Mapping Depth to Basement Using 2D Werner Inversion of High-Resolution AeroMagnetic (HRAM) Data

Hassan H. Hassan*
GEDCO, Calgary, AB, Canada
hassan@gedco.com

and

Robert A. Charters and John W. Peirce
GEDCO, Calgary, AB, Canada

Introduction

Mapping magnetic basement is an important tool for oil and gas exploration in a sedimentary basin because of the basement impact on the geology of the overlying sedimentary rocks and subsequently their control on the formation of oil and gas pools.

Numerous geophysical techniques have been developed to map the basement, but airborne magnetic data inversion is the only tool which can define the basement depth and structure in detail over large areas. It is also the most effective one because of the significant magnetic contrast between the magnetic basement rocks and overlying largely non-magnetic sedimentary rocks. Airborne magnetic surveys are fast and cost-effective relative to other geophysical techniques. However, the interpretation of magnetic data is in general non-unique and often needs to be constrained by other geological and geophysical information such as seismic data and deep boreholes that penetrate the basement. Because of great depth and often low acoustic impedance contrasts, the basement, in some cases, displays a weak reflection on seismic data. Also, often there is sparse well control at the basement level. Hence, the basement is poorly mapped from seismic and well data alone.

The main objective of this study is to map the basement using the 2D Werner inversion technique via an in-house developed approach called MaFIC (**M**agnetized **F**ault **I**dentification **C**ube). We use MaFIC to map faults and magnetic contacts and also to map the depth to the basement. However, this study is only concerned with mapping the depth to the basement. Magprobe™ (Fugro-LCT) is used to compute Werner inversions along profiles. Afterward, we used MaFIC to convert the computed depth solutions to a SEG-Y cube (3D volume). We import the SEG-Y Cube into a seismic interpretation platform in order to pick top of basement horizons. We use deep wells penetrating the basement to constrain our interpretation. However, without well information our interpretation is to some extent subjective.

In this work, we first applied MaFIC on synthetic data from the Bishop 3D Model (Reid, *et al.*, 2005; Williams, *et al.,* 2005) and after obtaining a satisfactory result we applied it on real data from the Dunvegan non-exclusive HRAM survey in Alberta. The results are very encouraging and suggest that 2D Werner inversion is useful in mapping basement, especially in areas with sparse well control.

Methodology

The Werner inversion technique is used to analyze the depth and position of magnetic sources as well as their magnetic susceptibilities and dip along profiles. The technique was developed in 1953 by S. Werner (Werner, 1953) and later automated by Ku and Sharp (1983). The Werner inversion is based on the assumption that magnetic anomalies can be approximated by either thin-sheet bodies or geological interfaces with infinite depth extent and arbitrary dip. Analysis of total magnetic intensity (TMI) yields these parameters for thin-sheet bodies such as dikes, sills and lava flows. Analysis of the horizontal derivative yields parameters for contrasts in magnetic susceptibility such as geological contacts, edges of igneous intrusions and faults. Werner inversion uses a least-squares approach to solve for the source body parameters in a series of moving windows along the profile. The accuracy and reliability of Werner inversion depend on many factors including the length of the inversion window, proximity of target geometry to the thin-sheet or geological interface model, interferences from shallow targets and sensitivity to noise.

We use the following steps to map the basement (Hassan, 2006):

1) Select the reduced-to-pole TMI grid (grid cell size ~ 1/4 or 1/3 of flight line spacing) as our input.

2) Re-sample the TMI grid to a 50m x 50m cell size. This step secures a sample interval of 50m along the profiles. Convert the re-sampled grid into an ASCII XYZ grid.

3) Extract two sets of 200m spacing orthogonal lines from the ASCII grid. These two sets of orthogonal lines represent profiles along which we run the Magprobe™ computation.

4) Build two databases (using Fugro-LCT Software) for the two orthogonal datasets. For example one for the E-W lines and the other for the N-S lines.

5) Apply Werner inversion along the line profiles of the two datasets. Prior to the inversion we apply a mild low pass filter (λ ~ 300m) in order to attenuate near-surface noise from the data. We use both the TMI and its horizontal derivative in the 2D Werner calculation. We define multiple widow sizes in order to cover the expected entire depth range.

6) Afterward we use an in-house developed Java-based computer program (Rhodes and Peirce, 1999) to convolve our Werner depth solutions from a scattered spray of points to a more coherent agglomerated cloud of solutions. In this way we can see the patterns in the data more clearly and make them easy to interpret.

7) Using the same computer program we create 3D SEG-Y files (aka SEG-Y cube) for the two orthogonal datasets. The advantage of converting the solutions into SEG-Y cubes is the ability to view and interpret the magnetic depth solutions on seismic workstations such as WinPICS™ (Divestco), Seis-X™ (Paradigm) or SeisWare™ (Zokero) and also to integrate the magnetic interpretation with seismic and well data. In addition, we are able to generate, interpret and visualize depth slices with ease in any orientation.

Results

Synthetic Data: First we tested MaFIC on the TMI grid of the Bishop 3D synthetic model (Fig. 1). The Bishop model is composed of a synthetic magnetic basement (Fig. 2) at depths ranging from 100m to 10,000m below the sea-level and overlain by non-magnetic sedimentary rocks. The base of the model was set to 15km below sea-level. The TMI response grid (Fig. 1) from the Bishop model computed at a geomagnetic field inclination of 90° and a declination of 0° was used as an input to our MaFIC test. The TMI response grid was calculated by using 3-D forward and inversion magnetic modeling software called GMSYS-3D™ (Northwest Geophysical Associates, NGA). The Bishop 3D model also used a basement with various magnetic susceptibilities ranging from 1000 µcgs to about 8000 µcgs. The depth to the basement as we interpreted using MaFIC is shown in Figure 3. The result shows in general a good match between the Bishop basement (Fig. 2) and the basement derived from MaFIC (Fig. 3).

Real Data: The real data were derived from the Dunvegan non-exclusive HRAM survey in Alberta. The Dunvegan HRAM survey was flown by Sander Geophysics Ltd. in 1996 with 800m spacing NS oriented flight lines and 2400m spacing EW oriented tie lines. The survey area (Fig. 4) is located at the intersection of two contrasting Precambrian magnetic terranes; Ksituan and Chinchaga. The Ksituan Terrane is highly magnetic and it is believed to be associated with magnetite-bearing (I-type) granites whereas the Chinchaga Terrane is magnetically low and probably associated with ilmenite-bearing (S-type) granites (Pilkington, *et al*, 2000). The reduced-to-pole TMI grid (Fig. 4) of the Dunvegan survey was processed in the same manner as the synthetic data. Figure 5 shows the depth to the basement derived from contouring the top of Precambrian basement intersected by wells. Depth to the basement using MaFIC is displayed in Figure 6. The results clearly show a significant agreement between the basement depth computed using well data (Fig. 5) and MaFIC (Fig. 6).

Conclusions

This work suggests that it is possible to map the depth to magnetic basement with reasonable accuracy using 2D Werner magnetic inversion technique and using MaFIC. This was demonstrated by the fair agreement between the depth to the basement obtained from MaFIC with the one derived from magnetic inversion of a synthetic model and with the one calculated from wells that intersected the Precambrian basement using real data from the Dunvegan HRAM survey.

References

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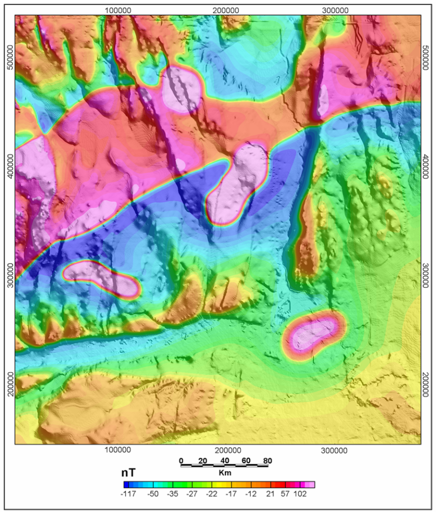

Figure 1. Calculated TMI response from Bishop model basement in Figure 2

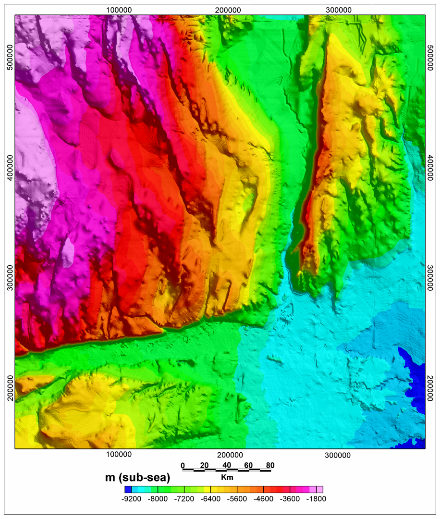

Figure 2. Depth to the basement of Bishop 3D synthetic model

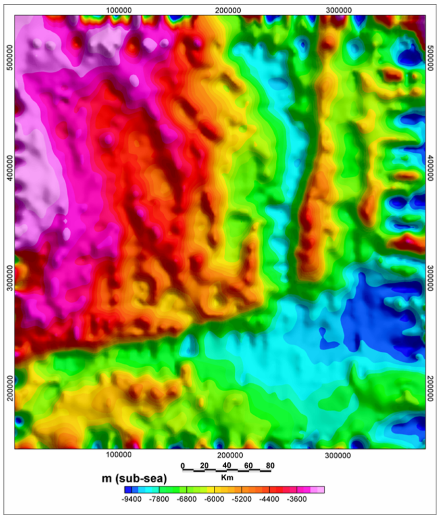

Figure 3. Depth to the basement derived from MaFIC

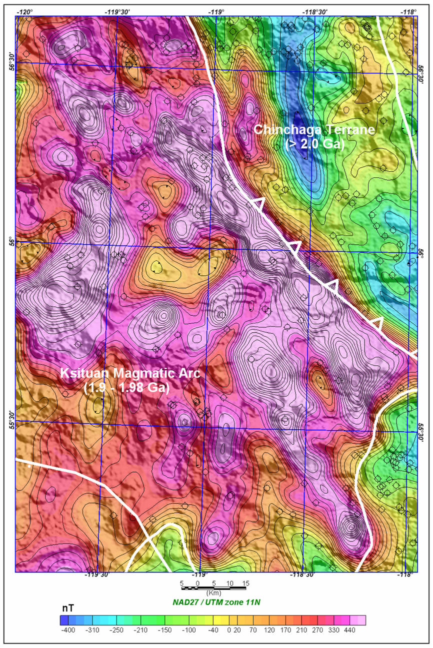

Figure 4. Reduced-to-pole TMI of the Dunvegan HRAM survey draped on NE- Shaded topography. Precambrian Magnetic terranes are plotted as white color lines.

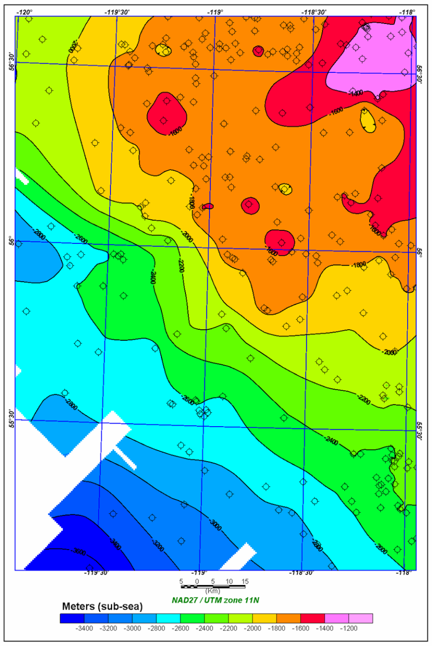

Figure 5. Depth to the Precambrian basement in the Dunvegan area contoured from wells.

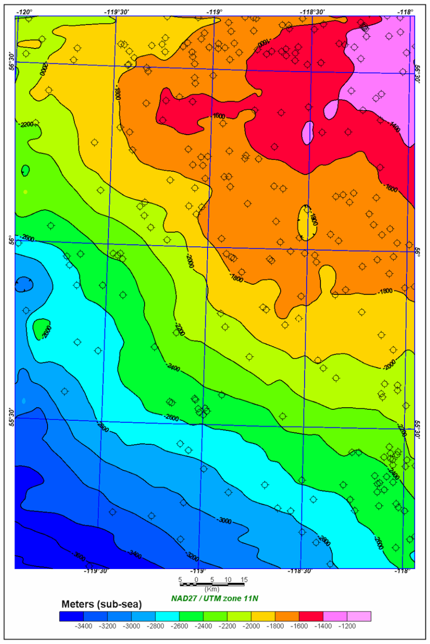

Figure 6. Depth to the basement in the Dunvegan area derived from MaFIC