetic mapping, but, in instances where this did appear, the ME Surface Integration enhanced the magnetic anomaly by providing a more detailed delineation. Many of the productive wells in Brooklyn field are also shown on Fig. 4 and are concentrated in sections 20, 21 and 16.

WRAP-UP

From airborne ME evaluation, very large regional areas can be defined as being anomalous. Once ground surveys are conducted, smaller areas within the larger airborne areas can be defined more concisely, and thus become prospective leads for further oil and gas exploration. In short, the synergistic application of magneto-electric (ME) exploration to NURE airborne magnetic data has been proven to be a cost-efficient method of defining regional trends and/or more specific locations most favorable for oil and gas accumulation.

ACKNOWLEDGMENTS

The author's success at utilizing the previously detailed exploration approach can partially be attributed to the excellence of the supplies and services that he utilizes on a daily basis. Among these are: (1) an EG&G Geometrics proton precession magnetometer (for ground magnetic surveys), (2) a Sperry Univac 1100 series computer system (for data processing and project evaluation studies) and (3) time-sharing on Tracor Inc.'s mainframe computer center in Austin, Texas.

Projective well log analysis: A retrospective and update

Ron Herzfeld, Independex, Inc., Dallas, Texas

10-second summary

Using existing well control to project hydrocarbon trends through the interpretation of electric and radioactive well logs was a method developed over 20 years ago. It was considered unconventional then, and still is, but its track record in the productive region of southern Florida has proven impressive and made projective well log interpretation worthy of review.

"PROJECTIVE WELL LOG INTERPRETATION is an unconventional well log analysis method for both electric and radioactivity logs designed to find areas of anomalous organic and inorganic mineralization of sediments genetically associated with oil and gas accumulations. The method's main objective is to project vertical and lateral extensions of such mineralization and to delineate hydrocarbon reservoirs regardless of whether they are structurally or stratigraphically controlled. Specifically, this new technique's objective is to define petroliferous trends from existing well control."

Twenty-three years ago, those words introduced a radically new, innovative concept of using logs to project areas or trends for potential hydrocarbon accumulations. The late Dr. Sylvain Pirson, world-renowned log analyst, professor and geoscientist founded this concept and published some results of its application in southern Florida in the October 1963 issue of WORLD OIL. Fig. 1 is the map Pirson published then that boldly defined several petroliferous trends, which were indicated from his work with projective well log analysis.

At the time of Pirson's 1963 study, drilling activity in the South Florida basin was relatively sparse and precluded a detailed depiction of its hydrocarbon potential. Nevertheless, well control was sufficient to provide a gross outline of promising hydrocarbon accumulations. That gross outline has remained surprisingly accurate after more than 20 years of exploration history.

The following text reveals the exploration/production history of the South Florida basin through 1985, how that corresponds to Pirson's projected trend and some details of his basic methodology.

PRODUCTION HISTORY

By 1963, there were two established, productive oil and gas areas along Pirson's Everglades Petroliferous Arch (Fig. 1). The Sunniland field, in Collier County, was discovered in 1943 and is still producing today. The Forty Mile Bend field, in Dade County, was discovered in 1954 and abandoned by 1956.

Between 1963 and 1984, there were 10 additional oil fields discovered along the axis of the Everglades Petroliferous Arch, and one field was found within close proximity (Fig. 2). The oil fields along this trend produce from rudistid reefs found in the upper 100 ft of the Sunniland formation of early Cretaceous age. The "Sunniland trend" in southern Florida currently includes 13 oil fields (nine active, one temporarily

TABLE 1—Sunniland trend fields, South Florida, current as of 1-1-86

Discovery date	Field	County	TD (ft) disc. well	Avg. Prod. depth (ft)	Avg. thk. (ft)	Oil grav. (°API)	Est. prod. ac.	1985 Prod. (bbl oil)	Cum. oil prod. to 1-1-86
9-26-43	Sunniland	Collier	11,626	11,570	22	26	2,080	129,841	18,327,841
2-01-54	Forty Mile Bend	Dade	11,557	11,340	1	21	320	Abandoned	32,888
7-22-64	Sunoco-Felda	Hendry	11,485	11,475	12	25	3,840	188,532	11,106,532
8-02-66	West Felda	Hendry	11,675	11,450	17	26	7,500	1,146,947	38,150,947
3-30-69	Lake Trafford	Collier	11,987	11,870	30	26	160	11,710	253,710
12-05-72	Bear Island	Collier	11,817	11,800	11	26	2,880	685,248	9,201,248
11-14-73	Seminole	Hendry	11,651	11,430	5	25	480	Abandoned	84,755
7-30-74	Lehigh Park	Lee	11,630	11,890	17	28	800	261,720	4,536,720
8-11-77	Baxter Island	Collier	11,823	11,510	3	22	160	Abandoned	1,859
10-13-77	Mid-Felda	Hendry	11,686	11,490	4	26	480	107,639	933,639
6-20-78	Raccoon Point	Collier	11,658	11,658	21	23	1,600	934,026	1,382,606
9-28-78	Pepper Hammock	Collier	11,897	11,897	NA	27	160	Shut-in	323
6-27-82	Townsend Canal	Hendry	11,462	11,462	8	28	640	99,866	224,727
Totals							21,100	3,565,529	84,237,795

shut in, three plugged and abandoned) trending in a northwest-southeast orientation in Lee, Hendry, Collier and Dade counties. Table 1 provides information on each of these 13 active and inactive fields in the South Florida basin province.

During 1985, the Corkscrew oil field was discovered (Nov. 10, 1985) and is located along the Sunniland trend, a couple of miles west-northwest of the Lake Trafford field. The field produced 9,472 bbl last year.

THE THEORY

The basic concept of projective well log interpretation is derived from observations made of electric logs and their SP curve gradients. The practice of projective well log interpretation requires at least one known field to serve as a calibration reference point at a significant stratigraphic level. While studying southern Florida, Pirson used the Sunniland field as a base of reference. A significant horizon about 7,000 ft shallower than the reservoir was found to provide consistent readings for calculations. The SP gradient extended over long distances of the logs, anywhere from 100 ft to thousands of feet and was most readily observable in thick shale sections or in thick resistive sections, such as anhydrite and gypsum, and even in chalk and thick limestones.

Pirson observed, through numerous field case studies, that an empirical relationship exists between the presence of hydrocarbon accumulations and the polarity of the SP gradient drift. When viewing an electric log from the bottom to the top, a positive SP gradient, or a drift to the right, was associated with the presence of hydrocarbons and was called an "oil gradient." Conversely, a negative SP gradient was most often associated with water-bearing formations at depth and was called a "water gradient." Both gradients were viewed as representing vertical fluid migration, and a mapping parameter was derived to define these gradient effects. This parameter was found to have significance in mapping the extent of petroliferous trends and in mapping areas in wildcat territories wherein a sufficient number of wildcat wells previously had been drilled.

The interpretation of these observations expresses that in the process of hydrocarbon migration and accumulation by a

***In 1963, well logs** from Sunniland field, in addition to those from 40 wildcats drilled elsewhere in southern Florida, led Pirson to project the petroliferous trends shown. This is exactly as Pirson published in 1963 (Fig. 1). The 12 fields discovered in southern Florida since Pirson's 1963 trend projection have largely fallen within his limits. The one exception, Seminole field, was very nearby and has already been abandoned. The latest discovery, Corkscrew field (11-10-85), is not plotted, but also falls along the Sunniland Trend, specifically near Lake Trafford field (Fig. 2). Obviously, the full extent of Pirson's trend is seriously underexplored.*

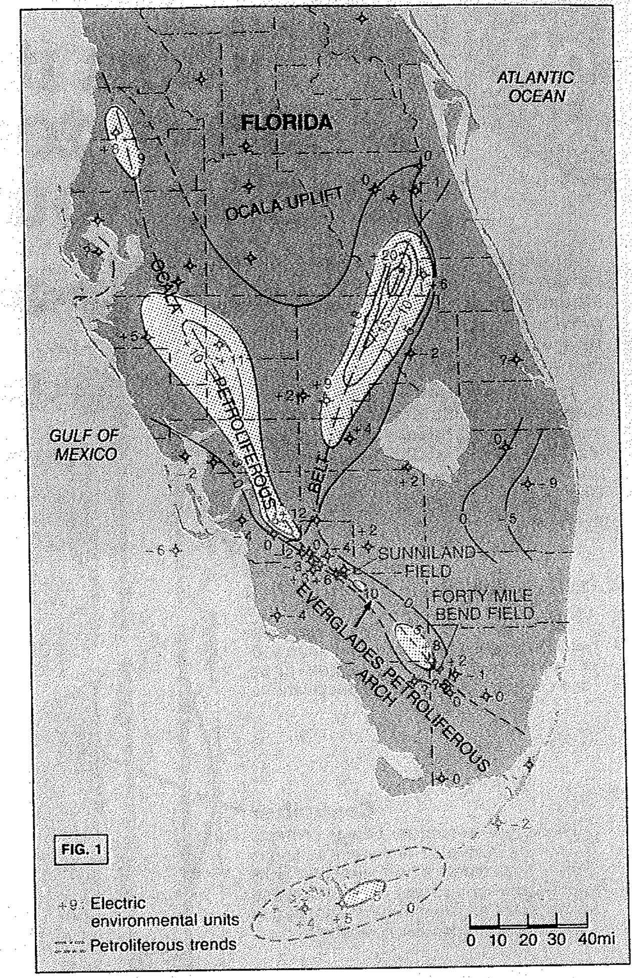


FIG. 1

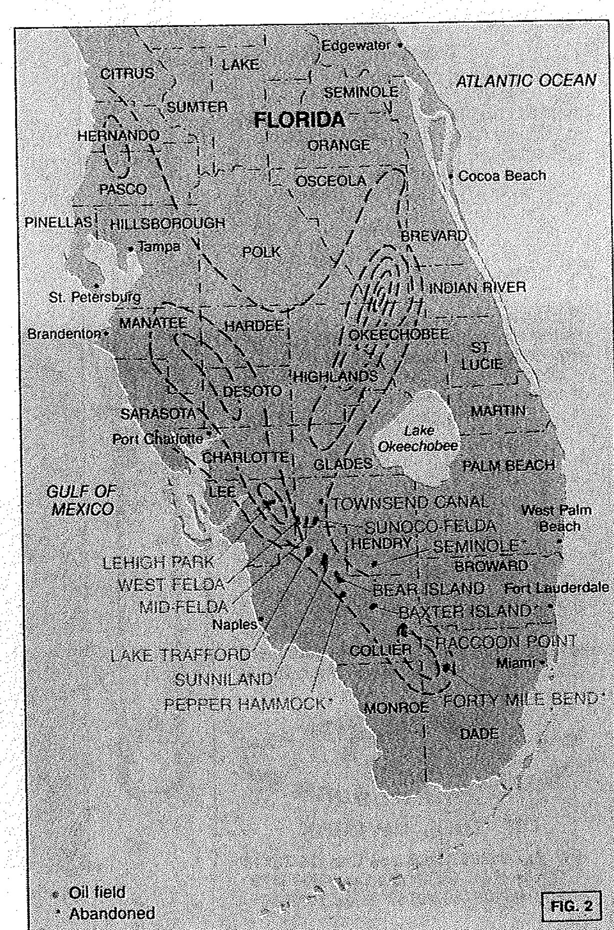


FIG. 2

water-borne process, hydrocarbons are filtered out, droplet by droplet, at the loci of entrapment. Filtered hydrocarbons then escape vertically upward above the loci of entrapment toward the Earth's surface. This vertical migration process modifies the overlying rock environment, making it more chemically reduced or "electron rich." It was noted that a "chimney like" area of rock with reduced characteristics is generally present over oil and gas fields. By contrast, rocks outside the reduced environment are oxidized, being deficient in electrons, and are generally in areas unfavorable for hydrocarbon accumulation.

It was seen through laboratory experiments and field studies, that when two media of different reduced-oxidized (redox) potentials are brought in contact, as in the case of the reduced chimney above an oil field, then an electric current flows spontaneously from the oxidized zone to the reduced zone. This information indicated to Pirson that electric currents flow downward over an oil field and upward around it. These electric currents were named electrotelluric currents (see Fig. 1) and became the explanation for SP oil and water gradients.

This work was further expanded by showing that such vertical currents create a magnetic field disturbance. When filtered out from Earth magnetic surveys through a surface integration procedure, the magnetic field disturbance corresponds in direction and in flux density to that calculated from the SP oil gradients. This filtering procedure enables surface measurement in areas where insufficient well control exists, and has been shown to be an effective, inexpensive avenue to delineate areas or trends favorable for hydrocarbon accumulations.

OBSERVATION

It would appear that Pirson's success in predicting the numerous subsequent oil fields in the South Florida basin trend was related more to scientific application than to coincidence. The present productive trend in the South Florida basin extends about 145 miles in length. The trend's width is estimated to be 12 miles. Within this 1,740 square miles (about 1,100,000 acres), the productive area of the 13 fields so far discovered is estimated to be 21,000 acres, or slightly less than 2% of the total trend area.

Exploration activity in South Florida basin remains limited, compared with other producing basins. There is much acreage to evaluate and probably many reservoirs yet to find. Projective well log interpretation is offered as a long-dormant, innovative, cost-effective process whose history indicates it deserves renewed application in this basin, and possibly elsewhere.

BIBLIOGRAPHY

Applegate, A. V., and Lloyd, J. M., *Summary of Florida petroleum production and exploration, onshore and offshore, through 1984,* Information Circular 101, Florida Geological Survey, Tallahassee, 1985.

Applegate, A. V., and Pontigo, F. E., Jr., *Stratigraphy and oil potential of the Lower Cretaceous Sunniland Formation in South Florida,* Report of Investigation No. 89, Bureau of Geology, Florida Department of Natural Resources, Tallahassee, 1984.

Davidson, M. J., "Explorationists can benefit from vertical migration now," *World Oil,* pp. 83–98, November 1985.

Herzfeld, R. M., "Magneto-electric exploration: Development of a statistical track record," *O&GJ,* pp. 125–131, Feb. 13, 1984.

Herzfeld, R. M., "Oil and gas exploration: A good place to start," *World Oil,* pp. 79–80, April 1985

Pirson, S. J., "Projective well log interpretation," *World Oil,* pp. 116–120, October 1963.

Pirson, S. J., "Significant advances in magnetoelectric exploration," in Gottlieb, B. M., ed., *Unconventional methods in exploration for petroleum and natural gas II,* Southern Methodist University Press, pp. 169–196, 1981.

Pirson, S.J., *Geologic Well Log Analysis,* Gulf Publishing Co., pp. 1–43, 1983. ■

"Mageneto-electric (ME) exploration," Technical Papers,
ASP and Ascm, 1984 Fall, pp. 620-623, Sep. 9-14, 1984.
San Antonio, Texas

Magneto-electric (ME) Exploration

R.M. Herzfeld
Independex, Inc.
5310 Harvest Hill, Suite 211
Dallas, Texas 75230

ABSTRACT

Magneto-electric (ME) exploration is a geophysical science, combining principles of magnetic and electric measurements. The basic premise of ME is that oil and gas accumulations create physico-chemical changes in rocks overlying the accumulation, by the vertical migration of hydrocarbons, thereby altering the rocks and resulting in an environment of excess electrons (reduced state). The environment outside the accumulation, (oxidized state) is deficient in electrons. A flow of electrotelluric (ET) currents is generated at the interface of the two environments; and, the flow of the ET currents locally disturb the earth's magnetic field. Through the patented process of ME exploration, the direction and magnitude of the ET currents can be calculated, which then can provide a surface indication of potential hydrocarbons at depth. The ME procedure, in part, involves projection and integration of vectors around a closed circuit, which provides a mathematical filter to derive the ET current flux intensity flowing through the area enclosed by the circuit of integration.

INTRODUCTION

In his quest for a direct oil and gas finding method, the late Dr. Sylvain Pirson, professor emeritus, University of Texas, dedicated the greater portion of his life to the development of a process whereby oil and gas accumulations could be delineated by surface measurement. Many avenues of thought were investigated, all contributing to the understanding as to how oil and gas may be found directly in location, extent, depth, quantity and productivity. Geochemistry, by soil and soil air analysis, Radioactivity exploration and Self Potential (SP) electrical techniques, all were evaluated, and each established, without question, the existence of environmental modifications above an oilfield.

GEOCHEMICAL CONTRIBUTION

Through research in Geochemistry, it was demonstrated that oil and gas reservoirs are non-equilibrium dynamic systems which are never at rest over geologic time. From that work, it was deduced that from the early time of precipitation of organic vegetable and animal decay products within the mud and ooze of sediments, migration of organic matter took place in a water-borne transportation process. As a result of sedimentary compaction and other diagenetic processes. Entrapment of organic matter in transit is visualized to take place within upward-converging semi-permeable rock strata, the hydrocarbons being retained in one or more sub-horizontal spaces therein. A hydrochemical plume is formed in the vertical escape path of the transporting waters. Those ascending waters can produce such effects as mineral alteration by leaching, changes in the redox properties of the rocks, temperature anomalies, residual traces of hydrocarbons, differential compaction, vertical electrotelluric currents, near surface electrical potential sinks and magneto-electric effects.

RADIOACTIVITY CONTRIBUTION

From his work with Radioactivity exploration, Dr. Pirson observed that low radioactivity in surface soils was reflected in the subsurface, especially in shaly sands. Numerous analyses were made and oilfields were being confirmed. Later it was seen that oilfields were being extended and many discovered as predicted by radioactivity mapping. Surface and subsurface radioactivity mapping established the existence of a modified environmental chimney over oil and gas fields, known as "reduced chimneys", the existence of which is the scientific basis for all of the vertical migration techniques for oil and gas exploration.

SELF POTENTIAL (SP) ELECTRICAL CONTRIBUTION

Self potential (SP) surveys are not new in geophysical exploration; in fact, they are the oldest geophysical method, having been used in England in the 1830's, though principally for detection of copper deposits. Field SP measurements may be made at the surface by open or by closed profiles. Open profiles determine only the directional flow of near surface telluric currents because they create an Ohmic potential drop in the near surface soils. Closed profile SP measurements have indicated that the electric potential measurements seldom close upon themselves when careful measurements are made. The advantage of the closed profile technique is that there is a possibility that depth penetration may be investigated. The concept of the depth of investigation versus the size of the enclosed survey area was developed at this time. It was theorized that the effect of the depth of investigation of a closed profile is equal to the square root of the area enclosed by each closed profile.

MAGNETO-ELECTRIC (ME) GENESIS

It was realized, from the work in Geochemistry, Radioactivity and Electrical measurements, that a new approach could be developed, to provide a new technique in sighting in on the target of finding oil and gas accumulations. The study of the earth's magnetic field, revealed that localized disturbances, when properly filtered, could relate to oil and gas accumulations.

The magnetic field of the earth is still a great enigma;

there are still serious questions about its origin and its nature. Perhaps, the only thing we know for certain is that it is a force field. It can be measured by the displacement of certain metal objects, it can compress springs, it can twist wire, displace wire carrying DC electric currents, it can spin electrons, and so on. Physicists who study the origin of the earth's magnetic field, claim there are two main parts: one derivable from a potential and the other, which is not. Many attempts were made by renown scientists the world over to find this earth's magnetic potential function, such as by Gauss, Schmidt, Mascar and Bauer. It was observed that 90 to 95% of the earth's magnetic field potential could be measured, but a misclosure of ± 5% was always present. Hypothetically this was attributed to telluric currents flowing in the earth's crust. In order to prove it, Gauss made a triangular magnetic integration trip from Gotingen, to Milan, to Paris and returned to Gotingen. He found that the line integral of the horizontal component of the earth's magnetic field in the direction of travel did not close and, therefore, there was in effect, an electric current leaving the earth and flowing into the atmosphere. The type of study conducted by the Gauss triangle, investigates too deep for oil and gas studies. They are far beyond the depth of the Curie point where all magnetic effects of rocks disappear because of heat; however, in oil and gas exploration, it is necessary to deal with relatively shallow depths of investigation.

The process of Magneto-electric exploration provides for the line integration of the earth's magnetic field around a closed circuit, which can be used for the determination of the intensity of the subsurface telluric currents, in direction and magnitude, so that their distribution below the surface of the earth can be measured. This procedure is based on the separation of the earth's magnetic field into two parts, one with potential, (which is discarded) and the other, without potential, which, when integrated around a closed circuit, gives the electrotelluric (ET) current flux intensity flowing through the area enclosed by the circuit of integration. The ET currents are generated by the physico-chemical alterations of the rocks overlying an oil and gas accumulation, according to the theory of ME. The environment of the reduced chimney contains an excess of electrons; whereas, the area outside the chimney is deficient in electrons, or oxidized. The resulting flow of telluric currents locally disturbs the earth's magnetic field. So, in essence, the process of Magneto-electrics is an electrical technique, which is derived from total field magnetic measurements.

Magnetic measurement can be gathered either on the ground, in the air or at sea. Airborne magnetics can rapidly and easily cover large areas, and is ideal for regional studies. There is a large data base of magnetics in the United States. In a recent program, sponsored by the U.S. Department of Energy, airborne magnetic surveys were conducted, surveying almost the entire continental United States, and portions of Alaska, which are available at a minimal cost. Airborne magnetics, provide only a regional overview. Ground surveys are needed to detail areas for better resolution and definition. With the evolution of the proton precession magnetometer, ground surveys can be carried out not only quicker, but with greater accuracy than surveys utilizing previously designed ground instrumentation.

Magneto-electric exploration has been utilized effectively as a follow-up to airborne magnetics, as well as a verification and delineation of remote sensing anomalies. The oil and gas industry has primarily used ME for pre-seismic orientation, in order to identify anomalous areas for exploration and cost reduction in laying out seismic lines. Ground surveys are rapid, depending upon the terrain traversed, and can generally cover 1200-1500 acres per hour if good road networks are available. In sectionized townships, an ME crew can cover as much as 5000 acres per hour, with a station density of 1 mile. During a recent U.S. Department of Energy grant program, ME work was conducted over 19 projects, covering an area of 523,555 acres in a time of 343.65 field hours, with an average of 6.3 stations per hour, or 9.5 minutes per station, and surveying 1,524 acres per hour. The primary purpose of this grant program was to develop a statistical track record for the process of ME. Numerous oil and gas exploration companies submitted areas scheduled for drilling wildcat tests. Ground surveys were conducted and ME interpretations were made, prior to actual drilling. During the grant period, twenty wells were drilled, with the following results:

Predicted	Actual	
6 Producers	5 Producers, 1 Dry	83.3%
14 Dry Holes	13 Dry, 1 Producer	92.9%

From the statistical study, the predictive capability of ME appears very high. With further drilling activity to define the limits of production, the high statistical results will most likely be reduced. From the initial evaluation, however, it can be concluded that the correlation between oil and gas accumulation and ME is relatively close, and warrants its acceptance as a contribution to oil and gas exploration.

REFERENCES

Pirson,Sylvain J. and Jacques E., March 9, 1976, U.S. Patent 3,943,436, Line Integral Method of Magneto-electric Exploration.

Pirson, Sylvain J. April 1981, Second ed., Second printing, Geologic Well Log Analysis, Hydrogeology 1: Hydrodynamics of Compaction, pp. 216-258, Gulf Publishing Co., Houston.

Herzfeld, R.M., February 13, 1984, Magneto-electric Exploration: development of a statistical track record, Oil & Gas Journal, pp. 125-131.

INNOVATIVE DIRECTIONS OF MAGNETOELECTRIC EXPLORATION

Ronald M. Herzfeld

INDEPENDEX, INC.

ABSTRACT

Magnetoelectric (ME) exploration is a geophysical science combining the principles of magnetic and electric measurements. The ME process is based on the discovery that producing and potentially productive oil and/or gas fields usually have associated with them vortices of electrotelluric (ET) currents which find their origin in the structural or stratigraphic reservoirs of oil and gas, and in the overlying lithologic environment which has been physicochemically modified by escaping reservoir waters and hydrocarbons.

The vertical ET currents generated in the earth by the "fuel cell" effect of oil and gas accumulations give rise to anomalies in the static earth magnetic field. Detection and measurement of the intensities, distribution, and direction of the ET currents are accomplished by measuring the magnetic intensities, directions, and signs of the perturbations created in the earth's magnetic field.

The magnetic perturbations may be measured directly and intentionally by performing total intensity magnetic surveys, either by means of sampling in the air, on the ground, or at sea.

In the data processing procedure, line-integral calculations of the total magnetic field are performed on one or more closed profiles. Through this procedure, it is possible to map the vertical flux of the ET currents in intensity and in direction, and to provide a surface indication of potential areas or trends favorable for the accumulation of hydrocarbons.

Recent experimental work in depth projection has established the possibilities of computer-depth determination, utilizing the principles of ME line-integral calculations, so that possible depth ranges of hydrocarbon accumulations might be derived.

INTRODUCTION

This paper is written in memory of Dr. Sylvain J. Pirson, a man who dedicated the greater portion of his life to the development of a process whereby oil and gas accumulations could be delineated by surface measurement. In his quest for a direct oil and gas finding method, Dr. Pirson investigated many avenues of thought, each contributing to the understanding of how oil and gas might be found in location, extent, depth, quantity, and productivity. Geochemical, radioactive, and electrical techniques were all evaluated, and each established without question the existence of environmental modifications above an oil field. Through the study of electric logs, SP shale-base-line drifts were observed (Pirson, 1981), which led to the theory that these drifts were a measure of the electrotelluric (ET) current flux that flows vertically within the sediments traversed by the borehole.

It was also observed that magnetic field perturbations were generated by the ET current flow (Pirson, 1977), and it was then realized that from the study of the earth's magnetic field, localized disturbances, when properly filtered, could relate to oil and gas accumulations.

The concept of magnetoelectric exploration establishes that the vertical ET currents generated in the earth by the "fuel cell" effects of oil and gas accumulations give rise to anomalies in the static earth magnetic field. This "fuel cell" effect is manifested by an oxidation-reduction potential formed at the interface of: (1) an oil-saturated environment, being reduced by the excess of electrons, and (2) a water-saturated environment, being oxidized and deficient of electrons.

In the data-processing procedure used in ME exploration, the effects of basement rock structure and of rock magnetic polarization are theoretically removed, and only the residual magnetic part related to vertical electric currents remains.

The process of ME exploration provides for the line integration of the earth's magnetic field around a closed circuit, which can be used for the determination of the intensity of the subsurface ET currents, in direction and in magnitude, so that their distribution below the surface of the earth can be measured.

The mapping and contouring of the polarity and of the intensity of such currents therefore depict the subsurface "fuel cell" anomalies, and thereby delineate the favorable areal extent of potential oil and gas accumulations (Herzfeld, 1985). They likewise denote areas that are unfavorable.

ME SURVEY: A PREDEVELOPMENT STUDY

An area in SE Illinois, situated in Edwards County, was surveyed to determine the potential for hydrocarbons in a leaseblock located in section 28 T1N R10E. Figure 1 shows the drilling activity prior to an ME ground magnetic survey. A survey was subsequently conducted over section 28 and a 1-mi area around the section. A station density pattern of ¼ mi was maintained. An anomalous condition was found to exist in a N-S axis through section 28, as seen in Figure 2. Immediately following the ME survey, development of the section commenced and resulted in seven Rosiclaire (Mississippian) wells, two O'Hara wells, one McClosky well, and three dry holes, as exhibited in Figure 3. It was apparent that the Rosiclaire trend followed the N-S axis of the ME survey and was confined within the limits of the 15 ma/ac (milliamp per acre) intensity value contour. The discovery well was completed in the SE NE SW 28-1N-10E flowing 180 bo/d from the Rosiclaire pay through perforations at 3,284–94 ft.

ME SURVEY OF AN ABANDONED FIELD

An ME survey was conducted over the Griffiths Field located in Clay County, Kansas, and situated in section 3-T9S-R4E. The field was abandoned in 1981, after producing 95,053 bbls of oil. A field statistical breakdown is shown in Table A. The Griffiths Field produced from the Mississippian chert, from fractured porosity along the axis of a plunging nose. The updip wells had no porosity development and the downdip wells dipped into water. The structural point of the top of the Mississippian chert horizon is shown in Figure 4. A ground magnetic survey was conducted in and around the environs of the Griffith Field, the results of which are seen in Figure 5. The stations were spaced at an approximate ½ mi density pattern, except in the center of section 3, where existing pipe was intentionally avoided in an attempt to avoid the influence of possible spurious readings. The adjusted total intensity values of the magnetic survey were viewed as a magnetic high in the north half of section 3. The magnetic data were processed using the ME procedure, and a surface integration map was created, as presented in Figure 6. An N-S axis anomaly was defined, with the productive wells situated within the boundary of the 10 ma/ac contour. A depth investigation study was conducted on this project, and a point at location X was used to investigate the change of milliamp current flow at various depth levels. Graph I was prepared from a computer printout of the Griffiths Field and surrounding

TABLE A

GRIFFITHS FIELD
Section 3, T9S R4E
Clay County, Kansas

Discovery date	May 30, 1957
Operator	Pure Oil Company
Well	#1 F.L. Griffiths
Location	C NE NW Sec. 3-9S-4E
Producing formation	Mississippian (Burlington-Keokuk) Chert
Initial production (Pot.)	Pump 86.5 bbls oil; 26 bbls water/day
Initial reservoir pressure	685 psi (DST)
Method of discovery	Subsurface geology
Nature of trap	Stratigraphic entrapment
Reservoir thickness	22–29 ft
Average depth	1,920 ft
Productive zone thickness	4 ft plus fractures
Porosity (log)	18% to 35% where porous and permeable
Water saturation	Variable
Water datum	−644 ft (related to permeability more than structure)
Productive area	Approximately 200 acres
Drive mechanism	Inadequate water drive
Oil Character	27° API @ 60°F
Gas	Too small to measure
Completion technique	Perforations
Treatment	Acidfrac; 6,000 gals frac acid, 6 gals Mar-flo, 6000# sand
Total producers drilled	4 wells; 1 abandoned, 8/1/59 (4,091 BO)
Cumulative production	95,053 bbls oil
Year field abandoned	1981

acreage. At location X there was a sharp increase in intensity value directly overlying the horizon of the top of the productive zone. It appears that the intensity values are greatest directly over the productive horizon penetrated.

ME SURVEY OF A PRODUCING FIELD

An ME survey was conducted over the Nimrod Field located in Eastland County, Texas, situated in sections 94 and 95, block 3, H&TC Survey. The field produces from the shallow Crosscut sand, at a depth of approximately 1,300–1,350 ft. Figure 7 is a structure map at the top of the Crosscut-sand porosity. The wells in the NE portion of section 94 produced from the Caddo lime formation at approximately 2,900 ft. An ME surface integration map, Figure 8, depicts the "fuel cell" effect over the Nimrod Field area. The productive limits of the field are situated within the boundary of the surface integration results. The definition of this anomalous area is probably rather regional, since the ground survey had a wide station density pattern of ½ mi to 1 mi. It nevertheless provided an adequate delineation of the "fuel cell" area and a distribution of the ET current flux.

A geologic cross section was created, through the wells shown in Figure 8. It was noted that there was an apparent shale-base-line drift on the SP curve of the electric logs of the field area. This drift is presented in Figure 9. The log on the left exhibited a strong water-gradient to the left, from the base of the log upward. This log is of a dry hole, with a wet horizon at the Crosscut, near the edge of the field. The other log exhibited an oil-gradient drift to the right, which is from a producing well. The vertical drifts present an example of the flow of electrotelluric currents (Pirson, 1981).

A computer depth study was conducted over the field area, which provided greater understanding for the ME depth projection interpretations (Pirson, 1982). Location A, on Figure 10, was chosen to demonstrate the vertical intensity differences at

TABLE B

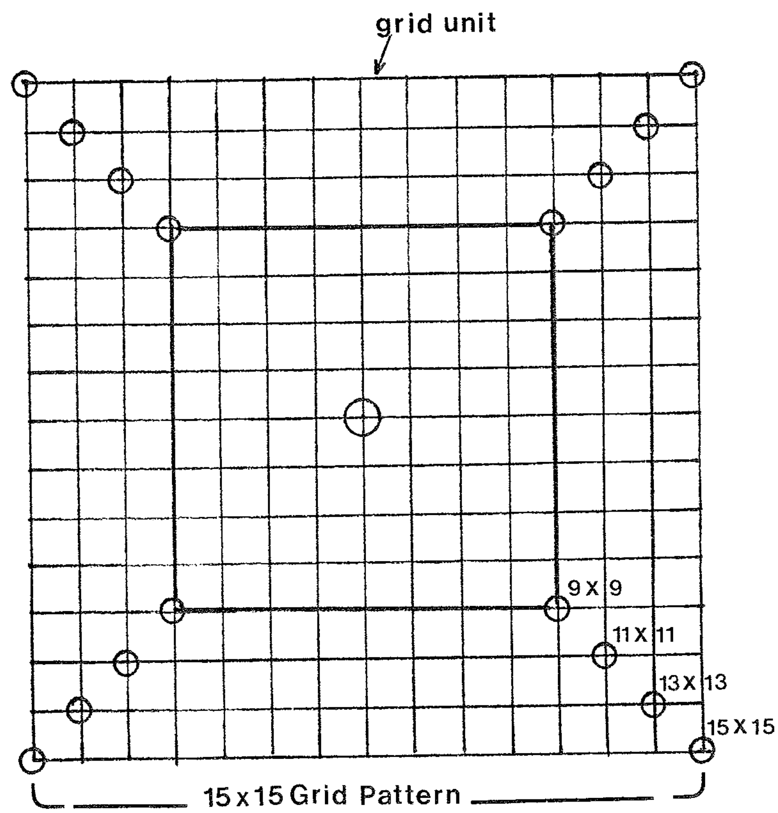
MAGNETOELECTRIC EXPLORATION DEPTH PROJECTION LEVELS

(Estimated Depth in Feet from Surface)

	Grid Unit Dimensions[1]						
Level	330′	660′	1320′	2000′	2640′	3960′	5280′
Z 1	80	165	330	500	660	990	1300
2	120	231	460	700	920	1386	1700
3	165	330	660	1000	1320	1980	2700
4	230	462	924	1400	1850	2772	3700
5	330	660	1320	2000	2640	3960	5300
6	410	825	1650	2500	3300	4950	6700
7	460	924	1848	2800	3700	5544	7500
8	530	1056	2110	3200	4220	6336	8500
9	580	1155	2310	3500	4620	6930	9300
10	610	1221	2440	3700	4880	7326	9900
11	660	1320	2640	4000	5280	7920	10700
12	690	1386	2770	4200	5540	8316	11200
13	740	1485	2970	4500	5940	8910	12000
14	780	1551	3100	4700	6200	9306	12500
15	810	1617	3230	4900	6470	9702	13000
16	840	1683	3370	5100	6730	10098	13600
17	875	1749	3500	5300	7000	10494	14100
18	940	1881	3760	5700	7520	11286	15200
19	960	1914	3830	5800	7660	11484	15500
20	990	1980	3960	6000	7920	11880	16000
Surface Requirements							
Acres	490	1960	7840	18000	31360	70560	125440
Sq Mi	.77	3.06	12.3	28.0	49.0	110.3	196.0
Mi Sq	.88	1.75	3.5	5.3	7.0	10.5	14.0

[1]ESTIMATED DEPTHS: We currently feel as though our depth projection work is still in the experimental phase of development, but offer this work as a potential evaluation process.

TABLE C



Our computer program is designed for a grid coordinate system of 15×15 grid points, as shown above. Each square, or grid unit dimension, can represent any scaled dimension. If each grid unit is 1,000 ft, then the distance on each side of the 15×15 grid pattern is 14,000 ft; and, if each grid unit is 1 mi, then the distance is 14 mi.

The 15×15 grid is superimposed over an adjusted, contoured total intensity map generated from magnetic measurements, and grid coordinates are designated at each grid corner by interpolating the contours of the total intensity map to the grid corners. The coordinates are then fed into the computer system for computation. During the process of integration, the deeper projections lose actual coverage area, as shown on the following table:

Depth Level	Actual Coverage
Z1–Z5	13×13 grid pattern
Z6–Z11	11×11 grid pattern
Z12–Z20	9×9 grid pattern

In essence, what may have been an initial 14 mi×14 mi coverage is reduced to 8 mi×8 mi at the Z12–Z20 levels, so it is desirable to center the project area for maximum results.

various depth horizons. The area was gridded for computer input. Tables B and C provide descriptive information concerning ME depth projections, based on a 15×15 grid pattern. A 9×9 grid pattern has also been developed for smaller areas. A 2,000 ft grid pattern was first studied at Nimrod; and on Graph II it was observed a shallow indication was present. The area directly above the Crosscut zone and another above the Caddo has a strong buildup in intensity, compared with other horizons. The same data were used, but interpolated to achieve a 500 ft grid pattern, which is smaller in areal extent and which fit within the 2,000 ft grid pattern, as outlined in Figure 10. From Graph III it was observed that the area directly over the Crosscut zone had a sharp increase in intensity. This discovery demonstrated that in the 2,000 ft grid pattern, the intensity buildup was at the third level of projection (Z3); whereas, in the 500 ft grid pattern, the buildup was at the thirteenth level (Z13), each level corresponding approximately to the same depth.

The depth projection capability of ME exploration may be valid, but the work is still considered to be very experimental and will require continued theoretical and empirical testing and evaluation.

CONCLUSIONS

Thorough knowledge of ME is still elusive; nevertheless, there have been substantial correlations between ME anomalies and actual productive results (Herzfeld, 1984). ME exploration has only begun to scratch the surface in fitting itself into the complex dynamics of the vertical migration process. The expansion of today's scientific understanding compels innovative investigation into magnetoelectric exploration.

REFERENCES

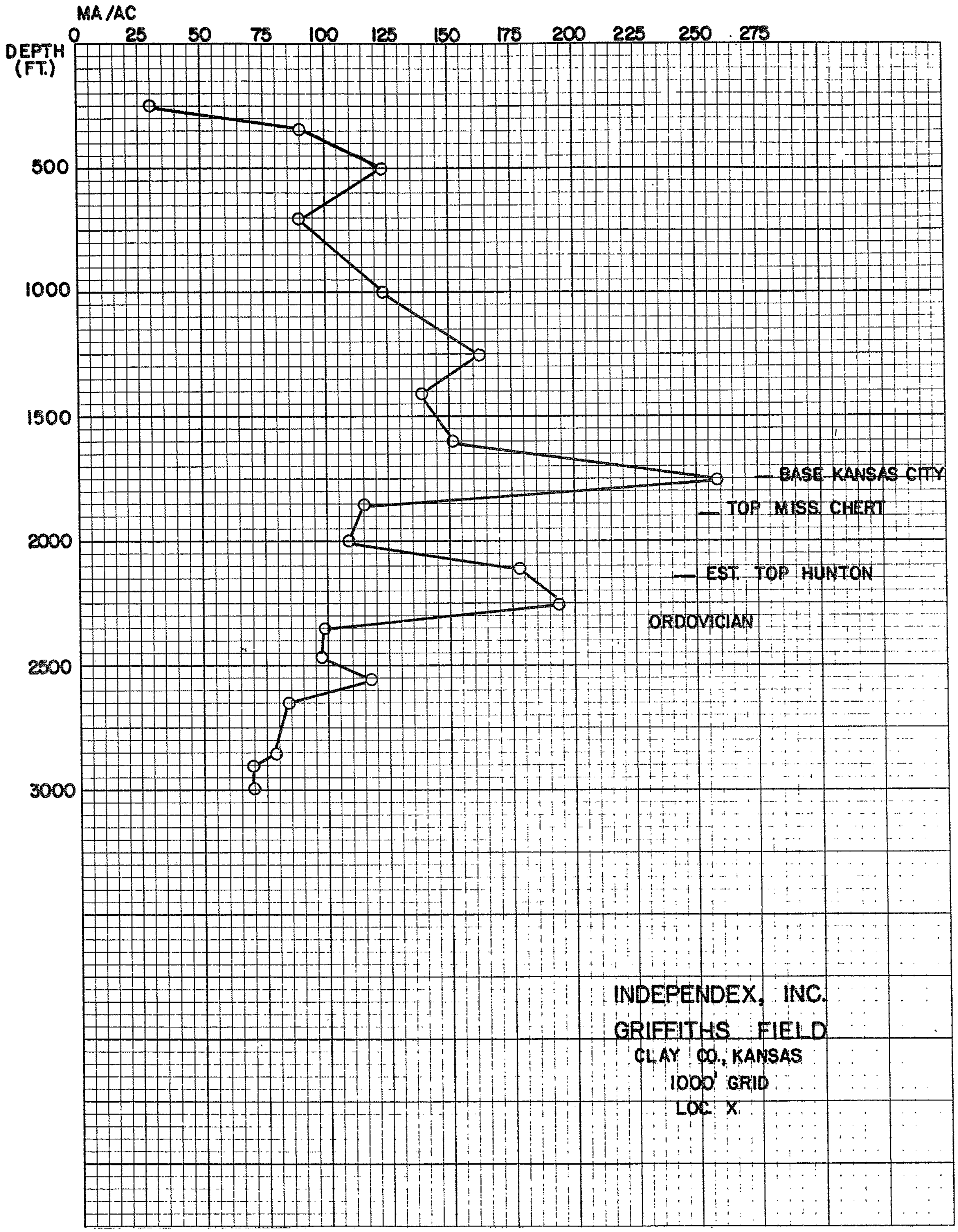
Herzfeld, R.M., 1984, Magneto-electric exploration:Development of a statistical track record: Oil and Gas Journal, February 13, 1984, p. 125–131.

———, 1985, Oil and Gas Exploration: A good place to start: World Oil, April 1985, p. 79–80.

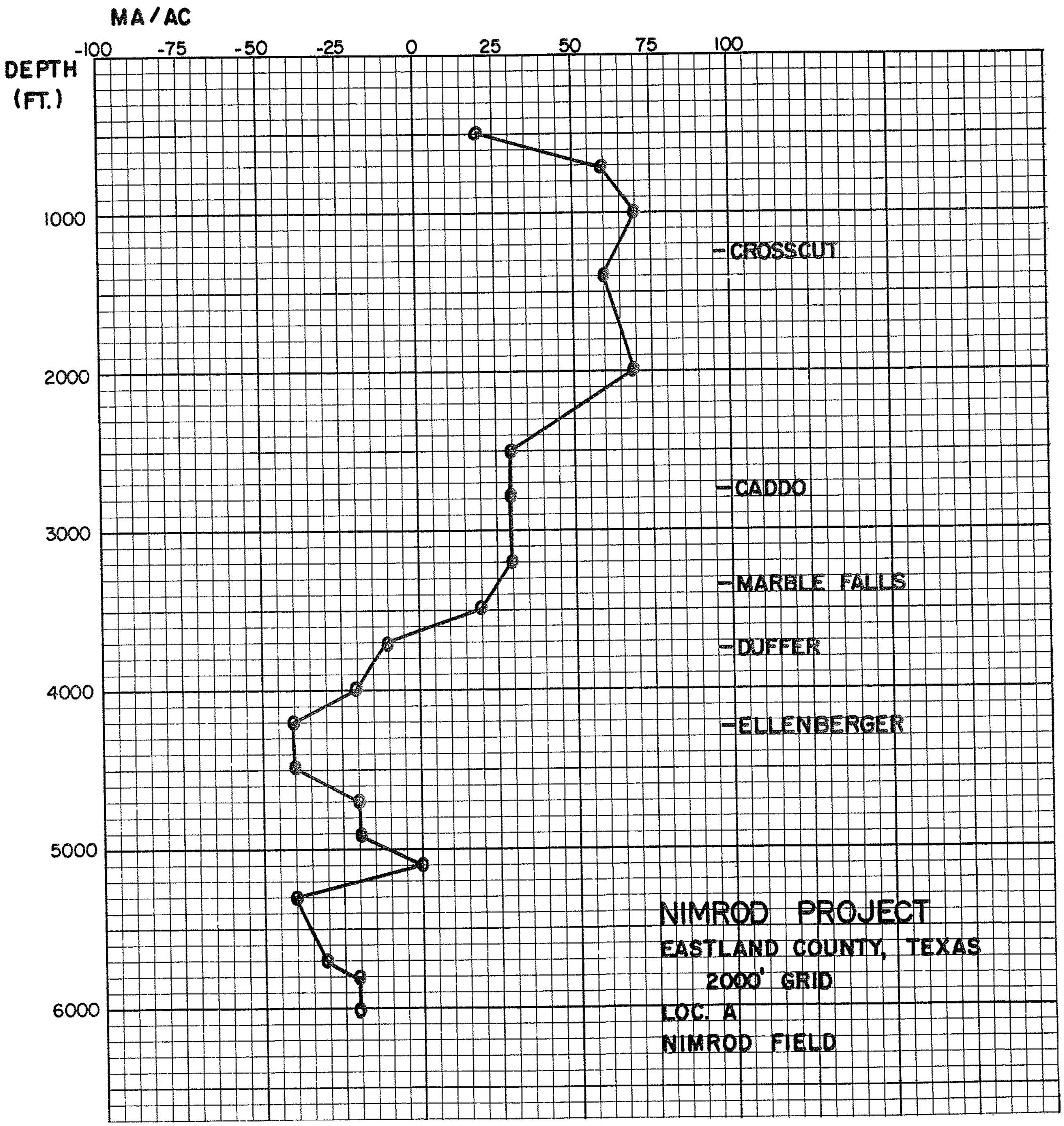
Pirson, S.J., 1977, Geologic Well Log Analysis (2nd ed.): Houston, Gulf Publishing Company, chap. 1.

———, 1981, Significant advances in magnetoelectric exploration, *in* Gottlieb, B. M., ed., Unconventional methods in exploration for petroleum and natural gas II: Dallas, Southern Methodist University Press, p. 169–196.

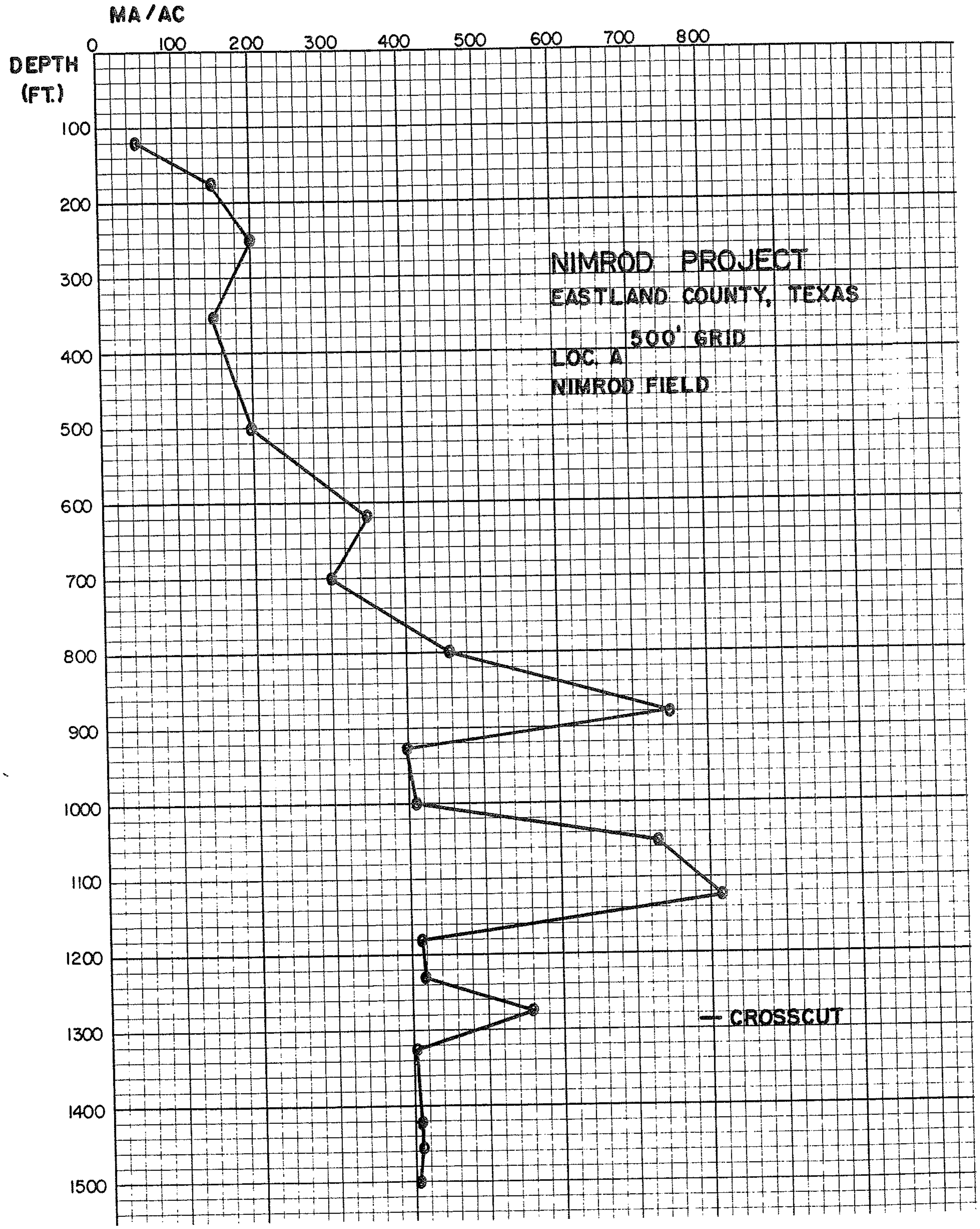
———, 1982, Progress in magneto-electric exploration: Oil and Gas Journal, October 11, 1982.


MA /AC
0
25
50
75
100
125
150
175
200
225
250
275
DEPTH (FT.)
500
1000
1500
2000
2500
3000
BASE KANSAS CITY
TOP MISS. CHERT
EST. TOP HUNTON
ORDOVICIAN
INDEPENDEX, INC.
GRIFFITHS FIELD
CLAY CO., KANSAS
1000' GRID
LOC. X

GRAPH I


MA / AC
-100
-75
-50
-25
0
25
50
75
100
DEPTH (FT.)
1000
2000
3000
4000
5000
6000
CROSSCUT
CADDO
MARBLE FALLS
DUFFER
ELLENBERGER
NIMROD PROJECT
EASTLAND COUNTY, TEXAS
2000' GRID
LOC. A
NIMROD FIELD

GRAPH II


MA / AC
0
100
200
300
400
500
600
700
800
DEPTH
(FT.)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
NIMROD PROJECT
EASTLAND COUNTY, TEXAS
500' GRID
LOC. A
NIMROD FIELD
CROSSCUT

GRAPH III

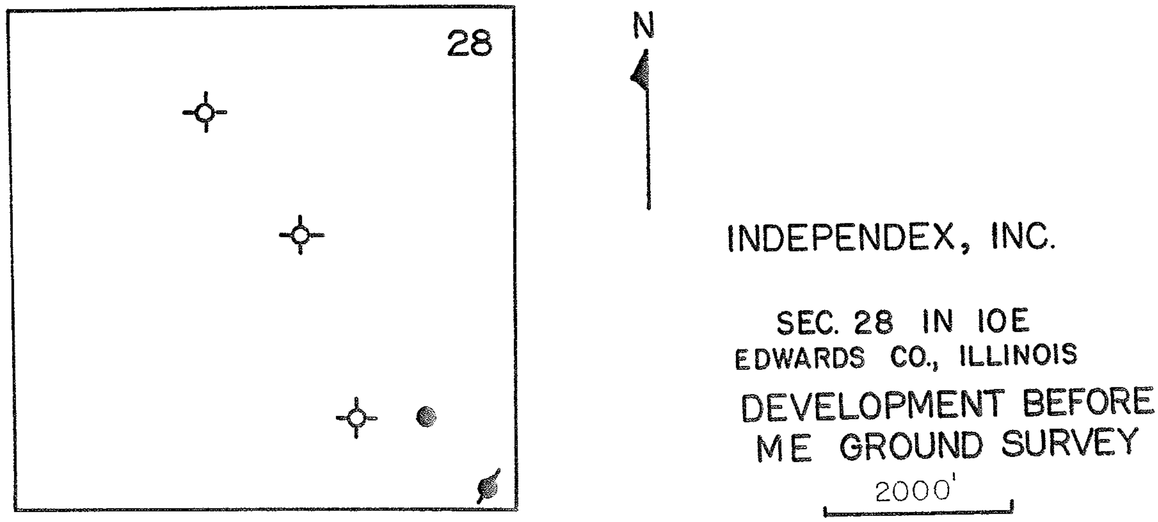


Fig. 1. Drilling activity prior to ME survey, section 28.

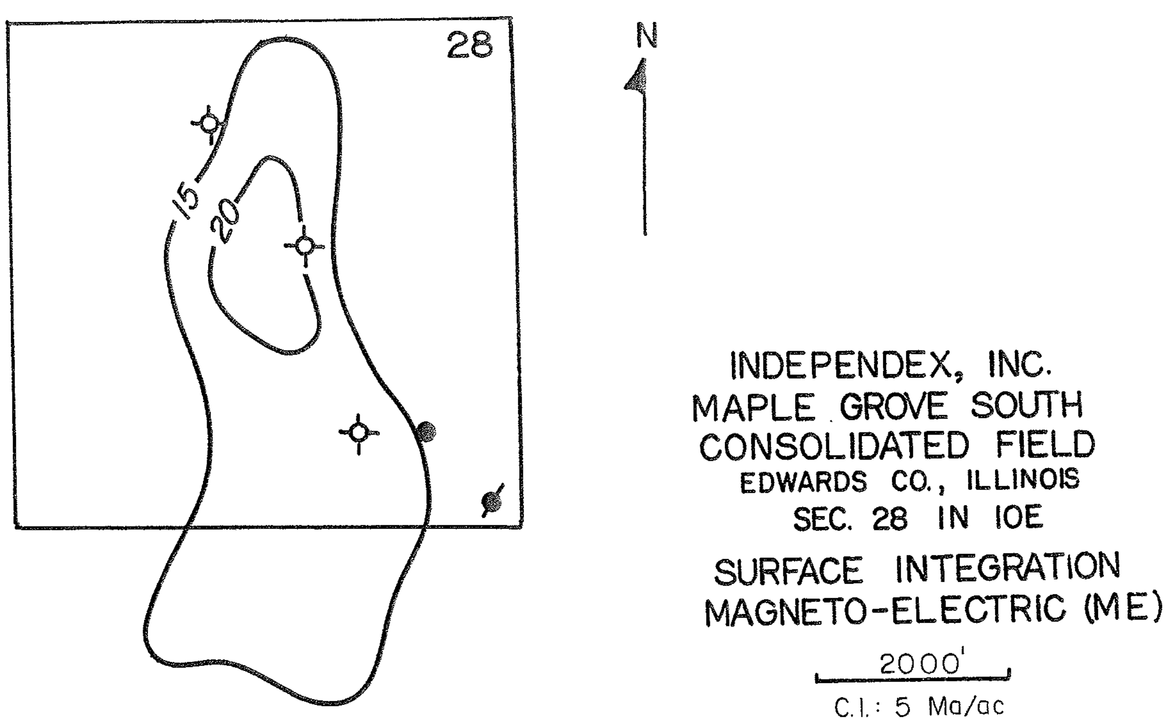


Fig. 2. ME anomaly, section 28.

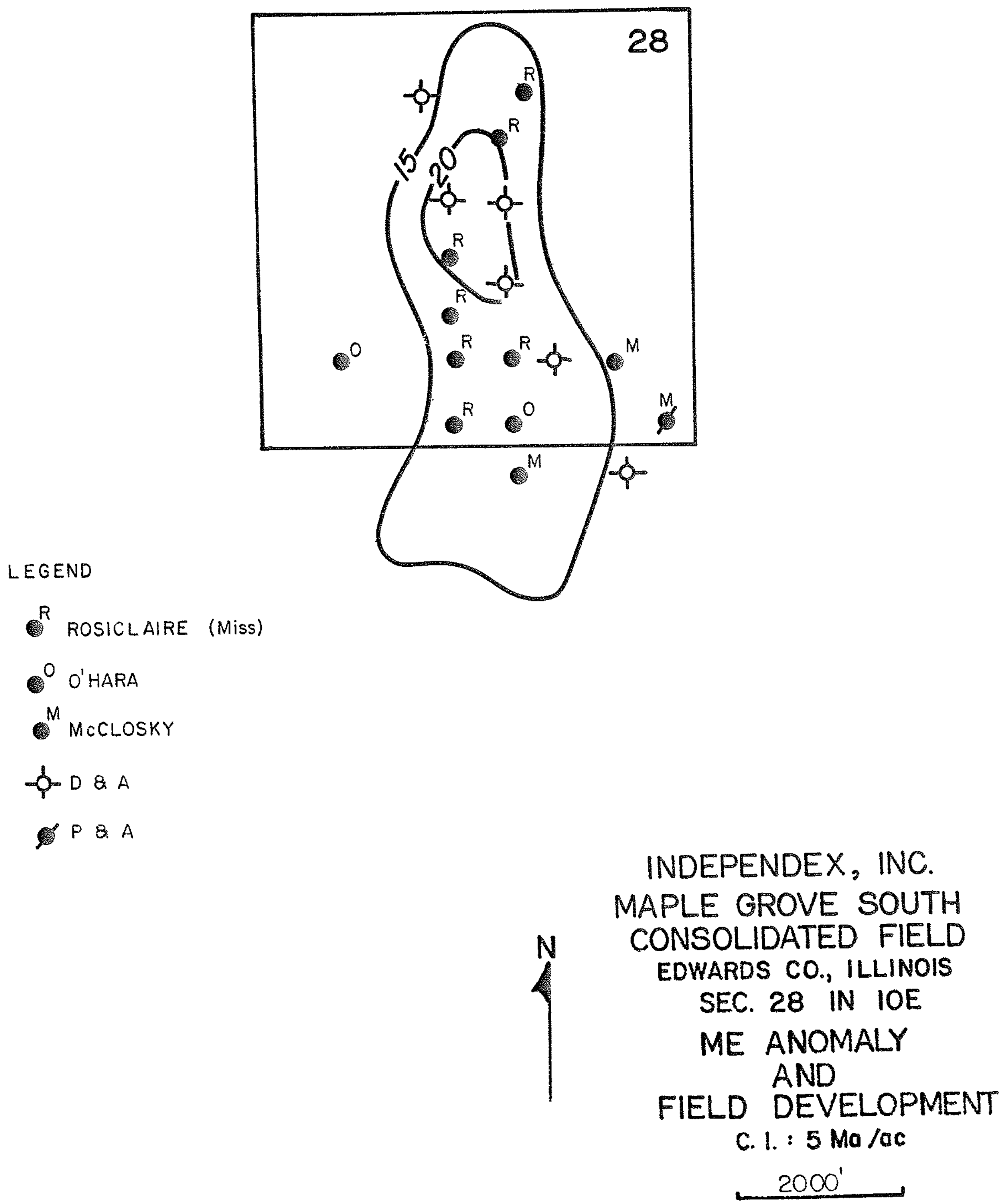


Fig. 3. ME anomaly and field development, section 28.

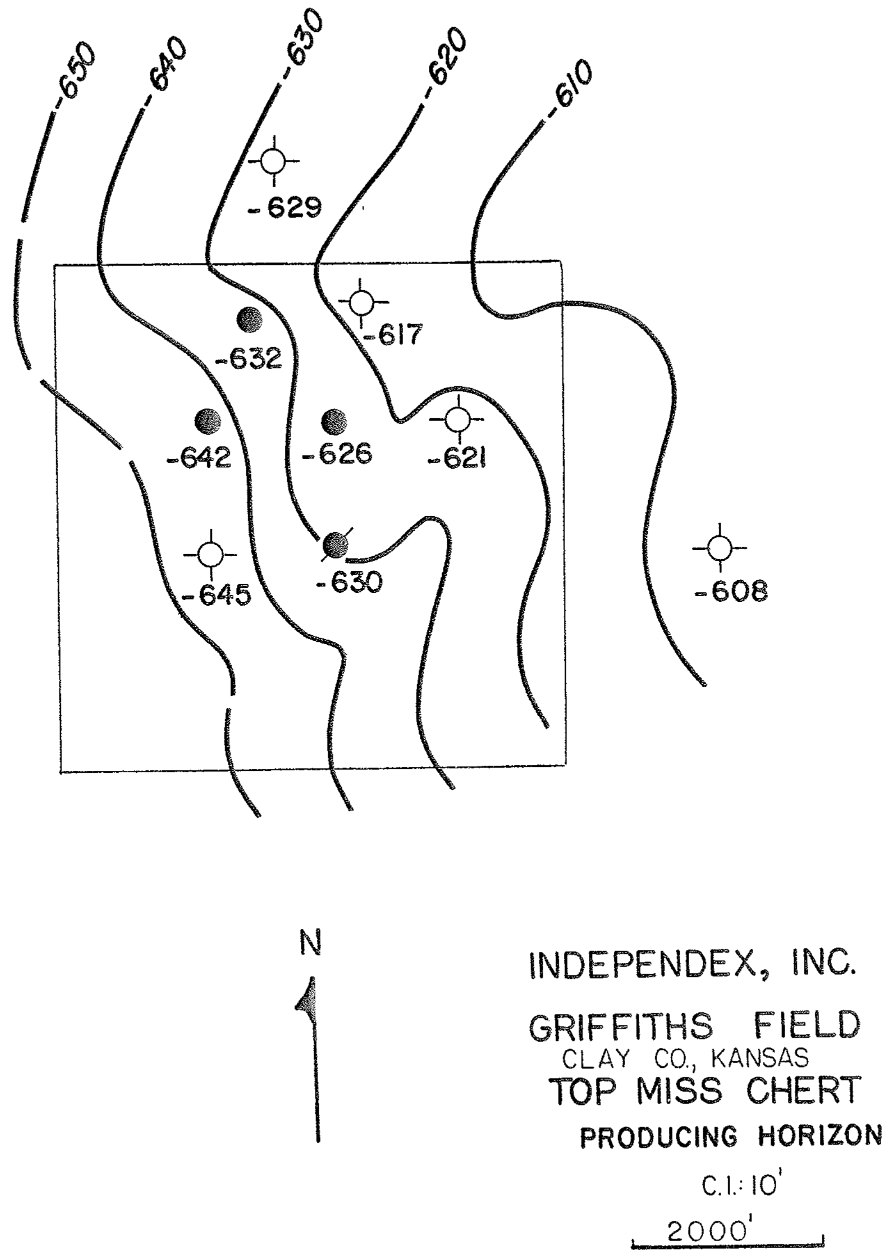


Fig. 4. Top Mississippian chert, Griffiths Field.

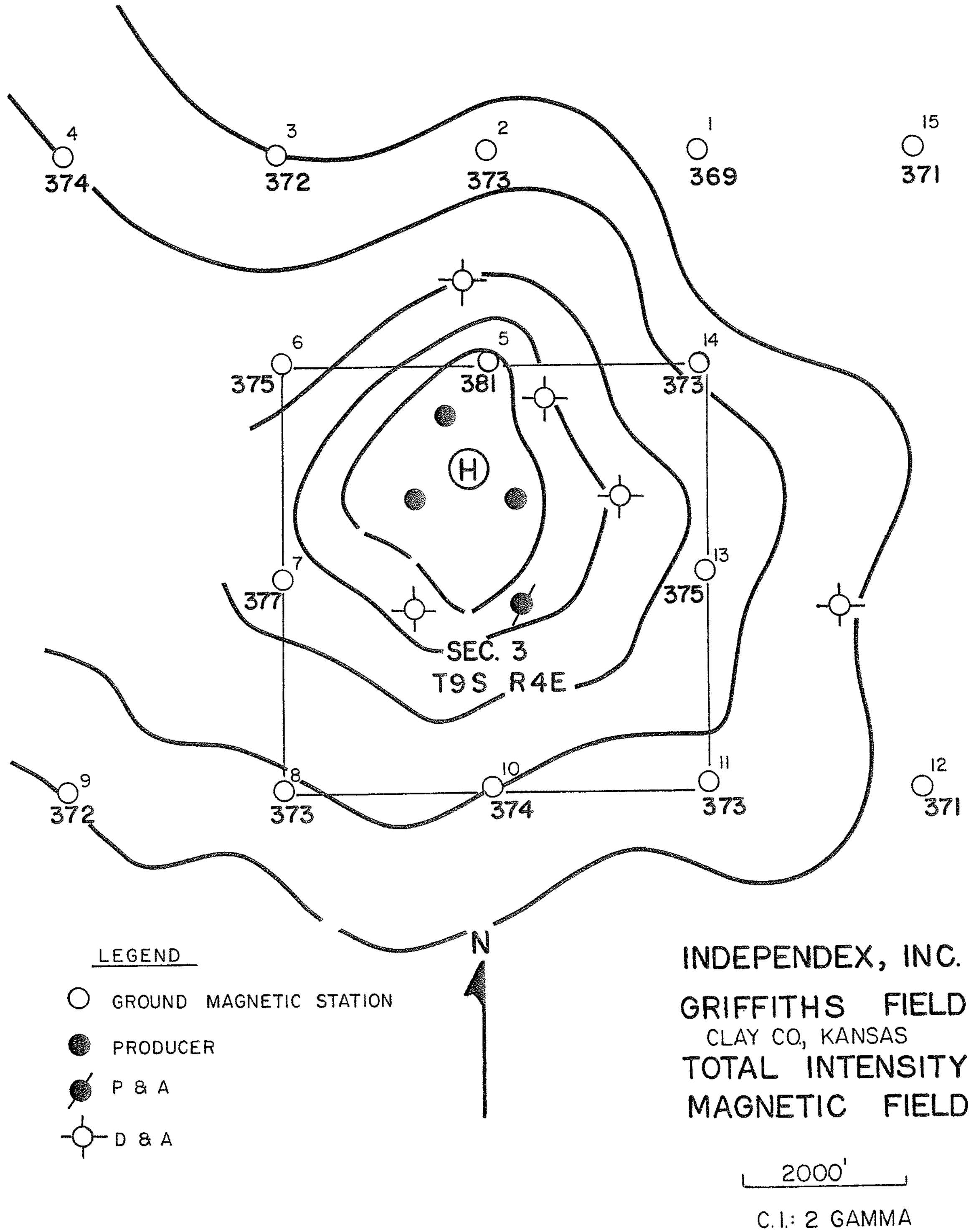


Fig. 5. Total intensity magnetic map, Griffiths Field.

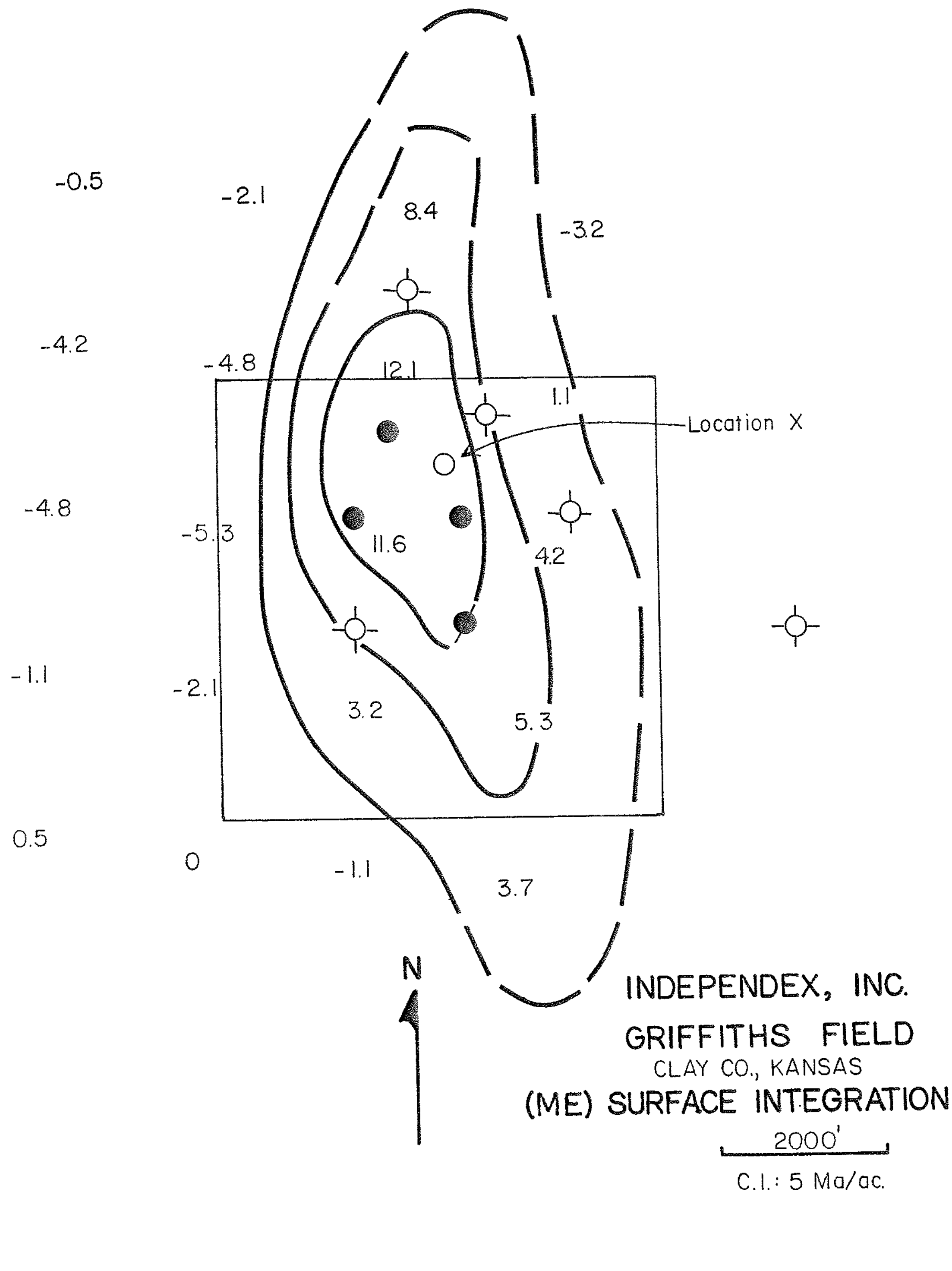


Fig. 6. ME surface integration, Griffiths Field.

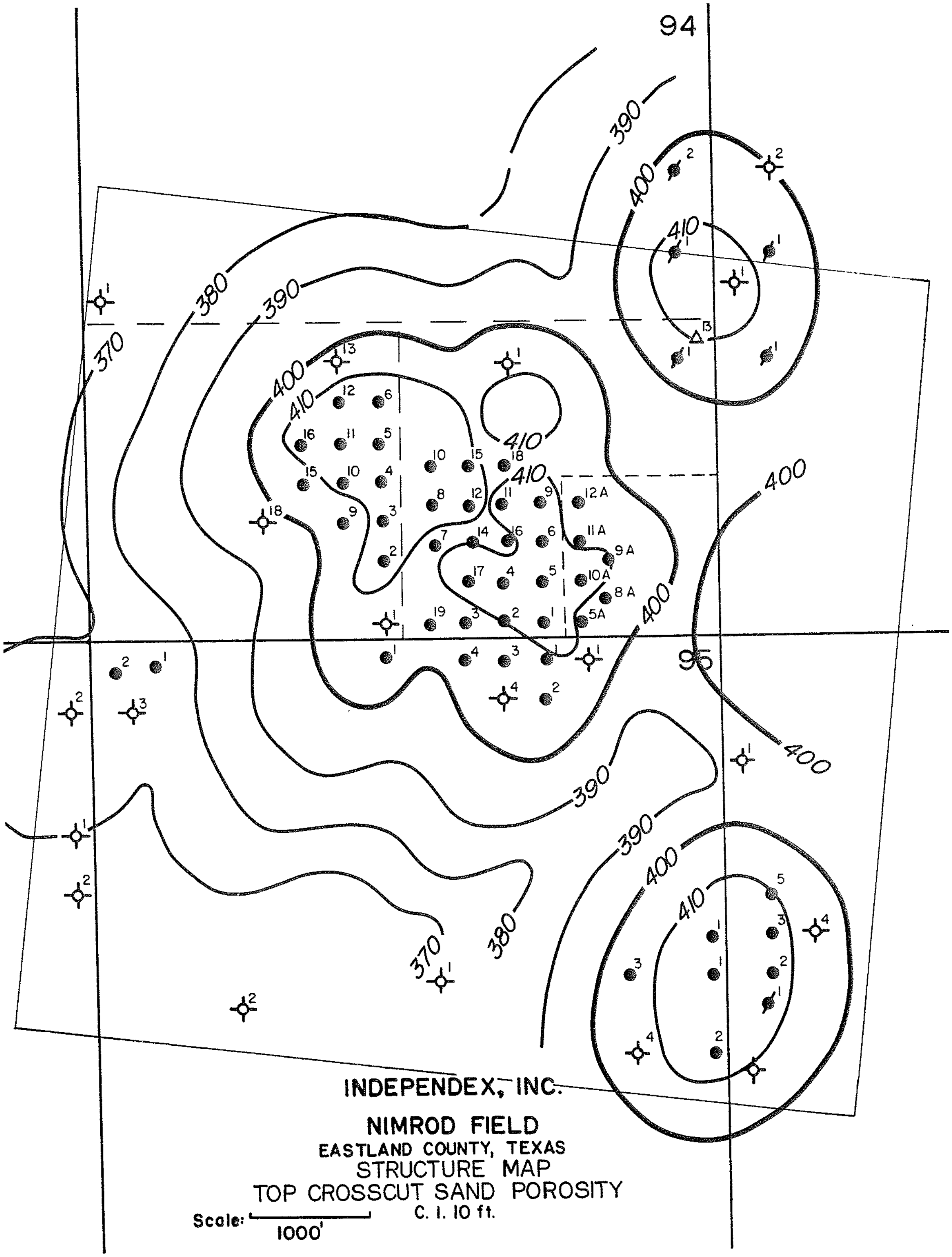


Fig. 7. Top Crosscut sand porosity, Nimrod Field.

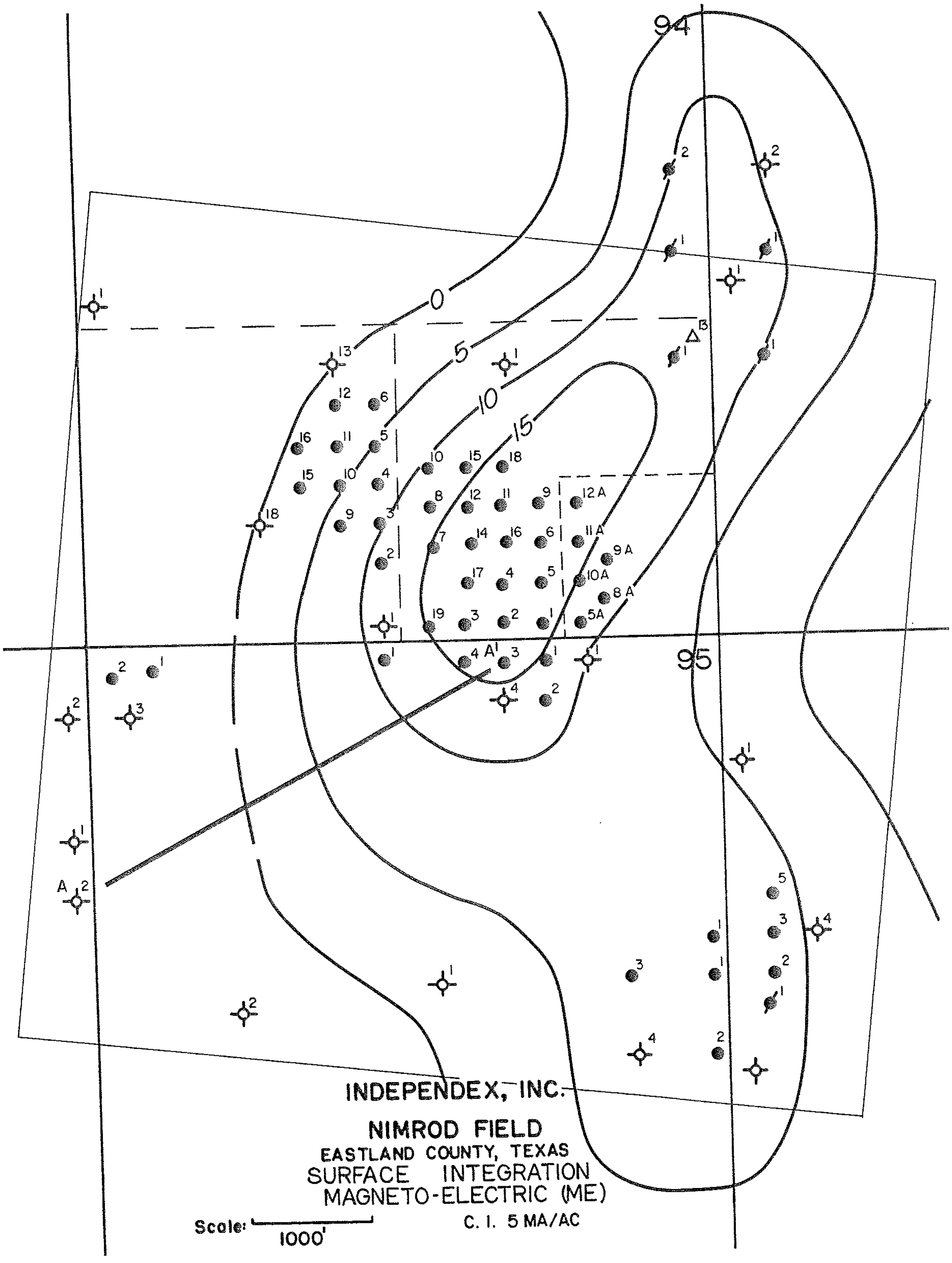


Fig. 8. ME surface integration, Nimrod Field.

Fig. 9. SP shale-base-line drift, section A–A′, Nimrod Field.

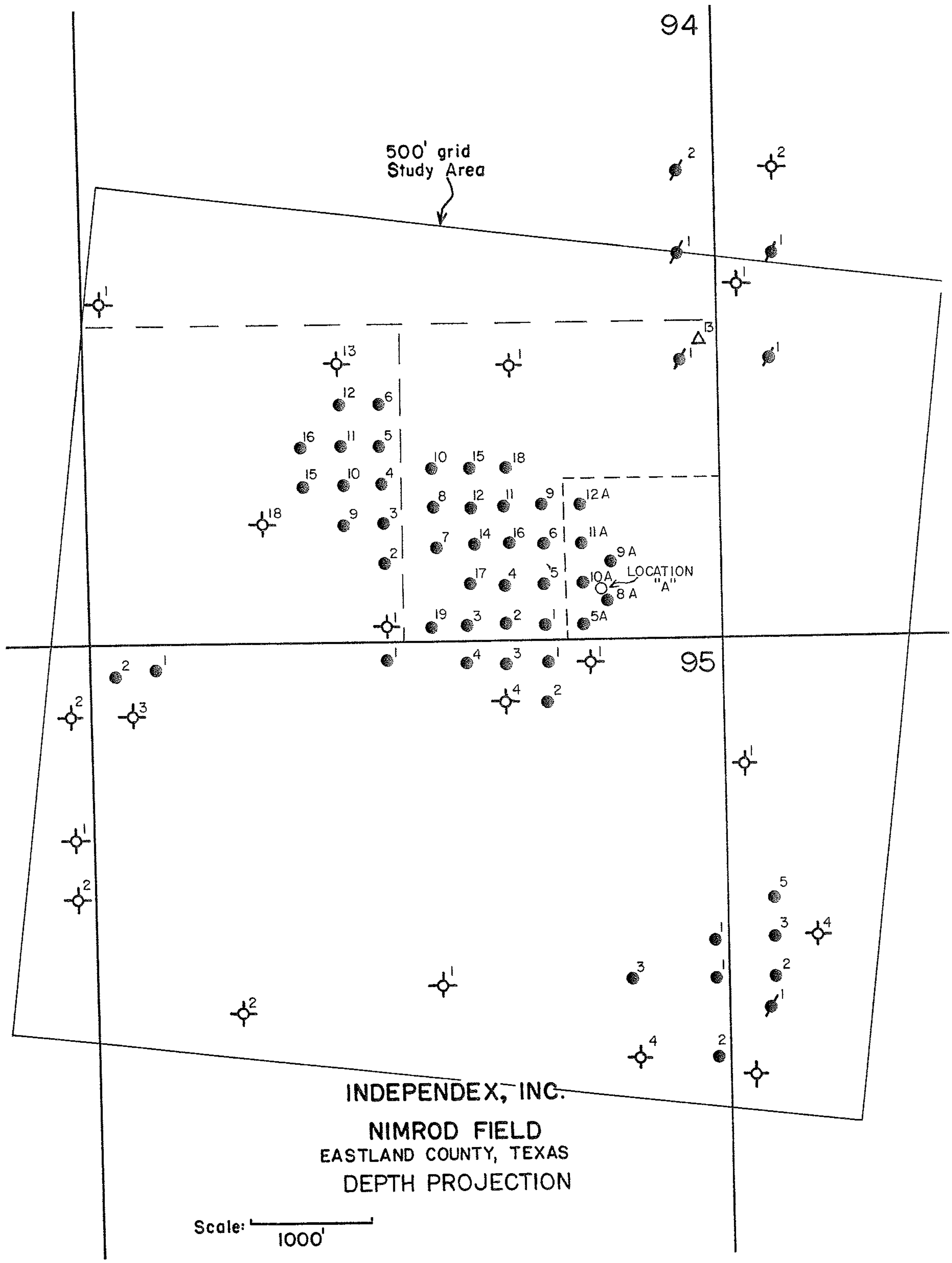


Fig. 10. Location "A", depth projection, Nimrod Field.