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Effective methods to highlight and delineate anomalies from geophysical images

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SUMMARY

Geophysical data interpretation is largely an anomaly detection task which involves recognising and synthesising anomalous patterns within single or multiple datasets. The accuracy and efficiency of these interpretations heavily relies on the skills and practices of interpreters, thus the greatest challenge is to minimise personal biases to produce objective and consistent interpretation outcomes. We present an innovative data visualisation method which can empower interpreters to effectively delineate anomalies of varying frequency scales within aeromagentic data using a single image display. This is achieved by harnessing the power of image enhancement and visualisation techniques to assist interpretation.

We adapted and extended the use of colour composite techniques to present different frequencies presented in potential field data. Aeromagnetic data from an area in Kirkland Lake, Ontario, Canada is used for our experiment. long wavelength and short wavelength anomalies are identified from the data using low pass- and high pass filters respectively. These two different frequency enhanced images and the original image are represented as separate colour channels which are then combined to generate a composite image. The luminance of the composite image is scaled to highlight high frequency signals as they hold the key for detailed structure interpretation. We use a technique called dynamic range compression, which preserves the integrity of the phase component of the signal while performing high pass filtering. The resulting display is compared to the geological map of the area to validate the effectiveness of the method. The proposed technique is widely adaptable for different types of datasets.

Key words: aeromagnetic data enhancement, data fusion, data interpretation

INTRODUCTION

The utilisation of aeromagnetic data is a standard practice for mineral exploration, as they can be collected at a relatively low cost for a large spatial extent of the area being explored. Aeromagnetic data can be used to map geology, and in poorly exposed, inaccessible or little-studied geological terrains, these data may be the only means of assessing the local geology. Geological interpretation of aeromagnetic data (or any other geoscientific data) is a challenging task as interpreters need to understand complex natural events using sub-sampled and often ambiguous observations. These interpretations are highly subjective and often inconsistent as the interpreter's biases such as presuppositions and expectations play an important role (Frodeman, 1995).

Aeromagnetic data interpretation typically involves the detection of anomalous patterns within data. One important aspect is to understand relative depths of causative sources of anomalies. Potential field theory dictates that the deeper the source, the lower the frequency of its signal. A standard practice to capture different levels of frequency is upward and downward continuation which simulates the effect of flying a survey a higher or lower altitude respectively. Upward continuation (i.e. a form of low pass filtering) smooths out high frequency signals to suppress the effect of shallow anomalies. In contrast, downward continuation (i.e. a form of high pass filtering) enhances high frequencies to highlight shallow anomalies (Millgan & Gunn, 1987).

For aeromagnetic and other potential field data, low pass filtering is commonly achieved using the upward continuation filter. High pass filtering can be achieved through downward continuation as well as different edge (or source boundary) enhancement techniques. They include the use of horizontal gradients (Blakely and Simpson, 1986); multi-scale derivative analysis (Fedi, 2002; Cella et al. 2009); and phase based edge detection (Cooper and Cowan, 2006).

This paper presents an aeromagnetic data display method to facilitate a perceptual separation of different levels of frequencies in a single display using colour channels. Further, image luminance is adjusted based on the local high frequency signal content to assist in anomaly detection. For geological interpretation, colours will allow clear separation of signals from deeper and shallow geological sources, and combined with high frequency enhancement, it provides a visually effective display towards identifying near-surface lithological boundaries and shear zones. In our experiment, a recently proposed high pass filtering method, namely Phase Preserving Dynamic Range Compression (PPDRC) (Kovesi, 2012) is employed. We used an aeromagnetic data from a region from the Archean Abitibi greenstone belt in the Superior Craton, Ontario, Canada. The resulting colour display is compared to the geological map of the area to understand the impact of the proposed display method for geological interpretation. In addition, comparison with an automated lineament detection output from using another high pass filtering method shows a close correlation to visual feature boundaries presented in the proposed display.

METHOD AND RESULTS

METHOD: Given an input aeromagnetic image, our approach is firstly to generate a composite colour image consisting of low pass filtered image, high pass filtered image and the input image. Then the luminance of the colour display is adjusted using the high pass filter output. The processing steps are described below.

1. *Generate a low pass filtered image*: A standard upward continuation filter is applied to the input image to simulate the survey at a specific height above ground. This output allows the detection of relatively deep anomalies.

2. *Generate a high pass filtered image*: The PPDRC high pass filtering algorithm (Kovesi, 2012) is applied. This allows high pass filtering of an image by analysing local frequencies. In the high pass filtering process, it analyses local high spatial frequency range to separate the phase and amplitude information of the image. Then in reconstructing the image, it preserves the phase values, while applying a range reducing function to the amplitude values, e.g. taking the logarithm. This algorithm suppresses the influence of very high magnitude anomalies in the image. The advantage over other algorithms such as the automatic gain control filter (Rajagopalan and Milligan, 1995) is that it doesn't over-normalise the data. Another advantage of this method is the compression of a large data range presented in the image (typical for aeromagnetic data) whilst preserving anomaly features, which is important for an effective contrast visualisation for interpreters.

3. *Generate a composite RGB image*: The output images from Steps 1 and 2, as well as the input aeromagnetic image are used to generate a 3 channel composite image. The high pass output (from Step 2) is presented in the red channel; the input aeromagnetic image in green; and the low pass output (from Step 1) is presented in blue.

4. *Scale Luminance using the High Pass Filter Output*: The composite RGB image is converted into the HSV (Hue Saturation Value) colour space where H represents colour; S represents the whiteness of colour; and V represents brightness/luminance. Then the V component of the image is adjusted based on the high pass filter output generated from Step 2. Note that this step is to emphasise high frequencies in data to aid anomaly tracing.

DATA: The Kirkland Lake – Lader Lake gold belt test area is in the southern Abitibi greenstone belt of the Archean Superior Province of Canada. This is a mature exploration area where the granite-greenstone terrain hosts a number of world class and smaller gold deposits and occurrences (Figure 1; Ispolatov et al., 2008). Generally, gold mineralisation is spatially located close to the Larder Lake deformation zone. The largest deposit in the area is the Kirkland lake deposit located approximately 2 km north of the deformation zone along a fault in the Larder Lake deformation zone. The aeromagnetic data of this region is shown in Fig. 2. This data was acquired along north-south survey lines spaced at 200 m and with a nominal terrain clearance of 73 m. The gridded aeromagnetic image has a 40 m spacing.

RESULT: The high pass filtered image is generated by applying PPDRC using a high pass cut off frequency of 1/80 (in pixels). This is shown in Figure 3(a). The upward continued data is generated (Figure 3(b)) to simulate the survey at 150m height above ground. This and the input aeromagnetic image are both histogram equalised. After normalising these images, the colour composite image is formed by representing PPDRC image, the input aeromagnetic image, and the upward continued image in red, green and blue channels respectively. Then the composite RGB image is converted into a HSV image, and the luminance (V value) is scaled by normalised PPDRC values. The resulting image is shown in Figure 3(c).

DISCUSSION: The resulting composite image is assessed using a geological map of the area, and also using lineaments that are automatically detected.

The geological map (Figure 2) shows that visible colour boundaries (i.e. representing separation of frequencies) in our composite display are closely correlated with the lithological boundaries shown in the geological map. Low frequencies in data are associated large scale geological units such as Timiskaming assemblage and lower Tisdale assemblage (lower unit). The upper Tisdale assemblage, comprising intermediate to felsic volcanic rocks however, defines a region of low magnetic intensity, and dominantly shorter wavelength anomalies. Our result clearly shows this region to be different to the surrounding units, characterised by low magnetisation at depth, with superimposed short wavelength magnetic highs. Intrusions have varied responses, but mostly have intense high luminance boundaries.

Another test is assess the visual impact using an automated lineament detection output from CET Grid Analysis Extension (Holden et al., 2010) for Geosoft Oasis Montaj. Using a combination of texture analysis and phase based ridge detection, lineaments are automatically delineated from the aeromagnetic data. These lineaments are overlaid on the composite display in Figure 3(d). It clearly shows a close correlation between the enhanced visual features in the display method and the lineaments.

CONCLUSIONS

This paper presented a visualisation method for aeromagnetic data to assist geological mapping. The proposed colour composite display shows clear separation of deep and shallow sources and enhanced high frequencies within a regional aeromagnetic data, which correlates well with local geology of the area. The ability to characterise, in one image, both intensity and wavelength is a significant advantage when interpreting geology under cover.

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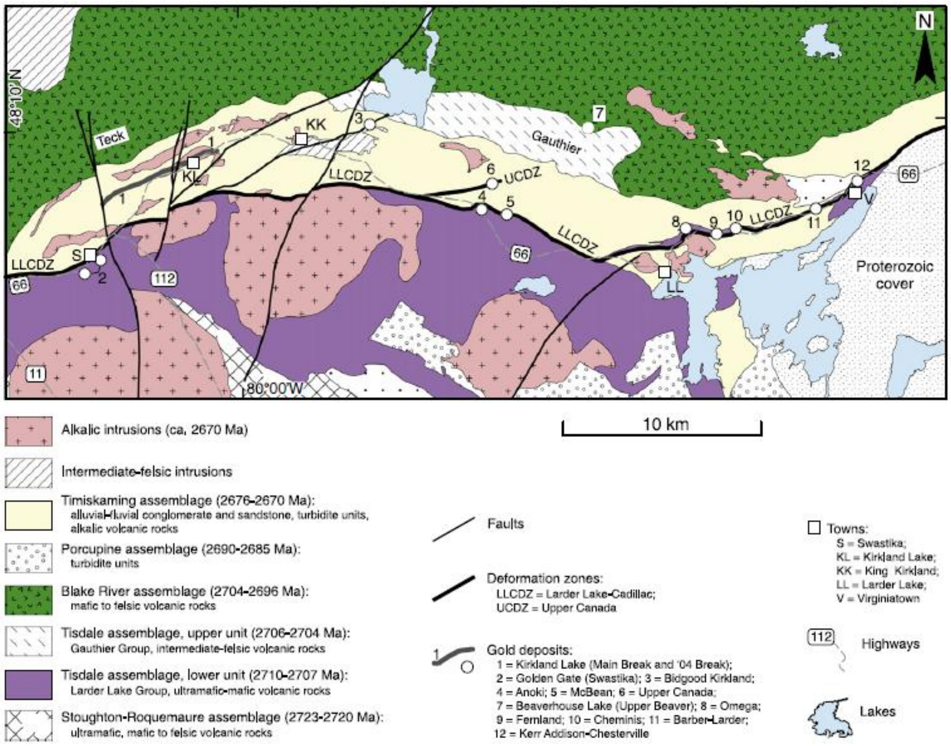

Figure 1: Generalised map of the Kirkland Lake–Larder Lake gold belt (Ispolatov et al., 2008).

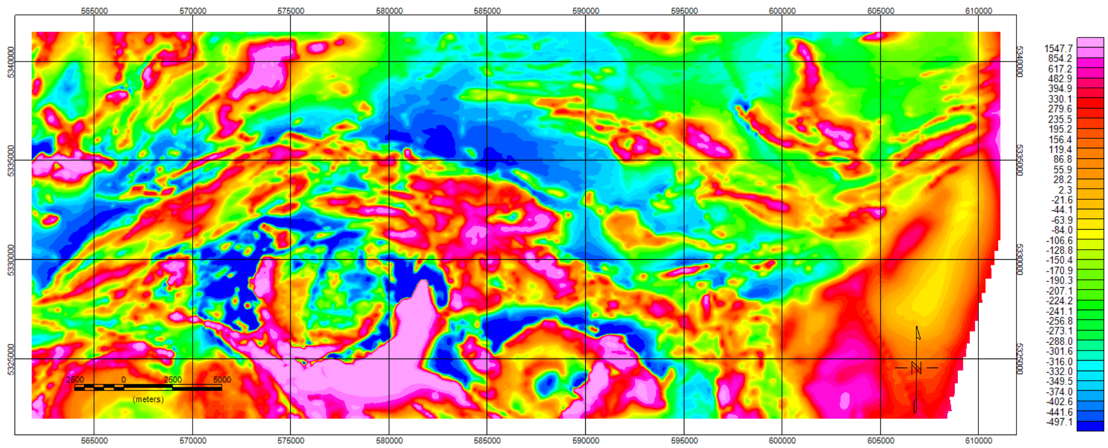

Figure 2. Aeromagnetic data from an area in Kirkland Lake–Larder Lake gold belt (Geological Survey of Ontario, Canada), which is displayed after histogram equalisation.

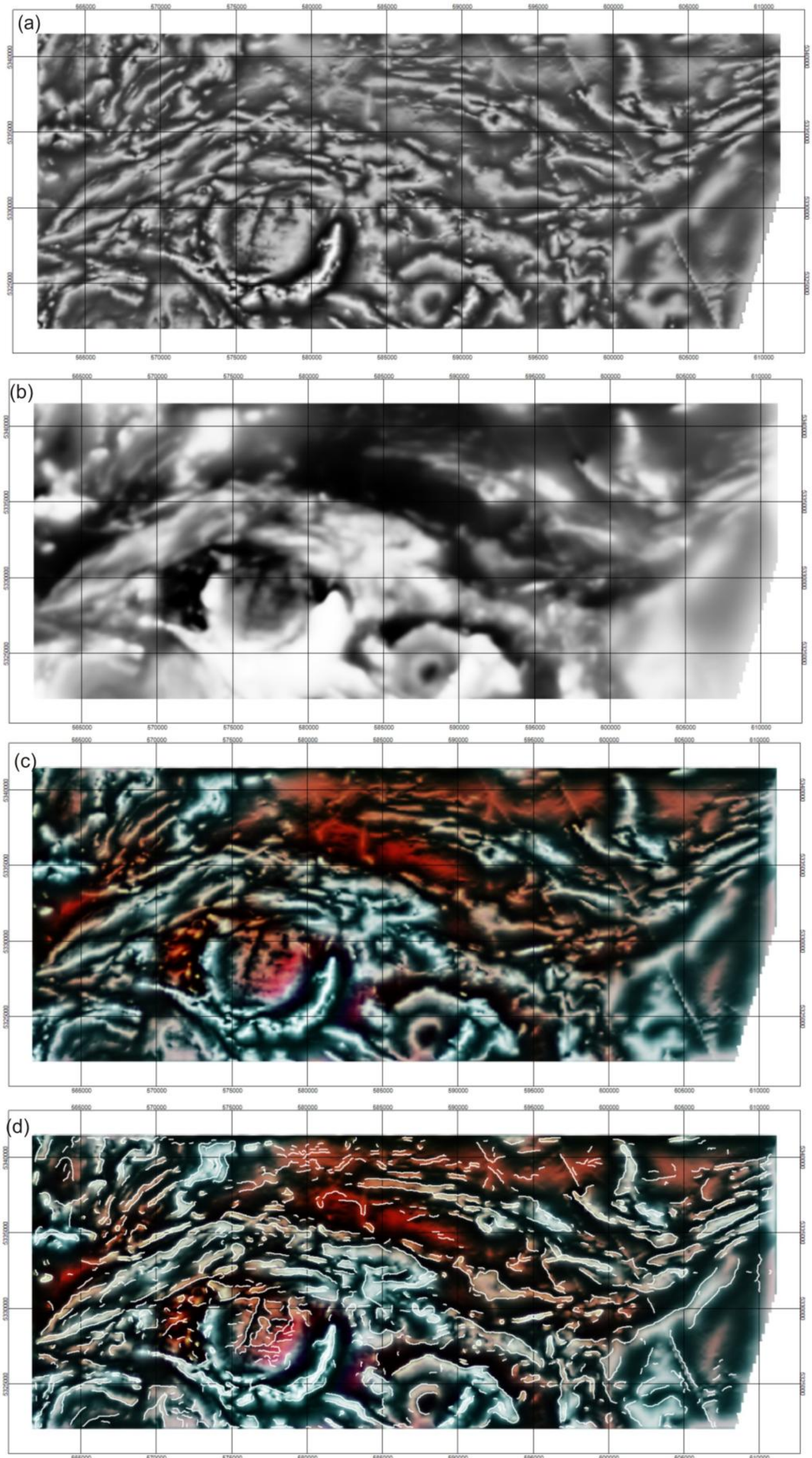

Figure 2. (a) DRC high pass filtered image displayed using 256 gray scale; (b) Upward continued image at 150 metres, displayed using 256 gray scale; (c) the proposed colour composite image with enhanced luminance; (d) automated lineament detection output overlaid on (c).