Fusion of airborne gravity and magnetic images for improved detection of structural control

Hassan H. Hassan*
hassan@gedco.com
and
John W. Peirce
GEDCO, Calgary, Alberta, Canada

Summary

Airborne gravity surveys are becoming increasingly more popular in the mining and the oil industry for exploration and geological mapping. Usually in airborne gravity surveys magnetic data are collected as well. Although the magnetic data acquired during gravity surveys generally have lower spectral and spatial resolution than standard high-resolution aeromagnetic (HRAM) data, they add significant value to the interpretation of the acquired gravity data. In many cases, the gravity and magnetic data are responding to the same geological source. For example, structural discontinuities such as faults, fractures and geological contacts can create lateral contrasts in density and magnetization of rocks. These contrasts often generate gravity and magnetic signatures. However, due to density and magnetic variations of the rocks these structural discontinuities are partly detected on the gravity image and partly on the magnetic image. Therefore, we think that if we combine the two images together in a single image and use it to detect lineaments, then we may see trends related to structural control more clearly.

This work tests a new technology called “Image Fusion” to combine gravity and magnetic images acquired through a single airborne survey into a single image. Image fusion combines images from different sources together to produce a fused image that provides an integrated combination of the information contained in each data set. In this work, we tested a discrete wavelet transform (DWT) based fusion technique on the gravity and magnetic images of the Turner Valley airborne gravity survey in the foothills of Alberta, Canada.

The main objective of our work was to test the power of image fusion technique through mapping lineaments in the Turner Valley area using the fused image. Filtered versions of the fused image highlight NE offsets in the Turner Valley structure that are probably related to pressure compartmentalization of the producing reservoir. Further work using steerable filters may highlight additional structural controls.

Introduction

The Turner Valley area is located at the eastern edge of the Rocky Mountain (Fig. 1) and it is dominated by northwesterly trending thrust faults associated with the foothills region (Fig. 2). The Turner Valley region, in general, is a well-established area for oil and gas production and is the site of the first Alberta oil boom in the 1920’s. New discoveries are still being drilled in the structure and in sub-thrust plays where accurate depth mapping from seismic data is a challenge. The principal producing zones are in porous Mississippian aged carbonate rocks carried in overthrust structures.

The gravity and magnetic data selected to test the image fusion technique is derived from an AIRGrav™ survey flown over the Turner Valley region of Alberta (Fig. 2) in the summer of 2001 by Sander Geophysics Ltd. (Peirce et al., 2002). The survey consists of over 12,000 line km of airborne gravity data flown on 250 m spaced east-west traverse lines and 1000 m spaced north-south control lines. The survey was flown with drape elevation that varies from 250 m height in the plains to over 500 m height in the mountains. After full processing on a line by line basis the data were leveled and the standard Bouguer reduction corrections, including outer terrain corrections using a reduction density of 2.67 gm/cc, were applied. In addition to gravity data, magnetic data was collected as well. The magnetic data was IGRF corrected, leveled and reduced to the pole. The gravity and the magnetic images used as input to the fusion processing are shown in Figures 3 and 4, respectively.

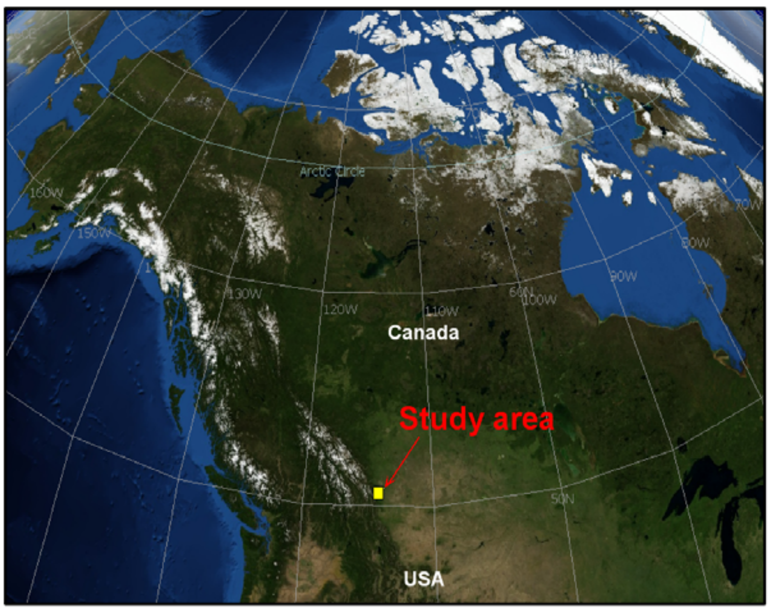

Figure 1. Index map showing the study area

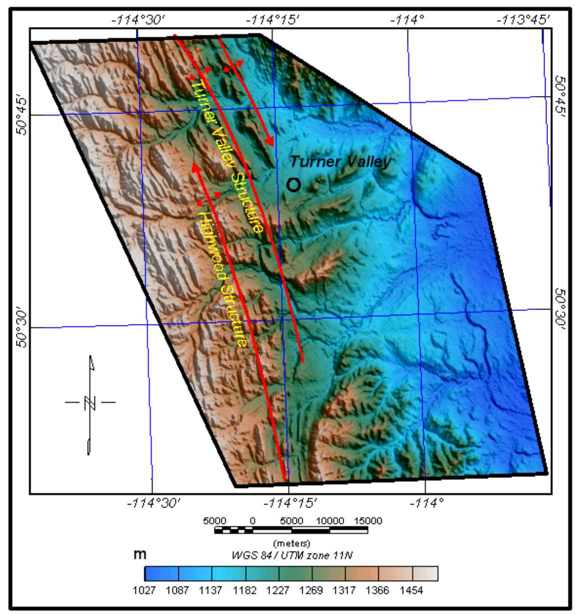

Figure 2. Topography of the Turner Valley area. The red lines indicate the axes of major structures.

Methodology

Fusion of two or more images can be performed by many techniques. These techniques are in general divided into two main categories; spatial domain fusion (for example principal component analysis, PCA) and transform based fusion (for example discrete wavelet transform, DWT). The DWT image fusion techniques show better enhancements in the spectral and spatial resolutions of the fused images (Scheunders and Backer, 2001, Gomez et al., 2001). Here we implemented the DWT technique to fuse our airborne gravity and magnetic images.

Our methodology is illustrated in Figure 5 and described in the following steps:

1. Decomposed the gravity and magnetic images by using 2D DWT. We applied one level of DWT decomposition with Daubechies wavelet of basis one.

2. Fused the decomposed images based on specific rules. In our case we used an equal weighted average values from both images. The fusion rules decide how the input wavelet transforms will be combined.
3. Performed the inverse wavelet transform to obtain the fused image.
4. Filter the resulting image and interpret for structural control.

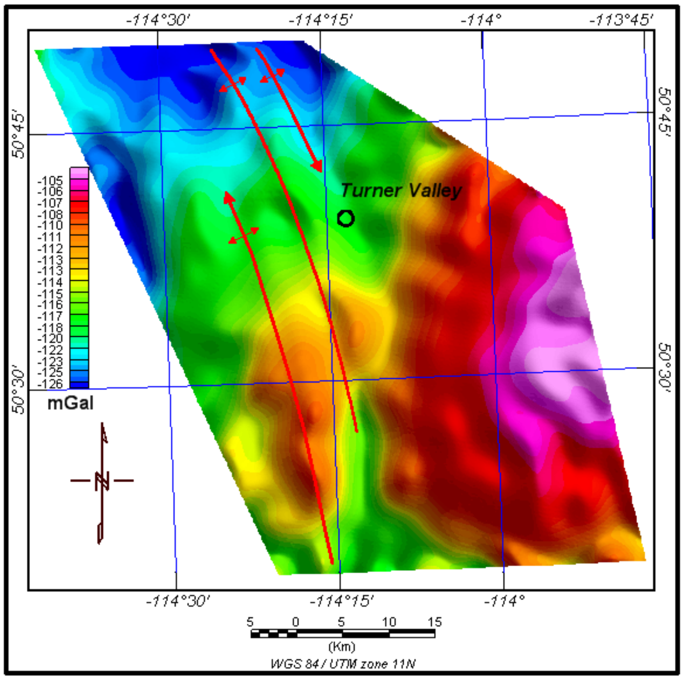

Figure 3. Image of the Bouguer gravity data

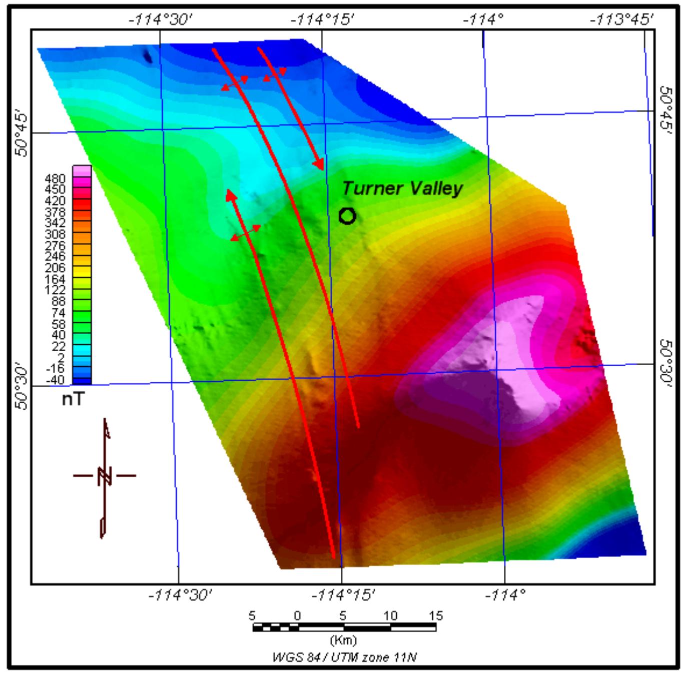

Figure 4. Image of the magnetic data (Total field, reduced to the pole).

Results

The final fused gravity and magnetic image is shown in Figure 5. The fused image has higher frequency content and a better resolution than the individual gravity (Fig. 3) and magnetic (Fig. 4) images. This increase in dominant frequency is a result of the wavelet analysis process. Note that the prominent geological structures in the area are more clearly reflected on the fused image than on the original images.

Figure 6 is a band pass filtered version of Figure 5 with several NE/SW lineaments interpreted. The Turner Valley structure is clearly broken up into several structural compartments. It would be interesting to compare these new results to the production history of the Turner Valley gas and oil reservoirs and see if pressure differences exist across these lineaments.

We have also run steerable filters (Mathews and Unser, 2004; Hassan and Peirce, 2007), followed by a Canny edge detector (Canny, 1986) on the fused image and detected a much stronger NE/NW grain than is evident on the fused image by itself. The steerable filter technique includes a filtering step which seems to highlight this new trend. We need to do more work to understand the spectral characteristics of this filter before trying to ascribe significance to the trends highlighted by the steerable filters.

Conclusions

The results of this work showed that the image fusion of gravity and magnetic data acquired during the same airborne survey is more powerful in mapping lineaments than if mapping was performed separately by the gravity and the magnetic images. Furthermore, the fused image appears to have a better spectral and spatial resolution than the original gravity and magnetic images. The filtered version of the fused image is the most easily interpretable image of the Turner Valley AIRGrav™ survey that we have achieved in many years of working with this data set.

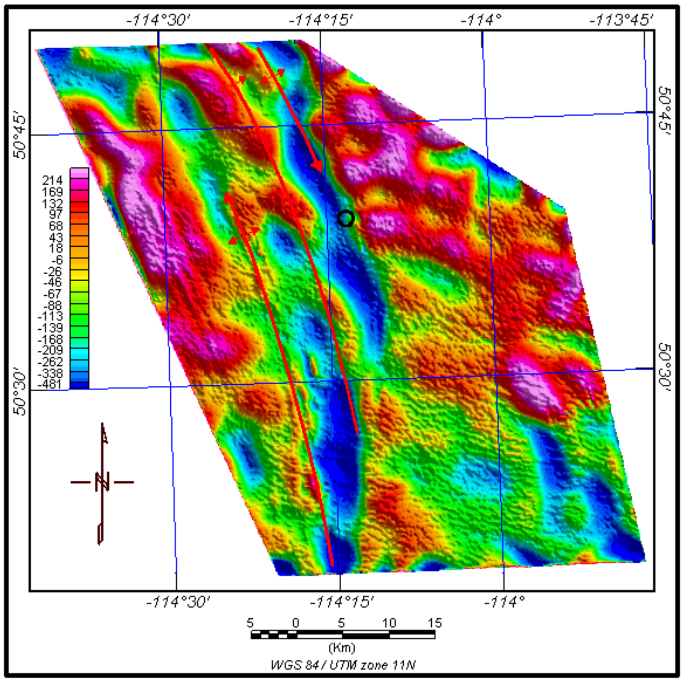

Figure 5. Fused gravity and magnetic images

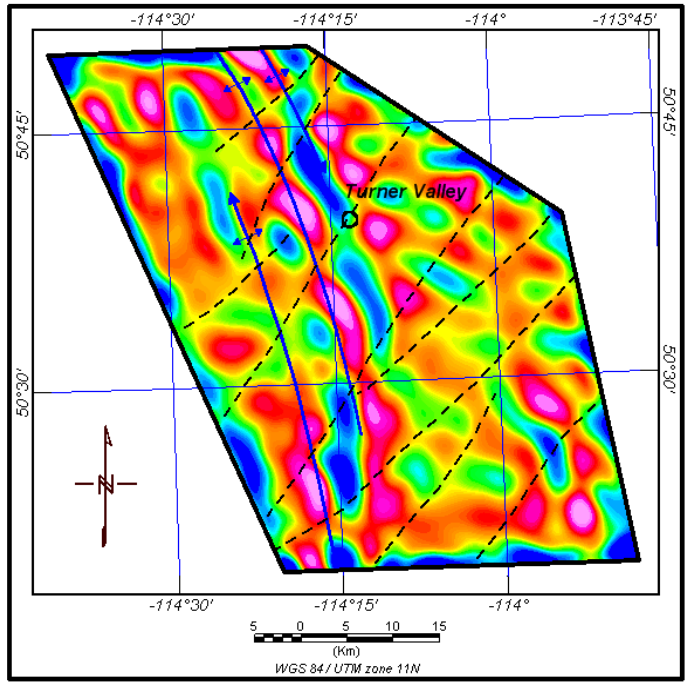

Figure 6. Band pass filter of 8-24 km of fused image with Interpreted lineaments. Note how the fused gravity and magnetic response Turner Valley structure is broken into several distinct compartments.

References

Canny, J., 1986, A Computational Approach to Edge Detection: IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. PAMI-8, No. 6, 679 - 698.

Gomez, R.B., Jazaeri, A., Kafatos, M. ,2001, Wavelet-based hyperspectral and multispectral image fusion: Proceedings of SPIE, Orlando, April 16–20, vol.4383, 36 - 42.

Hassan, H.H. and Peirce, J.W., 2007, Mapping geological features in HRAM data using 2D steerable filters and its comparison to 2D wavelet transform; 77th Annual SEG Meeting in San Antonio, Sept. 22 - 28, 2007.SEG Technical Program Expanded Abstracts, 795 -799.

Mathews J., and Unser, M., 2004, Design of Steerable Filters for Feature Detection Using Canny-Like Criteria: IEEE Transactions on Pattern Analysis and Machine Intelligence, 26, 1007 - 1019.

Peirce, J.W., Sander, S., Charters, R.A., and Lavoie, V., 2002, Turner Valley, Canada - A case history in contemporary airborne gravity: Society of Exploration Geophysicists International Exposition and 72nd Annual Meeting, 783 - 786.

Scheunders P., DeBackers S., 2001, Fusion and merging of multispectral images with use of multiscale fundamental forms: Journal of the Optical Society of America, A 18(10), 2468.