Major Recent Improvements to Airborne Transient Pulse Surveys for Hydrocarbon Exploration

Leonard A. LeSchack, Hectori Inc, Calgary, Alberta, John R. Jackson, Pinemont Technologies Inc, Littleton, CO; James K. Dirstein, Pinemont Technologies Australia Pty. Ltd., Subiaco, WA; William B. Ghazar, Certified Petroleum Geologist, Calgary, Alberta; and Natalya Ionkina, P.Geoph., Calgary, Alberta

INTRODUCTION

Authors LeSchack and Jackson (2006) presented “Airborne Measurement of Transient Pulses Locates Hydrocarbon Reservoirs” at the AAPG Annual Convention, April 9-12, 2006; Houston, Texas. That paper described a reliable, cost-effective, environmentally friendly remote sensing tool for finding oil and gas both onshore and offshore, the P-TEM (Passive Transient Electromagnetic) Survey. Recently, major improvements have been made (1) to automate the efficient collection of these airborne data, as well as (2) now being able to make estimates not only of the reservoirs’ horizontal location, but of the depth at which they would likely be encountered.

Our airborne surveys are based on the following theory: An inherent passive electromagnetic field is present in the earth that can be sensed at the earth’s surface and from low-flying aircraft. Vertical components of this field contain transient random impulses of energy varying across a wide frequency range, including in the audio range. Although speculative, it is widely believed that the impulses are related to a combination of the effects of solar plasmas, lightning activity around the world that produces electronic disturbances called “sprites” and “whistlers,” seismo-electric potentials within the earth, and REDOX cells generated by vertical hydrocarbon microseepage from reservoirs into the surrounding lithology (Boissonnas and Leonardon, 1948; Cummer, 1997; Garcia and Jones, 2002; Labson, etal., 1985; Pirson, 1969; Vozoff, 1972; Ward, 1959).

Although no “unifying theory” has yet to be postulated, empirical evidence points to Airborne Transient Pulse Surveys as being a most valuable reconnaissance exploration tool. Over 130 proprietary Airborne Transient Pulse Surveys have been already flown in Australia, Canada, Europe, Kyrgyzstan, New Zealand and the United States during the past decade, comprising more than 200,000 nautical miles of survey lines over productive areas, both onshore and offshore. Developed in 2001 by author Jackson, and first flown in 2002 over author LeSchack’s Devonian prospects in Alberta, more than 40 productive wells through 2007 have been documented as being drilled where Transient Pulse anomalies were present prior to drilling; only four known non-productive wells have been drilled on positive anomalies. Recent drilling results in central Kentucky in the U.S. using Pinemont’s recently developed A-EM technology (described below) resulted in eight productive wells out of 11 holes drilled (see Appendix for location of most survey areas).

Typical Airborne Transient Pulse Surveys are flown at an altitude of 100m above ground or water surface, and at a speed of about 90 knots. Both light planes and helicopters have been used as survey platforms. The light-weight portable sensing equipment and antenna are carried entirely within the aircraft. It does not matter if the airframe is made of aluminum or not; transient pulse signals are not attenuated either way. Cultural artifacts on the ground, wells, pipelines, utility lines, etc., have no affect on data quality. Flight line spacing is determined by the Operator based on the size of the expected reservoirs. Generally, East-West lines are flown.

The Airborne Transient Pulse Survey technology works not only onshore, but offshore also. Surveys have been flown over offshore areas of New Zealand's Tasman Sea, and North Sea, which was ice covered at the northern extremity of the survey. Ice cover on the water did not appear to affect data quality. The Tasman Sea survey (below) compares the airborne survey map (produced several years earlier) with a recent gas production map of the same area.

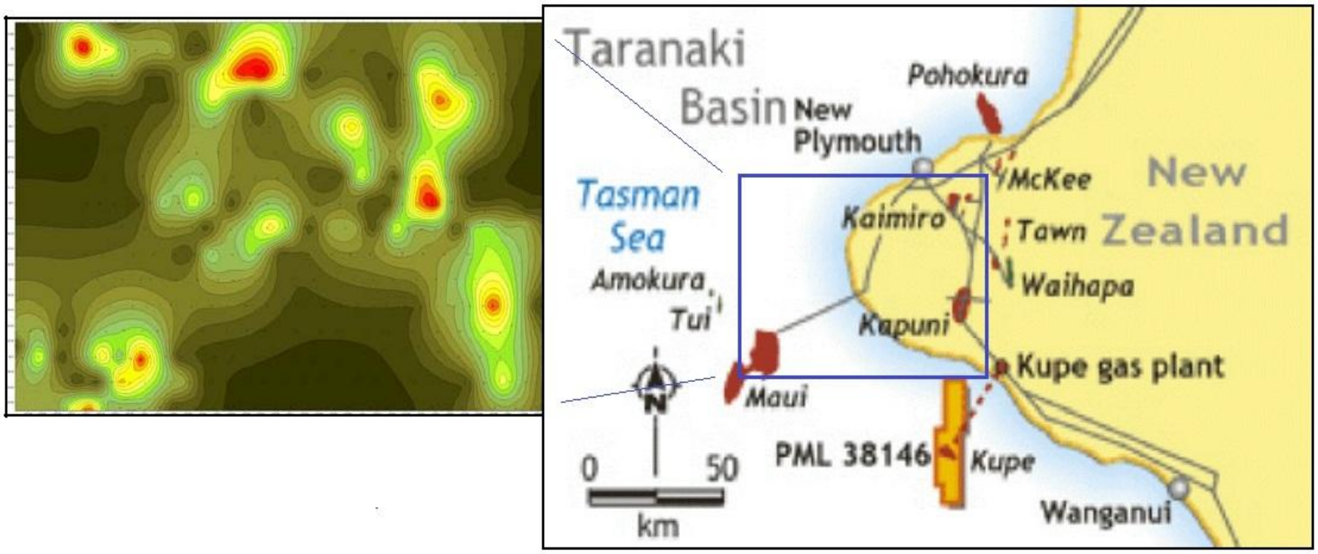


Figure 1: **(Left)** An Airborne Transient Pulse Survey flown southwest of New Plymouth, New Zealand is shown. The west half of the survey was flown offshore. The survey area is approximately 30 by 60 nautical miles. Maui Field, the southwest anomaly on the survey map, has produced over 2.9 TCF of gas and about 225 million barrels of condensate. Several as yet undrilled anomalies can be seen on the western half of the survey area. **(Right)** A production map, courtesy, "oil-price.net", for 17 March 2010.

HOW PREDICTIVE ARE THE AIRBORNE TRANSIENT PULSE SURVEYS?

We estimate that Transient Pulse surveys are better than 80% correct in predicting the likelihood of economic hydrocarbons in the earth below. We should note that this is also the typical exploration success suggested by LeSchack and Schumacher (2002) and Schumacher (2010) for choosing successful prospect drilling locations using those exploration techniques which depend on mircoseeping hydrocarbons, as Airborne Transient Pulse Surveys certainly do. Most of the time knowledge of success or failure of the survey is based on second-hand information. An Operator contracts with Pinemont to fly a proprietary survey over a given area. The survey is flown and the maps are made and presented to the Operator. The Operator does what he wishes with the data. Sometimes the Operator will tell us of his success with the technology. Usually, however, since we know what area was flown for any given survey, we can check the official oilfield records some years later to determine what new wells have been drilled in that area subsequent to flying the Airborne Transient Pulse Survey, and compare our anomaly locations with any new well locations to ascertain what was discovered. Such is what LeSchack and Jackson, (2006) had done to assess success. While arriving at likely success rates in the above manner is certainly encouraging, it is less satisfying than drilling one's own well based on a specific airborne survey. Recently, we had an opportunity to do just that.

In 2002 author Jackson flew his original test survey; it was over the Fenn-Big Valley area of Central Alberta, an area at which author LeSchack had been prospecting, using the methodology of LeSchack etal, (2004). One of the flight lines went over an area that was thought to be prospective for Devonian oil, as specifically discussed in LeSchack and Jackson (2006). Another line deliberately crossed an already known, nearby Leduc Pinnacle Reef/Nisku biostrome oil field, the Gulf-Leland Fenn West oil pool. The airborne transient pulse response was similar for both targets, as seen in Figure 2, below.

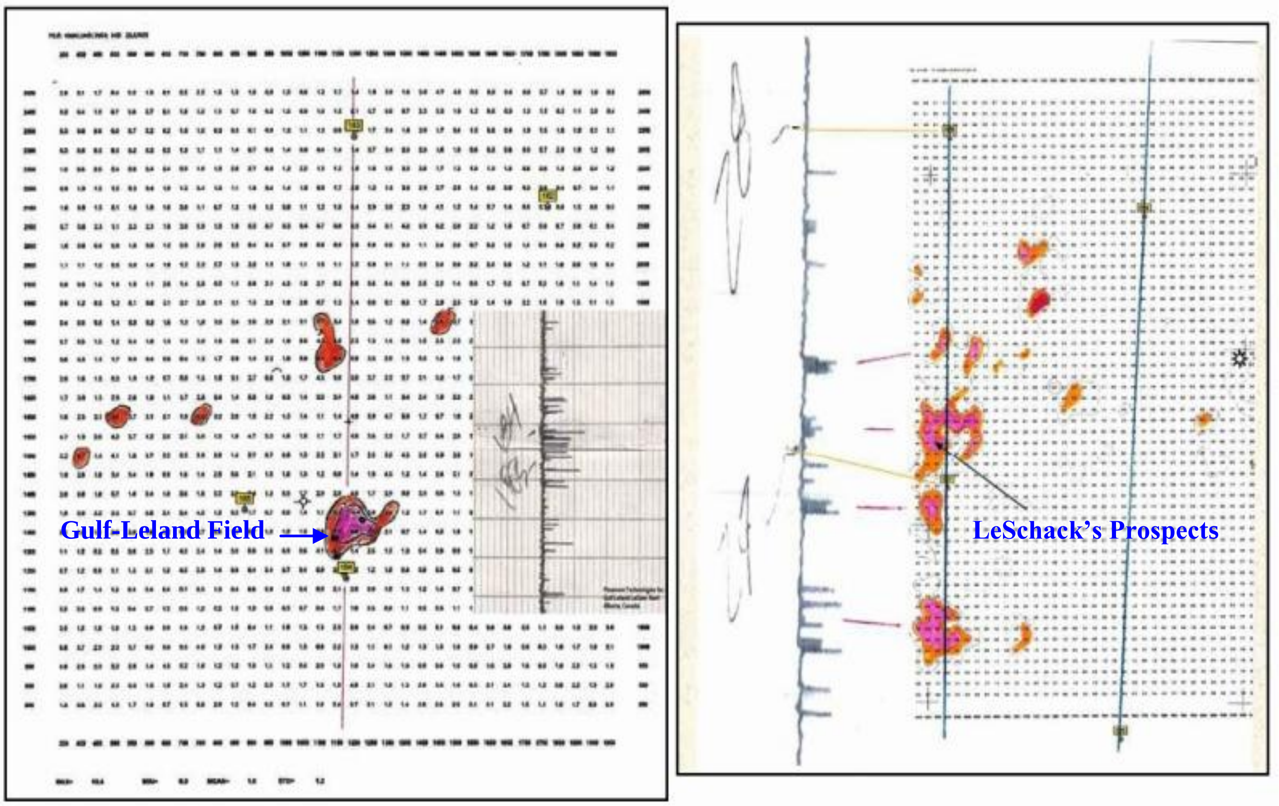


Figure 2: Author Jackson's first airborne survey in 2002 involved recording Transient Pulse data on analog strip-charts. Transient Pulse density can be ascertained by counting the number of excursions to the right of the strip-chart baseline. In 2002 flight lines were positioned with a hand-held GPS (small yellow rectangles on map) with GPS data points entered by hand, and the point number written on the chart every few seconds. Line spacing was about 800m apart. Anomalies (pink and orange), are high resolution ground magnetic (HRGM) HG' anomalies (LeSchack and Van Alstine, 2002). Grid points are 50m apart. **(Left)** This map shows flight line over the 100-m diameter Gulf-Leland Field, on production at time of flight. Three wells (black dots) were drilled and produced a cumulative 750,000 barrels from both the Nisku and Leduc Formations. **(Right)**, This map shows a flight line, that by chance, crosses one of author LeSchack's Devonian prospects. In 2007 an Operator drilled the largest HG' anomaly, as indicated by the black arrow. This location corresponds to a consecutive series of Airborne Transient Pulses on the strip-chart, predicting Devonian oil below. As a result of drilling, an 18m section of Devonian Nisku dolomite was encountered and a swab sample from this zone was analyzed and indicated 33.1 API oil from the Nisku stratigraphic trap.

We would like to say that well was an exploration success. However, as oilmen know, there are all sorts of obstacles to obtaining producing wells, even if an oil reservoir is discovered. In this case, problems with the well, and the Operator's tight budget, resulted in the well not being completed in the productive Nisku zone. Nonetheless, we do have well and mud logs that confirm the presence of oil. Author Ghazar, the independent well-site geologist on this well, observed, in the “Nisku Porosity” zone, oil shows from 1724.5m on his mud-log to 1748m. Author Ionkina, the independent petrophysicist who selected the log suites run, and analyzed the logs thereafter, ran a Magnetic Resonance log, which shows clearly the Nisku oil column. The mud log and the Magnetic Resonance log, for the same depths and at the same scale, are compared in Figure 3 below.

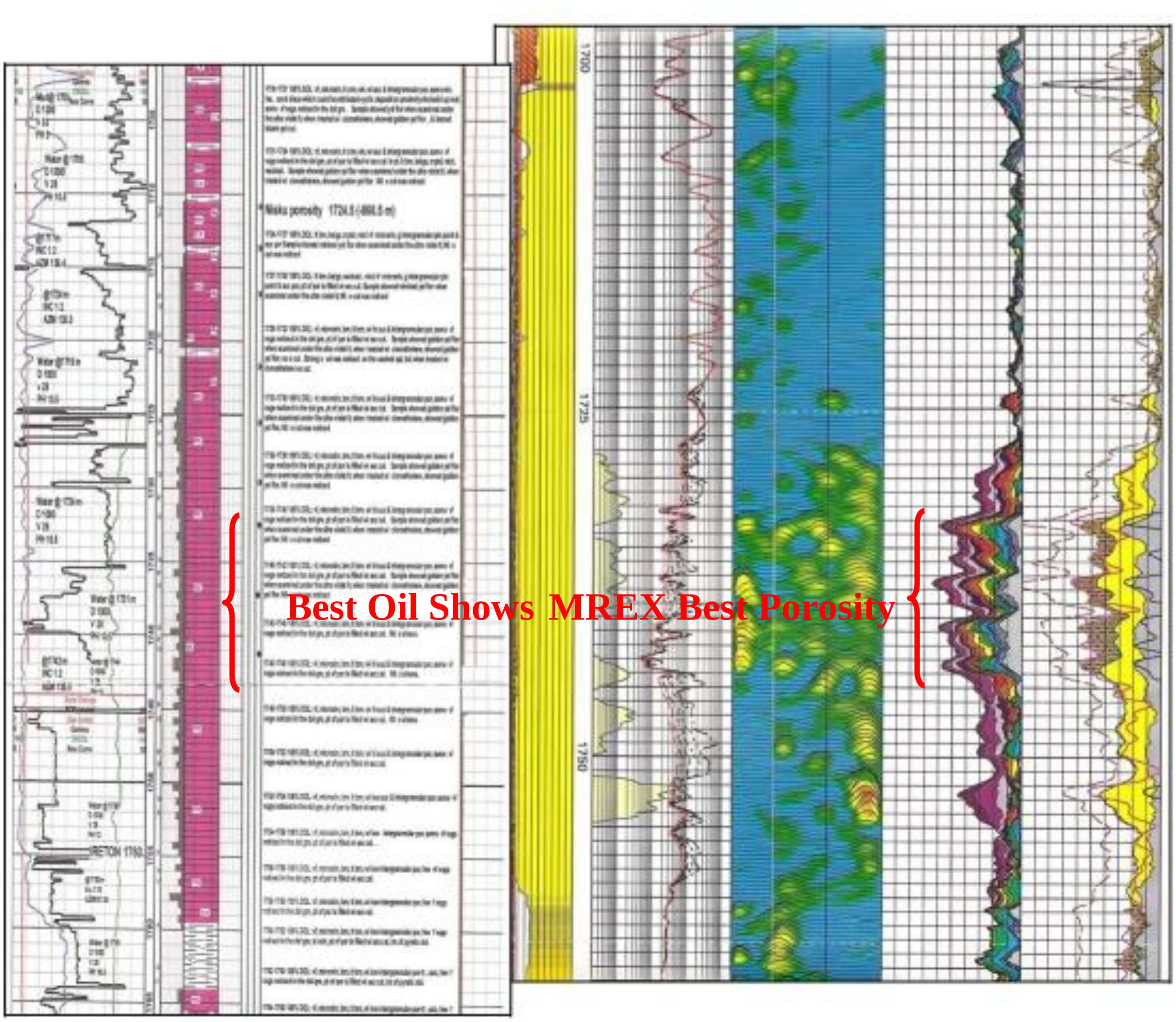


Figure 3: **(Left)** Author Ghazar’s mud log of the above-discussed well is compared with author Ionkina’s MRX Magnetic Resonance Log **(Right)**. On the first MRX track the yellow-shaded area represents a clean dolomite matrix of the Nisku formation. On the second track of the MRX log, the yellow-shaded curve indicates relative permeability. This is confirmed by the separation of Array Induction resistivity curves. On the third MRX track is the T2 spectra image with the thin vertical blue line being the 92ms T2 BVI (Bulk Volume Index) cutoff, showing the indication of oil to the right of the line, while indicating that water is to the left of that line. The Nisku oil column begins at about 1728 MKB and extends to about 1755 MKB. This is represented by the continuous band of magenta-colors on the fourth track of the MRX log. There is effectively about 18m of pay in the column, with an average porosity of 12%. Porosity logs are shown on the last track; (brown) = Neutron porosity, (magenta) = Density porosity dolomite matrix, and the (black curves) = effective and bound fluid porosities. Note on the mud log (at left) that the three significant oil shows (filled-in black circles along center vertical strip), between 1730-1745m, correspond closely with the most significant porosity distribution (magenta-areas) of the MRX log.

Author Ionkina has examined the well logs of the nearby Gulf-Leland Nisku wells, 02-14-35-21W4 (which cumulatively made 100,000 barrels of oil) and 03-14-35-21W4 (which cumulatively made 300,000 barrels of oil), and compared them with the log suite of the well drilled on author Jackson's 2002 Airborne Transient Pulse anomaly shown in Figure 2. Although the log suites of the two Gulf-Leland Nisku wells appear similar in many ways to the logs of our well, there appears to be more water saturation in our well. Nonetheless, author Ionkina believes that if our well had been properly completed, and optimal production rates employed, the well would have been, if not an economic success, at least would have paid itself out. Author Ghazar, with 40 years experience of sitting wells in Canada, agrees.

THE CURRENT AIRBORNE TECHNOLOGY

As opposed to the technology discussed by LeSchack and Jackson (2006), the current technology, which we call Airborne "Audio-Frequency Electromagnetics" or A-EM, records from a low-flying aircraft the earth's passively-generated transient pulses that specifically are associated with REDOX cells (Pirson, 1969). The technology is based in part on technologies discussed by Ward (1959), Kober and Procter-Gregg (1987), Thompson and Gist (1996), and particularly Jackson (1998). A-EM measures from an airborne platform apparent conductivity as a function of depth in the earth. We note that the higher the conductivity of any given horizon, the fewer the number of transient pulses emanating from that horizon, while the lower the conductivity, the greater the number of pulses from that same horizon. Author Jackson empirically derived a continuous, but non-linear function which relates inherent frequency of the pulse energy to the depth beneath the surface from which the pulses emanated.

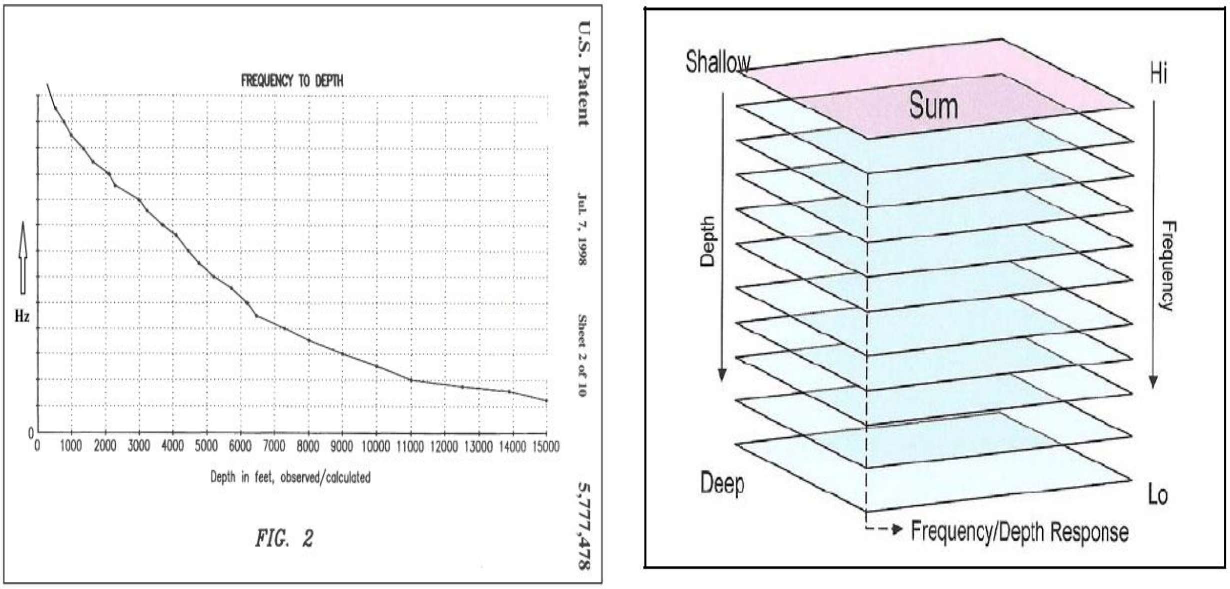
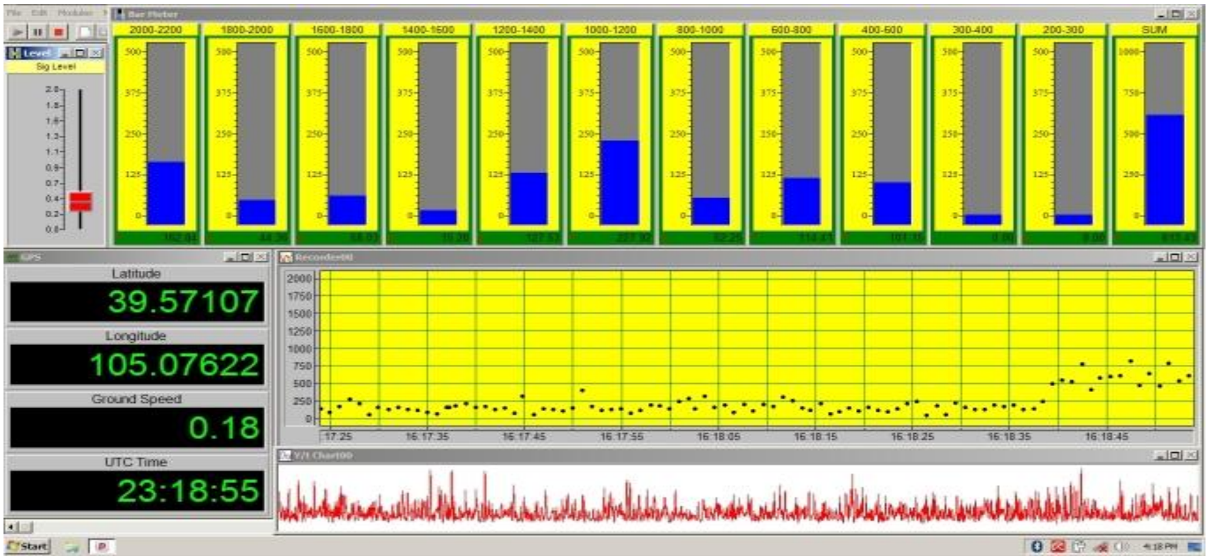


Figure 4: above, shows **(Left)** a "Frequency vs Depth" curve, derived empirically by author Jackson from measurements of frequencies of "passive electromagnetic pulses" observed over numerous hydrocarbon reservoirs at various depths in the United States (No specific "Frequency Axis" values are given since frequency values vs. depth may vary from region to region and the curve should be recalibrated for new exploration provinces). Since the general function derived clearly appears continuous, it follows **(Right)** that if the transient pulses are processed through a series of band-pass filters, the transient pulse data can be parsed into finite depth groupings and be displayed in three dimensions. This is the kernel of our discussed Airborne Transient Pulse A-EM technology. Filters, computer algorithms, and software have been developed to process these depth-related transient pulse data on a laptop computer that can be easily installed in essentially any aircraft.

By combining all of the above-cited research, author Jackson developed an operator-friendly, cost-effective, and fully digital airborne survey tool using compact computer equipment that can easily be placed on any aircraft, including light planes. He developed computer hardware and software that collects the transient-pulse signals using an onboard E-field antenna, then processes these data along with GPS, ground speed and time data, and then segments a frequency spectrum of pulses from 200 hz to 2200 hz (the audio spectrum) into 11 frequency bands. These data are then continually averaged, and dumped into memory every second as in Figure 5 below.



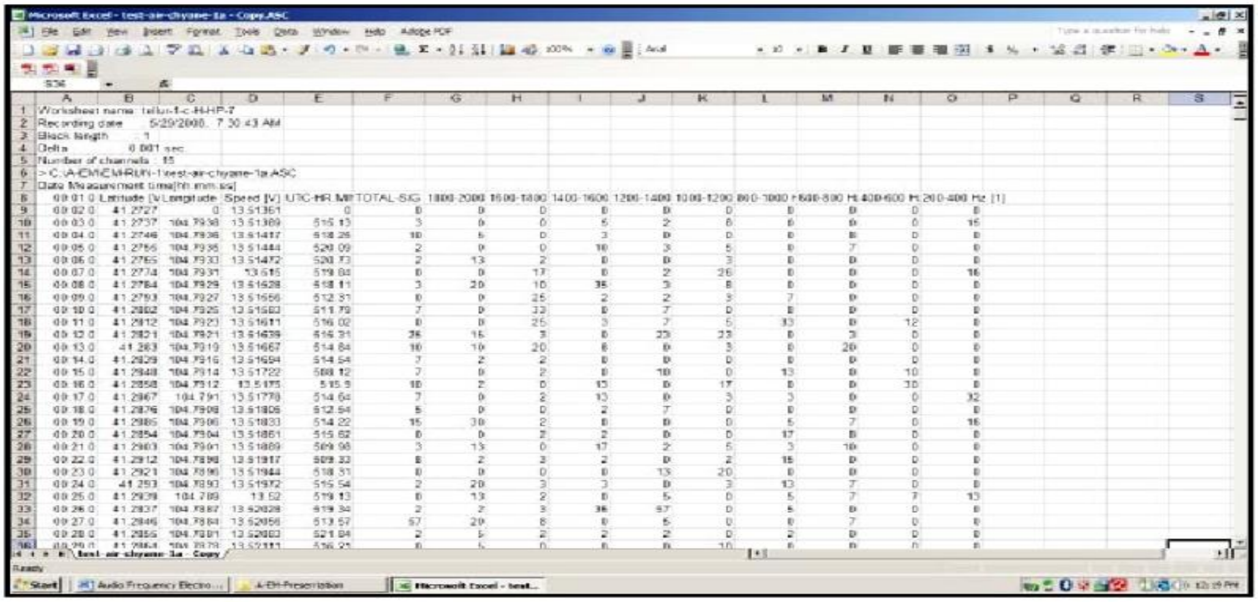
Latitude
39.57107

Longitude
105.07622

Ground Speed
0.18

UTC Time
23:18:55

Figure 5: **(Above)** A photograph of the screen of the onboard computer processing the parsed pulse frequency data into segregated bands, representing discrete depths. The fuller each bin, the more recorded pulses per unit time, the less the conductivity at the depth that that associated bin represents, and therefore, the greater the likelihood of hydrocarbons at the corresponding depth. These pulse data are collected along with Latitude, Longitude, ground speed, and time. The top-right data bin on the screen is the summation of all the preceding bandwidth segments. **(Below)** All of these data are recorded in spreadsheet format as a function of time, for the entire survey, at the conclusion of which appropriate processing for map-making can take place.



An example of such map-making is shown below in Figure 6 illustrating how these frequency-segmented bands of Airborne Transient Pulse Survey data can be interpreted and presented as stacked lithological maps.

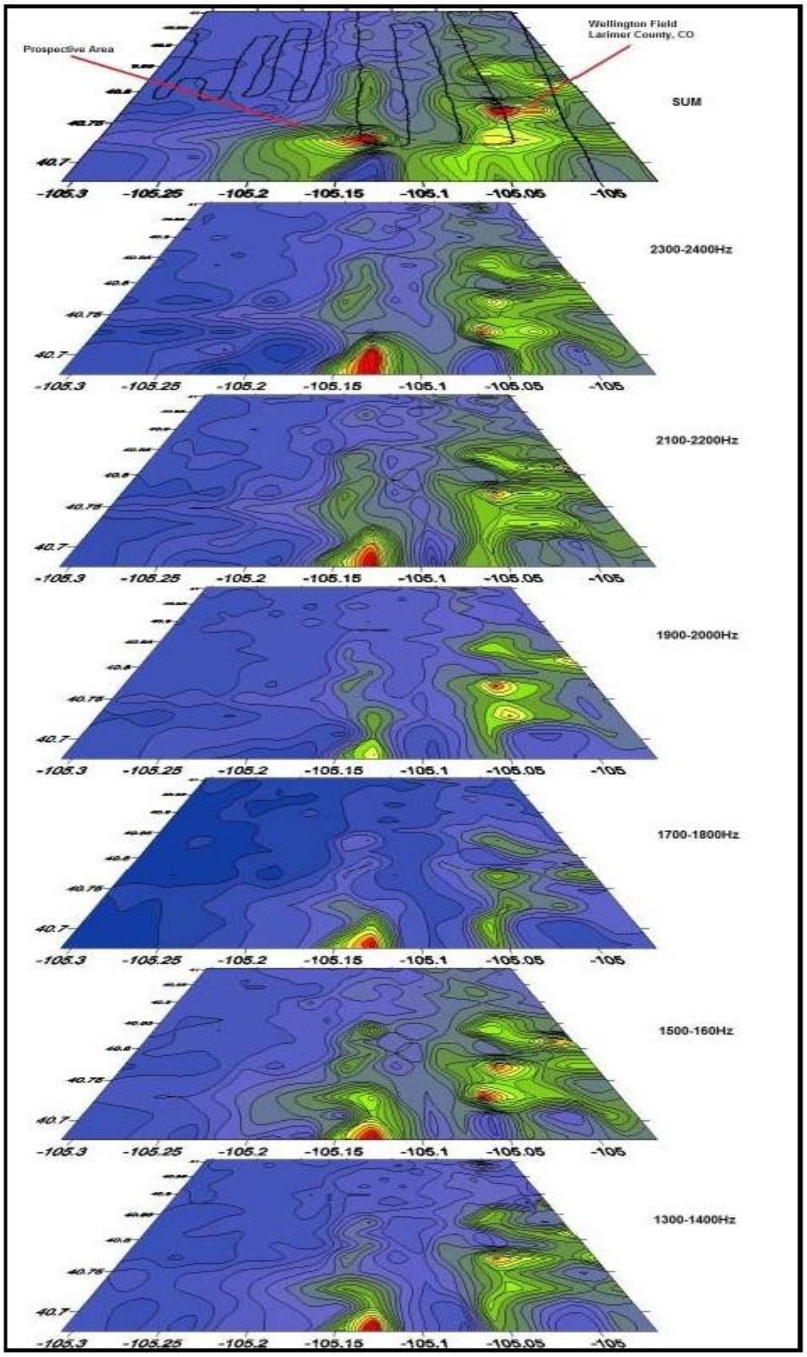


Figure 6: Some Frequency-Depth slices of an A-EM survey flown over an oilfield in Colorado are individually mapped and stacked by frequency/depth, and suggest the producing area for this mature field as being between the bottom two slices, i.e., 1280m and 1370m, from the Frequency-Depth Curve (as calibrated for the United States). The top slice, the Summation of all slices, is at the top. That slice also shows the flight line path, as well as suggesting an as yet undrilled anomaly.

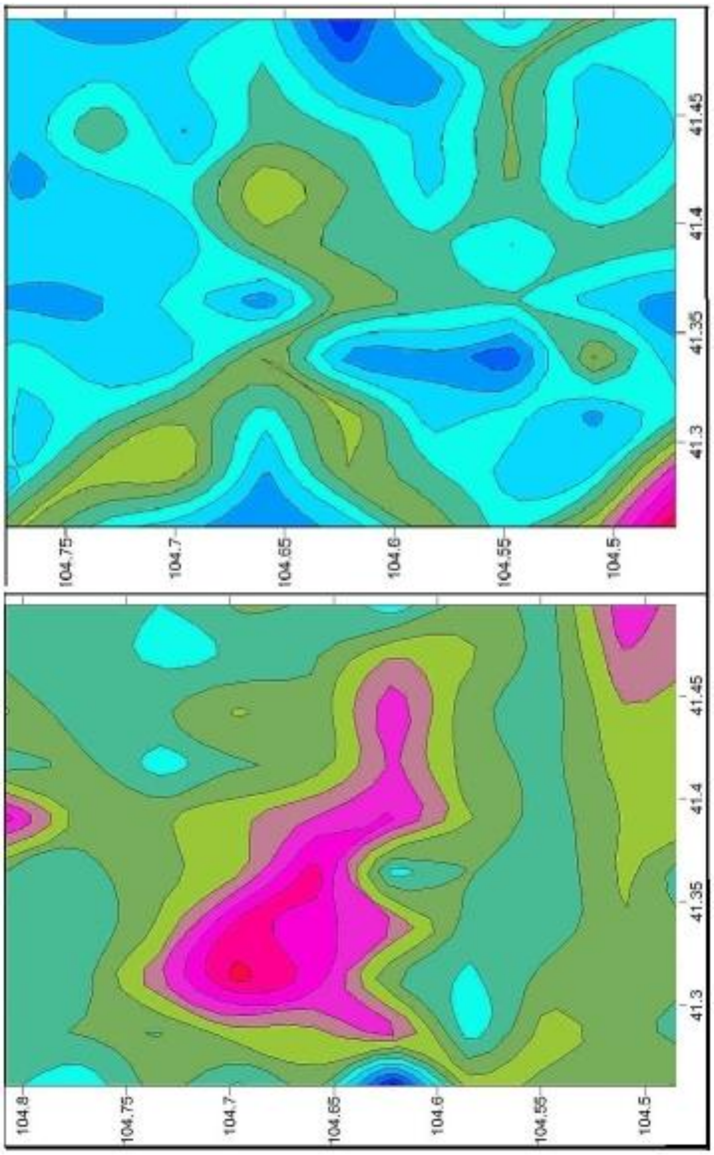


Figure 7: An Airborne A-EM Survey was conducted over the Silo Oil Field in SE Wyoming, producing from the Niobrara Formation. Only two Frequency-Depth slices are shown here: they illustrate the dramatic difference of contour values when hydrocarbons are present (as opposed to where they are not) as differentiated by pulse-frequency parsing. **(Above)** The slice corresponds to the 620m-930m depth and **(Below)**, the slice corresponds to 2230m-2640m depth; this is the producing interval. The contour color scale for both depth-slices is the same. Reds and pinks represent the greatest pulse density, or lowest conductivity, as is expected when hydrocarbons are present.

CONCLUSION

During the past decade over 130 proprietary Airborne Transient Pulse Surveys have been flown worldwide: in Australia, Canada, Europe, Kyrgyzstan, New Zealand, the United States and the North Sea. This comprises more than 200,000 nautical miles of survey lines over productive areas, both onshore and offshore, as well as over ice-covered waters. Both light planes and helicopters have been used as survey platforms. The light-weight portable sensing equipment and antenna are carried entirely within the aircraft. It does not matter if the airframe is made of aluminum or not; transient pulse signals are not attenuated either way. Cultural artifacts on the ground, wells, pipelines, utility lines, etc., have no affect on data quality.

Developed in 2001 and first flown in 2002 in Alberta, more than 40 productive wells through 2007 have been documented as being associated with transient pulse anomalies; only four known non-productive wells were drilled on positive anomalies, **suggesting a success rate exceeding 80% for this survey tool.** Eleven recent wells drilled in Kentucky using the new A-EM technology resulted in eight productive wells and three dry holes. As with all geophysical exploration technologies in which a non-unique solution is developed, independent geological, geophysical and geochemical technologies should be used to assist confirmation, thus improving chances of economic success**.**

Although no "unifying theory" has yet to be postulated, empirical evidence points to Airborne Transient Pulse Surveys as being a most cost-effective and non-invasive reconnaissance exploration tool. Our exploration statistics point to a valuable reconnaissance tool for industry. It should especially be considered by nations desirous of conducting offshore and on land reconnaissance surveys where highly expensive and environmentally disruptive seismic surveys are not feasible.

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APPENDIX

Airborne Transient Pulse Surveys (P-TEM=Yellow Pin, A-EM=Red Pin) flown in North America and Southeast Asia, conducted by Pinemont and its affiliate in Perth, Australia. Typical surveys range from 15 X 15 miles to 40 X 120 miles, averaging 40 x 40 miles. These two maps show locations of most surveys.