Remote mapping of the 3D Structural Geology 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 airphoto mosaic to provide a spatial reference for geological field mapping project. Nowadays DGPS sensors and accurately georeferenced satellite imagery 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. In this study we present an example where an original air photo analysis lead to an incorrect geological structural model. By looking at the same region and integrating aeromagnetic data and a more detailed assessment of the aerial photography, we show that it is possible to achieve the correct geological structural model.

REGIONAL GEOLOGY

Sedimentary rocks of the Huronian Supergroup within the Southern Province outcrop along the north shore of Lake Huron, Ontario (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. 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 (Figure 2). Based on a compilation of the then available 1:250,000 scale aerial photography Dallmeyer and Taylor (1973) argued that the visible quartzite ridge could be explained by a simple open fold structure. Young (1974), who at the same time had been doing detailed geological mapping in the Whitefish Falls area, responded demonstrating that the proposed aerial photographic interpretation was completely incorrect.

DATA SOURCES

Topographic Imagery

The topographic data used in this study is CDED (Canadian Digital Elevation Data), which was originally computed from the aerial photographic surveys (Figure 2). The DEM was computed using a standard minimum curvature gridding algorithm (Oasis Montaj by Geosoft) using a 50m grid cell size. Rendering of the DEM as a 3D image was achieved using ER Mapper.

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 have been mis-interpreted as a open fold structure. On closer inspection a N-S profile across either limb of this supposed fold reveals two distinct topographic highs (Figure 3). This morphology could have a number of geological 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 these four options. Critical to making a choice is some knowledge regarding the sense of "younging" or way-up. For uniformly dipping beds the sense of younging is constant across the section, while folded beds have opposing younging directions on opposing limbs of the fold (Figure 3).An alternative approach would be to look for lithologic repetitions. Any fold structure will exhibit a mirror repetition of lithologies about the central fold axis plane (Figure 3).

Aeromagnetic Data

The magnetic data used in this investigation is derived from the Ontario Geological Survey Province-wide data compilation. Standard noise minimisation (microlevelling) and band-pass filtering techniques were used to accentuate anomalies associated with near-surface magnetic sources. 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 (Figure 4). 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 the magnetic highs demonstrate a clear mirror image repetition is a clear indication that this feature must correspond to some form of fold structure.

Modelling the magnetic anomalies on either side of the Quartzite ridge using a simple dipping slab approach could theoretically provide some estimate of the sense of dip on either limb of the fold. Unfortunately in this situation both the dip of the bedding and the dip of effective magnetic vector are very steep. Further the magnetic anomalies associated with each of the fold overlap. And it must be remembered that this coarse regional scale data. In this situation deriving any estimate of the dip of the beds would be precarious (Figure 6).

Aerial Photographic Mosaic

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 for the Whitefish Falls area has been constructed using 1:50,000 photographic imagery acquired in 1992. Accurate georeferencing of each individual photograph was achieved by reference to a single calibrated 2002 Ikonos image having a spatial resolution of 4m (Figure 7). Draping the resulting mosaic over the topographic image shows that the two ridges are separated by a series of co-linear lakes (Figure 7).

On closer inspection the airphoto mosaic reveals the presence of large-scale bedforms in the Lorraine Quartzite (Figure 8, 9). The features are not imaged by the current coarse resolution topographic image, and they were not apparent in the 1:250,000 imagery examined by Dallmeyer and Taylor (1973). Comparing the geometry of these features to the regional bedding it is possible to show that for both ridges the sense of "younging" is inward towards the common fold axis(Figure 8). This arrangement can only be compatible with a tight synclinal structure.

CONCLUSIONS

By integrating complementary imagery data, such as topography, airborne magnetics, and airphoto mosaics it is possible to derive geologically meaningful structural models. Using this data integration approach we are able to REMOTELY map the topographic ridge associated with the Lorraine Formation, part of the Huronian Supergroup within the Southern Province as a series of ENE plunging syncline - anticline - syncline (Figure 9) in complete agreement with the field mapping acquired by Young (1974).

In this example additional stratigraphic constraint was provided by the aeromagnetic data. However, inversion of the magnetic data could not differentiate the type of fold present. This was resolved by careful examination of the high -resolution airphoto mosaic.

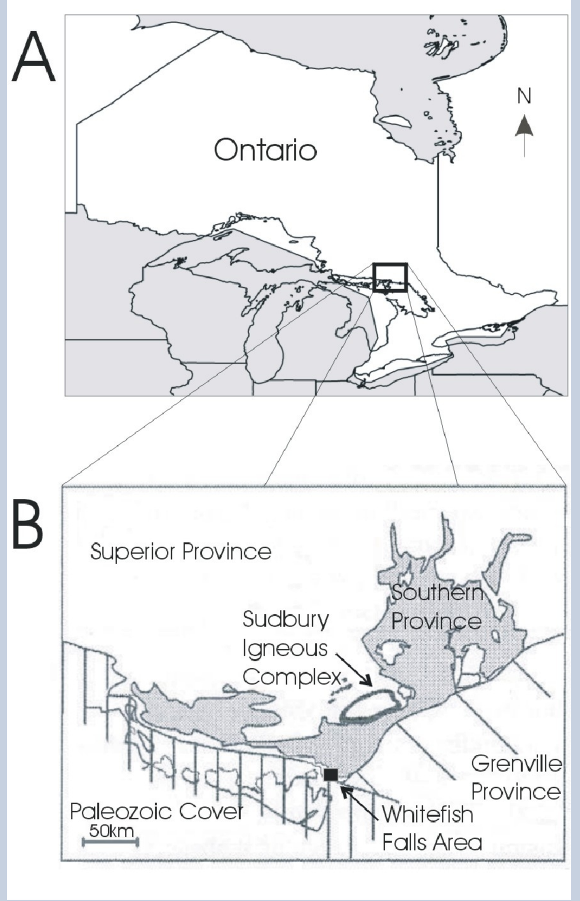

Figure 1
A) Location of Southern Province on north shore of Lake Huron.
B) Spatial extent of Huronian Supergroup

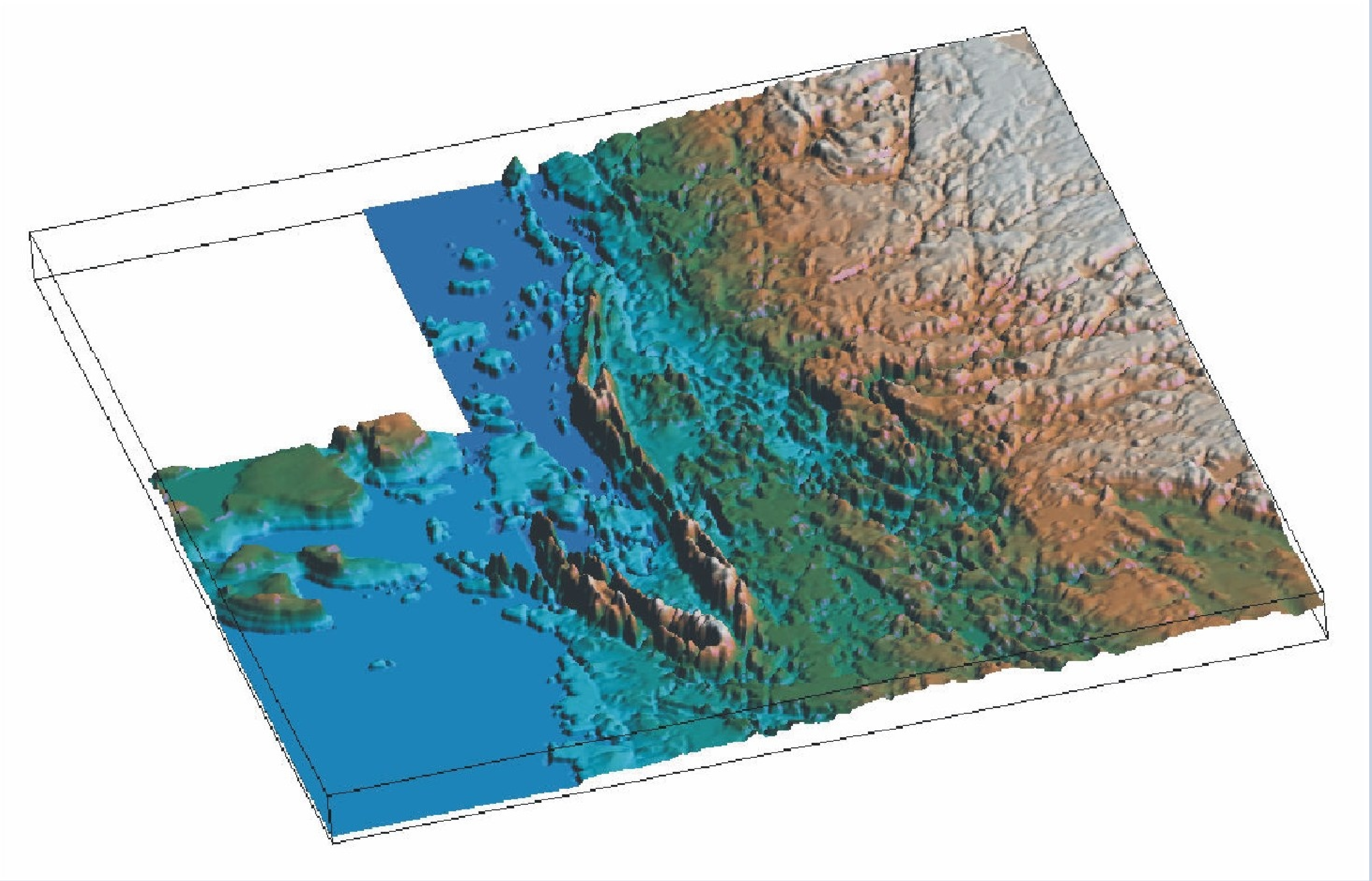

Figure 2
Topographic variation along north shore of Lake Huron. The Lorraine Quartzite forma a pair of very steep parallel ridges.

DEM surface was computed from CDED data using a 50m grid cell and a minimum curvature gridding algorithm (Oasis Montaj, Geosoft
Visualisation of the DEM was performed in ER Mapper.

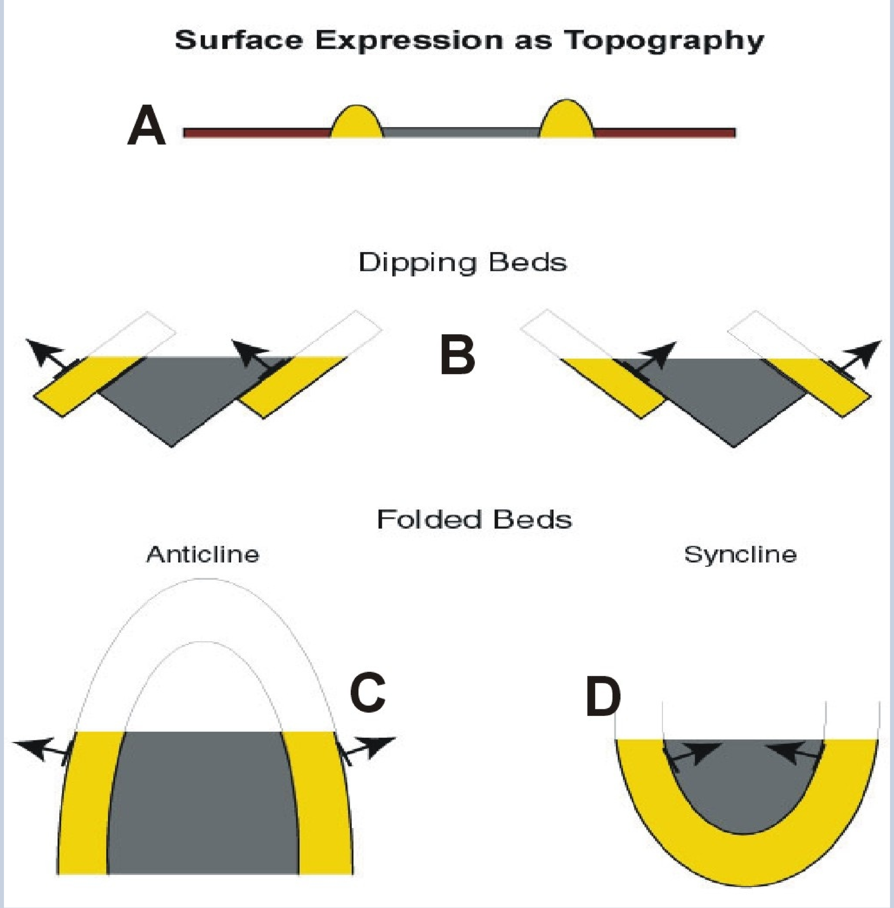

Figure 3
A) Diagrammatic representation of topographic variation along an average N-S profile.
B) Possible interpretation of topographic profile in terms of parallel dipping beds.
C, D) Possible interpretations of topographic profiles in terms of anticlinal, or synclinal folds

To differentiate between the models requires bedding dip information, and /or the sense of younging

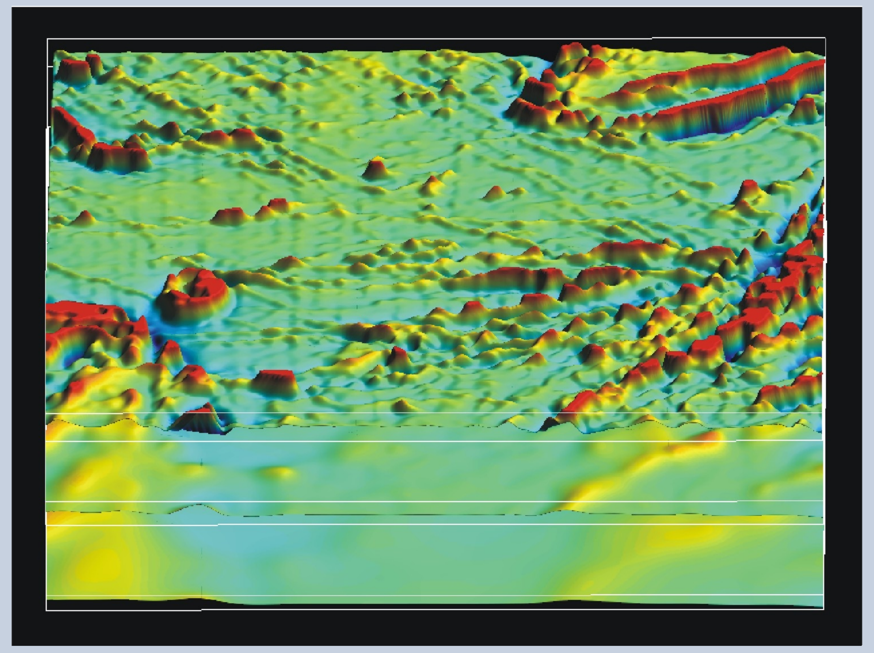

Figure 4
Pseudo-topographic representation of TMI variation over study area. Image based on Ontario Provincial data set after micro-levelling and band-pass filtering to accentuate near surface sources.

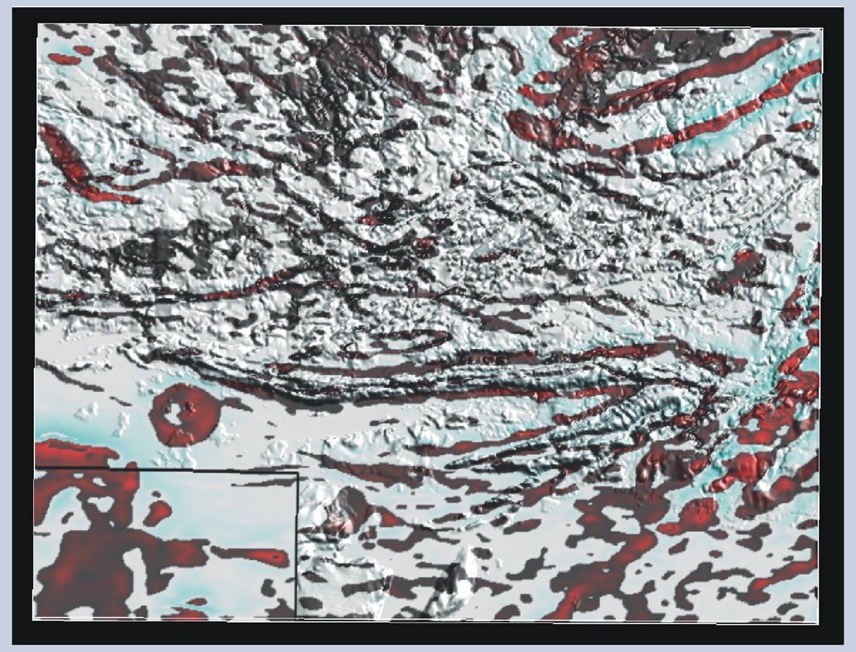

Figure 5
Aeromagnetic data draped over topographic surface. Histogram distribution of magnetic data is modified to accentuate magnetic highs (red) and lows (blue).
Mirror image repetition of magnetic high about topographic ridges provides definitive evidence for a fold structure.

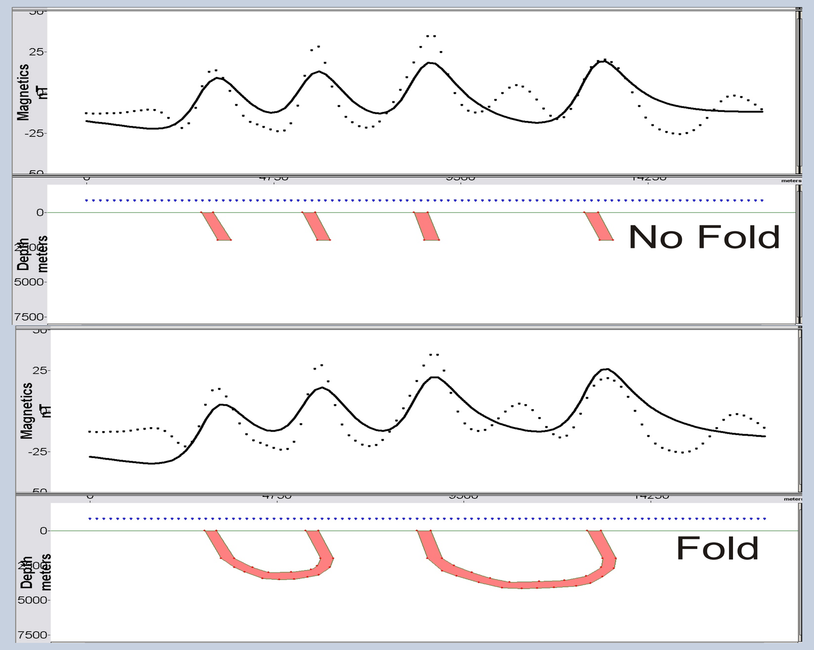

Figure 6
Comparison of simple fold and no-fold model magnetic inversion model computer on N-S profile across topographic ridge.
Inversion cannot differentiate form of fold present because of a) steep dip of bedding and effective magnetic vector, b) coarse regional scale resolution of magnetic data, and c) overlap between adjacent magnetic anomalies.

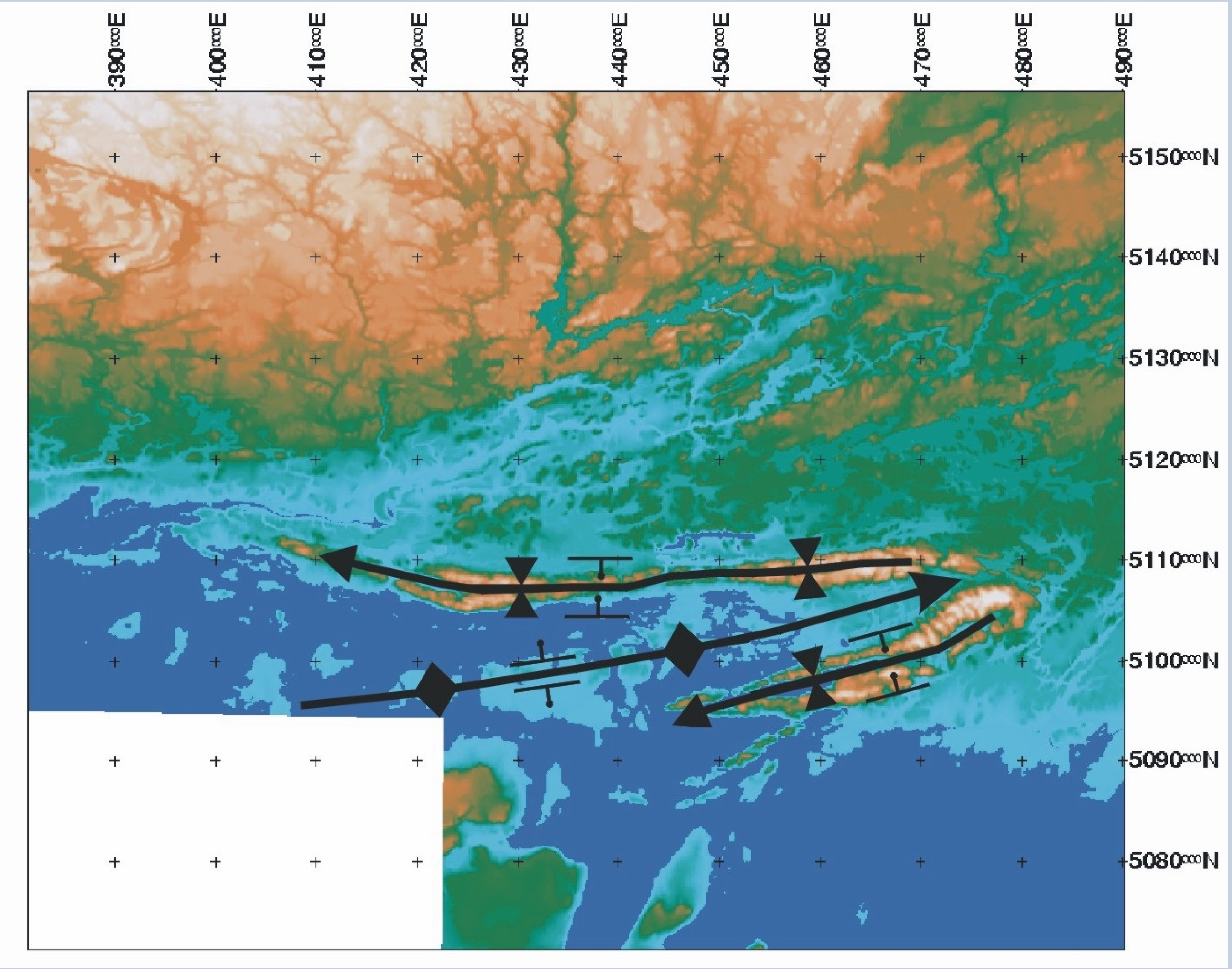

Figure 9
Final structural model for Huronian Supergroup along north shore of Lake Huron remotely derived from integration of topography, aerial photography and aeromagnetic data.

From North to South the regional structure comprises a series of ENE plunging syncline - anticline - synclines. The synclines are very tight with near very limbs, while the anticline is very broad.

While the topographic data alone appears to suggest a simple open fold structure as originally suggested by Dallmeyer and Taylor integration of the aeromagnetic data suggests that the Quartzite ridge actually represents some form of fold structure. New higher - resolution aerial photography contains sufficient resolution to distinguish the presence of bedforms which permit discrimination of steep synclinal axis associated with the paired Quartzite ridges.

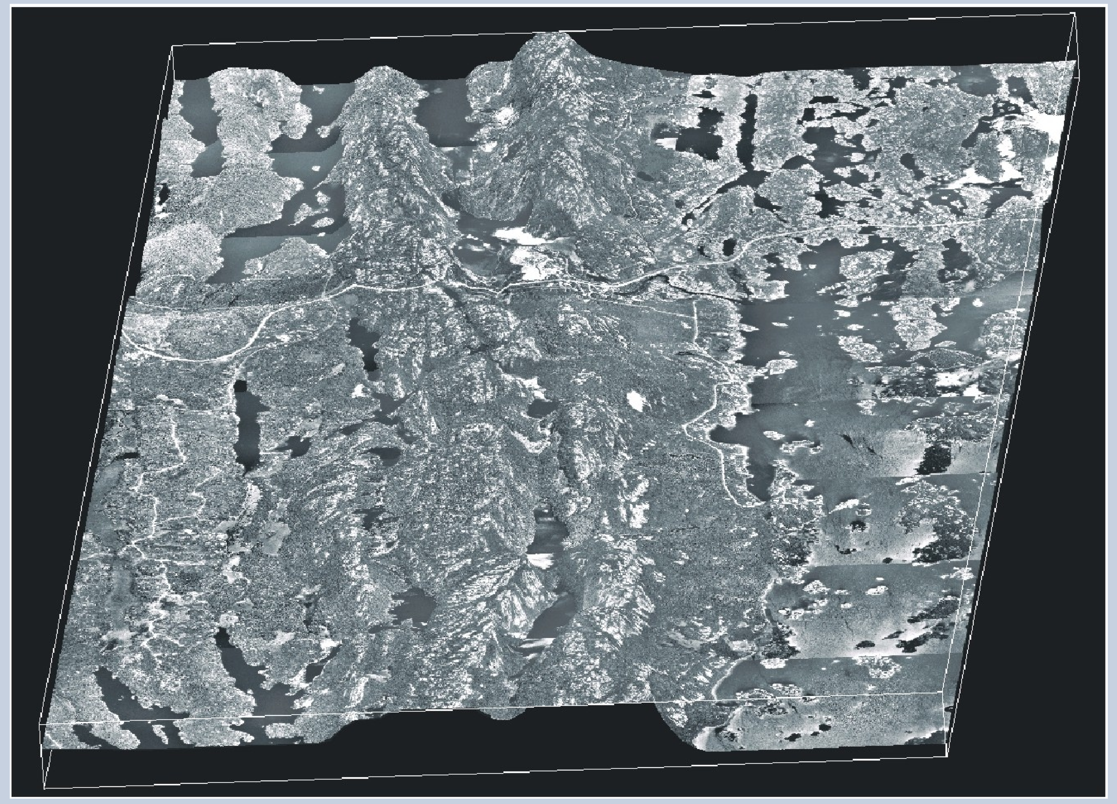

Figure 7
Airphoto mosaic of Whitefish Falls area compiled from 1992 1:50,000 images draped over CDED topography. Each airphoto was georeferenced to a single 2002 4m resolution Ikonos image.

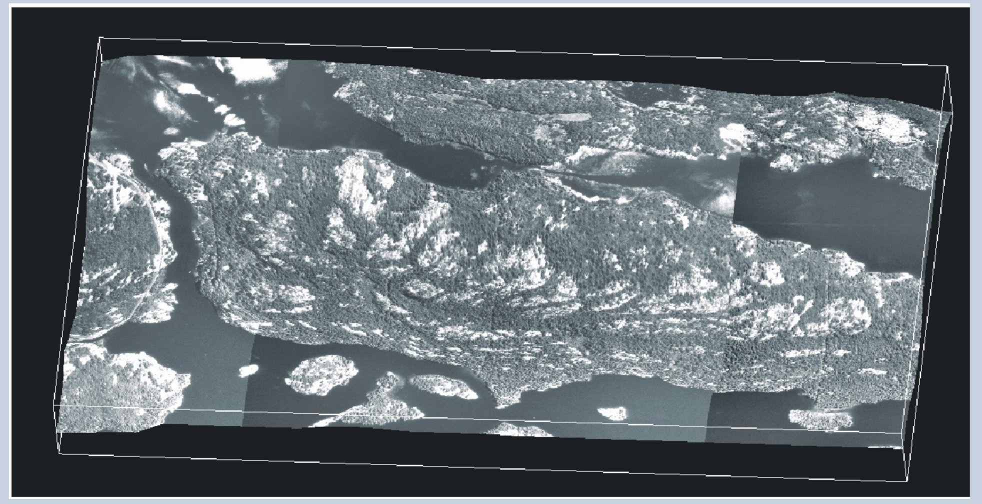

Figure 8
Detailed view of aerial photo mosaic looking from North to South. At this scale it is possible to decipher bedforms in the Quartzite that are indicative of the younging direction.