Improved edge detection in potential field maps and graphical estimation of depth-to-the-top

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Summary

We present an algorithm that improves the detection of minor anomalies and patterns in potential field maps. Its use in conjunction with standard edge detection algorithms provides a tool for visual estimation of depth-to-the-source in gravity and magnetic maps.

Introduction

In traditional visual interpretation of potential field maps, trained geoscientists analyze the main anomalies in the signal in order to relate them to geological structures underground.

The recognition of anomalies and patterns is closely related to 'edge detection' in image processing. Blakely and Simpson (1986) proposed edge detection algorithms to locate the horizontal extent of sources in gravity and magnetic maps.

The work of Mallat and Zhong (1992) gave a formal mathematical interpretation to the role of edges within the framework of multiscale analysis and wavelet theory. They showed that the set of multiscale edges contains the same information as the original image, yielding new powerful tools for image processing.

More recently Hornby et al. (1999) extended Mallat and Zhong's theory to the analysis of potential fields. It was shown that the multiscale edges (which we colloquially call 'worms') contain information about the location and type of anomalous geological sources. New tools, specifically designed for the analysis of potential field maps were envisaged, with application to feature removal, de-noising and inversion.

In this abstract we propose an accurate edge detection method that attempts to overcome some limitations in standard algorithms. Its applications include enhanced detection of anomalies and structures in images, as well as visual estimation of the depth-to-the-top of anomalous sources.

Edge picking algorithm

Edge detection is a major topic of research in image processing. Many definitions of 'edge' are currently available. One of the most widely accepted is one where an edge is a local maximum in the slope of a signal along its local gradient. Many different algorithms are available to implement such a definition.

When applied to gravity images (or magnetic images after performing a pseudo-gravity transformation) such algorithms may 'miss' edges close to large anomalies. A typical case is a dyke intersecting a large body. Figure 1 shows a synthetic example. We have a large square deep body in the center and two smaller perpendicular dykes forming a cross and cutting the large body.

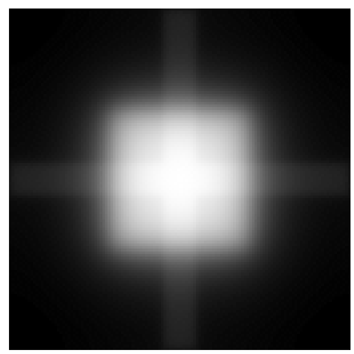

Figure 1. The gravity response of a large body cut by two perpendicular dykes.

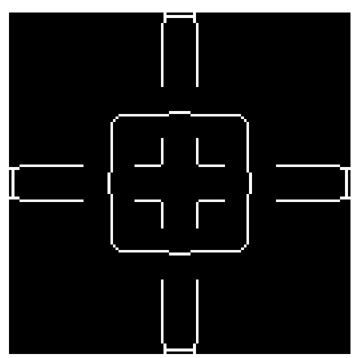

Figure 2. Results from a standard edge detection algorithm applied to the gravity image of Figure 1.

The result from the standard edge-picking algorithm is shown in Figure 2. The large body is clearly detected. The dykes are detected far from their intersection with the central body. Close to the intersections however, the dyke edges are not detected.

The reason for this effect lies in the fact that the local gradient at such locations is predominantly due to the large body and perpendicular to it. Since the algorithm looks for edges along the gradient, the edges due to the dykes near the main body's edges are missed.

One approach to solving this problem is to detect edges in sharper images, i.e., in images where the effect of adjacent bodies is reduced. First vertical derivative (1^{st} VD) images of potential field maps are well suited for this purpose. However a modification to the edge-picking algorithm is required before applying it to 1^{st} VD images in order to avoid the detection of spurious edges.

Figure 3 shows the gravity response of a point source. Two edges are generated, one on each flank of the response.

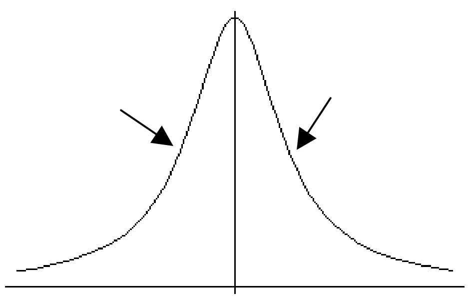

Figure 3. Edges on the gravity signal due to a point source.

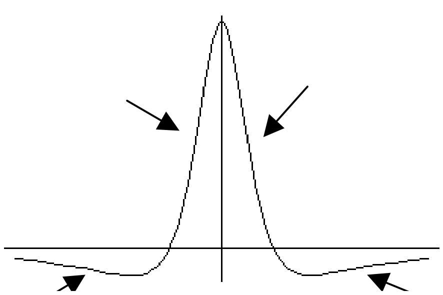

Figure 4. Edges on 1^{st} VD of the gravity signal due to a point source.

Figure 4 shows the 1^{st} VD response to a point source. Because of the shape of the response, four edges exist, two on the positive flanks and two on the negative ones. Our algorithm is designed to recognize the two edges on the negative flanks and reject them. Also notice that, since the 1^{st} VD signal is sharper, such edges are closer to the source.

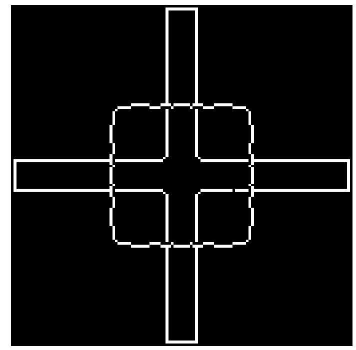

Figure 5. Improved edge detection on gravity image in Figure 1.

Figure 5 shows the result of the proposed algorithm on the test case. Now the dykes are properly detected even close to the large body. Our practical experience with real data confirms that this algorithm is able to detect structures that would have otherwise been missed by standard algorithms, as well as by visual inspection of images.

Visual estimation of depth-to-the-top

In Hornby et al. (1999) we proposed the use of multiscale edges for the analysis of potential field data. Multiscale edges are generated by detecting edges on images at different levels of upward continuation. Examples of the application of this technique can be found in Archibald et al (1998).

While the edge detection algorithm we proposed above improves the detection of smaller anomalies, standard algorithms detect larger anomalies equally well (e.g. compare Figures 2 and 5 for the large body). However, the edges picked on the standard gravity images and the ones picked on the 1^{st} VD images behave differently at different levels of upward continuation. This is due partly to the fact that the 1^{st} VD edges are closer to the source and partly to the different way the signals are affected by interacting anomalies.

Figure 6 shows two sets of multiscale edges due to a synthetic dyke, plotted on top of its gravity response. The inner set of edges is due to the 1^{st} VD field and the outer set is due to the gravity field. The two sets of edges tend to diverge at increasing heights. More importantly the opposite is also true: the two sets of edges converge at decreasing height, each getting closer to the source. At the source location the two sets intersect. This is easily understood by imagining the sharpening of Figures 3 and 4. Both the gravity response and its 1^{st} VD reduce to a delta function at the source location where both sets of edges coincide with the source itself.

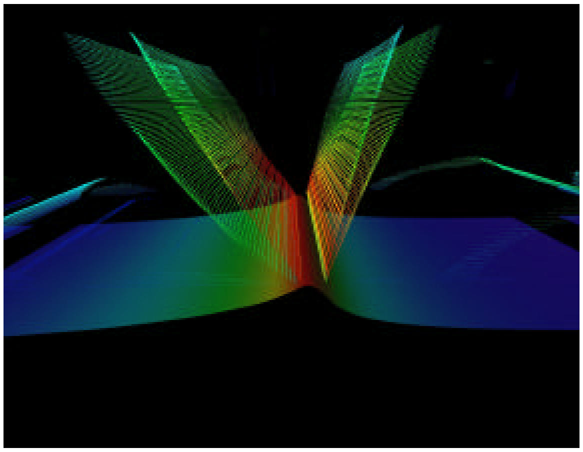

Figure 6. Multiscale edges from 1VD signal (inner edges) and standard gravity signal. They converge toward the top of the source.

This phenomenon can be used to obtain a visual estimation of the depth-to-the-top.

Examples

Figure 7 is a synthetic example, showing a thin dyke (its width is exaggerated for visual purposes) with a notch in its upper border. Its top is located 10 meters below the flight height on the left side and 20 meters below on the right side.

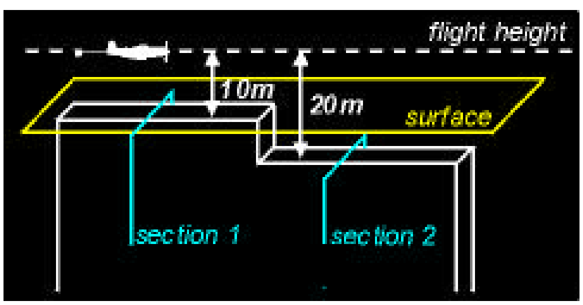

Figure 7. Synthetic model of a dyke buried at different depth.

Map view data are modeled in 2D and upward continued to different heights. To help visualize the results, the worms for the two vertical cross-sections (sections 1 and 2 in Figure 7) are plotted in 2D and displayed in Figures 8 and 9.

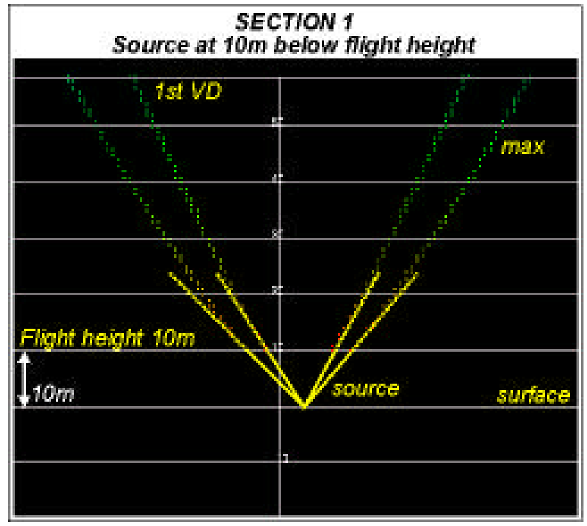

Figure 8. Multiscale edges on section 1 in Figure 7. The depth-to-the-top is correctly found at the intersection of the inner with the outer sets of edges. Yellow lines are tangent to the lower part of the multiscale edges.

Figure 8 shows the multiscale edges from both the gravity and the 1st VD fields in the plane of section 1. The edges are detected between the flight height and the maximum level of upward continuation. Then the two sets of edges are visually 'continued' downward (using a local tangent) until they meet. In this example, they meet at a single point. This point is 10 meters below the flight line, as expected. If the synthetic dyke had been wider than one pixel thick, the two sets of edge continuations should define two intersections, one on the left border, and one on the right.

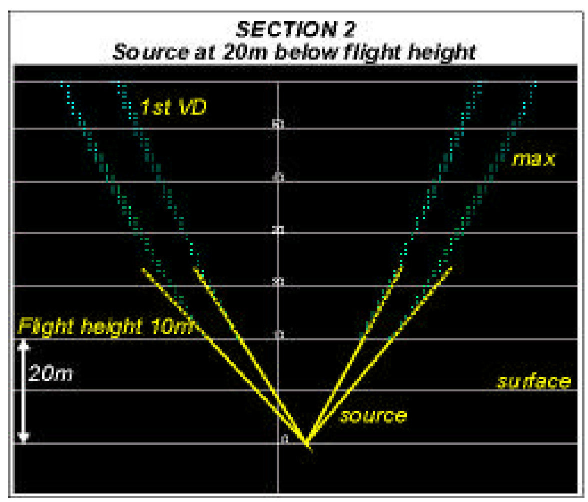

Figure 9. Multiscale edges on section 2 in Figure 7. The depth-to-the-top is again properly estimated at 20 meters.

Figure 9 shows the same technique applied to section 2. Now the depth-to-the-top is 20 meters and the sets of edges intersect at the correct depth.

Finally, an example of application to real data collected in a gravity survey in Australia in presented in Figure 10.

Discussion

Potential field inverse problems are known to be highly non-unique. Accordingly any 'inverse' result, including estimation of depth-to-the-top, has to rely either on additional information or on 'a priori' assumptions. In the method just described no additional information is used. The 'a priori' assumption implicit in our approach is that we look for sources that are compact and sharply bounded. Simply put, "rocks have edges".

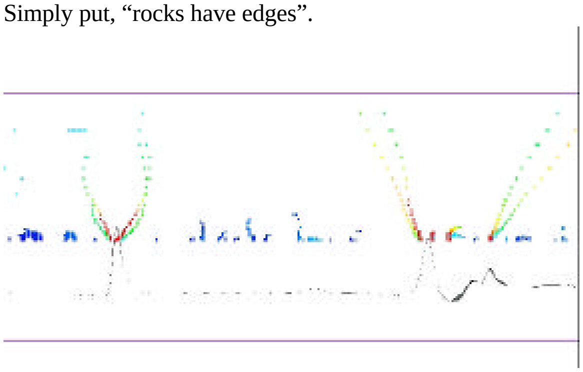

Figure 10. Multiscale edges on a real gravity profile. The lower set of points (black) is the gravity profile. The upper, colored sets of points are the picked edges. Near each main anomaly, the inner sets of points are edges in the 1st VD, and the outer sets are edges in the gravity field.

Currently the method is aimed at interpreters with experience or training in its use. We anticipate them combining information from the multiscale edges with their geological knowledge of the area. The implementation of an algorithm for a numerical estimation of the depth-to-the-top is under development.

Conclusions

Image processing tools based on multiscale wavelet analysis can greatly enhance the traditional visual interpretation of potential field maps. Since they are based on solid mathematical foundations, they offer tools that are rigorous yet easy to understand. They are incorporated into traditional geophysical/geological analysis in a user-friendly manner. The method we presented in this abstract fits nicely with this approach. It enhances the traditional visual interpretation of gravity and magnetic maps and provides a tool for estimation of depth-to-the-top in a purely visual/graphical fashion. Moreover, no new software is needed, since the 1st VD is a standard transformation in geophysical applications.

References

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Acknowledgements

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