Airborne Transient Pulse Surveys Identify Subtle Stratigraphic FDD Channel Sand Reservoirs in Australia, Namibia and South Africa*

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Abstract

The Fluvial-Dominated-Deltaic (FDD) reservoir is the most common and important onshore reservoir in the United States, and is responsible for the majority of its oil and gas production from sandstone reservoirs (Johnson, 2001). It is quite possible that this may be true in other countries also, for we see such reservoirs elsewhere. Typically FDD reservoirs are subtle stratigraphic traps which are not easily found by seismic exploration, but can be readily identified by Airborne Transient Pulse Surveys, if those airborne data are properly recorded, processed, and mapped using appropriate Kriging parameters.

LeSchack and Jackson (2006) first showed the potential for surveying for hydrocarbon reservoirs from aircraft using Airborne Transient Pulse Surveys. Four years later, major improvements were made to this technology by Pinemont Technology Inc. that included fully computerized digital recording and processing with the additional capability of not only mapping potential oil fields, but estimating the depth at which they could likely be encountered (LeSchack et al., 2011).

In October 2010 surveys were flown for clients in Namibia and South Africa over areas which the clients believed to be petroliferous. Upon processing of these Airborne Surveys, a petroleum geologist seeing these maps can readily recognize plan views of FDD reservoirs, the type reservoir earlier predicted for these areas from classical geological study of outcrops (Johnson et al., 2001). Although there is not yet onshore production in either country, in these areas oil seeps had already been found, water wells drilled that occasionally encountered oil, and random soil samples analyzed thereby identifying oil and gas rich regions.

Significant exploration and drilling, however, have already been reported for an offshore area nearby our Namibia Airborne Survey (Figure 5) . A comparison is made between (a) the Ibhubesi Gas Field offshore South Africa as mapped by seismic attributes and other inversion processing of a 312 km 3-D survey (Berge et al., 2002), and (b) a key portion of the nearby onshore Namibia Airborne Survey (Figure 6).

The Ibhubesi Field map shows FDD channel sands and a derived hydrocarbon map based on "seismic attributes". This comparison strongly suggests similar FDD reservoir characteristics for both maps and an analogous onshore reservoir. This "offshore-onshore" geological similarity is supported by Stanisstreet and Stollhoffen (1999). The channel and oxbow sands on both maps exhibit similar shapes and sizes, and soil samples coincident with the Airborne anomalies, however, suggest oil rather than gas will be encountered upon drilling onshore. Our Airborne methodology, which is directly linked to microseeping hydrocarbons, seems more definitive, more quickly accomplished, and is certainly a vastly less expensive form of exploration for finding subtle stratigraphic traps.

In addition to this offshore-onshore comparison, Airborne maps of FDD reservoirs in Australia (Figure 4) as well as Namibia and South Africa are presented and discussed, as is the capability of differentiating multiple stacked channels in single-channel belts. Significant anomalies identified in the South African Airborne Survey have been complemented by 26 soil samples, geochemically analyzed, which suggest that area as being highly prospective for both oil and gas.

Examples

A good example of an FDD sand deposition map is that of the Booch Delta of eastern Oklahoma, displaying both meandering and braided channels (Andrews, 1995) (Figure 1). The Hawkins Field (red arrow) is one of numerous oil fields associated with the Booch Delta FDD system. An isopotential map of the Hawkins Field is shown at right (Figure 1) indicating initial production (Levorsen, 1954). Basically, the reservoirs are channel-fill sands deposited in channels created by ancient, but classical meandering stream systems as well-described in physical geology texts. Depositional systems like this often create reservoirs that exhibit no seismic structure, but if they contain hydrocarbons, are identified around the world by Airborne Transient Pulse Surveys (Figure 3).

South Africa

An Airborne A-EM (Audio Electromagnetic) Survey (LeSchack et al., 2011) was flown over the Lydenburg area, east-northeast of Johannesburg in 2010. Flight line spacing was 900 m apart at an altitude of 100 m. Upon processing the data shortly thereafter, and using a Kriging algorithm for preparing contour maps, five separate overlying depth zones, essentially evenly spaced between a depth of 1600 m and 400 m, appeared individually prospective for FDD hydrocarbon reservoirs. The estimated depths of each of the five overlying frequency/depth slices, according to the relationship developed by John Jackson's methodology shown in Figure 7, and discussed in LeSchack et al. (2011).

Author Jackson empirically observed that the dominant frequencies of Transient Pulses emanating from the subsurface varied as a function of depth. These frequencies, in the audio range, were plotted as seen in Figure 7 and appear to be a continuous function, as described in his U.S. Patent 5,777,478.

It follows, therefore, that electronically parsing pulses of different frequencies in a survey can estimate the depths from which they emanated. The F-D curve may vary around the world, and recalibration over nearby oil fields should be conducted. (Note: We use Airborne A-EM Transient Pulses for identification of apparent resistivity; Pinemont Technologies).

During the first quarter of 2012, twenty-six soil sample locations were chosen at the Burgersfort prospect area based on the best A-EM anomalies on each of the five overlying maps (each about 5 nautical miles on a side). This permitted evaluation of essentially vertical hydrocarbon microseepage from all depths of this overall prospect area. These data were analyzed according to the methods of Rice et al. (2002) and are shown in Table 1. From soil chemistry analyses of these soil samples (related map in Figure 8), Dr. Gary Rice of GeoFrontiers Corporation concluded:

• Significant petroleum gas seepage was observed throughout the sampled area.

• An oil signature was found in the northern (Figure 9) and central (Figure 10) parts of the survey, and separate gas or condensate data were indicated in the south.

• Liquid petroleum seepage was detected in the northern part of the area.

• High liquid petroleum concentrations in the central part of the sampled area were also noted. Rice suggested these high values (Points 13-15) may have been caused by sample contamination due to near-roadside collection, or alternatively from larger fractures in this area, allowing migration of liquid hydrocarbons. The present author suspects larger fractures are the cause. Earlier studies suggests a north-south trending fault is nearby that allows migration of liquid hydrocarbons. It is also noted that Point 1 shows no similar high values as do Points 13-15. It was taken two miles farther north along the same paved road just off of which roadside samples 13-15 were also taken. The remaining soil samples were taken just off of lightly traveled gravel farm roads.

Conclusions

• Airborne Transient Pulse Surveys can map *live* subsurface hydrocarbons worldwide, both onshore and offshore, whether in structural or stratigraphic traps. More than 130 surveys have been flown worldwide. Some surveys flown and analyzed indicate Fluvial-Dominated Deltaic (FDD) reservoirs in Australia, and most recently in Namibia and South Africa.

• FDD reservoirs are mostly stratigraphic traps that are hard to find by seismic exploration, but appear easily mapped by Airborne A-EM Surveys in continental areas around the world. We see them in Australia, Namibia, South Africa, and in the US, where they are the largest source of sandstone oil production.

• The Airborne A-EM maps, although clearly seeming to identify locations of subsurface FDD reservoirs, need several independent layers of on-the-ground verification prior to drilling, owing to statistical errors introduced in the data collection and map-making process, and for better estimating geographic position and depth. In our program in South Africa, we began this verification using geochemical analyses of 26 soil samples analyzed by GeoFrontiers.

• From this combined study of the verification by geochemical analysis of soils collected specifically over significant Airborne A-EM anomalies, the Burgersfort, South Africa Concession is a highly prospective area for discovering both oil and gas.

References

Andrews, R.D., 1995, Fluvial-Dominated Deltaic (FDD) oil reservoirs in Oklahoma - The Booch Play: Oklahoma Geological Survey, Special Pub 95-3, 67 p.

Berge, T.B., F. Aminzadeh, P. deGroot, and T. Oldenziel, 2002, Seismic inversion successfully predicts reservoir, porosity, and gas content in Ibhubesi Field, Orange Basin, South Africa: The Leading Edge, v. 21/4, p. 338-348.

Busch, D.A., 1953, The significance of deltas in subsurface exploration: Tulsa Geological Society Digest, v. 21, p. 71-80.

Busch, D.A., 1959, Prospecting for stratigraphic traps: AAPG Bulletin, v. 43, p. 2829-2843.

Hamlin, S., S.P. Dutton, N. Tyler, J.S. Yeh, R.J. Saggie, P. Lansom, and G.B. Asquith, 1994, Resource Optimization through Facies-Based Characterization of a Braid-Delta Sandstone Reservoir, Tirrawarra Oil Field, Cooper Basin, South Australia. Web accessed 24 March 2012, AAPG Search and Discovery Article #90986 AAPG Annual Convention Abstracts, Denver, CO, June 12-15.

Johnson, Jr., L.A., 2001, Fiddler Creek polymer augmentation project, Final Report: Western Research Institute, Laramie, Wyoming, U.S. Department of Energy (DOE), 47 p., digital file.

Levorsen, A.I., 1954, Geology of Petroleum: W.H. Freeman, San Francisco, California, 703 p.

Johnson, M.R., C.R. Anhaeusser, and R.J. Thomas, (eds.), 2001, The Geology of South Africa: Geological Society of South Africa, Johannesburg and the Council for Geoscience, Pretoria, South Africa, 691 p.

LeSchack, L.A., R. Wyman, and J. Jackson, 2004, Surface Exploration Successful in Finding Alberta Leduc Pinnacle Reefs: AAPG Annual Meeting Abstract, April 18-21, 2004, Dallas, Texas. Web accessed 24 March 2012, http://www.searchanddiscovery.com/abstracts/html/2004/annual/abstracts/LeSchack.htm?q=%2BtextStrip%3Aleschack

LeSchack, L.A., and J.R. Jackson, 2006, Airborne Measurement of Transient Pulses Locates Hydrocarbon Reservoirs: AAPG Annual Meeting Abstract, Dallas, Texas. Web accessed 27 March 2012, http://www.searchanddiscovery.com/documents/2006/06088houston_abs/abstracts/leschack.htm?q=%2BtextStrip%3Aleschack

LeSchack, L., J. Jackson, J.K. Dirstein, W.B. Ghazar, and N. Ionkina, 2010, Major Recent Improvements to Airborne Transient Pulse Surveys for Hydrocarbon Exploration: AAPG 2010 International Convention and Exhibition Abstract, Calgary, Canada. Web accessed 27 March 2012, http://www.searchanddiscovery.com/abstracts/pdf/2010/intl/abstracts/ndx_leschack02.pdf

Pirson, S., 1969, Geological, geophysical and chemical modifications of sediments in the environment of oil fields, *in* W.B. Heroy, (ed.), Unconventional methods in exploration for petroleum and natural gas: Dallas, Southern Methodist University, p. 159-186.

Rice, G.K., J.Q. Belt, Jr., and G.E. Berg, 2002, Soil-gas hydrocarbon pattern changes during a West Texas waterflood, *in* D. Schumacher and L.A. LeSchack, (eds.), Surface exploration case histories: applications of geochemistry, magnetics and remote sensing: AAPG Studies in Geology No. 48 and SEG Geophysical References Series No. 11, p. 157-174.

Stanisstreet, I., and H. Stollhofen, 1999, Onshore equivalents of the main Kudu gas reservoir in Namibia, *in* N.R. Cameron, R.H. Bate, and V.S. Clure, (eds.), The Oil and Gas Habitats of the South Atlantic: Geological Society of London, Special Publications 153, p. 345-365.

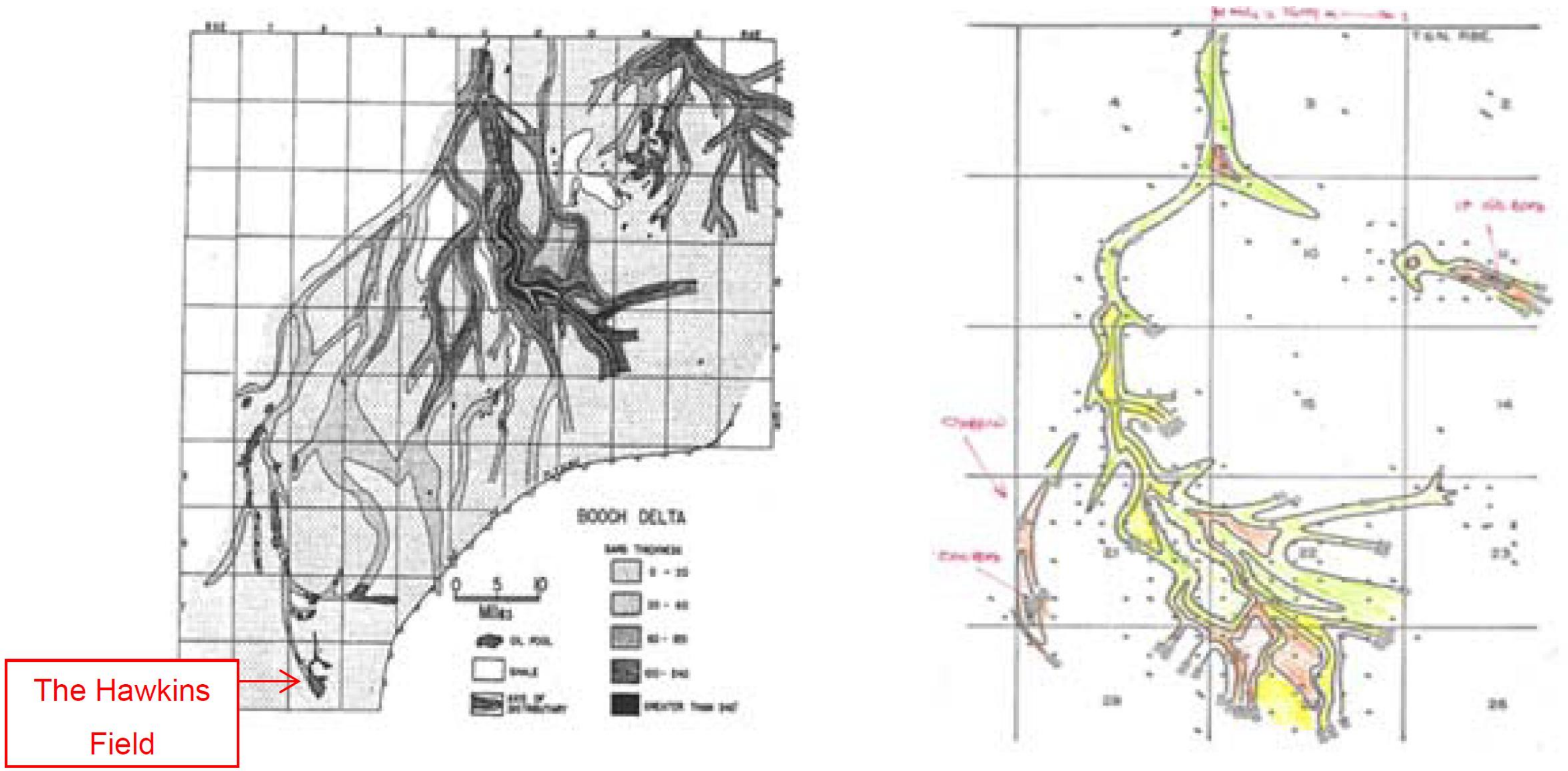


Figure 1. The Fluvial-Dominated-Deltaic (FDD) Reservoir is the most common and important onshore reservoir in the United States, and is responsible for the majority of its oil and gas production from sandstone reservoirs (Johnson, 2001).

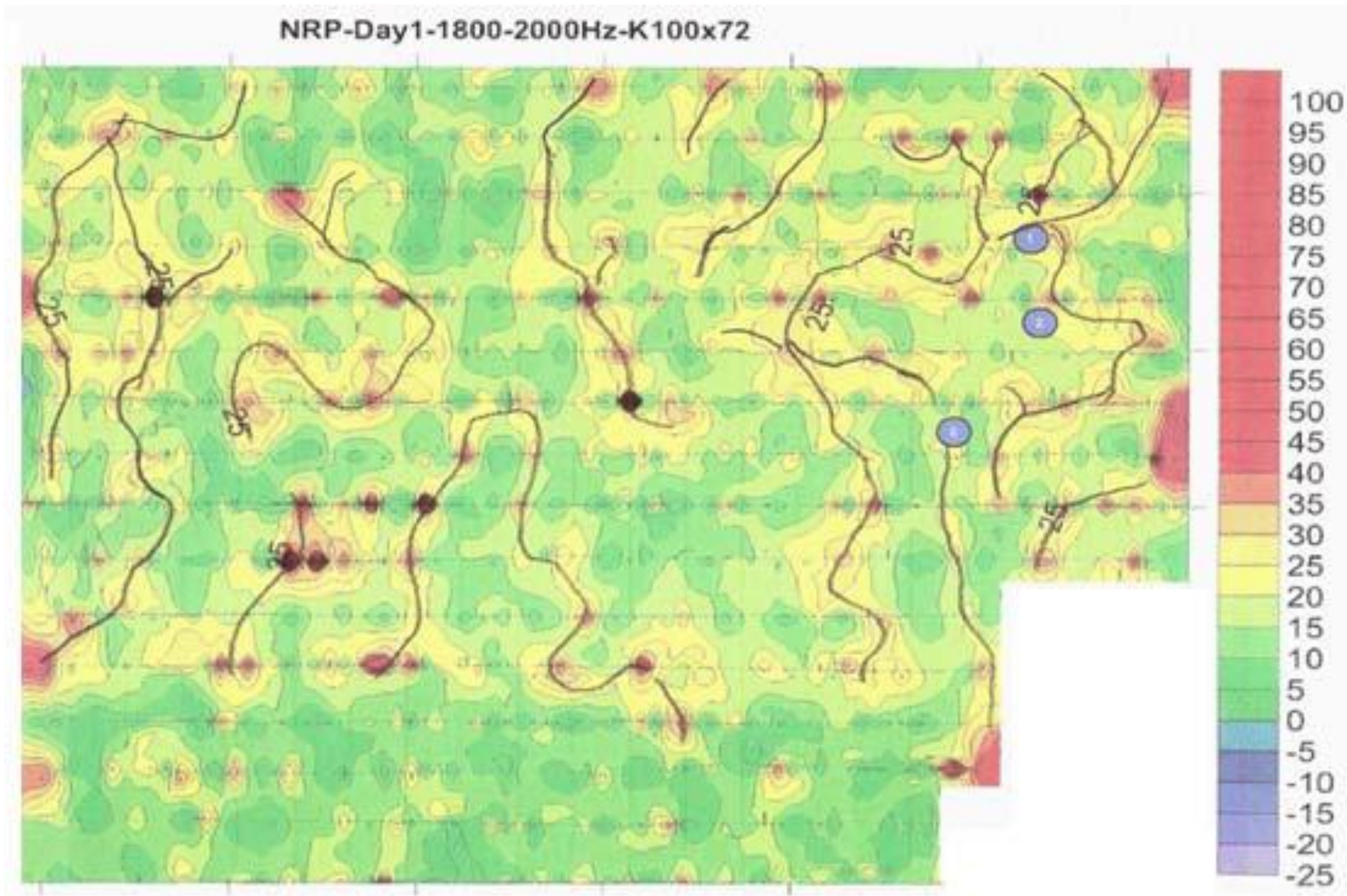


Figure 2. An Airborne Transient Pulse Survey (LeSchack et al., 2011) of a 15 by 15 NM area of on-shore continental Namibia close by the offshore Ihubesi Field exhibits an FDD paleo-environment resulting in the formation of riverine channels, braided streams and isolated oxbows, now likely hydrocarbon pools. The red and yellow contours are the locus of the highest values of Transient Pulses directly related to Pirson REDOX Cells (Pirson, 1969) caused by microseeping hydrocarbons. The hotter the color contour, the more likely the occurrence of hydrocarbon in the reservoirs. Penciled in are the likely paleo-stream channels. Likely "oxbow" crescents are suggested. Points 1, 2 and 3 are locations where prior to the Airborne Survey, soil samples were taken and analyzed by GeoFrontiers (Rice et al., 2002) suggesting that oil, rather than gas was most likely to be encountered upon drilling.

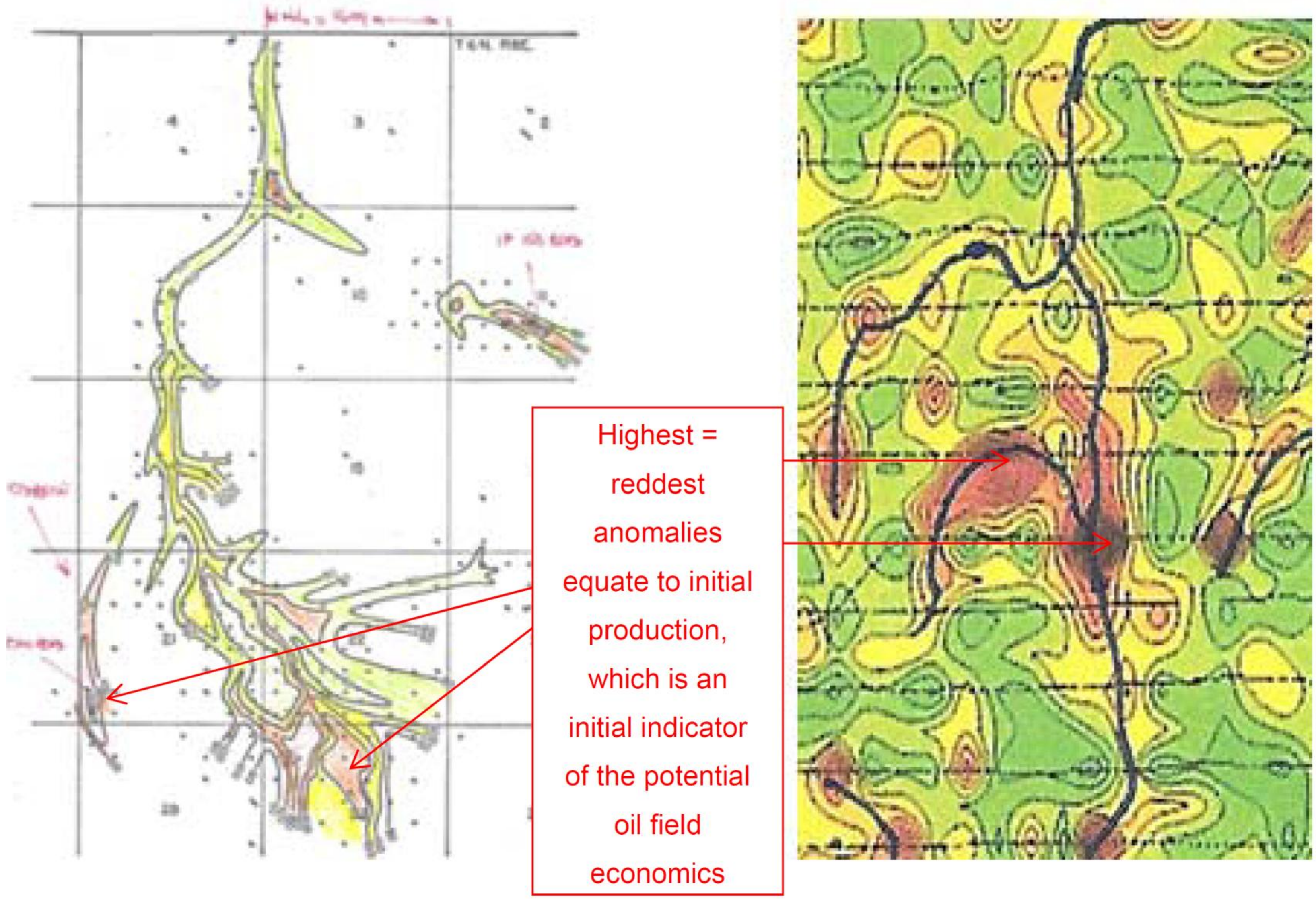


Figure 3. (Left) initial production (IP) of the Hawkins Field, Oklahoma. Pink and orange contours show areas of high initial production. Compare this with ancient stream systems (Right) and likely shoestring sand hydrocarbon reservoirs, as mapped in South Africa by Airborne A-EM Surveys, and presented at a similar scale. Red Arrows (Left) = maximum IP. Red Arrows (Right) = maximum A-EM pulse density. Note similarities of the two maps, even though a world apart. This should not be surprising, since the paleo-environment is likely also similar.

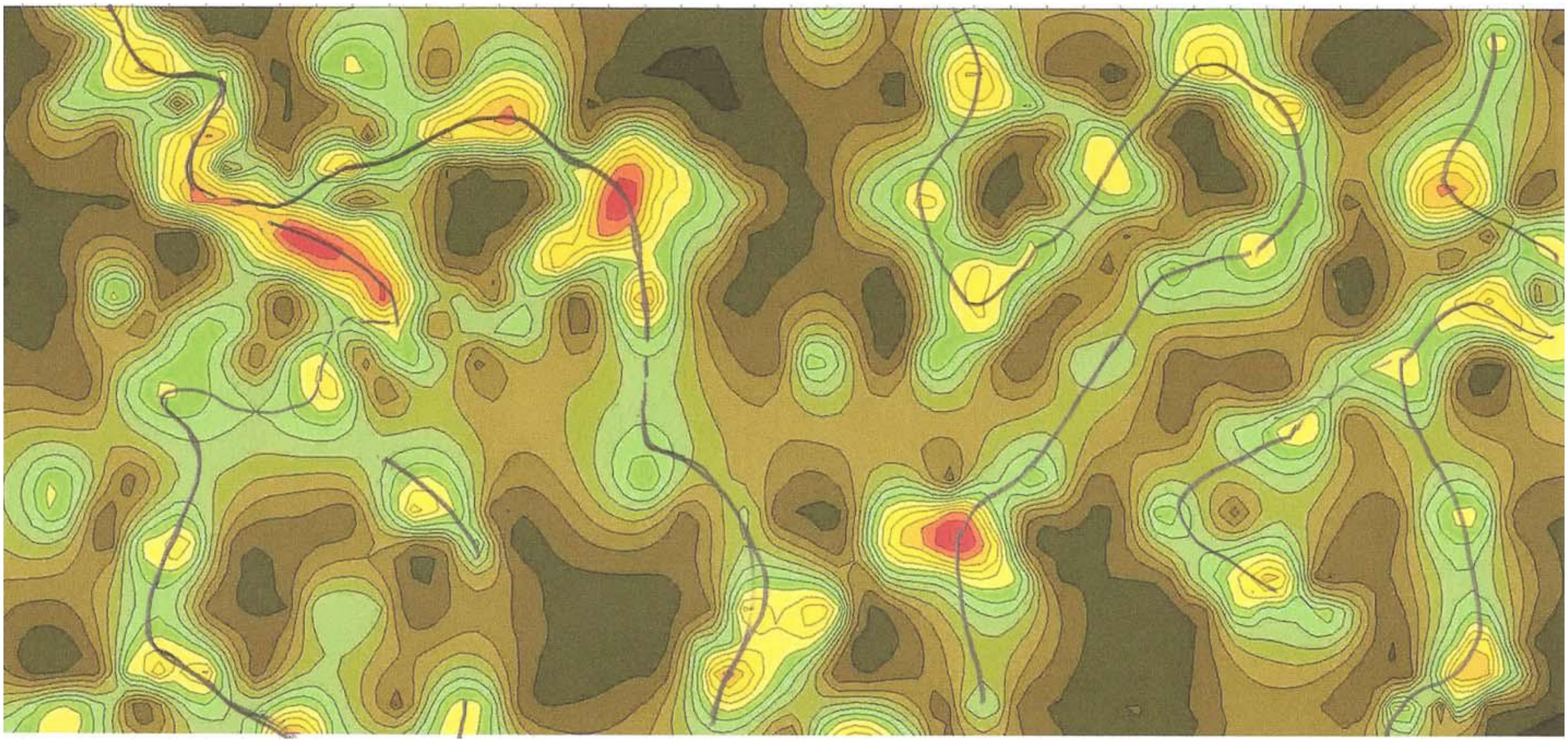


Figure 4. An Airborne Transient Pulse Survey (LeSchack and Jackson, 2006) maps a 45 by 90 NM area over the Cooper Basin, Australia where more than 80% of the oil in this basin is contained in the Early Permian braid delta and braided stream sandstone reservoirs found here (Hamlin et al., 1994). This means an FDD paleo-environment has governed the deposition of the productive Tirrawarra Sandstone. It is therefore likely that the typical channel-fill stream systems seen penciled in here are Tirrawarra stratigraphic reservoirs that generally show little or no seismic expression, unless they have been subsequently modified by faulting. The Booch Delta Sandstones channels seen in Figure 1 seem similar in shape as do the channel sands seen in this Figure.

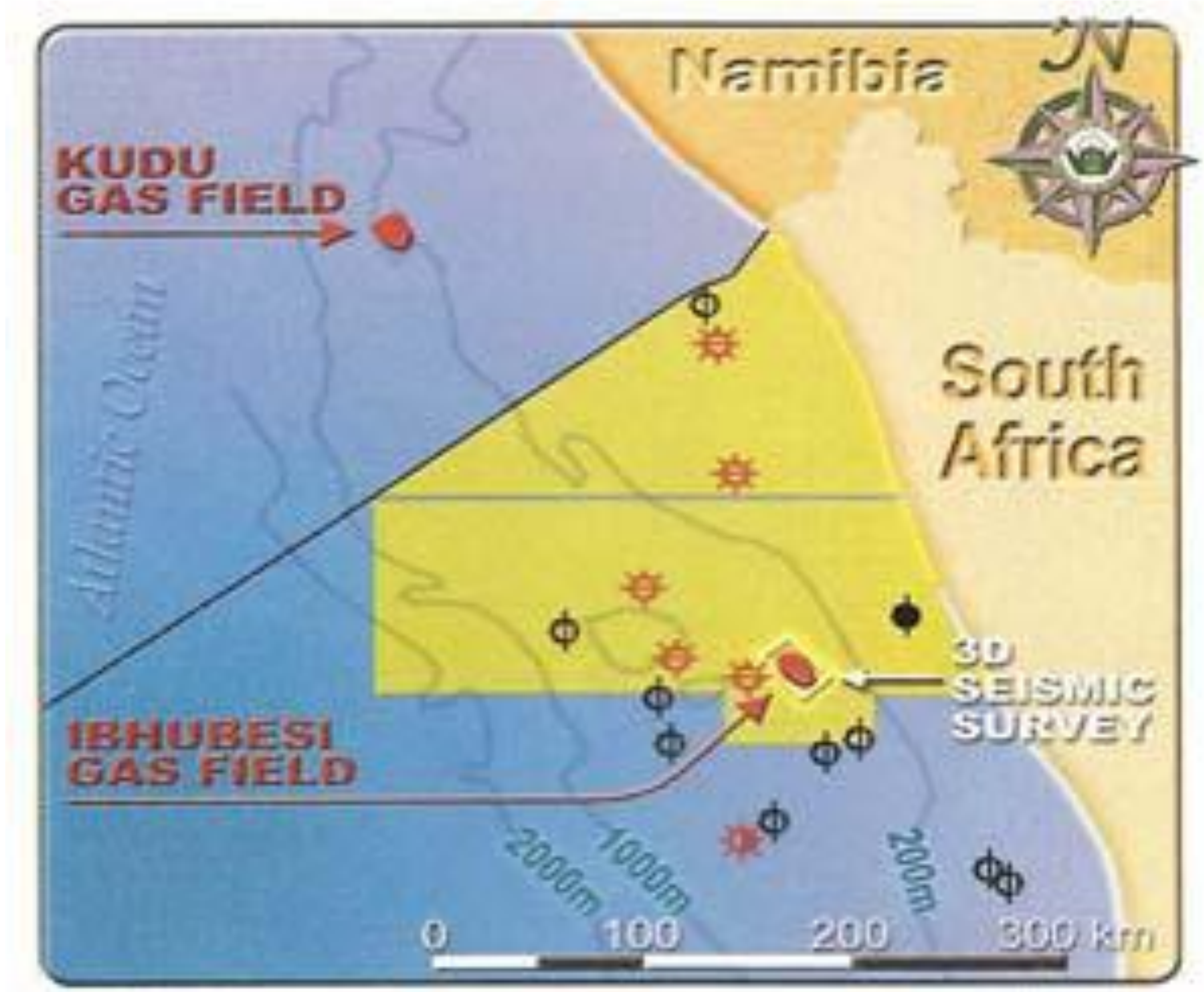


Figure 5. In 2000 Forest Oil International shot a 312 km 3-D seismic survey over the offshore Ibhubesi Field where shown on the map below. The field is a stratigraphic trap. According to Berge et al. (2002), “attribute processing and other inversion techniques were used to predict the presence and properties of the reservoir, to assess reserves, and plan a drilling campaign to delineate the field. Individual gas accumulations in meandering fluvial channels and other component facies of the fluvial-deltaic systems tract were clearly identified in the resulting volumes.” The reservoirs identified by this costly seismic survey and its associated intensive processing are known as “Fluvial-Dominated-Deltaic” reservoirs; they are common, and were also long predicted onshore in this region by classical geologists from analyzing outcrops in this South Africa/Namibia area and comparing them with geology of the Kudu Offshore Field, also shown on the map (Stanistreet and Stollhoffen,1999).

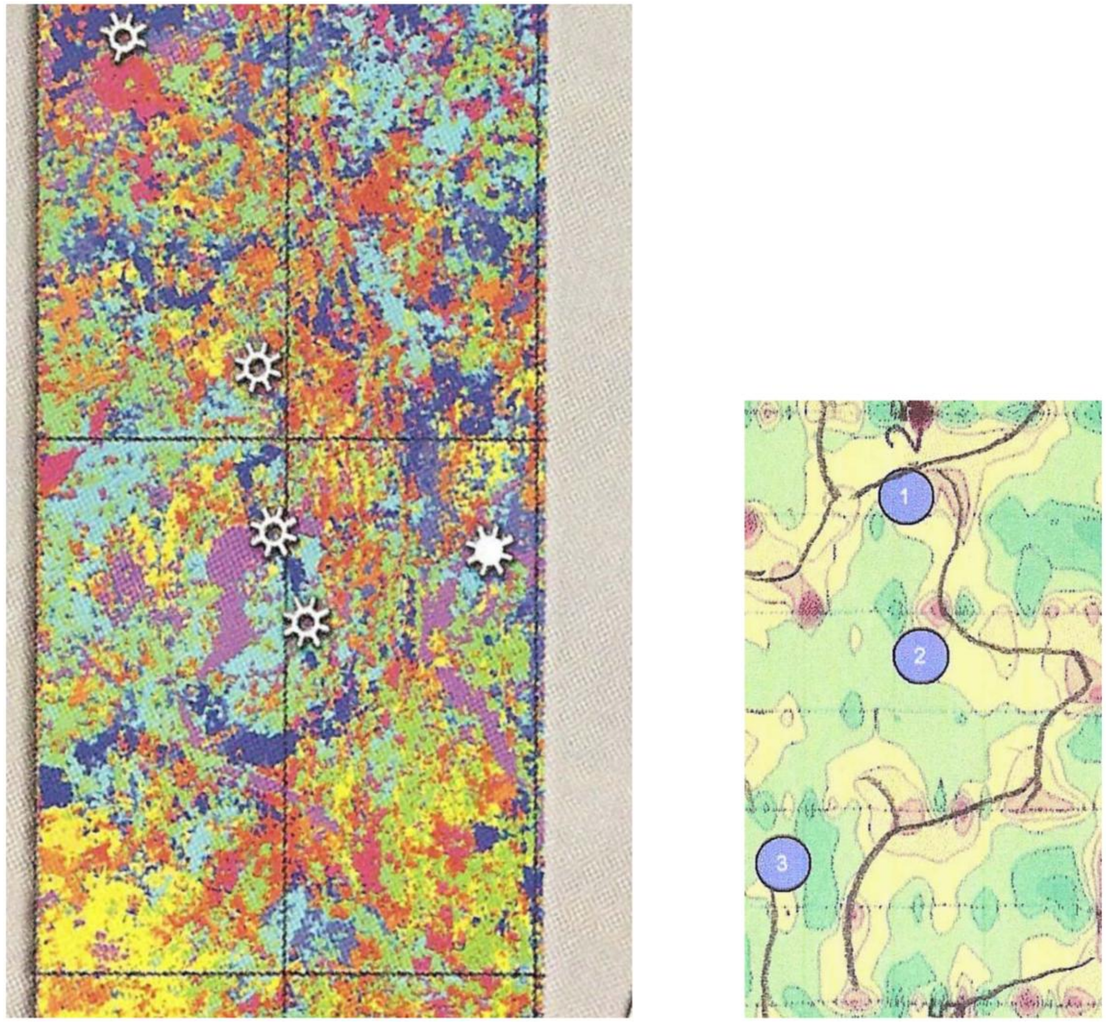


Figure 6. A side-by-side comparison at the same scale is made between the stratigraphic Ibhubesi Field offshore South Africa (as mapped by seismic attributes and other inversion processing of the 312 km survey shown in Figure 5) and a key portion of the nearby onshore Namibia Airborne A-EM Survey. The Ibhubesi Field map shows FDD channel sands and a derived hydrocarbon map based on “seismic attributes”, (Berge et al., 2002). Their map (Figure 7 in their paper), (at Left), is compared with (at Right) the NE corner of the Airborne A-EM map flown nearby over onshore Namibia (Figure 2). This comparison strongly suggests similar FDD reservoir characteristics on both maps. The channel sands on both maps exhibit similar shapes and sizes, and soil samples 1-3 on the Airborne map all suggest oil rather than gas will be encountered upon drilling. Our methodology seems more definitive, more quickly accomplished, and is certainly vastly less expensive than seismic exploration.

Level	Transient pulse frequency range in Hertz	Depth range in meters below the surface
Level 1	2,000 – 2,200	400 – 610
Level 2	1,800 – 2,000	610 – 910
Level 3	1,600 – 1,800	910 – 1,130
Level 4	1,400 – 1,600	1,130 – 1,370
Level 5	1,200 – 1,400	1,370 – 1,580

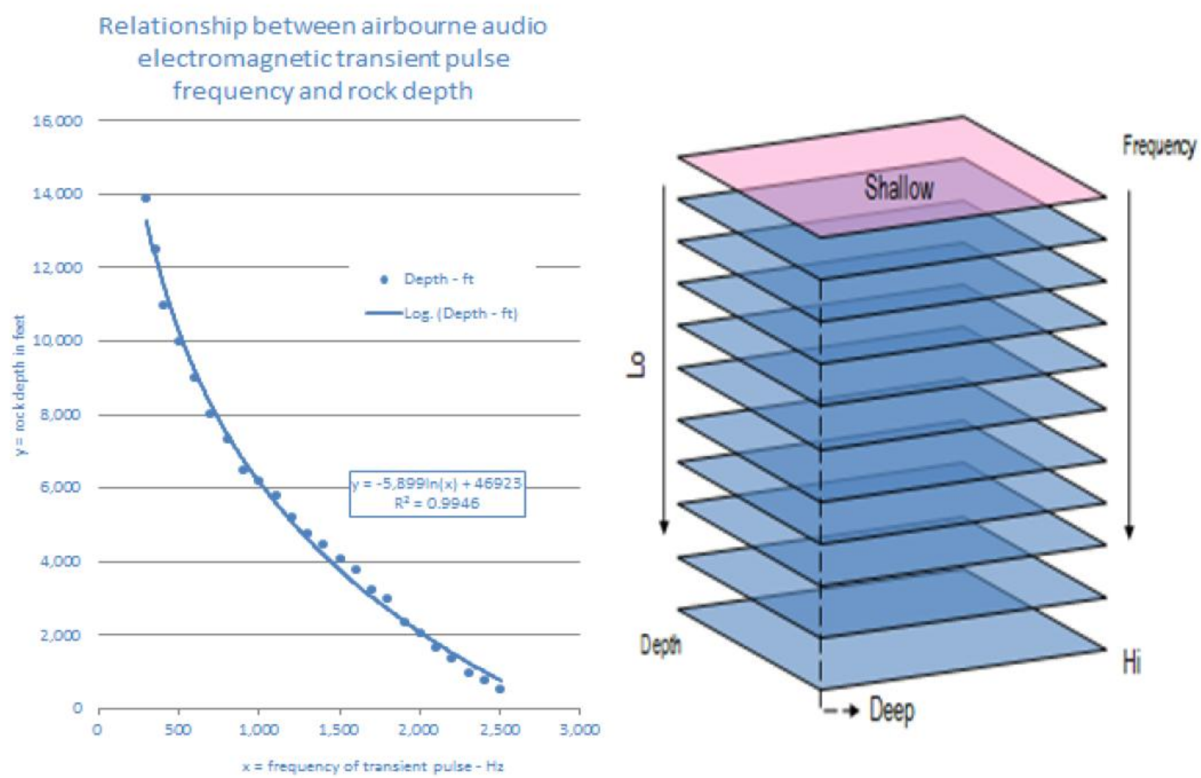


Figure 7. A-EM Survey and Frequency-Depth Calibration, from LeSchack et al., 2011.

Sample	n-Paraffin C2-C4	ECI	% Methane	2-Ring GeoPAC	3-Ring GeoPAC	Total GeoPAC	3-/2-Ring Int Ratio
1	6.4	60.73	82.1%	1541	9457	10998	15.23
2	0.1	45.91	96.0%	569	832	1401	3.63
3	0.2	57.13	94.6%	475	566	1041	2.95
4	0.3	70.08	94.8%	213	149	362	1.74
5	3.3	62.54	81.5%	144	64	207	1.10
6	2.2	61.13	82.4%	375	179	554	1.19
7	9.9	64.68	81.8%	437	340	776	1.93
8	5.9	66.38	84.1%	462	353	815	1.90
9	1.0	60.88	88.0%	158	185	343	2.90
10	0.3	67.18	92.9%	152	124	276	2.03
11	0.3	65.15	92.0%	911	574	1485	1.57
12	0.4	64.24	91.6%	297	307	604	2.56
13	3.5	65.14	84.4%	20369	112797	133165	13.74
14	1.0	69.10	87.6%	12367	65474	77840	13.14
15	6.7	63.92	87.0%	27708	132811	160519	11.90
16	0.9	66.59	88.0%	227	180	406	1.97
17	0.8	65.22	83.9%	230	146	377	1.58
18	5.5	74.11	83.4%	6231	32036	38267	12.76
19	1.0	71.47	90.8%	326	896	1222	6.81
20	7.0	72.31	91.1%	280	655	935	5.81
21	45.0	75.24	91.1%	455	1131	1586	6.17
22	1.3	64.31	89.3%	305	201	506	1.64
23	3.8	71.48	87.6%	502	203	704	1.00
24	13.0	68.86	85.9%	399	185	584	1.15
25	4.4	66.77	85.6%	2387	4162	6549	4.33
26	4.4	64.69	85.1%	358	167	526	1.16

Table 1. Analysis of soil samples collected to evaluate microseeping hydrocarbons over previously mapped Airborne A-EM anomalies. Gas data units are ppmv (parts per million by volume). Fluorescence data units are ppbw (parts per billion by weight).

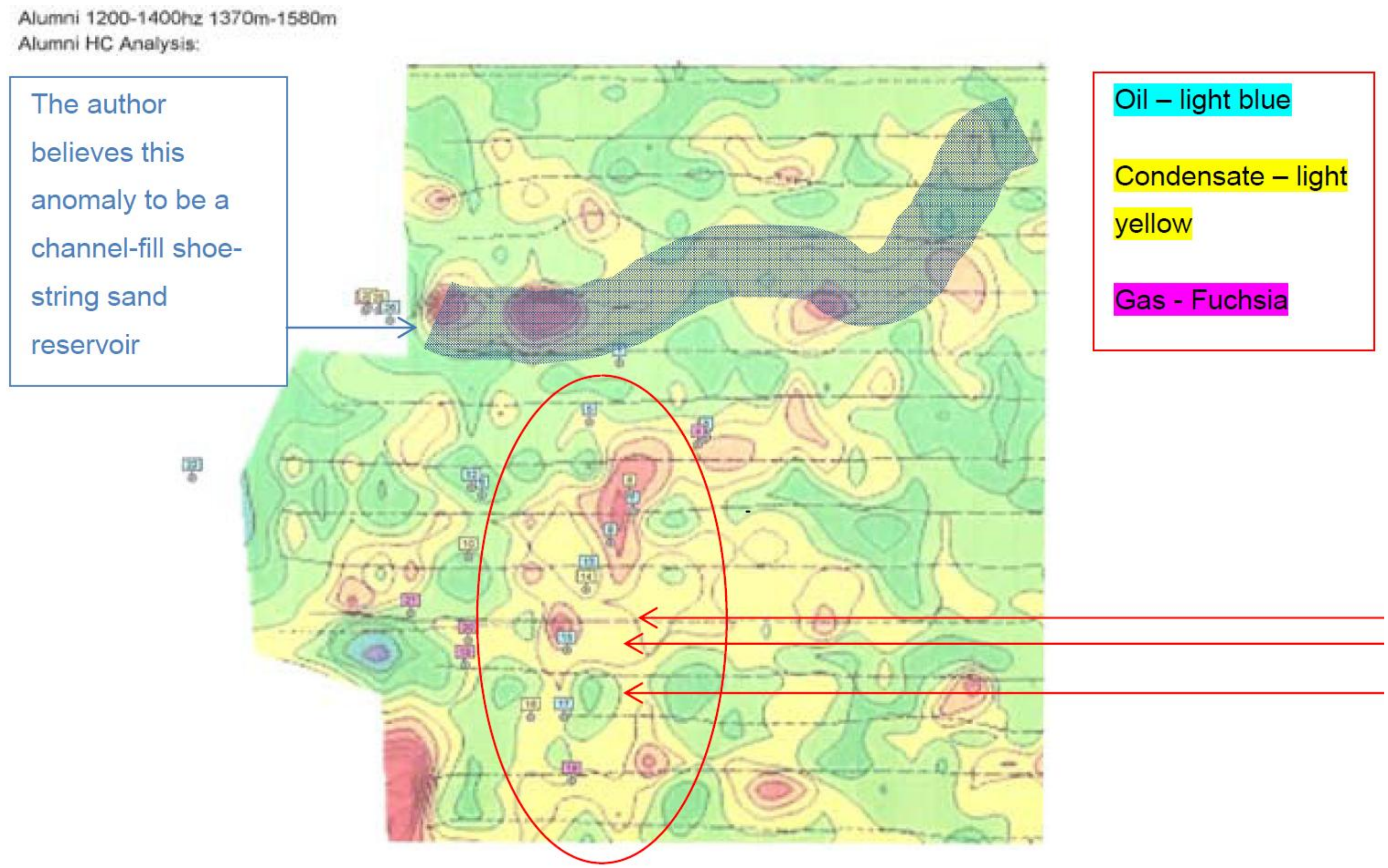


Figure 8. Dr. Rice's conclusions are underlined:

- <u>An oil signature was found in the northern and central parts of the survey</u>
- Nine oil and condensate samples all fall on what appear to be large anomalies formed by channel-fills and of overbank deposits, i.e. that overflowed channel banks, nearly in the center of the map.
- The northern oil anomaly source is likely on the shallower 1400-1600 Hz or 1800-2000 Hz maps.
- <u>High liquid petroleum concentrations in the central part of the sampled area may have been caused by sample contamination due to roadside collection.</u> Note sample 15 with the highest GeoPac score is directly on a small, but intense A-EM anomaly, and Samples 13 and 14 are in close proximity to high A-EM anomalies, suggesting the high GeoPac anomalies result from natural HC seepage, not roadway contamination (See arrow).

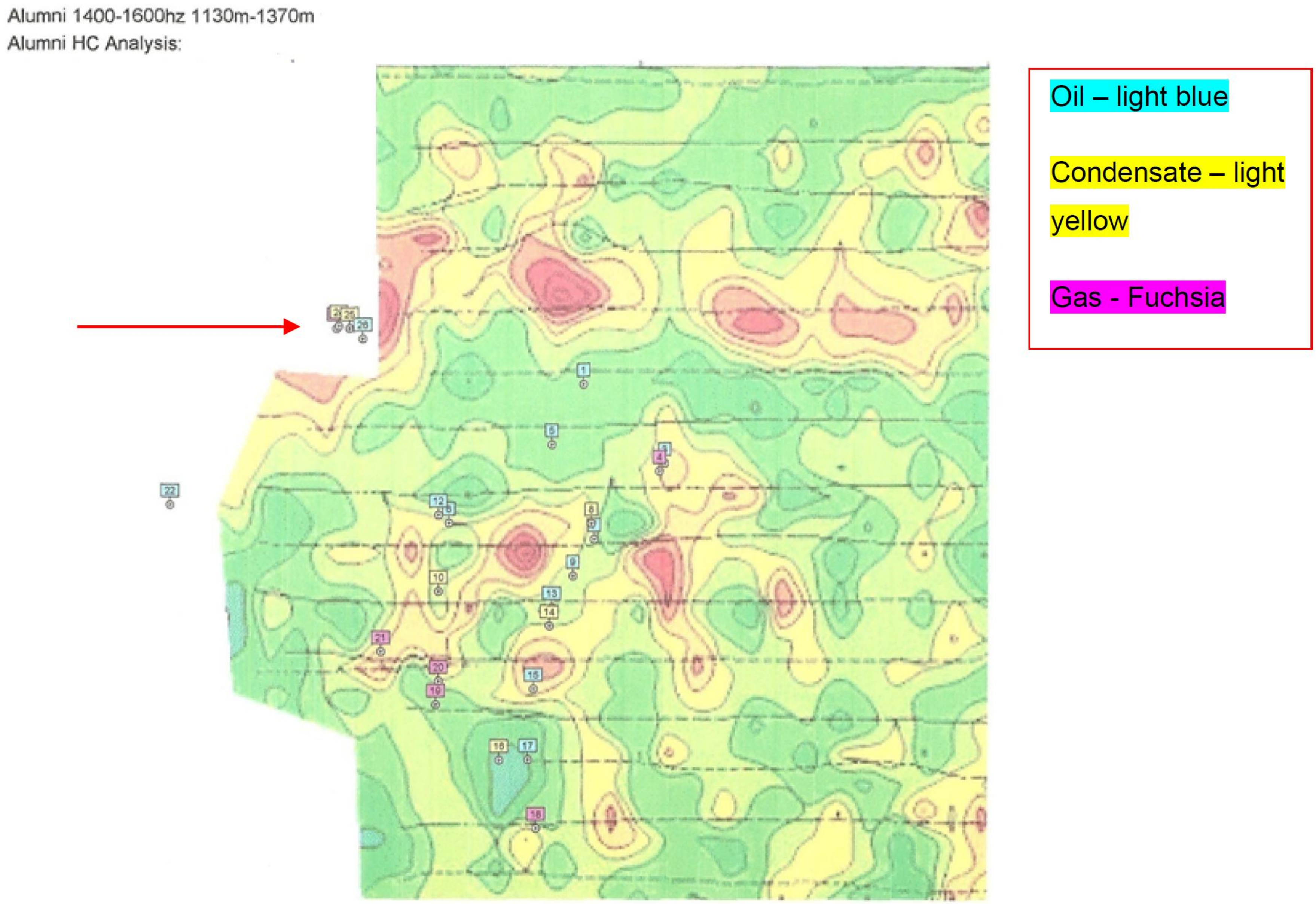


Figure 9. An oil signature was found in the northern part of the survey (red arrow).

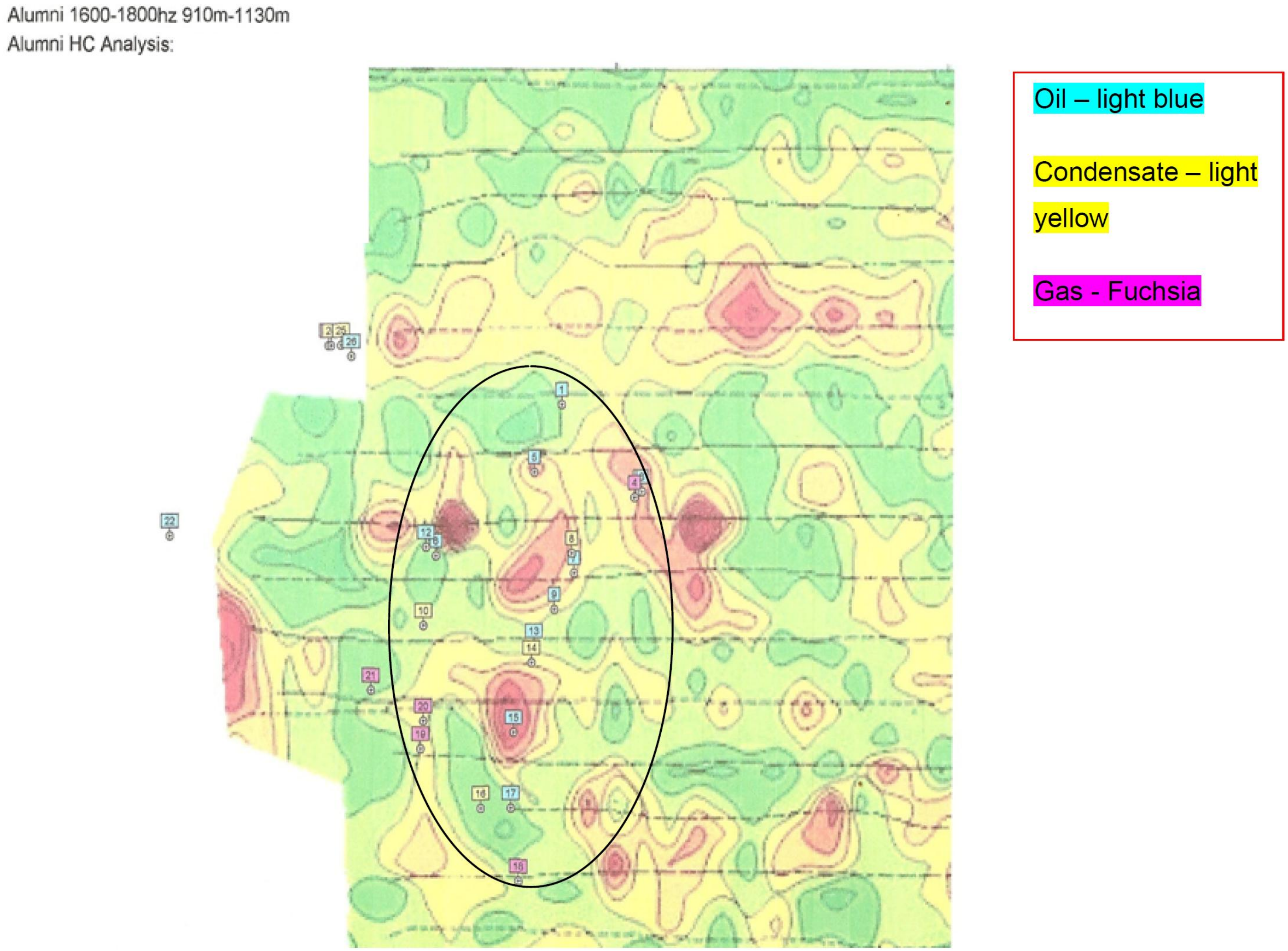


Figure10. Another possible source of the oil and condensate microseepage in the center of the area could also be from 1600-1800 Hz horizon. Here, 12 oil and condensate signatures were observed from possible oxbow shaped reservoirs. On-the-ground Passive Telluric surveys (LeSchack, et al., 2004) could resolve this ambiguity (circled area).

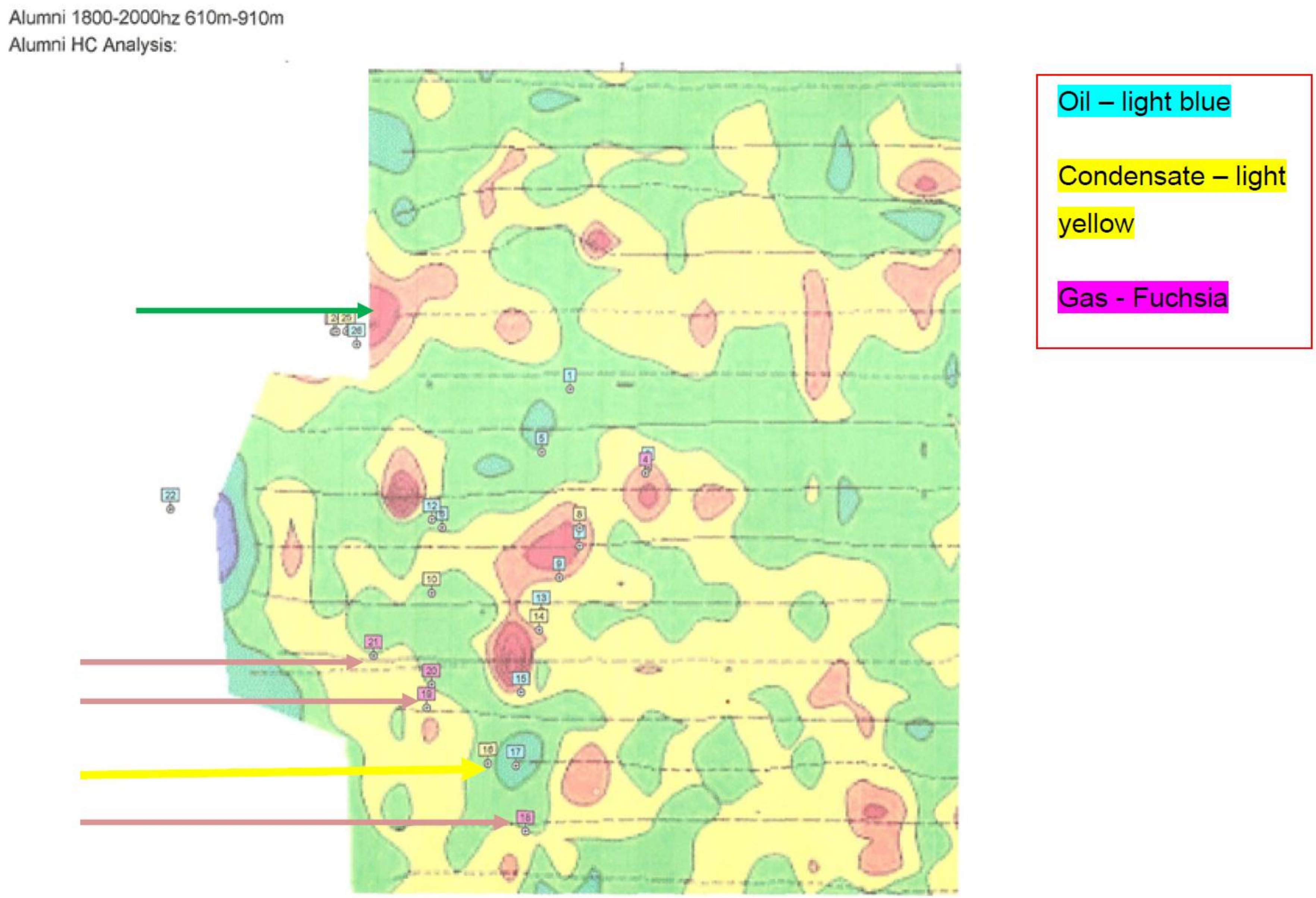
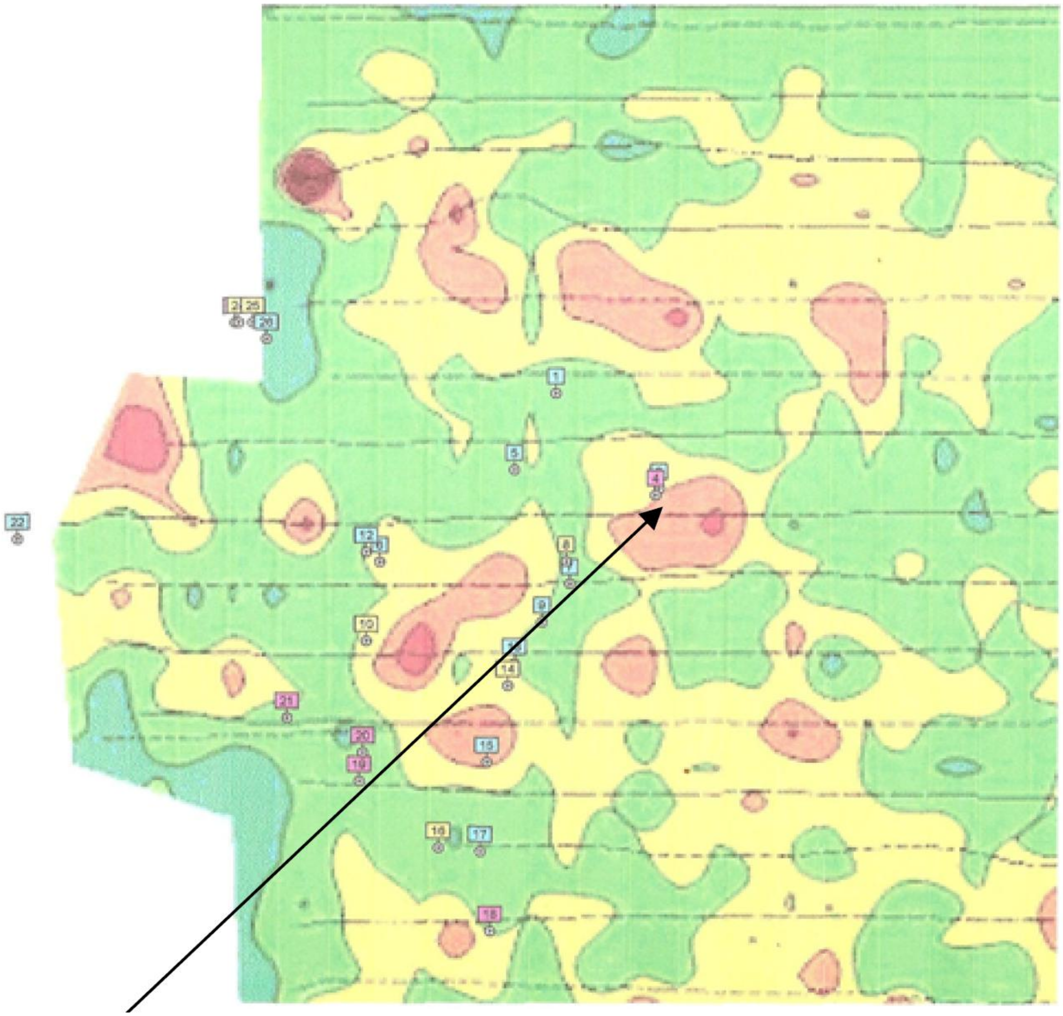


Figure 11. A northern oil signature was found (green arrow). A separate gas (fuscia arrows) or condensate area (yellow arrow) was indicated in the south; this reservoir looks much like a typical FDD overbank deposit.

Alumni 2000-2200hz 400m-610m
Alumni HC Analysis:



Oil – light blue

Condensate – light yellow

Gas - Fuchsia

Figure 12. Only 3 soil anomalies (Points 2, 3, 4) fall on significant A-EM anomalies at this shallow horizon. This, therefore, either may not be a likely productive zone, or it may simply be untested by the soil analyses, for most of the soil samples did not fall on A-EM anomalies at this depth.

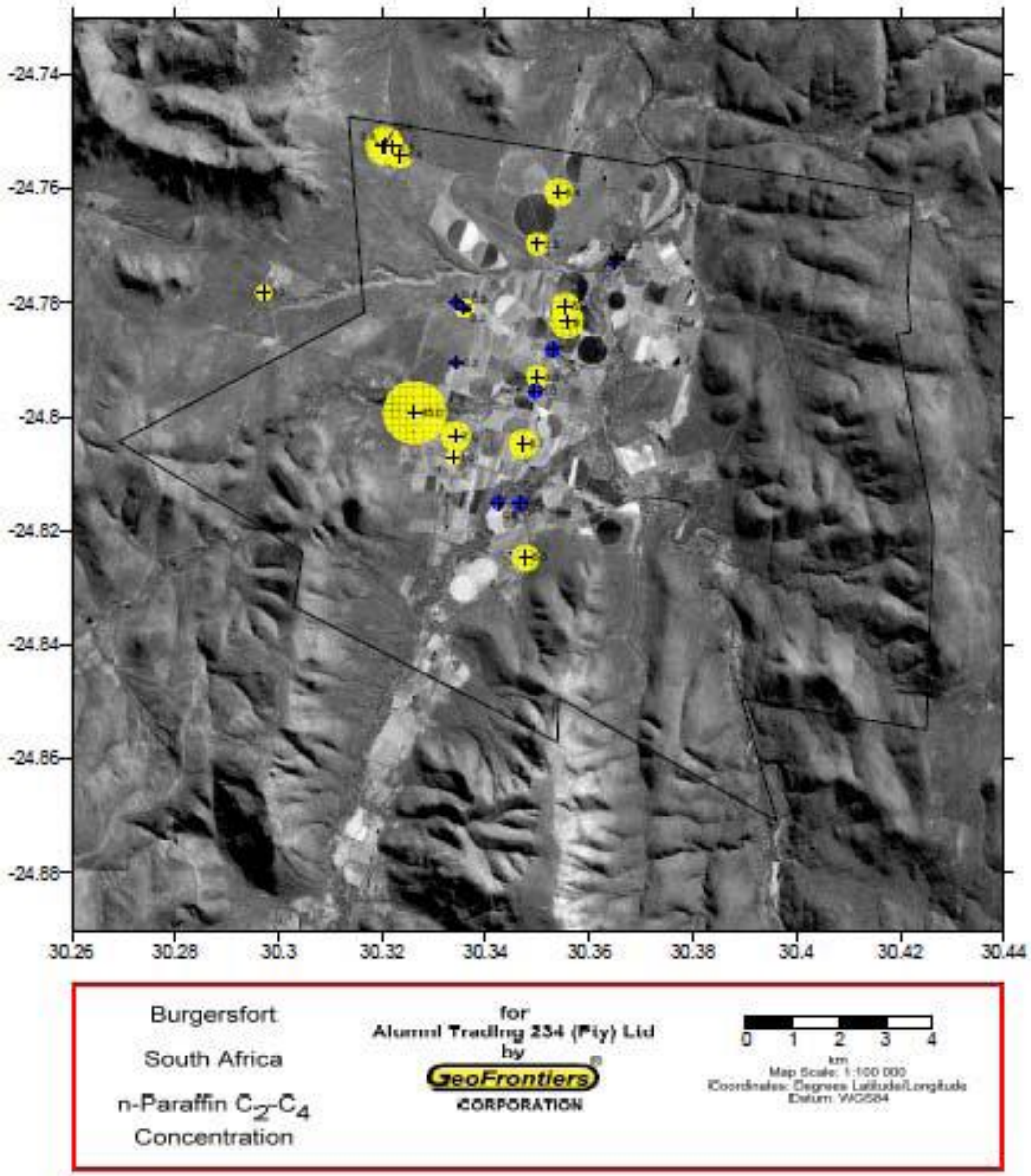


Figure 13. n-Paraffin C_2-C_4 Concentration map in values of ppm by volume. This map is used for identifying concentration trends. Size of yellow dots is proportional to the square root of n-Paraffin C_2-C_4 Concentration.

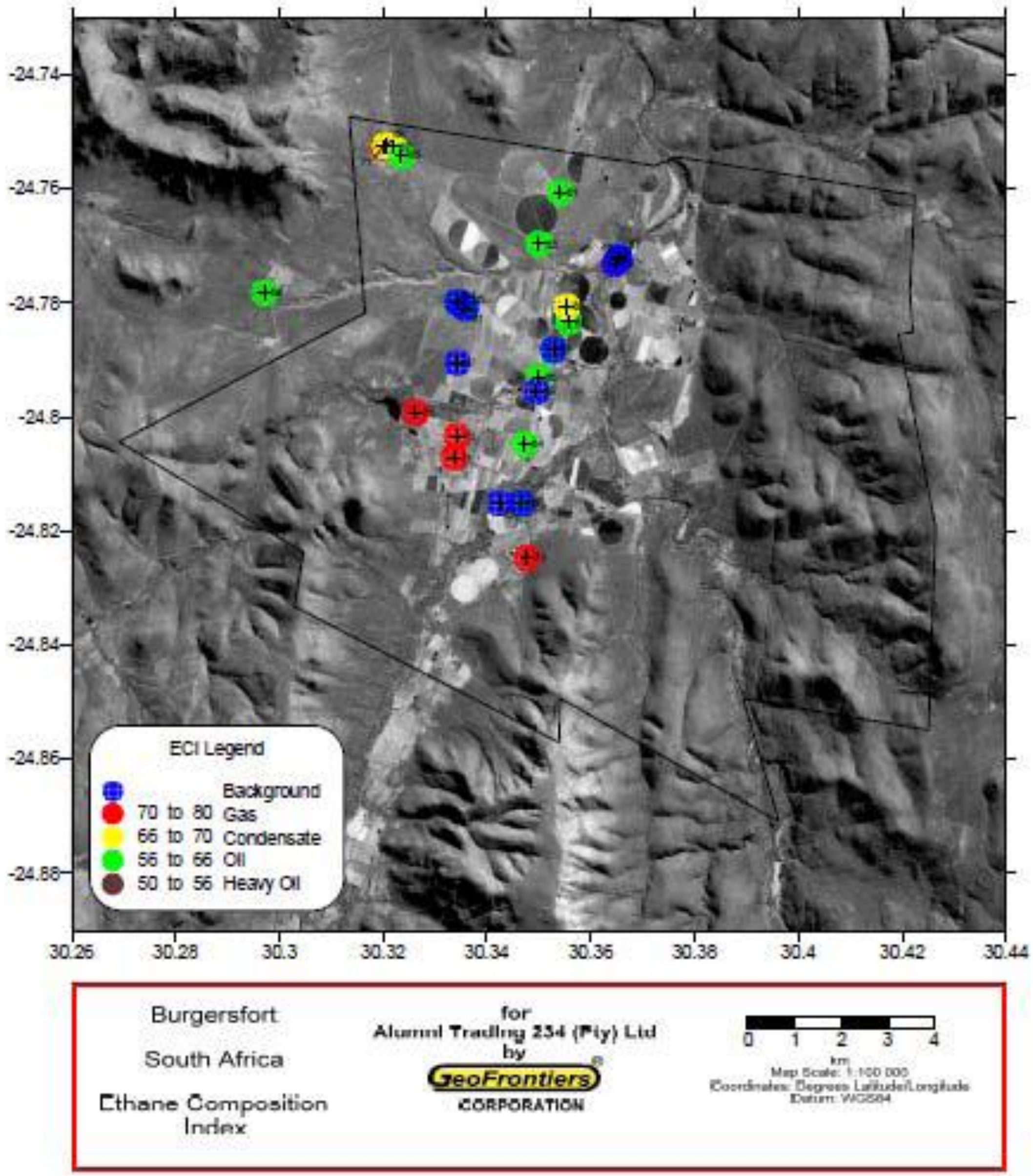


Figure 14. Ethane Composition Index (ECI) map indicates likelihood of oil, condensate, or gas.

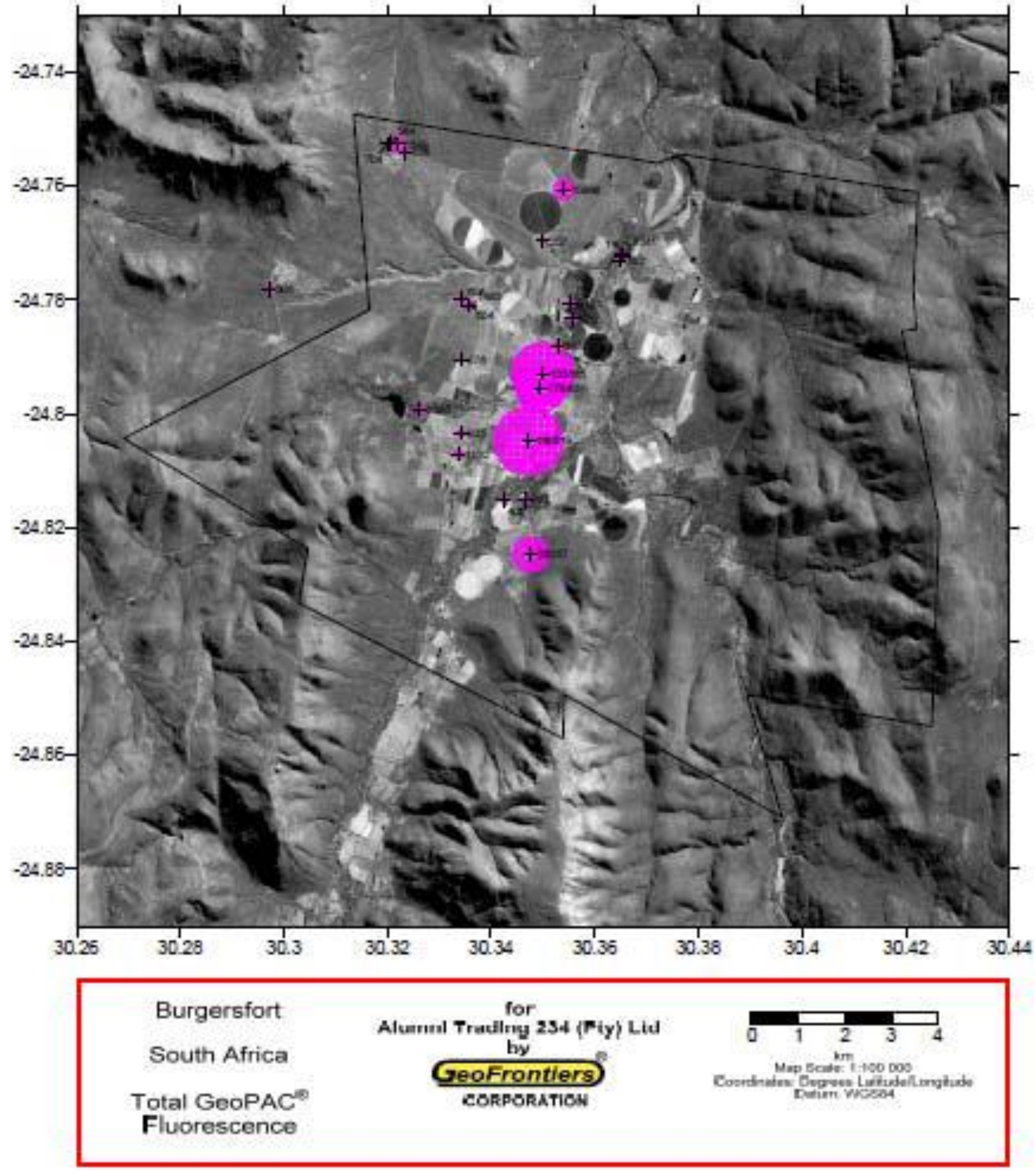


Figure 15. Total GeoPAC Fluorescence shows concentration of 2-ring and 3-ring hydrocarbons that can map larger fractures that allow liquid hydrocarbon migration.