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Detecting lineaments of Athabasca region by integrated geophysical data interpretation

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Summary

A High Resolution Aeromagnetic (HRAM) survey in conjunction with reflection seismic data is used to investigate the intrasedimentary structural elements in Athabasca region, northeast of Alberta. This area covers a part of Athabasca oil sand deposits and is under investigation for petroleum and geothermal development. Therefore describing the structural elements has a significant role to indicate the sweet spots for such developments in the sedimentary basin. In the present work qualitative interpretation methods such as multi-direction derivatives and modeling are applied to the HRAM with the final goal of enhancing signature of intrasedimentary lineaments. On the basis of amplitude and wavelength, some short wavelength and high amplitude shallow linear anomalies are recegnized which turn out to be related to intrusive bodies deeper than 200 m and thicker than 60 m. These features seem to have a common upper stratigraphic limit within the late Devonian to early Cretaceous sediments and have a root in the basement crystaline rocks. Having the ability to correlate the location and depth of these structural features on the reflection seismic data ensure the accuracy of our HRAM interpretation.

Introduction

The objective of this study is to emphasize the significant role of HRAM data and joint seismic interpretation to delineate the present structural lineaments of a geologically interesting area in northeastern of Alberta.

The studied HRAM data has short spacing and therefore high resolution in contrast with the publicly available aeromagnetic data obtained by Geological Survey of Canada which is used in pervious publications (Sprenke et al., 1986; Ross et al., 1991; Ross et al., 1997; Lyatsky and Pana, 2003) on regional magnetic anomalies of Alberta. In other words the present study is the very first integrated interpretation of HRAM and seismic in Athabasca region to our knowlwdge.

The “Total Magnetic-Reduced To Pole” (TMAG-RTP) and its shaded relief first vertical derivative (VDRV) with illumination from northwest are illustrated in Figure 1a and 1b. The 2D seismic profiles and boreholes locations are superimposed by solid black lines and red circles respectively in Figure 1b. The dashed black lines show the seismic profiles (SP-03, SP-04) to be discussed in the following section.

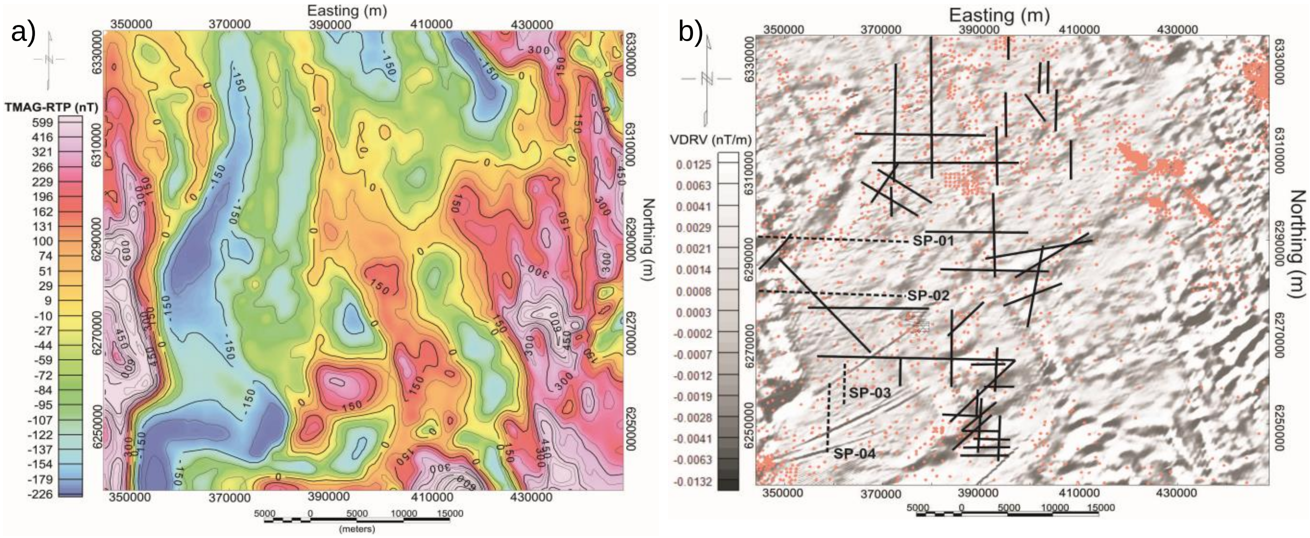

Figure 1. (a) Reduced to pole total magnetic intensity map. High amplitudes are colored in pink and lows in blue, (b) shaded relief first vertical derivative of TMAG map (VDRV) with illumination from northwest. The seismic profiles and boreholes locations are shown by black lines and red circles, respectively.

Integrated interpretation

The HRAM data reveal the presence of striking short wavelength anomalies that are different from longer wavelength anomalies (Figure 1b) in the southwest of study area. The observed signatures related to these lineaments on the residual TMAG curves (Figure 2a and 2c) and corresponding seismic profiles (SP-03 and SP-05) (Figure 2b and 2d) are highlighted by colored arrows at the exact location of intersecting seismic profiles and linear anomalies. Removal of a low order polynomial trend from the TMAG data enhances the visibility of these anomalies. These linear anomalies range between 5 to 20 nT in amplitude. They appear on TMAG-VDRV in a length of 10 to 15 km (Figure 1b). These anomalies look exactly similar to those produced by Sweetgrass (Ross et al., 1997) mafic potassic dykes of Eocene age exposed in Alberta and Northern Montana.

The zones highlighted in white circles on each of the seismic profiles (Figure 2b and 2d) are pointed by the same colored arrows in Figure 2a and 2c that indicate where the seismic profiles cross the lineaments. In each of these highlighted vertical zones the sesmic reflection discontinuity can be identified. These features seem to have a common upper stratigraphic limit within the late Devonian to early Cretaceous sediments and have a root in the basement crystaline rocks.

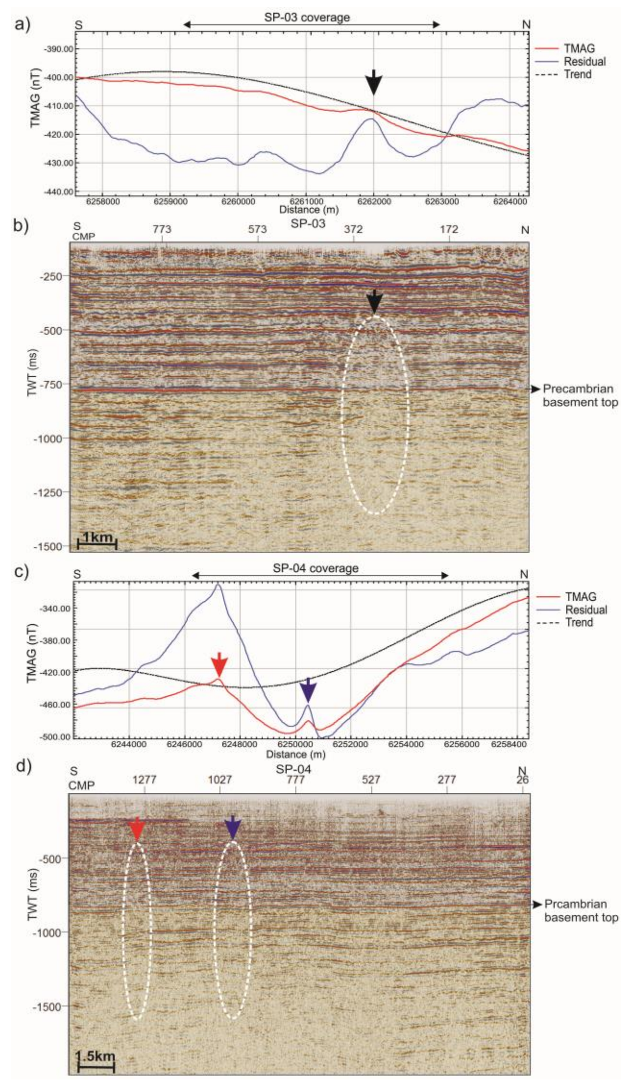

Figure 2. Portions of two seismic profiles and their corresponding TMAG in red, residual magnetic in blue and removed trend in black dashed curves. (a) TMAG, Residual and Trend curves related to the SP-03, (b) seismic profile 03 (SP-03) in two way traveltime, (c) TMAG, Residual and Trend curves related to the SP-04, (d) seismic profile 04 (SP-04) in two way traveltime.

The TMAG signature of two cultural and two geologic causative bodies are modeled in order to gain better underestanding of the source of these short wavelength anomalies (Figure 3). The cultural causative bodies include a single dipole (Figure 3a) that simulates a borehole casing with a middle point depth of 100 m and a horizontal cylinder (Figure 3b) that simulates a pipeline with exaggerated 5 m diameter and depth of 10 m. The magnetic responses caused by these two types of manmade structures are very high amplitude and very spiky in comparison with the observed anomalies (Figure 2). A modeled signature of a vertical fault simulated by two semi-infinite horizontal 2D sheets with vertically offset that slabs at 1400 m and 1450 m depths is illustrated in Figure 3c. The strike of the fault plane assumed to be identical to the strike of the observed lineaments on HRAM data. The modeled dyke signature (Figure 3d) has the half thickness of 30 m and depth of 250 m to the upper horizontal surface of the dyke.

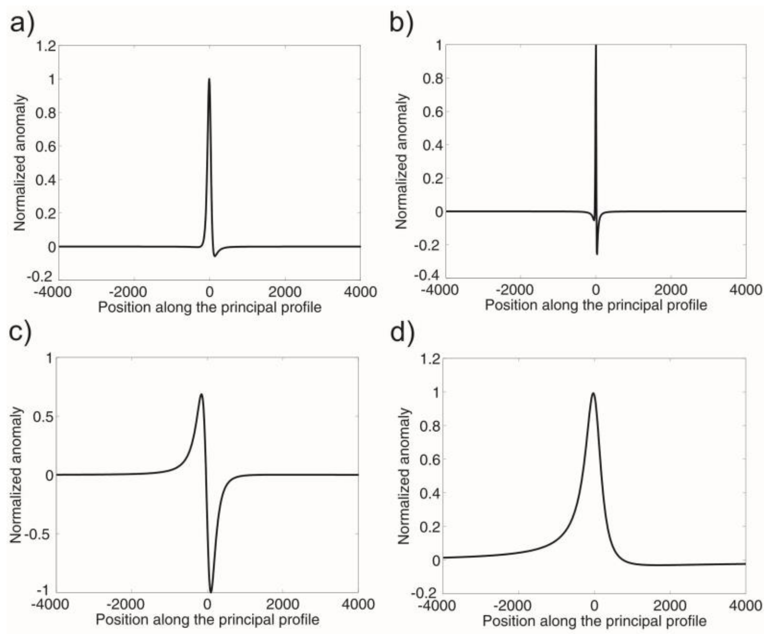

Figure 3. Modeled magnetic signature of (a) borehole casing (single dipole), (b) pipeline (horizontal cylinder), (c) fault (two semi-finite horizontal sheets), (d) dyke (semi-infinite).

The equation for the horizontal cylinder is extracted from Prakasa Rao et al. (1986), and the equation for dyke comes from Ram Babu et al. (1986) and Hood (1984). The rest of equations are taken from Telford et al. (1990) and Gay (1963). Note that in all of the equations used the demagnetization is not taken into account and it is assumed that the body magnetized solely by induction caused by earth's magnetic field. The x value in Figure 3 shows the location of the points at which the magnetic anomalies are calculated and its direction is a principal profile. The principal profile for 2D bodies (dykes and fault) is the direction perpendicular to the strike and positive in the northern geomagnetic half-plane of the unprimed system. The strike is measured positive clockwise in same way.

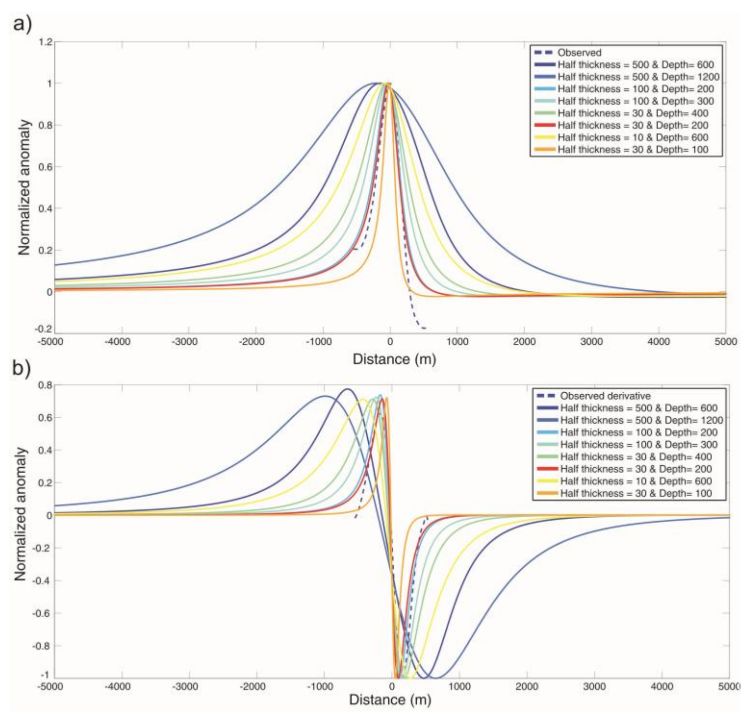

Figure 4. Comparison of the (a) observed residual anomaly and (b) its vertical derivative with model dyke responses and their vertical derivatives calculated with different source depth and thickness.

Although the modeled vertical fault response (Figure 3c) does not resemble our observation of HRAM profile; it is much similar to the modeled dyke in shape. To further clarify the resemblance of the computed and observed signature, the observed residual anomaly and its vertical derivative (Figure 2c: highlighted by the blue arrow) is compared with the modeled dyke responses and their vertical derivatives calculated with different source depth and thickness (Figure 4). The observed anomaly is illustrated in blue dashed line and modeled responses are shown in different colors which differ by half thickness and depth to the top of the modeled dyke. This comparison determines the thickness and depth of the causative body could be more than 60 m and 200 m respectively. Furthermore observing a disturbance of the lateral continuity of seismic reflectors, the presence of strong diffractions extending to depth in the section, interference patterns between the diffractions and horizontal reflectors and apparent pull-up and pull-down in our seismic reflection data (Figure 2) confirm the intrusive bodies as the source of the TMAG observations.

Conclusions

The intent of this work was to show that integrated study of HRAM, and seismic reflection data could provide comprehensive information in delineating geologic structures of Athabasca region. In general the HRAM texture is more influenced by the Precambrian metamorphic basement than the sedimentary basin since the sedimentary basement is very thin in comparison with Canadian Shield in this area and contains few magnetic minerals. Short wavelength and high amplitude anomalies in southwest of Athabasca region are introduced as dykes on the basis of magnetic signature modeling. The evidence of their existence is observed on seismic images. According to the forward modeling results these features could be deeper than 200 m and thicker than 60 m.

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