Aeromagnetic Depth Solutions Indicate Numerous Magnetic Sources within the Sedimentary Section of the Western Canada Sedimentary Basin

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Abstract

The application of aeromagnetic data to hydrocarbon exploration has increased significantly in the last decade. Improved data acquisition accuracy and development of PC and workstation based, interactive processing and interpretation software have contributed to this renewed interest in aeromagnetic survey data. The more recently acquired aeromagnetic survey data permit greater resolution of magnetic sources within the sedimentary section and at the earth's surface. The traditional depth solution analyses of these modern data reveal abundant intrasedimentary magnetic sources. Although the geologic source of these intra-sedimentary magnetic anomalies is poorly documented, they may be associated with magnetic sedimentary horizons and faults, and with hydrothermal and igneous activity in the sedimentary basin.

One approach to the study of depth solutions computed for large, two-dimensional grids is to load them into a 3D volume. The grid locations are the x and y coordinates and the depth solutions are the z coordinates. In order to facilitate this study, MaFIC (Rhodes and Peirce, 1999) is used to systematically sum the number of depth solutions within a selected bin size in the data cube. The MaFIC results can be viewed in several 3D volume rendering systems used to view 3D seismic data. The 3D magnetic depth solutions can be viewed in section or as horizons. Sedimentary horizons, determined by other means such as well data or seismic interpretation, can be placed into the magnetic depth solution volume. A direct comparison can be made between the imported horizons and the magnetic depth solutions. Several studies of the Western Canada Sedimentary Basin (WCSB) aeromagnetic data sets have revealed numerous depth solutions at or just above the Pre-Cretaceous erosion surface. In many areas, this surface is at the top of Mississippian or Devonian carbonates. One might expect some magnetic susceptibility contrast between the Cretaceous clastics and the Paleozoic carbonates that could generate the observed magnetic anomalies at this depth. However, the magnetic anomalies may also be associated with faults, hydrothermal alteration, or igneous rocks.

Introduction

Aeromagnetic survey data have been used by the petroleum industry since the aeromagnetic method was first developed after World War II (McIntyre, 1980). The first surveys were not particularly accurate. However, new developments made in the method over the last few decades have created an excellent tool for geologic mapping and resource exploration (Peirce et al., 1998). The aeromagnetic survey method is particularly useful for regional structure interpretations (Kivior and Boyd, 1998). Identification of intra-sedimentary magnetic sources can be important to hydrocarbon exploration (McIntyre, 1980; Gay and Hawley, 1991; and Yong-Xia, 1994). Modern surveys over sedimentary basins commonly reveal new information about the basin, particularly the presence of igneous intrusions. Recent surveys of the North Sea area revealed the presence of Tertiary dikes (Brown et al., 1994) and surveys of southern Alberta revealed the presence of Eocene dikes (Ross et al., 1994; and Kjarsgaard et al. 1994). Diamond exploration in Alberta and Saskatchewan has located many kimberlite pipes of Cretaceous age in the WCSB (Leckie et al., 1997). The kimberlite pipes commonly have a distinct, and typically high amplitude magnetic signature. Igneous intrusive activity is typically associated with a tectonic extension event. Therefore, the presence of the dikes and pipes has implications for sedimentation and faulting, and for hydrocarbon migration and trapping. Brown et al. (1994) also point out that the Tertiary dikes impacted the velocity models used for seismic data migration. This impact was not understood until the magnetic survey data revealed the dikes. Abaco (2001) has presented results that show a significant presence of magnetic horizons in the Cretaceous and Tertiary section west of Sundre, Alberta. Therefore, it should be important to hydrocarbon exploration in the WCSB to locate and to understand the importance of the intrasedimentary magnetic sources. Although few in number in the Western Canada Sedimentary Basin, impact structures commonly have distinct magnetic signature and may be important to hydrocarbon prospecting (Goussev et al., 2002).

Aeromagnetic Data Analyses

There are several papers that discuss the processing of modern aeromagnetic data. Depth analyses of aeromagnetic data and the application of MaFIC have been described by Rhodes and Peirce (1999). Basically, MaFIC is a computer program which composites a large number of depth solutions computed by Euler (Reid, 1998) and Werner Deconvolution (Ku and Sharp, 1983) methods and places them into a 3D SEGY volume as a magnetic attribute cube. Depth solution techniques operate on the magnetic data profile. One or more operator length or gate width may be used to generate depths equivalent to differing wavelength properties of the profile data. There is a general rule that the longer wavelength anomalies are from deeper sources than the shorter wavelength anomalies. In MaFIC the depth solutions are "summed" for a selected 3D bin size. After binning, a 3D wavelet, whose dimensions are based on the statistical error of the depth solution estimates, is convolved with the volume data. This process transforms a spike dataset into a spatially continuous dataset and enhances the correlation of cross-line anomalies. A SEGY volume can be created for one of the common seismic data volume rendering systems. Typically, a depth solution volume will be created for more than one set of depth solutions. For example, three volumes may be created, one for a set of Euler depth solutions and two for Werner depth solutions, one each for two orthogonal grid directions. All the techniques that are available to view the seismic 3D data cube can be used to view the MaFIC data volume. The one important difference is that the magnetic depth solutions do not create a continuous data set, as does the seismic data. Vertical and horizontal slices through the data volume are commonly studied to interpret magnetic source distributions and fault locations. Examples of the MaFIC slices are presented to illustrate the method and to demonstrate the magnetic sources at various depths. Particular emphasis is given to the intra-sedimentary sources and their interpretation.

Examples

Three examples are presented from modern aeromagnetic survey data in the WCSB. The first example, over the Peace River Arch (PRA) is shown in Figure 1. It is an east west section through a Werner depth solution volume. Wells are included at the east end of the line and were used to define the Mississippian Debolt and to help to pick the Precambrian horizon, also shown in the figure. The horizons have been interpreted to the west using the depth solutions. Near vertical faults are also interpreted on the section from the depth solutions. The faults are interpreted along the depth solution maximum since it is believed the solutions represent thin bodies, Rhodes and Peirce, (1999).

Pure geometry results in a single depth solution cluster at the top of the fault. Imperfections cause this cluster to be stretched out along the fault.In both cases, the fault extends to depth. Note that some faults only are evident in the sedimentary section. They may continue into basement but are not indicated in the data. Other faults are defined only in the basement. It is interesting that some of the faults appear to reach the surface.

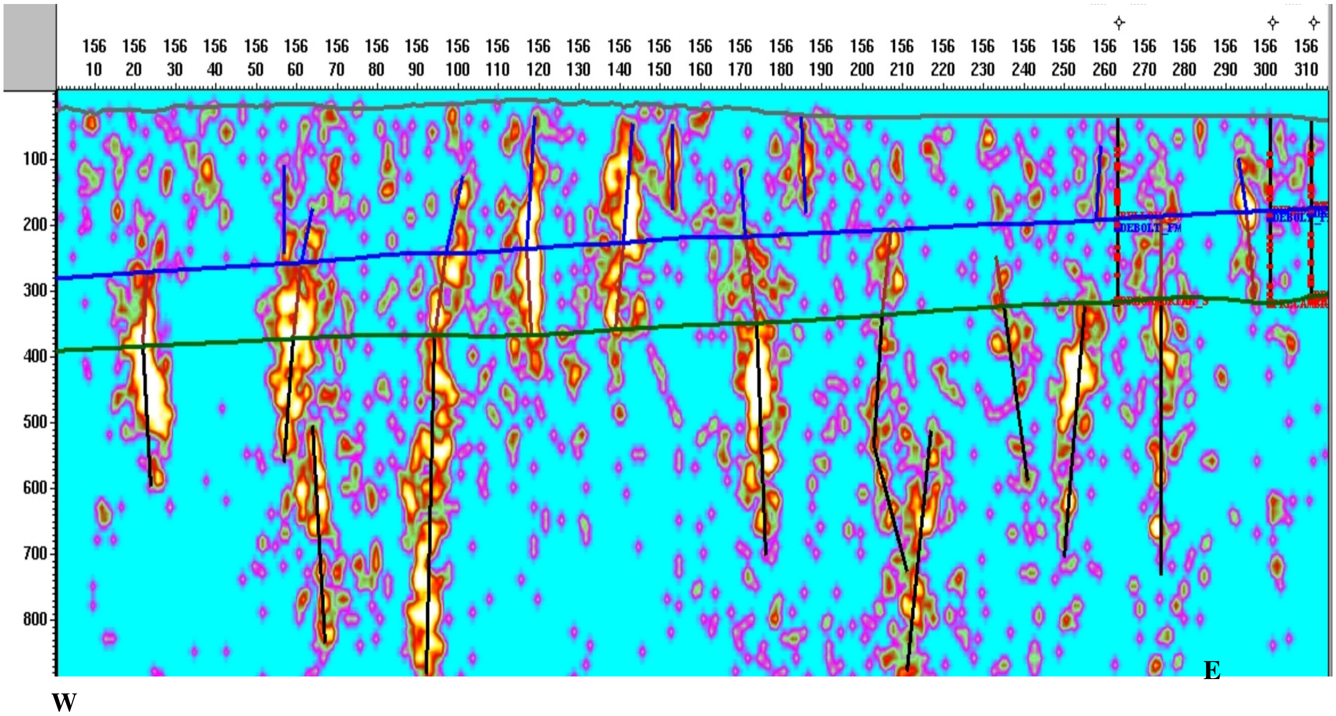
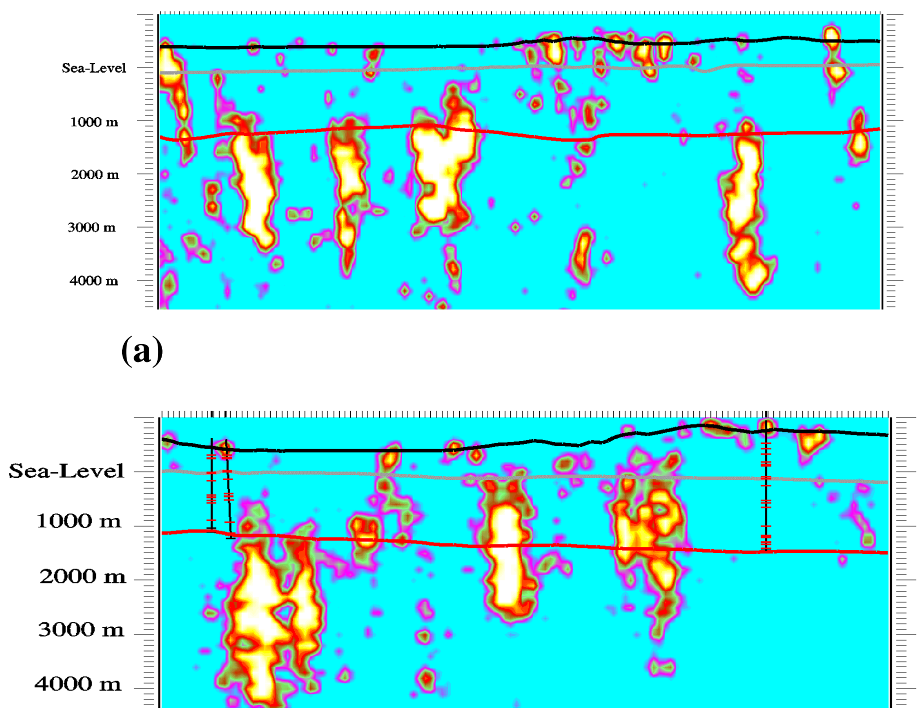


Figure 1: An east west MaFIC section through a Werner depth solution volume for an area over the PRA. Wells at east of line were used to pick formation depths. Blue is Debolt and Green is Precambrian. Near vertical fault traces, in black, are interpreted on the depth solutions. Line is about 120 km long.

The second example, shown in Figure 2, is from an area east of the PRA. The sections are again for Werner depth solutions. Here, vertical sections for both an east west, Figure 2(a), and a north south, Figure 2(b), Werner depth solution volume are shown. The east west volume section has several very clear depth solutions at the Precambrian level and almost no solutions within the sedimentary section. However, it is interesting that the point of highest topography does show a weak distribution of solutions from surface to the Precambrian. This depth solution character suggests that a fault zone may occur at this point. The lateral distribution of solutions increases from Precambrian to the surface and this change may imply a wide fault zone that may have a flower structure.



(b)

Figure 2: (a) North-South and (b) East-West section through a Werner depth volume for an area east of the PRA. Wells shown in (b) with formation picks, Precambrian in red, Debolt in grey and surface in black. Wells projected to the line. Sections are about 50 km long.

The third example, shown in Figure 3, is from the area of the Red Deer magnetic high. Here, a depth slice through an east-west Werner depth solution cube is shown. The depth is about 1600 meters sub-sea, which is about the Precambrian level. The depth solutions in this example cover most of the area and the example represents one of the areas where depth solutions provide considerable detail. Several northeast and northwest linear trends are marked in Figure 3. The northwest trends are clearly faults since they offset the northeast trends. The one northeast trend marked is drawn along the depth solutions and is interpreted as indicated for the faults in Figure 1. If the northeast trend is a fault, then it is offset. If the magnetic depth solutions follow a magnetic source within the sedimentary horizon at this depth, then it may indicate a particular facies. Many other faults and magnetic trends are evident in Figure 3 and not interpreted here.

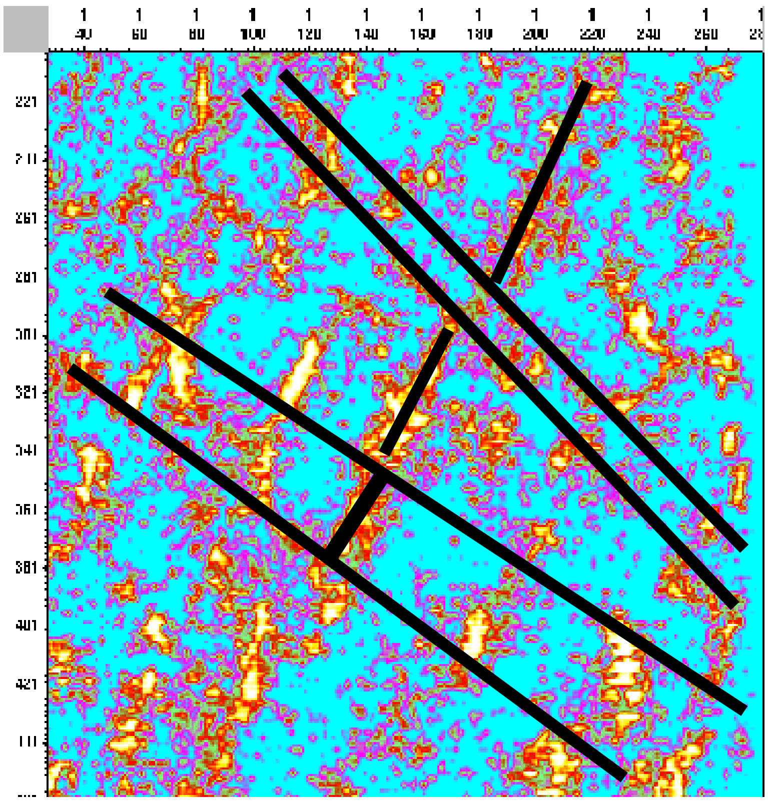


Figure 3: Depth slice through Werner East-West depth solution volume at about 1600 m sub-sea for an area south of the PRA. Several faults are interpreted on the depth slices. The area is about 100 km square.

Conclusions

Magnetic depth solutions for several modern aeromagnetic surveys in the WCSB have indicated a large number of intrasedimentary magnetic sources. These sources may be interpreted in terms of hydrothermal alteration, magnetic sediments, faults and igneous intrusions. The nature of the source can be important to hydrocarbon exploration in the WCSB. The larger number of depth sources lying near the Pre-Cretaceous unconformity may be linked to early faulting associated with development of the foreland basin or with the early Cretaceous kimberlite intrusions. Modeling the sources only gives some indication of the possible characteristics of the magnetic anomalies. Integrating the magnetic results with other data could help establish the most likely source for the magnetic anomalies. Understanding how these magnetic sources interact with the sedimentary basin could be a major benefit to contemporary oil and gas exploration. Drill core through the sources would provide the best constraints on the source models.

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