Using Remote Sensing Data to Find and Illustrate an Oil and Gas Prospect*

Robert Olson[1]

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[1]Olson Exploration, Tulsa, OK
Consulting Geologist, DMT Technologies, Tulsa Oklahoma; dawoods@ix.netcom.com

Abstract

Windowed radiometrics is the lead-in remote-sensing technology used to highlight an area of interest. Radiometric and magnetic data were collected on a 1 by 2 degree quadrangle basis over most of the continental United States by the U.S. Department of Energy during the National Uranium Resource Evaluation (NURE) program between 1974 and 1982. The processed data released to the public included potassium, uranium, and thorium surface concentrations along with residual magnetics. The data covering Oklahoma, East Texas, South Texas, Kansas, eastern Colorado, Illinois, Indiana, and western Ohio were reprocessed and analyzed seeking potential prospects.

Introduction

The mapping of one of the radiometric anomaly areas (Figure 1, Sec. 4, 6N-1W, Lawrence County, Indiana) is shown as an example of remote-sensing oil and gas exploration, using surface geology (structure), windowed radiometrics (an indirect hydrocarbon indicator associated with microseepage), micromagnetics, and high resolution magnetotellurics (MT). Each of these exploration tools is discussed and added to a base map to build the prospect. Then an example is shown of extending radiometrics and magnetotellurics for wildcat exploration.

Prospect Location and Discussion

Figure 1 is a wellspot orientation map in central Indiana showing the location of the prospect in Sec. 4, 6N - 1W, Lawrence County, Indiana (in yellow). Figure 2 is a portion of the U.S. topographic map with the radiometric anomaly of interest overlay. Please note the significant potassium – uranium crossplot crossover (colored in red). This is the primary indirect hydrocarbon indicator obtained from radiometric analysis. Please note the two fault traces (down to the north) on each side of the main surface topographic feature shown in Figure 2. These would form the main element of the trap. Also, please note that at point A, Figure 2, the micromagnetic curve (derived from the NURE residual magnetic data, (Foote, 1984; Foote, 1996)) shows decreased activity concurrently with the decrease in radiometric activity at the west end of the radiometric anomaly. This is a positive but not a determinative attribute herein (Wolleben, 2002; Schumacher, 2014).

The hydrocarbon-indicating radiometric anomaly is created by vertical hydrocarbon microseepage (Weart and Heimberg, 1981; Saunders, 1993, 1995; Le Schack, 2002). The mechanics of this microseepage begins with catalytic cracking of hydrocarbons at or just above the reservoir (Tomkins, 1990). Catalytic cracking of hydrocarbons at the reservoir breaks the hydrocarbon compounds into "pieces." These pieces are called free radicals and carry a negative electrical charge. This creates a strong negative electrical charge at the reservoir. The surface of the earth is a relative positive charge. This situation has the configuration of a flat plate capacitor, which may explain the regular spacing of the individual Pirson Cell (Pirson, 1981) microseepage "chimneys" across the anomaly (Figure 3). The rocks between the hydrocarbon accumulation and the surface are similar to a leaky capacitor dialectric (Hegg, 2004), with the free radicals traveling up the chimneys.

Figure 3 illustrates the relationship of the vertical microseepage chimneys between the surface and the subsurface hydrocarbon accumulation. An arbitrary radiometric flight line is also plotted. The positive earth's surface pulls the negatively charged free radicals, along the electromagnetic chimney, vertically toward the surface. The transport mechanism is diffusion (Tedesco, 1995), but is electromagnetically guided diffusion. This is the basic Pirson Cell (Pirson, 1981). The dynamic system of free radical hydrocarbon microseepage would have differing vertical rates of transport. This would mean variable electric currents between or among individual Pirson Cell chimney footprints at the surface.

Oxidation of the ascending hydrocarbon free radicals by bacteria in the chimneys and at the surface produces carbon dioxide and organic acids (Price, 1986). In this acidic-reducing environment, uranium is precipitated and potassium is leached (Price, 1985; Price, 1986; Saunders, 1993; Saunders,1995; Schumacher, 1996). This is a dynamic process. A hydrocarbon-indicating radiometric anomaly is the cumulative result of microseepage alteration of the geochemistry at the surface to maintain the chemical valence state of the relatively insoluble uranium and to maintain the leaching of potassium. Since both uranium and potassium have associated radioactive isotopes, with different gamma decay energies, windowed radiometrics can indicate their relative concentrations at the surface.

Patterns are very important in the interpretation of radiometric data (Klusman, 2002). Two windowed radiometric attribute patterns that may indicate hydrocarbons at depth are:

1. The K – U Couplet : The individual symmetrical divergence of the potassium - uranium concentration crossplot (Saunders, 1993; Saunders, 1995). See Figure 2.
2. The simultaneous concentration periodicity of multiple K – U couplets. See Figure 4.

K – U Couplet Example

The strong crossplot crossover shown in Figure 2, (colored red) is the radiometric indirect hydrocarbon indicator. The micromagnetic information shown in Figure 2 may be sourced from precipitated ferromagnetic minerals (Schumacher, 2014; Foote, 1996) or from the electromagnetic fields associated with the microseepage chimneys or both.

Periodicity

Figure 4 shows strong periodicity of the high points of the K – U Couplets across the radiometric anomaly, which is on the flank of a residual magnetic anomaly. These high points are interpreted as the radiological cumulative effect of the surface footprint of the hydrocarbon-microseepage electromagnetic chimneys. The regularity of the periodicity indicates that the detail of the radiometric anomaly is most likely caused by actual data, not random noise. Some of the slight irregularity across the top of the anomaly may be caused by some slight aliasing due to some differences between chimney spacing and sample-point spacing. If the data acquisition flight line crosses a microseepage footprint on the edge, a reduced apparent magnitude data point may be recorded; simulating noise.

Magnetotellurics (MT)

Positive indirect surface hydrocarbon indicators decrease prospect risk but none can show depth to the hydrocarbon accumulation. However, magnetotellurics (MT), as a direct hydrocarbon indicator, can indicate depth as well as thickness and fluid presence and type. For a comparison of MT results and seismic results, see the reports on the salt cavern at the former I&W facility at Carlsbad, New Mexico (Goodman, 2009; Land, 2011; Woods, 2011; Land, 2012). The quotation below supports that claim as to formation correlation and illustrated are examples of good downhole electric log correlation with a majority of the MT electric log formation identifications shown herein. Le Schack (2004), writes:

"A comparison of the Kober-Procter-Gregg telluric log recorded at the drilling location several months prior to the actual drilling, shows a remarkable similarity to the down-hole log recorded after drilling. The formation tops and hydrocarbon content identified from the telluric log are consistent with the drill cuttings and down-hole logs after drilling." (Le Schack, 2004).

"The present authors acknowledge that although the passive telluric technology is neither intuitive nor much used by explorationists, it is effective. The data recorded by these technologies can be mapped as subsurface geology, and used just as geologists would use classical subsurface geological maps."(Le Schack, 2004; Kober and Procter-Gregg 1987).

With the success of Controlled-Source ElectroMagnetics (CSEM) offshore, interest in onshore electromagnetic oil exploration has increased. Magnetotellurics (MT) is a passive electromagnetic system that uses the natural electromagnetic waves produced by the interaction of the earth's ionosphere and the solar wind as the input energy source (Brady et al, 2009). These electromagnetic waves penetrate the earth. When these waves encounter an impedance boundary at depth, the wave at that depth -- frequency is slightly modified. (Impedance here is the resistance to the passage of an electromagnetic wave, which is different than the resistance to the passage of an electric current (resistivity)). A portion of the modified wave is propagated back to the surface carrying all the modified information and frequencies (Brady et al, 2009). At the surface, the electric field and the magnetic field portions of the returning wave are recorded separately for analysis. Analysis accuracy is normally +/- 25(8 m) ft on depth, +/- 5 (1.5 m) ft on thickness, and 100% on water. Good porosity can be differentiated from marginal porosity. The oil or gas signal determination is not 100% because false positives do occur. A good way to reduce oil or gas false positives is to record enough data to find water downdip. That reduces the risk of a false positive caused by hydrocarbon-rich black shale. An even better way to reduce false positives is to find the gas/oil/water contact and determine if it is (or they are) flat.

The magnetotellurics (MT) result is an electric log that is site specific and depth specific to the desired depth interval. One significant pitfall is to skip logging of known nearby calibration wells that would provide the MT response to known formations. A second significant exploration pitfall is to skip "uphole" logging to marker formations and thus miss the regional stratigraphic tie. Any future depth correlation errors are primarily the author's fault for not logging sufficient calibration wells. However, part of the problem in Indiana is that very few wells drilled deep into the Knox carbonate complex, thus limiting the number of suitable calibration wells available.

The Lawrence County, Indiana MT Example Prospect

The key radiometric anomaly for the example prospect is the radiometric anomaly shown in Figure 2. The nearest suitable calibration well for the example prospect is seven miles (11 km) to the northeast. See Figure 1. MT data were acquired at Stations 811-4 and 811-5. Station 811-5 analysis intervals were selected to include the projected New Albany, Trenton, Joachim formations as well as the top of the Knox Formation. The MT electric log for the example prospect is in excellent correlation as to rock unit thicknesses and fluid content with the Kesler #1 Howe calibration well across the New Albany Shale interval. This excellent correlation solidifies the New Albany to be a strong MT electric log marker zone. See Figure 5. The Trenton zone indicated oil but also indicated tight reservoir. The downhole density log indicates approximately 6% porosity. The MT electric log signature for the Joachim dolomite at 2322 ft (708 m) is distinctive enough to be used as a MT electric log logging marker zone (Figure 6). The MT electric log does not identify the St. Peter Sand (2 ft (0.6m) thick) at the Knox unconformity. Two feet is below the resolution of the MT electric log response. The lack of significant changes on the MT electric log between the base of the Joachim dolomite at 2345 ft (715m) down to 2997 ft (914 m) MT logging depth suggests the Upper Knox zone has been cemented enough to eliminate significant electromagnetic wave impedance boundaries. Analysis was extended approximately 200 ft (61 m) below the TD of the calibration well and found a zone with 25 ft (7.6 m) of good oil signal and good indicated porosity (Figure 6) at 2997 ft (914 m). The oil signal at 2997 ft (914 m) MT logging depth shows an excellent impedance boundary expression. This is the classic MT electric log oil signal along with the good porosity indication on an MT electric log (Figure 6). Figure 7 illustrates how the MT electric logs can be correlated from point to point. Figure 8 shows the same style prospect as is built using standard downhole electric logs with equivalent e-log calculations for indications of production.

Exploration Extension of Magnetotellurics

The MT Station 815-Ind-48 was acquired on the radiometric anomaly shown in Figure 4. The data were analyzed over the depth interval from 800 ft (245 m) to 4000 ft (1220 m). The New Albany Shale zone in the MT electric log stratigraphically correlates quite well with the New Albany Shale zone in the Cabot #1 Williams dry hole (Figure 9), over 15 miles (25 km) away. The MT electric log exhibits a response at 2690 ft (820 m) (See Figures 9 and 10) that appears similar to the Joachim dolomite in the Kesler Exploration #1A Howe calibration well density log (Figure 6). That Joachim dolomite type response also is in approximately the correct stratigraphic position, approximately 100 ft above the Knox unconformity at 2806 (855 m) in the Cabot Williams #1 well. The correlation with the Joachim dolomite in the Cabot Williams #1 downhole density log is at 2704 ft (824 m). The total depth of the Cabot Williams #1 is 3534 ft (1077 m). The 815-Ind-48 MT electric log indicates an oil signal zone from 3374 ft (1030 m) to 3423 ft (1045 m) with 38 ft (11.6 m) of oil signal and a second oil signal zone from 3826 ft (1166 m) to 3850 ft (1174 m) with 24 ft (7.3 m) of oil signal. See Figure 9 (the upper half of the Cabot Williams #1 density log) and Figure

10 (the lowerhalf of the Cabot Williams #1 density log). These oil signal zones appear to be within the basal part of the ‘greater” Knox Formation.

Conclusion

The above-outlined exploration methodology has not been utilized to any significant extent by the oil and gas exploration industry. The exploration area reviewed herein is essentially the state of Indiana. The Lawrence County prospect was selected to illustrate the use of a suite of remote sensing technologies to find and define a prospect. The 815-Ind-48 MT electric log was selected to illustrate the added exploration potential of the MT technology. If the MT oil signal zones, shown in Figure 10, are borne out by drilling, the lower Knox in southern Indiana may be a new conventional oil play.

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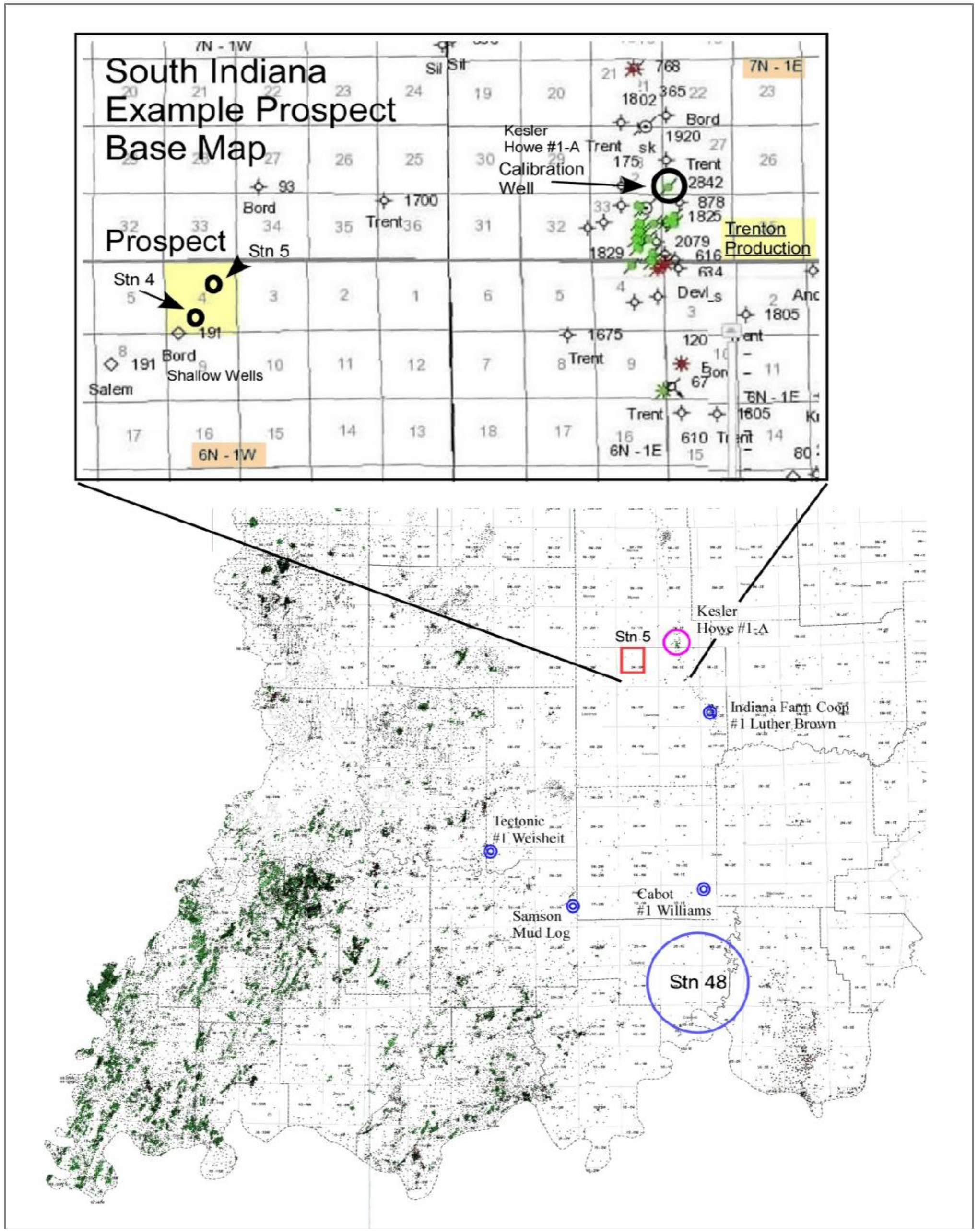

Figure 1. Location map for prospect, South Indiana.

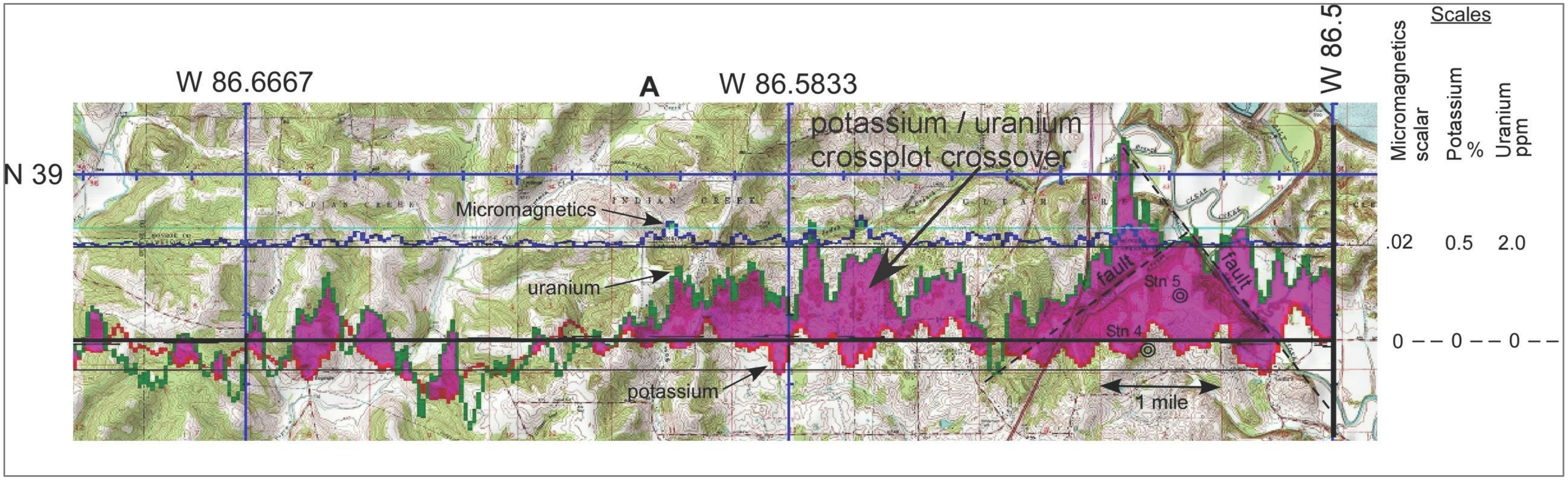

Figure 2. Radiometric anomaly overlay on topographic map.

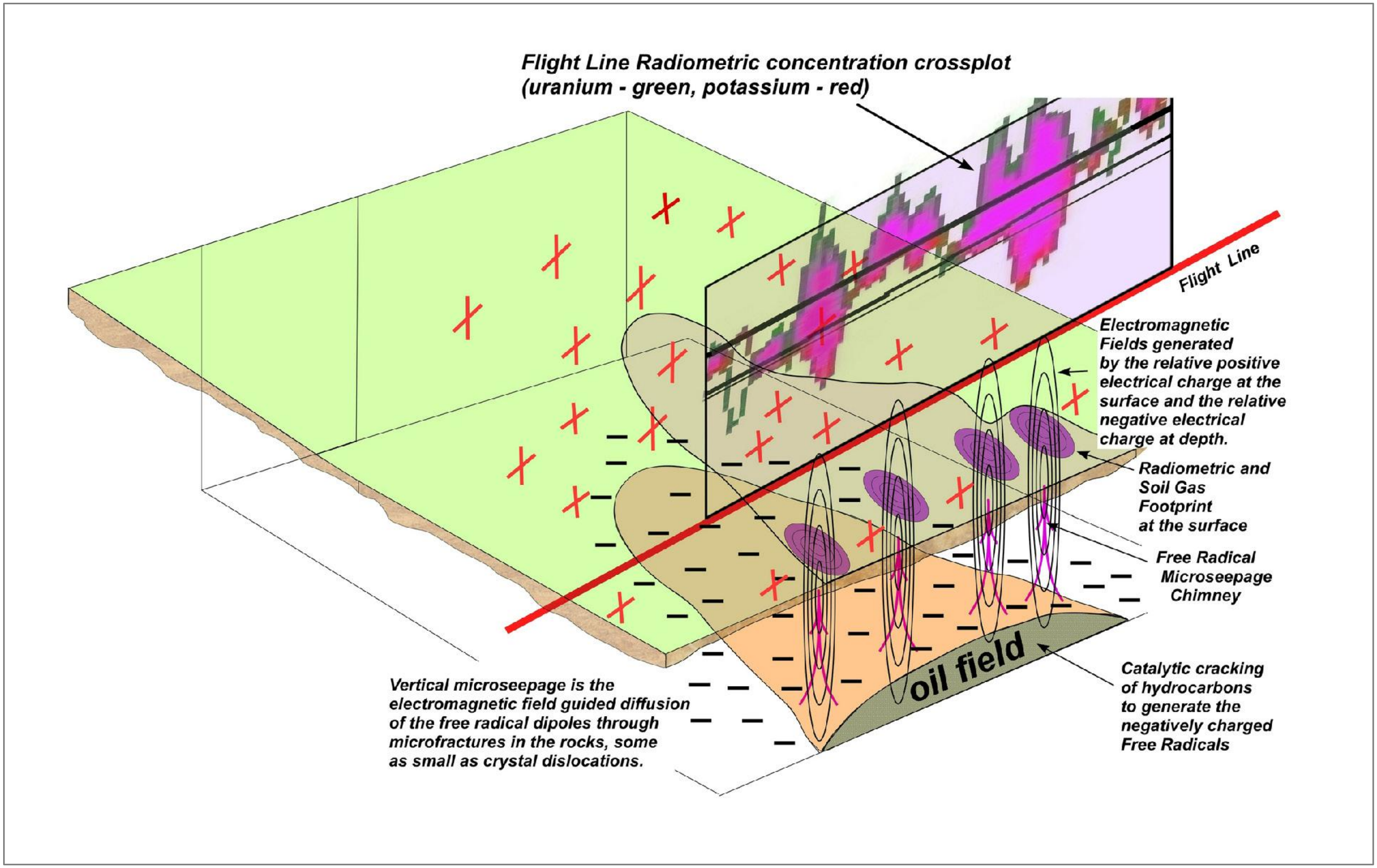

Figure 3. The free radical microseepage mechanics with the radiometric hydrocarbon indicator flight line position.

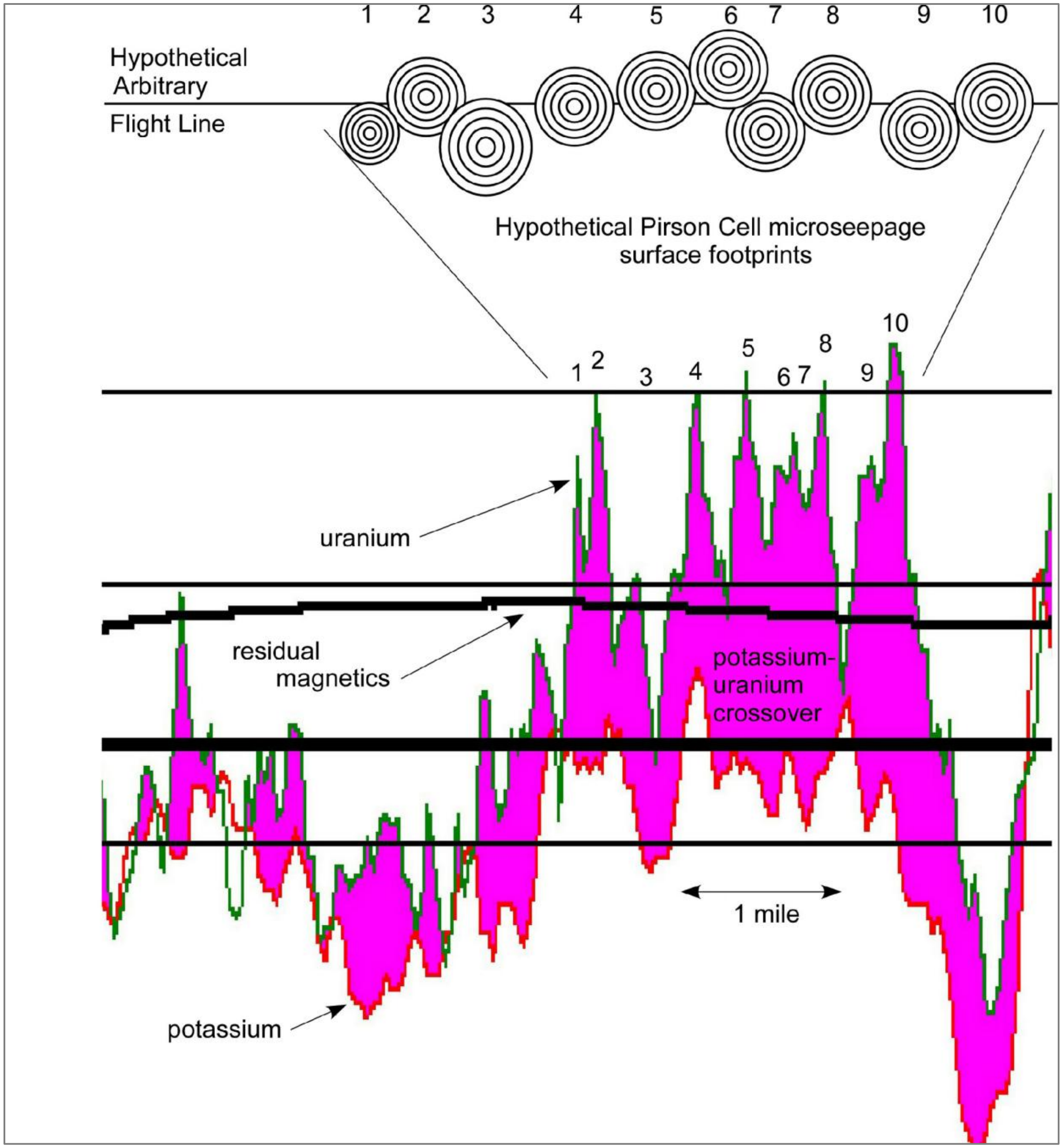

Figure 4. The complex radiometric signature of the Indiana Station 48 area.

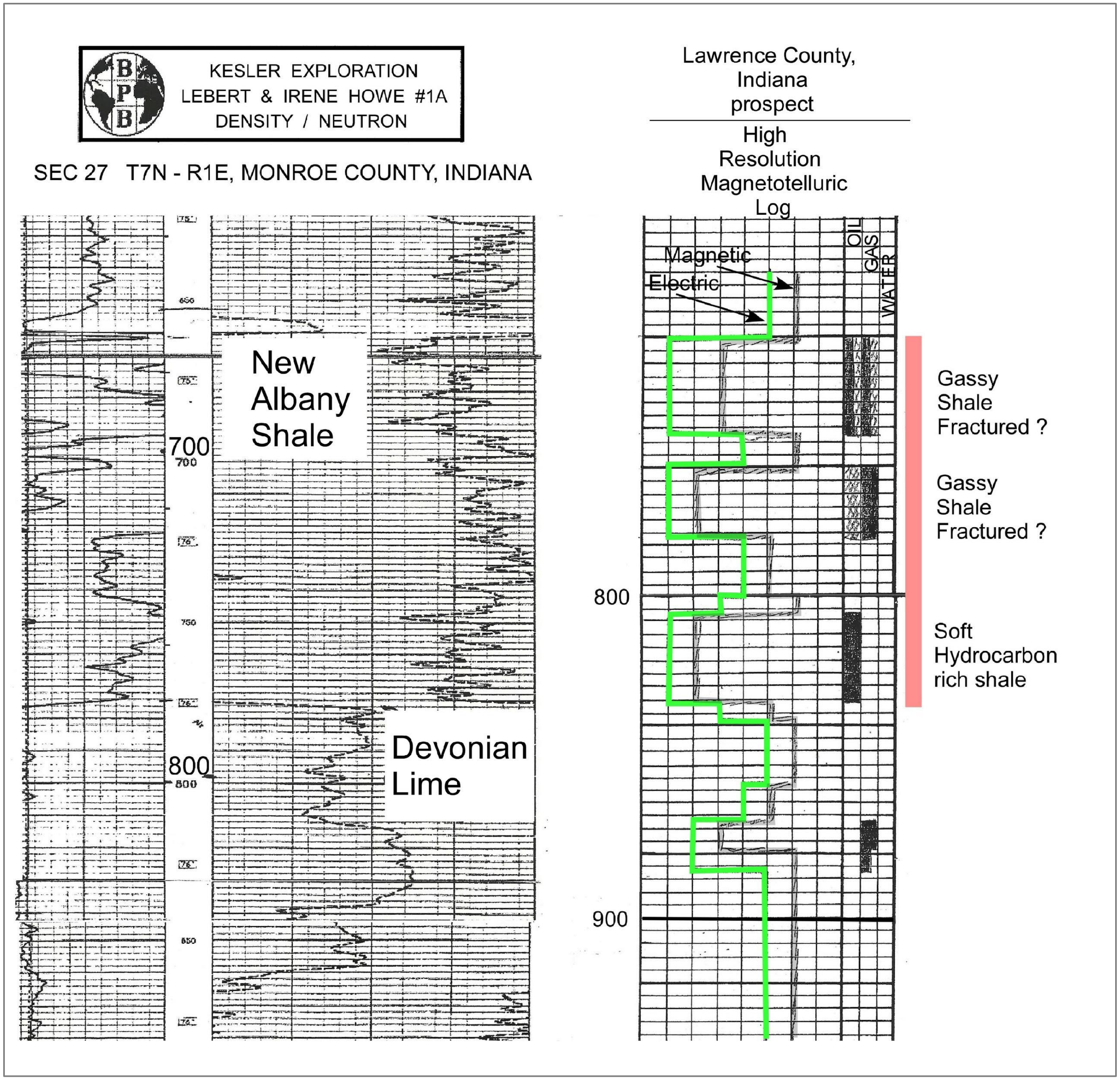

Figure 5. Correlation between downhole density log and the magnetotelluric electric log of the New Albany Shale zone.

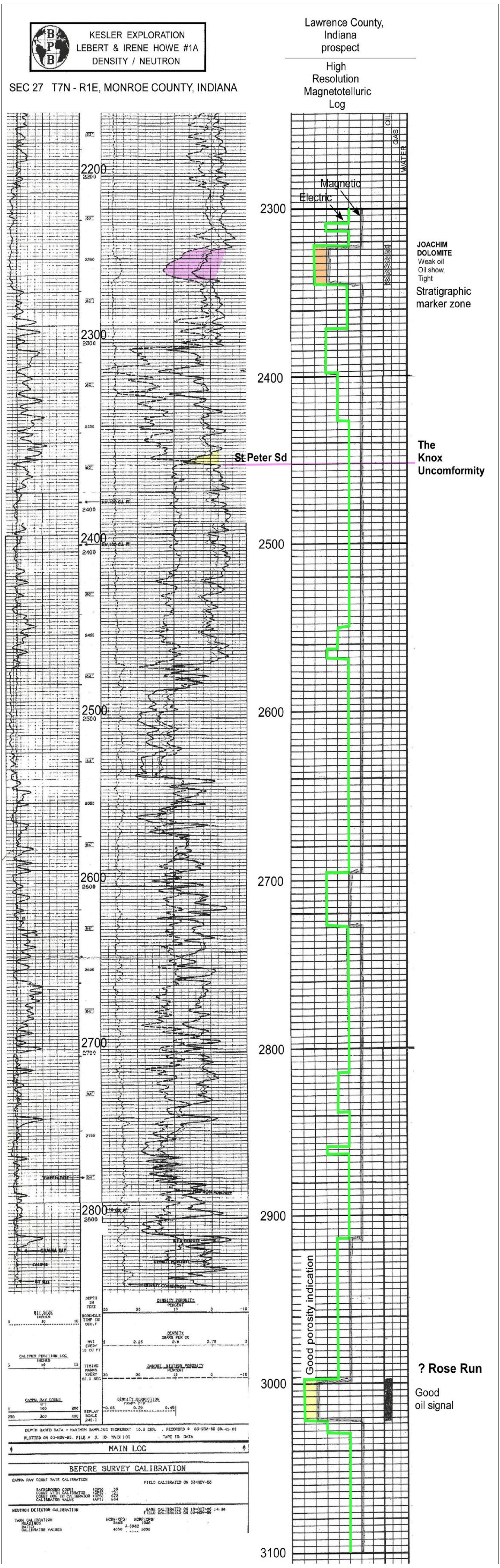

Figure 6. Correlation with the downhole density log and the magnetotulleric log near top of Knox Formation, The extended depth zone of analysis of exploratory interest.

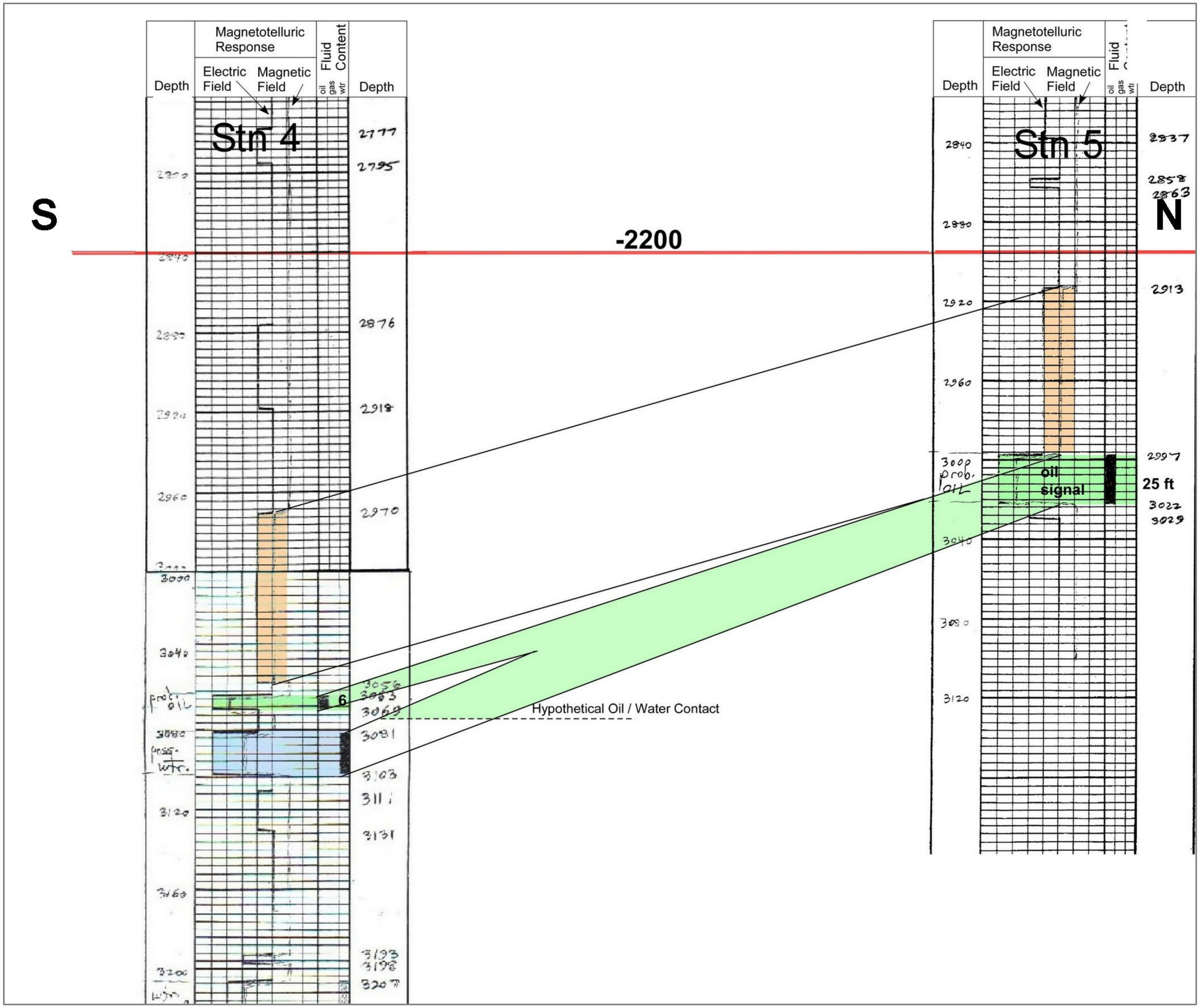

Figure 7. Lawrence County prospect showing the correlation between Station 4 and Station 5. See Figure 1 for locations.

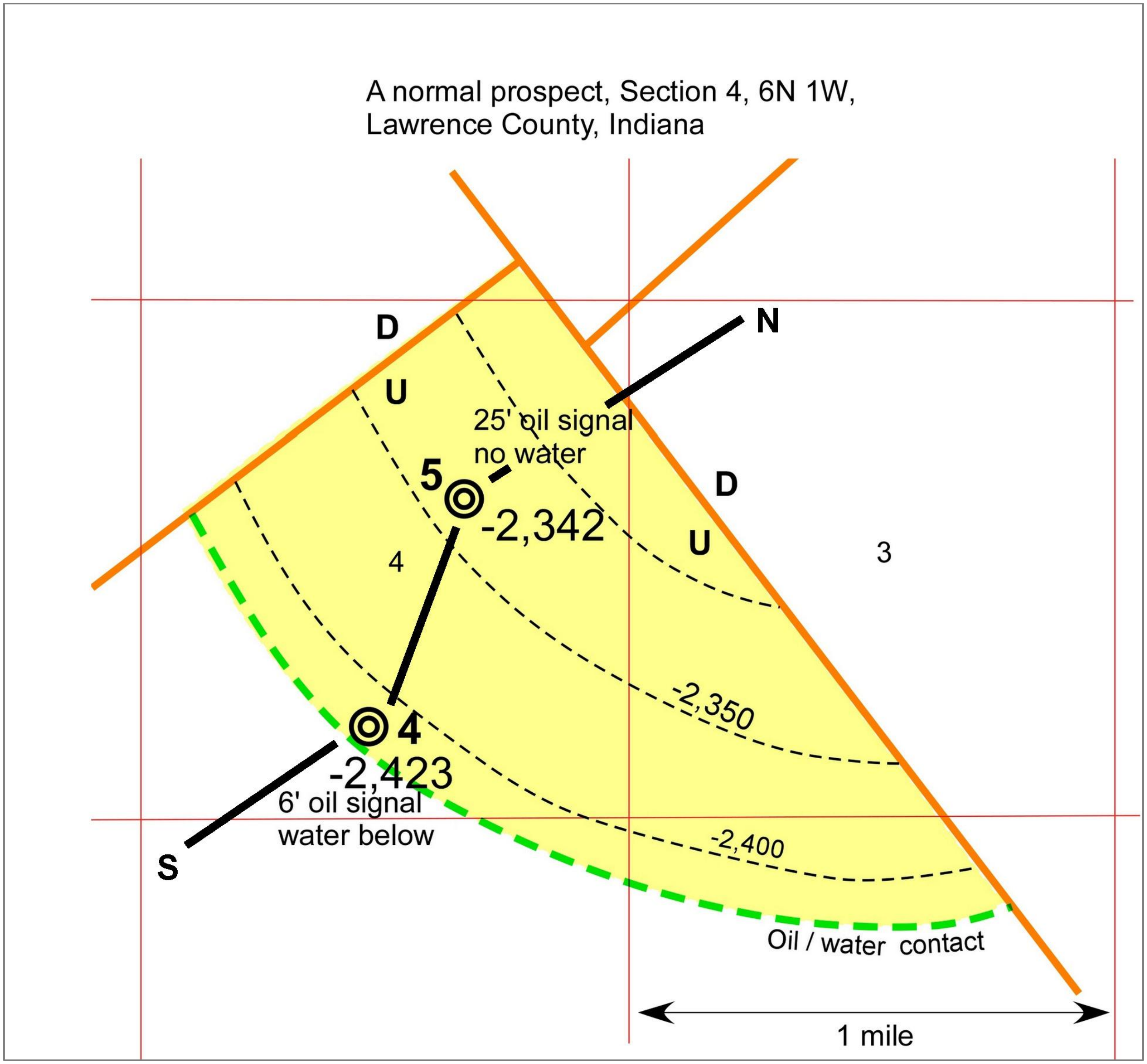

Figure 8. The Lawrence County, Indiana, prospect.

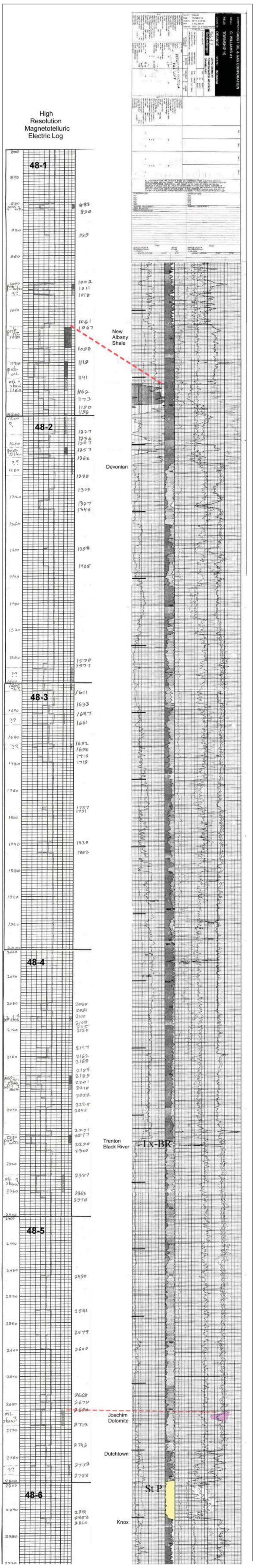

Figure 9. MT Station 815-Ind-48 magnetotelluric electric log, from ~800 to 2920 ft and Cabot Oil & Gas Corporation C. Williams #1 litho-density compensated neutron gamma-ray log, from ~2600 to 3520 ft.

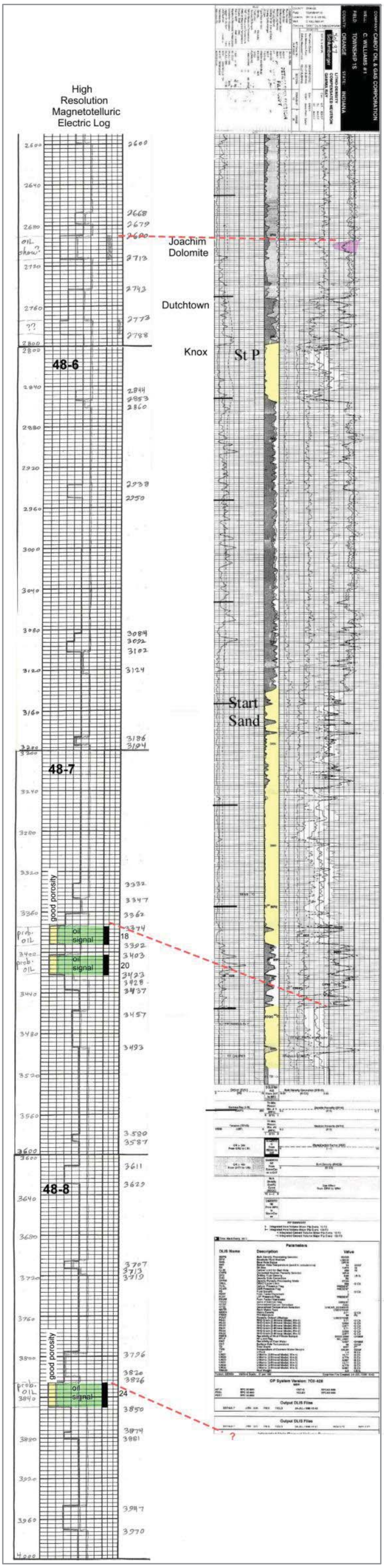

Figure 10. MT Station 815-Ind-48 magnetotelluric electric log, from ~2600 to 4000 ft and Cabot Oil & Gas Corporation C. Williams #1 litho-density compensated neutron gamma-ray log, from ~2600 to 3520 ft.