Potential Field investigation of Williston Basin Basement

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Summary

Major faults and domains are identified in the Precambrian basement of the Williston basin from reprocessed Bouguer gravity and aeromagnetic data combined with seismic and well information. Processing methods include horizontal and vertical derivatives, analytic signal, local wavenumber, Euler deconvolution; reduction to pole, downward continuation, and nonlinear interface inversion. The interpretation based on these new attribute maps suggests a structural framework and description of basement faulting distribution that are more detailed than previously known.

Introduction

The study area of the Targeted Geoscience Initiative Phase II Project extends from W96º - 106º, N49º - 56º and covers most of SE Saskatchewan and SW-S Manitoba. The overall objective of the project is to produce a geological model of Phanerozoic rocks over a significant portion of Saskatchewan and Manitoba to enhance our understanding of their hydrocarbon and mineral potential. This goal is being approached through subsurface geophysical and geological mapping, hydro-geological mapping, and remotely sensed imagery analysis. The specific objectives of this geophysical study is to incorporate seismic, aeromagnetic, gravity, and remotely sensed imagery into a seamless 3D regional geological model of the subsurface to improve our understanding of the Precambrian basement and possible tectonic relationship with the overlying Phanerozoic rocks.

As potential field compilations extend to the entire basin, it becomes possible to achieve seamless coverage, link the existing isolated interpretations provide basin-scale perspectives on geological structure and evolution, and extend geological mapping from the exposed regions into sediment-covered areas. A fundamental building block in these interpretations is the geophysical domain, distinguished on the basis of its potential-field anomaly trend, texture and amplitude. Where the basement is exposed, these domains often coincide with lithotectonic domains, which depend on the scale of investigation. Structural trends identified from the geophysical anomalies may indicate the types of crustal and basin deformations in the area. Gravity and magnetic signatures reflect the tectonic and structural characters of the area most closely, and potential-field data also provide the necessary spatial continuity of coverage. However, due its inherent limitation, potential field mapping needs to be further calibrated and constrained by the available well logs and seismic data.

Gravity data have been used successfully to map crustal-scale and basin-scale structural domains. The shorter-wavelength features result from density variations within the sedimentary rocks overlying the crystalline basement. Due to a faster fall-off of magnetic response with distance compared to the gravity, the observed magnetic anomalies could be a better indicator of the character of the basement in the covered regions.

Data

The datasets consist of 235413 gravity and 785560 aeromagnetic survey points. Gravity data were collected from the 1950's to 1990' s at various survey scales. In Saskatchewan and in Manitoba, data sampling was highly variable, ranging in density from <1 km in the areas of oil and mineral exploration to 10 km or even over 20 km in the E-NE parts of the basin.

Data processing methods

To improve the gravity and magnetic resolution and emphasize the effects of the geological contacts critical for the structural framework of the area, our data processing methods generally focus on accurate downward continuation and enhancement of the short-wavelength and linear features in the data. The key processing steps include:

- Interpolation and gridding of the gravity data (Figure 1);
- Gridding and reduction to pole (RTP) of the aeromagnetic data (Figure 2);

- Computation of the horizontal and vertical gradients.

Based on these operations, the following advanced inversion steps were performed.

- **Derivation of a 3-D analytic signal**. The analytic signal could be useful to reveal the basement structure. The maxima of analytic signal are located close to the outlines of source (gravity or magnetic) bodies.
- **Local Wavenumber attributes (TDR and THDR)**. These operations effect suppresses the longer-wavelength anomalies and emphasizes the effects of the sediments and basement.
- **3-D Euler deconvolution**. It provides automatic estimations of source location and depth, including the faults affecting magnetic strata.
- **Nonlinear gravity interface inversion**. From the existing well data, the basement depth changes from 50 m below the sea-level in the NE to 2500 m in the SW of the study area. After first removing the gravity effects of this regional basement variation, the residual long-wavelength gravity signature is interpreted as contributed by the variations in the total crustal thickness. Following removal of both of these regional gravity fields, a nonlinear inversion scheme is adopted to reveal the shorter-scale local topography on the basement.

3-D Euler deconvolution is performed through solving the equation (Thomson 1982, Reid 1990, Silva 2003):

$$(x - x_0)\frac{\partial}{\partial x}T(x, y, z) + (y - y_0)\frac{\partial}{\partial y}T(x, y, z) + (z - z_0)\frac{\partial}{\partial z}T(x, y, z) = N(B - T(x, y, z)) .$$

Local wavenumber attributes (Figures 3 and 4) are defined from the vertical derivative (VDR) and the total horizontal derivative of the gridded field (THDR) as (Verduzco et al., 2004; Firhead et al , 2004):

Tilt derivative (Figure 3): $TDR = \tan^{-1}(\frac{VDR}{THDR})$,

Total horizontal derivative of TDR: $TDR\_THDR = \sqrt{\left(\frac{\partial TDR}{\partial x}\right)^2 + \left(\frac{\partial TDR}{\partial y}\right)^2}$.

Delineation of the faults and structural domains

Identification of the major faults and domain boundaries is the key application of potential fields to geological interpretation. The faults are determined mainly from the horizontal gradient and analytic signal maps. Domain boundaries are then roughly delineated by the areas of parallel or sub-parallel trends that have comparable anomaly amplitudes. This method was applied to both gravity and magnetic data. From a combination of gravity and magnetic results, we present the interpreted faults and domain definitions based on additional and improved potential field attributes, use of seismic data and well logs, and from geological constraints.

Conclusions

Using the accepted and recently developed potential data processing methods, Williston Basin faults and structural domain are identified. Among the horizontal and total gradient, analytic signal, Euler deconvolution and local wavenumber attributes, the local wavenumber maps offer the best horizontal resolution.

Williston Basin basement structure is complex and controlled by several group of NE-SW –trending faults intersected by localized E-W trends that define the geological structural domains. In the processed magnetic maps, narrow and long W-E-trending faults appear to cross nearly the entire basin and are nearly coincident with the basement iso-depth contour.

The boundaries of fault and domains are similar to those obtained from the previous investigations (Miles et al 1997, Pilkington et al 2001) based on the conventional gradient processing method. In addition, local wavenumber and Euler deconvolution provide more exact horizontal positions of the faults and source bodies.

Acknowledgments

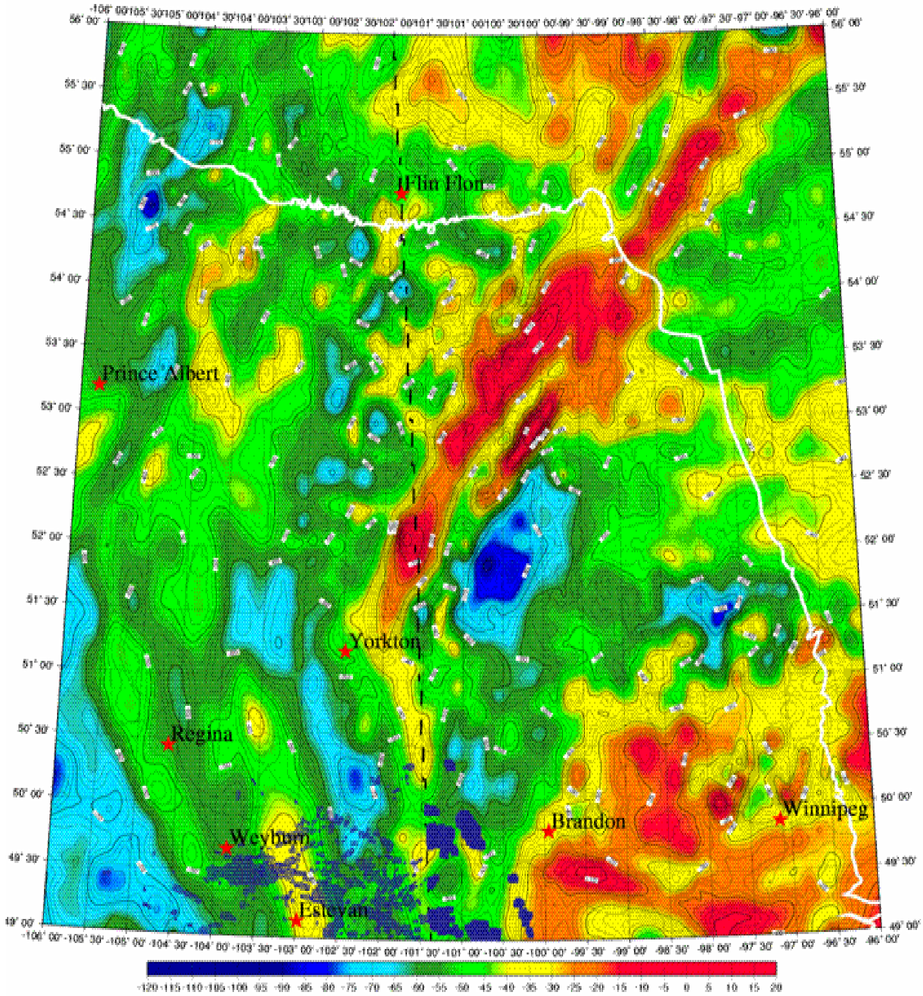

Figure 1. Interpolated and gridded Williston Basin Bouguer gravity.

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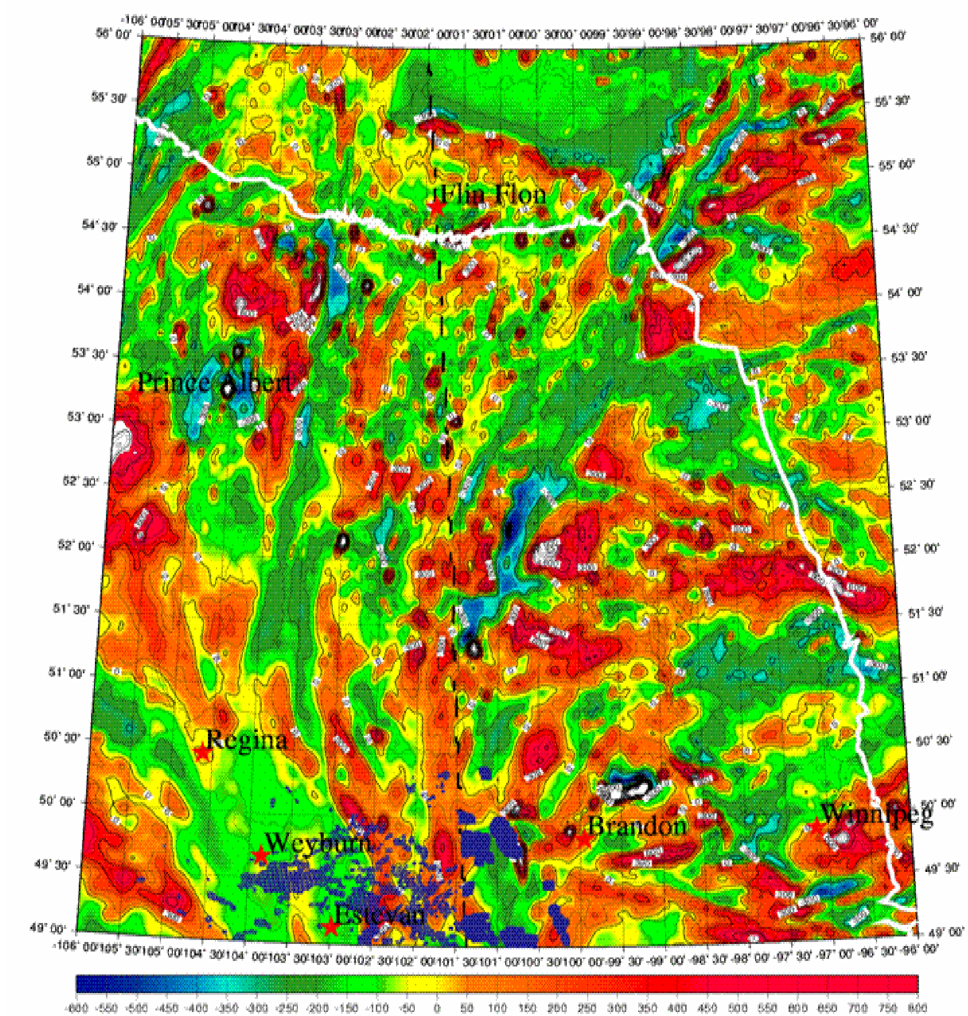

Figure 2. Gridded Williston Basin Aeromagnetic data.

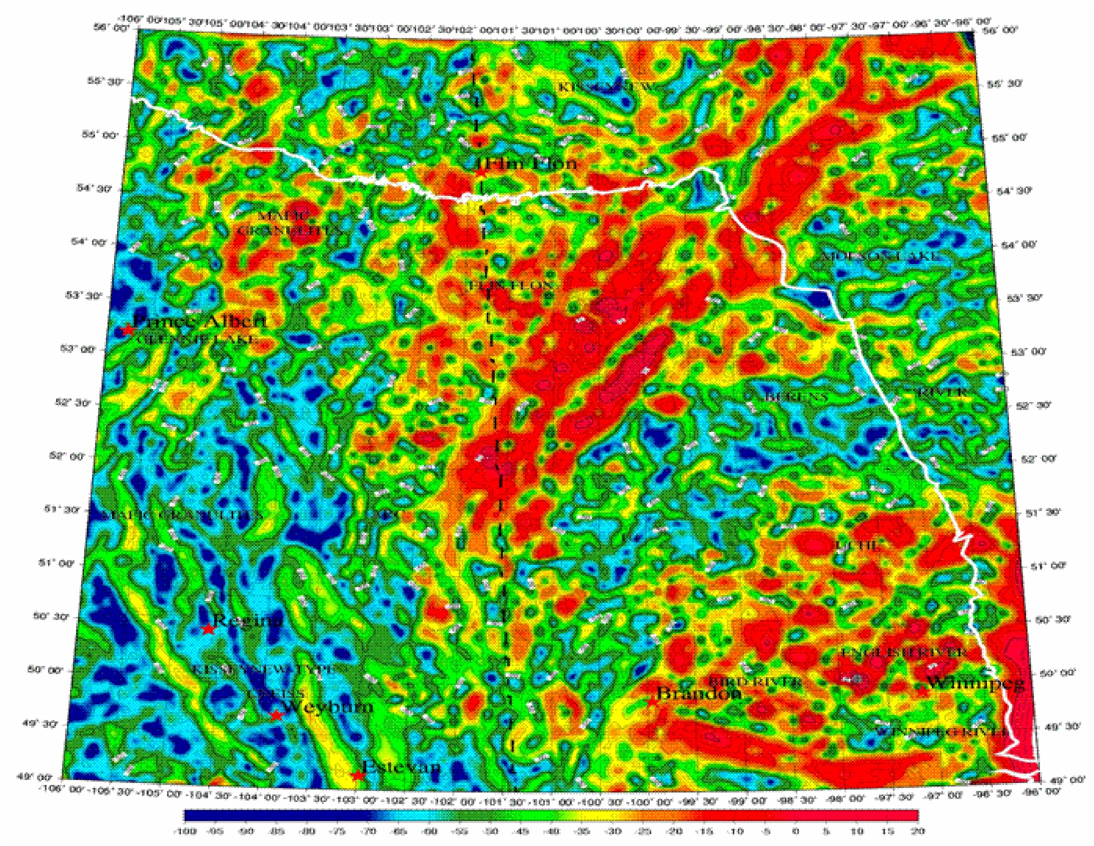

Figure 3. Bouguer Gravity Tilt derivative. Note the NW-SE-trending anomalies in the souhern part of the study area.

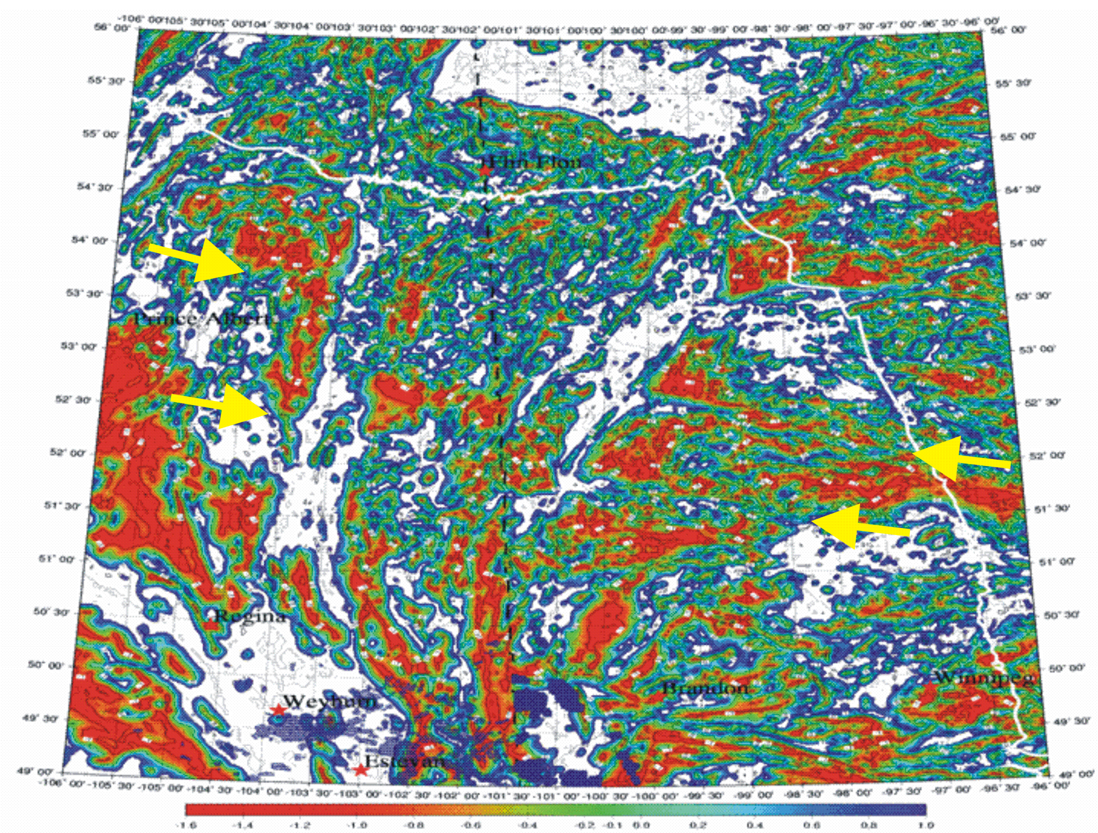

Figure 4. Magnetic Local Wavenumber map. This attribute emphasizes the boundaries of tectonic and structural domains at higher spatial resolution. Note the shallow W-E positive anomaly along the northern part of the basin (yellow arrows).