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HIGH RESOLUTION AEROMAGNETIC SURVEYS FOR HYDROCARBON EXPLORATION: PROSPECT SCALE INTERPRETATION

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ABSTRACT

Aeromagnetic surveys have become more common to hydrocarbon exploration in recent years. The development of more accurate magnetometers, aircraft positioning, and data processing has led to acquisition of "high resolution" aeromagnetic surveys. These surveys permit resolution of weak magnetic sources within the sedimentary section and a more complete analysis of magnetic sources within the crystalline rocks beneath the sedimentary basins. The modern high resolution data are more robust than earlier data, which supports greater processing flexibility and analyses with tools such as the Fourier transform. Analysis of data using the association of wavelength to depth-to-source provides several alternate data presentations that improve structure interpretations.

Three aeromagnetic survey data sets from Alberta demonstrate the improved interpretation provided by high resolution aeromagnetic surveys. Structural elements of the basin, in particular faults, can be resolved much better with high resolution aeromagnetic data.

INTRODUCTION

Aeromagnetic data have long been used by the petroleum industry to map structure in and to estimate depth to magnetic basement (Steenland, 1965). In the 1960s, computers began to be used for processing and interpreting geophysical data. One application that became popular was estimation of depth to basement from potential field data, particularly aeromagnetic data (Spector and Grant, 1970). The second application, that of mapping basement structure, was not automated and was used by a dwindling number of practitioners (Gay and Bronson, 1991). In fact, practitioners of potential field geophysics became a rarity in petroleum exploration. A brief, renewed interest was stimulated by the "Donovan" anomalies (Donovan et al., 1979). Shallow magnetic anomalies were described over oil fields and were interpreted to be produced by seepage and alteration above oil reservoirs. No consistent, predictable relationship between seepage processes and magnetic anomalies has been demonstrated, so the flying of aeromagnetic surveys to detect them became uncommon. The seepage phenomenon is still a focus of research and debate (AAPG Hedberg Conference, 1994; Gay, 1994).

However, over the same period the petroleum industry was acquiring less aeromagnetic data, advances were being made in the acquisition, processing and interpretation of aeromagnetic data. The method was widely applied to the exploration for minerals and geothermal resources. The method was "re-discovered" by the petroleum industry in the early 1990s. It has been demonstrated in contractor presentations, the literature and other forums that high resolution aeromagnetic data provide valuable data to solve petroleum exploration problems. High resolution aeromagnetic data for petroleum exploration are commonly defined as data collected at a flight line spacing of 800 metres or less, at flight heights of 150 metres or less, at 15 metres or less sample spacing along the flight lines and at better than 0.1 nT accuracy. This definition is necessary since these parameters would not describe a high resolution mineral survey.

Most aeromagnetic surveys flown for petroleum exploration prior to 1992 were intended to map magnetic crystalline rocks that were known to be buried several kilometres below "non-magnetic" sedimentary rocks. Therefore, the surveys were flown at a ground clearance designed to eliminate or minimize signal from surface features and at a line spacing adequate to sample any deep source adequately, which may be a line spacing equal to one-half the depth to the sources (Reid, 1980). The recent application of aeromagnetic data to petroleum exploration uses a much different survey design. It can be demonstrated that surface features contain valuable exploration data and the line spacing and terrain clearance must be small enough to properly map these features. Also, high resolution surveys enhance delineation of both subtle basement features and intrasedimentary sources. The traditional, wider spaced data obtained at higher altitudes may contain spatial aliasing. These data could contain surface and shallow intrasedimentary signals, but are under sampled. Also, they may not adequately sample the deeper sourced anomalies, particularly where sources have multiple strike directions.

EXPLORATION EXAMPLES

Three data sets will be used to illustrate that it is important to obtain high resolution aeromagnetic data, particularly for prospect scale interpretation.

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Fig. 1(a). Horizontal gradient of the total magnetic field from the GSC Cypress Hills data. Township overlay for scale.

Fig. 1 (b). First vertical derivative of total field magnetics, GSC Cypress Hill data. Township overlay for scale.

Fig. 2. Pseudo-depth Slice 1 showing comparison of older (unmarked) and modern drainage systems (green) – World Geoscience Rainbow Zama survey.

The first example is the Geological Survey of Canada's Cypress Hills survey from southern Alberta. The survey was flown at an 800 by 5000 metre line spacing and a 150 metre flight height. These data have been discussed widely in recent years and are the data chosen for study in many of the CSEG HRAM Forum papers.

Brown et al. (1994) noted that Tertiary dikes in the North Sea went unrecognized for years since there were no good magnetic data available. Once the magnetic data were collected and studied, it was concluded that one of the serious velocity problems with the seismic data could be attributed to the Tertiary dikes. The Cypress Hills data also reveal shallow dikes and demonstrate that the Eocene extensional event well known in Montana and further west in British Columbia affected southern Alberta (Ross et al., 1994). There is no published evidence the dikes have controlled hydrocarbon migration and trapping. However, it is clear that an Eocene tectonic event affected southern Alberta and this would be at a time of great importance to oil migration. A copy of the horizontal gradient and first vertical derivative of these data are shown in Figure 1. By convention, in all figures, red colours are high values and blue colours are low values. Shallow to outcropping magnetic sources within the area covered by the data shown in Figure 1 are dikes. The dike magnetic signatures are the long, linear short wavelength anomalies trending northwest. The most obvious dike is located in the second township from the right at the top of the map in Figure 1. The rectangular grid is township borders and one can easily see that the dike swarms cover several sections of land in a number of townships. Therefore, the dikes should be an important consideration to prospecting in any of these areas. The larger scale magnetic highs and lows are due to magnetic sources in the Precambrian rocks beneath the sedimentary rocks.

Both derivative maps delineate the northwest trending dikes, particularly in the northeast part of the area shown in Figure 1. A prominent dike, traversing the cluster of magnetic highs in the east central part the map, appears to follow an older, basement fault. The southwestern anomaly in the cluster of highs is offset, as is a magnetic high to the northwest, also transected by this dike. Both offsets are indicative of a basement fault. This observation suggests that, with an Eocene dike spatially located with an older fault, the fault is probably reactivated.

The high frequency, hence shallow, curvilinear north south trending anomalies along the western edge of the data shown in Figure 1, are either another set of dikes or a series of faults associated with the Laramide thrust belt.

The second example is World Geoscience's Rainbow Zama high resolution aeromagnetic survey. The survey was flown at a 400 by 1200 line spacing. Psuedo-depth Slice* 1 of the total magnetic field for a small part of the survey, about six townships in area, is shown in Figure 2. Psuedo-depth Slice 1 contains wavelengths representing the shallowest

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*Trade Mark of World Geosciences

Fig. 3. Pseudo-depth Slice 2 with Interpreted Faults. Manning, Alberta. A few magnetic units highlighted in dashed white lines to show offset or truncation on faults

sourced features, surface and near surface sources, in the data. The dominant north-east striking magnetic anomaly is the well known Hay River Fault/Great Slave Lake Shear Zone (GSLSZ). Note the magnetic high just west of the word "modern" in Figure 2. Seismic data (not shown) over this anomaly indicates that it is a structural high. Not all magnetic highs are structural highs.

Also evident in the data in Figure 2 are various high frequency anomaly trends that can be interpreted as drainage patterns. The modern drainage (green lines in Fig. 2) is overlain for reference. It is very evident that the modern drainage reoccupies only a small portion of an older drainage system that is also obvious in the data. The older drainage is either on the pre-Pleistocene surface or imbedded in the Cretaceous subcrop. The Bad Heart Formation, for example, is known to contain significant amounts of iron oxides and subcrops in the region, (Green and Melon, 1962). If channels cut the magnetic surface and magnetic material is removed, the channels would give rise to the image seen in the data. The modern drainage simply positions weakly magnetic sediments against air in the channels, which is all that is necessary to produce the anomalous patterns. Note again the magnetic high just west of the word "modern" in Figure 2. Both drainage systems either divert around or drain from this magnetic high indicating this location to be a long lived structural high. However, the two drainage systems suggest that the axis of the high may have migrated westward over time. If the older drainage system is mid-Cretaceous in age, this shift has some implications for change with time of hydrocarbon migration pathways and trapping.

Note that the coherency of the anomalous pattern associated with the drainage systems would not be as coherent if gridded and contoured from more widely spaced data. Also, if the survey were flown at a wider spacing and at a few hundred metres greater height, some of these surface, drainage anomalies would have been severely under sampled and would have generated data with serious spatial aliasing. With these surface features properly sampled, it is a straight forward process to filter them out of the data in order to study sources from greater depths.

The third and final example is from an area near Manning, Alberta. A proprietary, test survey to obtain high resolution aeromagnetic data over an area of 12 townships was flown for Chevron Canada Resources by World Geoscience in 1993. The survey was flown at a 400 by 1200 metre line spacing and a 100 metre terrain clearance. The area was chosen because of a Gilwood discovery made by Chevron in 1989. The reservoir is perched on an early-developed horst block oriented in a north-northwest direction, just north of

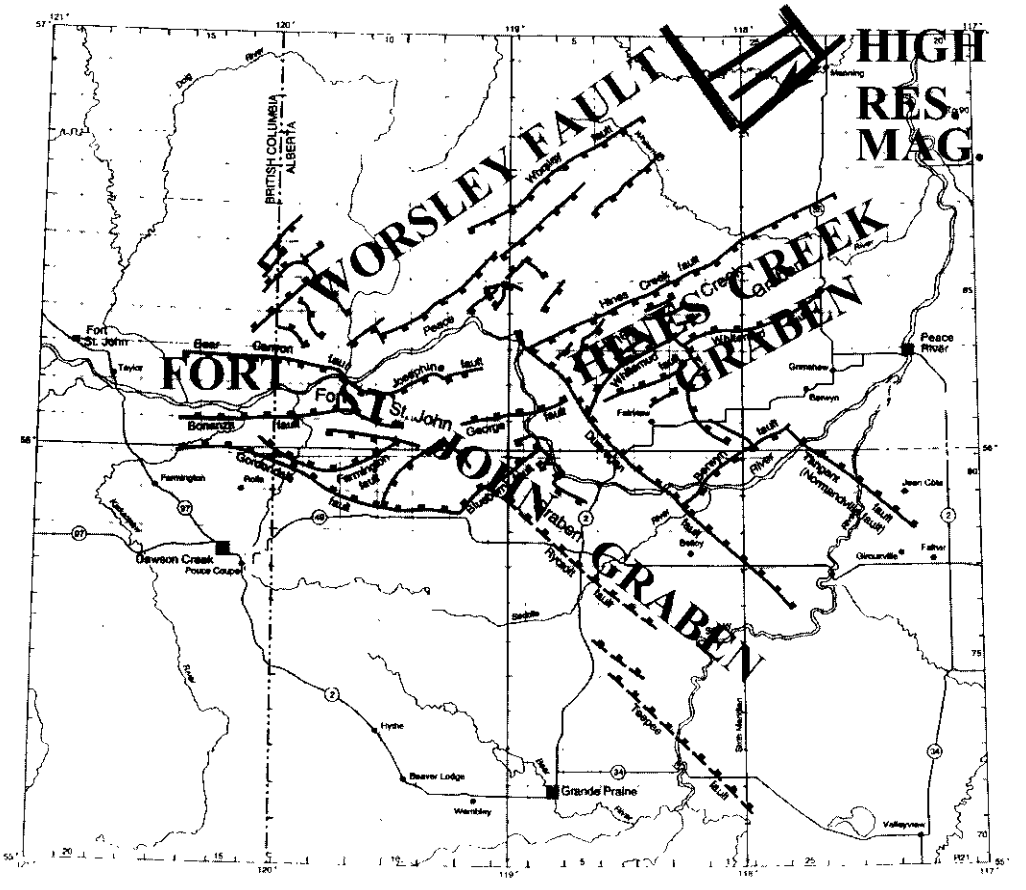

Fig. 4. Interpreted faults from aeromagnetic data project along strike from mapped faults (Richards et al., 1994, Geological Atlas of WCSB, p. 223)

the east end of the Peace River Arch. The Mississippian collapse of the Peace River Arch and development of the Fort St. John graben system later affected the area.

As with most exploration, several kinds of data are integrated to develop the geologic model for the area. Here, the aeromagnetic data were integrated with geologic, seismic and Landsat data to interpret faults (Glenn, 1997). Figure 3 shows the Pseudo-depth Slice 2 rendering of the aeromagnetic data. Pseudo-depth Slice 2 inlcudes signals from magnetic sources from surface to the Precambrian in the area, about 2200 to 2500 metres depth. Three interpreted fault traces are located on the map. Dashed white lines are sketched along selected magnetic features to indicate either offset or truncation of magnetic units used to identify the fault locations. The two longer fault traces are also sketched within the outline of the high resolution aeromagnetic survey area shown in Figure 4. The more northern of the two faults can be traced to the Worsley fault, part of the Fort St. John Graben system, Figure 4. This interpreted extension of the Worsely fault is important to prospects along strike. The fault can be associated with reservoir properties, hydrocarbon migration and hydrocarbon trapping. The location of the fault had significance to the southeastern limits of the oil reservoir. The fault vertical offset was less than either the aeromagnetic or seismic data resolution. The ability to link it to the Worsely Fault gave an indication of the likely up and down thrown sides of the fault, thereby giving an assessment of risk to drilling further southeast.

CONCLUSIONS

The high resolution regional Cypress Hills and Rainbow Zama surveys both show magnetic sources within the sedimentary section. These sources are not evident in older data. The Eocene dikes of southern Alberta support an extensional tectonic event at the time of hydrocarbon generation and migration. The change in drainage systems depicted in the Rainbow Zama data can be interpreted in terms of a changing regional tilt in the basin. This change has implications to hydrocarbon migration and trapping.

The faults interpreted in the Manning survey were not defined in older data in Chevron's files. The older data were obtained at about a 3 km line spacing and 300 to 400 metre-flight height. In contrast, the high resolution data obtained at a 400 metre line spacing and a 100 metre flight height helped resolve a number of faults important to prospecting for hydrocarbons in the area.

There is much more information in all three data sets discussed here, but that discussion is outside the scope of this paper.

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