Paper 73

3D Structural Geometry of a plunging fold within the Southern Province: Integration of Aerial Photography, Magnetics and topography data

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ABSTRACT

Common practice in the past was to use a high-resolution aerial photograph mosaic to provide a spatial reference for geological field mapping projects. Nowadays DGPS sensors are used to provide locational information. Differential weathering of lithologically distinct strata can produce features that are present in both the airphoto mosaic and the digital elevation model derived from stereoscopic interpretation of aerial photographic surveys. However, the integration of complementary information such as airborne photography, topography and geophysics is not always achieved effectively. In this study we present an example where an original air photo interpretation leads to the wrong interpretation of geological structure. By looking at this same region and including results from inversion of an aeromagnetic data set and a more detailed assessment of the aerial photography, we show that it is possible to achieve a correct interpretation of tectonic structure.

INTRODUCTION

All types of geological and geophysical maps comprise three layers of information. The primary layer is the raster (map) image on which the physical property variation (such as lithology, topography, magnetics) that is used to describe the geology is recorded. The second layer is a vector layer consisting of lines, and symbols that describe geometrical relationships (illustrating bedding dip, folds, faults and other features) between individual layers of the lithology. The third layer is the stratigraphic column this gives a summary of the temporal relationships between lithologies. More specifically the stratigraphic column identifies which rock units exhibit a common morphological character; that is it contains the stratigraphic nomenclature of Formations, Groups and Supergroups.

By adopting a remote predictive mapping approach one attempts to construct a meaningful geological map through the interpretation of remotely sensed images (Banerjee and Mitra 2004). Often these images provide clear indications of lithological boundaries present within a study area, but without the additional constraints provided by the geometrical relationships it is possible to derive geological relationships that are erroneous. In this study we present an example where an original air photo interpretation leads to the wrong interpretation of geological structure. Looking at this same region we show that by including results from inversion of an aeromagnetic data set and a more detailed assessment of the aerial photography it is possible to achieve the correct tectonic structure.

REGIONAL GEOLOGY

Sedimentary units of the Huronian Supergroup within the Southern Province outcrop along the north shore of Lake Huron (Figure 1). Repetitive lithologic sequences of diamict – argillite – quartzite have been interpreted by numerous authors in terms of a series of glacial advances and retreats (Young et al., 2004). Detailed geological mapping of the Huronian Supergroup in the Whitefish Falls area of Ontario has been reported by numerous authors (Card, 1984; Junilla and Young, 1995; Long 2004). The timing of the end of sedimentation in the Huronian sequence is constrained by the dates associated with cross-cutting Nipissing diabase intrusions. Taking the oldest of the three distinct pulses of intrusion that have been termed Nipissing suggests an age of around 2.2Ga. Rocks in the Whitefish Falls area have been subject to two distinct periods of deformation. The Blezardian Orogeny, which extended from around 2.1 Ga to 1.95 Ga, produced the east-west trending fold structures with the anticlines tending to be open box folds and the synclines being tight and near vertical (Riller et al., 1999). A younger Penokean event, which occurred around 1.85 Ga produced right lateral shearing and localized northward verging thrusts (Zolnai et al., 1984).
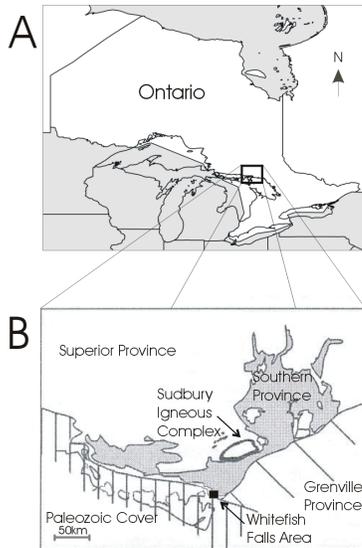
Figure 1: A) Location of the Southern Province along the north shore of Lake Huron; B) Spatial extent of the Huronian Supergroup, which dominates the Southern Province and the location of the study area at Whitefish Falls, Ontario

One of the quartzite units, the Lorraine Formation, forms a distinctive topographic ridge that is readily apparent in all topographic and photographic images of the area. Based on a compilation of then available 1:250,000 aerial photography Dallmeyer and Taylor (1973) argued that the visible quartzite ridge could be explained by a simple single open fold structure. Young (1974), who at the same time had been doing detailed geological mapping in the Whitefish Falls area, countered showing the proposed aerial photographic interpretation was incorrect.

DATA SOURCES

Topographic Imagery

The topographic data used in this study is CDED (Canadian Digital Elevation Data), which was originally derived from stereoscopic interpretation of aerial photographic surveys (Figure 2). While the aerial photographs had a spatial resolution of better than 1m, the resulting topographic data set is limited to a resolution of 50m. The spatial resolution of the calculated topographic image is always significantly less than the spatial resolution of the optical image. In part this arises from a limitation imposed by the requirement of pixel matching to generate topography. However, more commonly the reduced resolution arises because of computational limitations, such as how long one is willing to permit the topographic calculation to run.
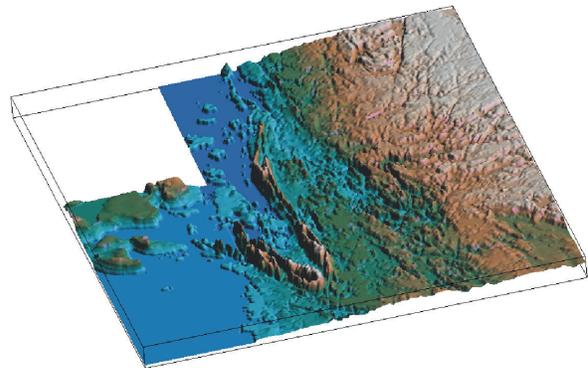

Figure 2: Topographic variation along the north shore of Lake Huron. The Lorraine Quartzite forms a pair of very steep parallel ridges.

The fact that the Lorraine Quartzite makes steep ridges gives a direct indication that the dip of these beds must be near vertical. It is easy to see how this feature could be misconstrued as single open fold structure. On closer inspection a profile across either limb of this supposed fold reveals two topographic highs. As shown by Figure 3 this configuration could have a number of different interpretations: a) north dipping beds, b) south dipping beds, c) a syncline, or d) an anticline. Without any additional information it is impossible to differentiate between
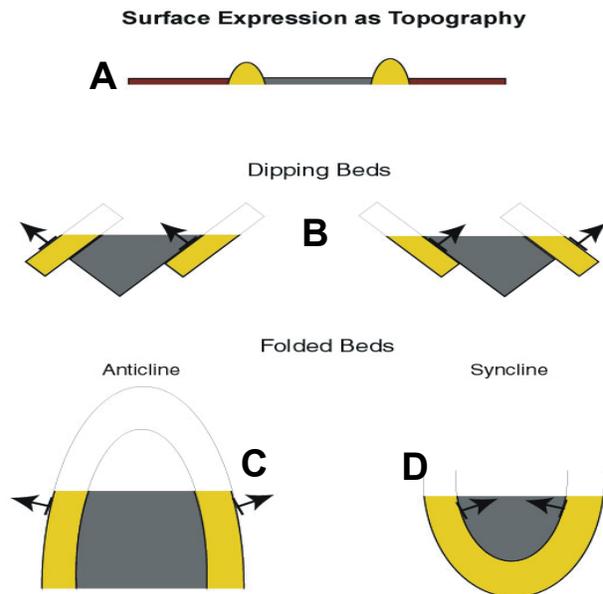

Figure 3: A) Diagrammatic representation of an average N-S oriented profile across the observed topographic surface. B) Possible interpretations of the topographic profile in terms of a pair of south or north parallel dipping beds having similar lithology. C) Possible interpretations of the topographic profile in terms of a synclinal, or anticlinal fold structure. To differentiate between the fold models requires bedding dip information, and/or the direction of younging.

these various options. Critical to making a choice is the requirement for some additional information that could constrain the sense of "younging". For options a) and b) the "younging" direction would be consistent across the profile, while for option c) the beds would young inward from the two ridges, and for option d) the beds would young outward. An alternative approach would be to look for bed repetitions, seen as a common sequence of lithological types.
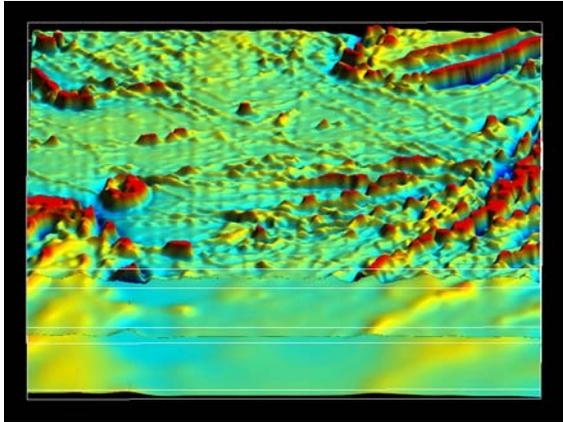
Airborne Magnetic Data

Figure 4: Pseudo-topographic representation of variation of total magnetic field variation over study area. Image based on Ontario Provincial data set after micro-levelling and band-pass filtering to accentuate near – surface sources.
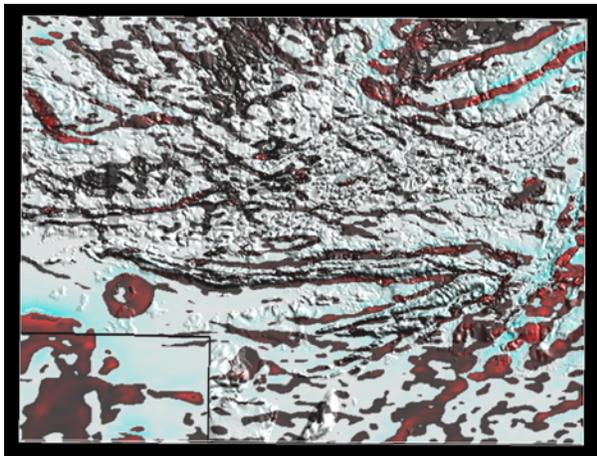

Figure 5: Aeromagnetic data draped over topographic surface. Histogram distribution of magnetic data set is modified to accentuate magnetic highs (red) and lows (blue).

The magnetic data used in this investigation was provided by the Ontario Geological Survey province-wide data compilation. While the original data may have been collected using a finer line spacing the data set was degraded to a uniform 800m grid cell size. Of primary interest for this study are the magnetic signals associated with the near surface lithological units. To emphasize this near-surface contribution and minimize noise

effects the regional data were subject to a standard series of processing steps. Corrugations associated with noise were minimized using a combination of high-pass Butterworth and directional cosine filtering following the proposed microlevelling procedures outlined by Minty (1991). Elimination of the deeper seated source contributions was achieved through the application of a band-pass filter chosen to eliminate long wavelengths which are supposed to represent deeper source bodies. The cut-off wavelengths were selected on the basis of discontinuities in the radially average power spectrum. The resulting magnetic image (Figure 4) shows many apparent similarities to the topographic image shown above (Figure 2). The open fold structure seen in the topographic image is repeated in the magnetic image, but the wavelength of the folds appears to be larger.

Overlaying the magnetic data on the topographic image shows that the magnetic highs present in the TMI image are located on the outer edges of the prominent topographic ridges (Figure 5). The fact that these magnetic highs do not occur in a uniform relationship (both to the south, or vice versa) to the topographic ridges is a clear indication that this feature must correspond to some form of fold structure. The relationship cannot be explained by the parallel dipping beds.

Modelling the magnetic anomalies adjacent to the Quartzite ridge using a simple dipping slab approach provides some indication of the sense of dip of the rock units. This approach assumes that the magnetization in this magnetic rock unit is predominantly induced. However, paleomagnetic studies of the Gowganda argillite, which corresponds to this zone of magnetic high, has shown that these rocks have a strong remanent magnetic signature associated with the production of secondary magnetite as a consequence regional metamorphism related remagnetisation (Morris 1977). Fortunately, the remagnetisation direction is not grossly dissimilar from the Present Earth's Field direction and therefore does not impact on the resulting geometry of the magnetic model.
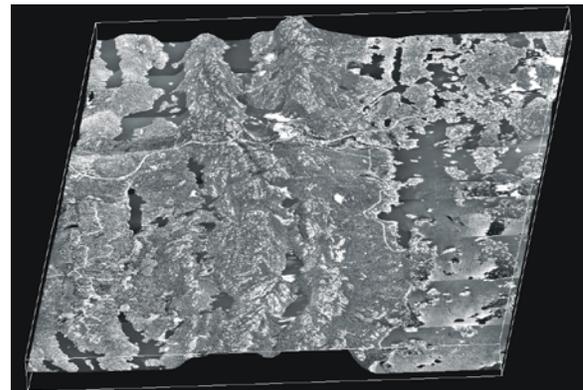
Aerial Photographic Mosaic

Figure 6: Aerial photograph mosaic compiled from 1:50,000 images draped over CDED topography.

Subsequent to the original aerial photography employed by Dallmeyer and Taylor (1973) the Whitefish Falls area has been overflown a number of times using modern camera systems and GPS flight navigation control. An air photograph mosaic of the Whitefish Falls area was compiled using photographic imagery acquired in 1992. To overcome photographic distortion effects and to generate a mosaic in an absolute reference frame compatible with the available topographic data each image was georectified to a calibrated 2002 Ikonos satellite image having a spatial resolution of approximately 4m. Draping the resulting airphoto mosaic over the topographic surface provides a visual rendition of the details of the two topographic ridges. Figure 6 shows how the two ridges are separated by a series of co-linear lakes.

On closer inspection the airphoto mosaic reveals the presence of large-scale bedforms present in the Lorraine Quartzite. These features are not imaged by the current coarse resolution topographic imagery. Rather they are accentuated by the presence of enhanced vegetation. These bedforms indicate that both ridges "young" inward confirming that the parallel ridges describe a tight synclinal structure.

3D Model Development

The steep sided topographic ridges suggest that the Lorraine Quartzite must have a steep bedding dip. Controlled inversion of the magnetic data provides a number of dipping slab solutions. Finally the detailed air photo mosaic shows that the two parallel ridges are associated in a tight synclinal axis. Incorporating these features into a common model suggests that the Huronian sediments along the North Shore of Lake Huron form a series of ENE plunging syncline – anticline – syncline. This interpretation derived from remotely acquired imagery is fully compatible with the ground based mapping results. These elements will be incorporated into a more complete 3D Geomodeller based model.

CONCLUSIONS

By integrating complementary imagery data, such as topography, airborne magnetics and airphoto mosaics we demonstrate that it is possible to derive geologically meaningful models. Inversion of geophysical data provided a number of dipping slab solutions that were subsequently constrained by the airphoto mosaic and topography. Using this data integration approach the topographic ridge of the Lorraine Formation, part of the Huronian Supergroup within the Southern Province, in the area of Whitefish Falls, Ontario was correctly interpreted as a series of ENE plunging syncline – anticline – syncline.
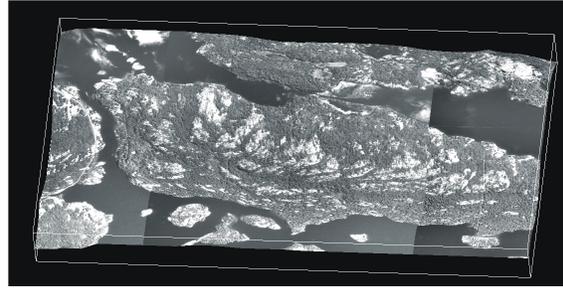

Figure 7: Detailed view of aerial photo mosaic looking from North to South. At this scale it is possible to decipher bedforms in the quartzite that are indicative of "younging" direction.
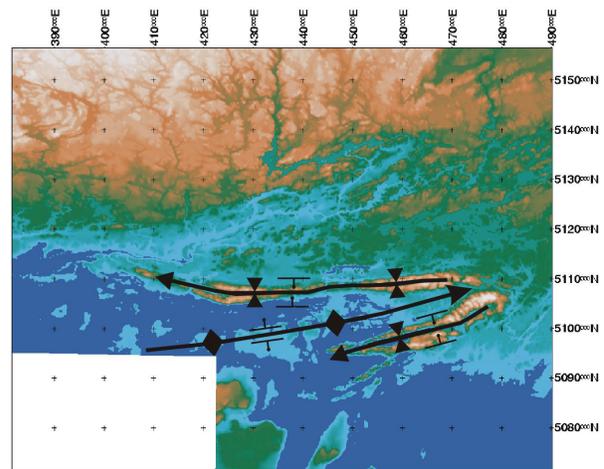

Figure 8: Topography of the area with the final interpretation model of the area.

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