ANALYSIS AND INVERSION OF POTENTIAL FIELD DATA IN THE WAVELET DOMAIN

ABSTRACT

By analysing potential field data in the wavelet domain and performing a multi scale edge detection we can automate what in geologic jargon is commonly called 'worm analysis', i.e., the traditional visual inspection of gravity and aeromagnetic data in order to detect shallow faults, lineaments, contacts etc. More importantly, with the use of an appropriate wavelet, defined by the physics of the problem, information about the depth extent of major geological features can be obtained and consequently the method can be seen as an inversion strategy.

PURPOSE OF THE WORK

The collection and analysis of potential field data represents one of the cheapest forms of geophysical exploration. By the use of airborne surveying, it also has the advantage of allowing a relatively easy exploration on remote and hardly accessible areas. For these reasons it has been the object of extensive research for many decades.

Currently the techniques used in potential field analysis may be broadly divided into two classes. The first is represented by the visual inspection of aeromagnetic/gravity maps by geoscientists. More or less sophisticated image processing tools and different kinds of enhancements (first/second derivatives, sun-angle illumination, map colouring) are used in order to allow human analysts to better discriminate geometrical features present in the data. The targets of this kind of analysis are mainly shallow geological lineaments such as faults, folds, geological contacts, and, more rarely, broad information about the extension and depth of the main causative bodies. Basically, the main aim is to reproduce an approximate 2-D geologic map. This approach has the flavour of an art and requires specific training and experience. As such, it has the disadvantage of being partly subjective, being influenced by the specific background and field of expertise of the analysing geoscientist.

The second kind of approach can be generically defined as inversion. Here more or less sophisticated algorithm are employed in order to determine the geological setting(s) that may be responsible for a particular data set. The target of this kind of analysis is typically the location and depth extension of main geological bodies.

The two methods differ not only in their targets and in the tools they employ but also in the scale of their analysis. Visual inspection of data sets allows a high resolution analysis of very large maps, while inversion techniques, due to the complexity of the search space and the limitation in computation capabilities, are normally constrained to much coarser parameterisation, or, conversely, to small maps.

We developed a technique that attempts to unify the visual and inversion approach mentioned above into a single procedure by the use of wavelet analysis. An edge detector algorithm, based on multiscale wavelet analysis, is

applied to potential field data. The algorithm is able to extract lineaments information related to the position of the major geological bodies (i.e. to automatically produce what in geological jargon is commonly defined 'worm diagram') without the bias implied in human interpretation. With the use of an appropriate wavelet the multiscale analysis of such features can give quantitative information on the position/extension of causative bodies at depth and consequently help in approximately reconstruct a 3-D image of the geology of the area under analysis.
The details of this technique are presented in the following sections.

METHOD

The location and characteristics of irregularities often carry most of the information found in signals. In image processing for example, it is known that the detection of main irregularities is crucial to recognise and discriminate large object and main patters in the data (Mallat and Zhong, 1992). In the visual inspection of potential field data, irregularities correspond to geological contacts, faults, lineaments that are indeed the main target of the analysis. In order to detect such features we applied a multiscale edge detector to potential field maps.

Edge detection algorithms applied to the analysis of potential field data have already been proposed in the literature (e.g., Blakely and Simpson, 1986). However, an analysis in the wavelet domain offers an advantage in that it implicitly leads to an analysis of data at different scales. The crucial observation is this: the potential field or its spatial derivatives, *are* wavelet transforms of the source distribution. In potential field data it can be shown that from this information, and through the use of an appropriate wavelet, quantitative information on the position, type and strength of contrasts in potential field sources can be obtained. Consequently this approach can be seen as a form of 3-D inversion.

RESULTS

The method has been applied to a number of regional scale aeromagnetic data sets. The results have been analysed by experienced geoscietists who confirmed the accuracy of the edge detection and its ability to give an unbiased reconstruction also on features that would be hardly seen by simple visual inspection. This provides the analyst with a tool that is able to reliably automate a very time consuming process routinely employed in the analysis of potential field data.
This technique however allows us to go far beyond the simple automation of the visual analysis. The method's potential in the data inversion, i.e. in the reconstruction of the shape and location of the causative geological bodies, is illustrated with the help Figure 1. It represents a synthetic test. In the bottom we can see a 3-D synthetic section simulating some of the features typical of geological exploration settings. It models a deep buried paleo-channel (Z-shaped structure) cut by three deep and long vertical dykes that reach the surface. Superimposed to the entire domain we can see many small, randomly scattered, bodies. All these features are characterised by a positive density contrast with the background. On top of this block we can see the corresponding synthetic gravitational field. The location of the main features, as well as of the superficial small bodies can clearly be seen. On top of the image we can see the lineaments representing the edges detected by our algorithm at eight different scales, with coarser scales plotted at higher levels.

A number of conclusion can be draw from this image. First, the edges at the finest scale are clearly able to detected the horizontal location of the features in the gravity map. Not only the main features but also the location of the small scattered bodies is well recovered. Secondly, the behaviour of the edges corresponding to the deep features and the shallow ones is different: edges corresponding to deep features are still present at coarse scales, i.e. at the higer levels in the picture, while edges corresponding to shallow features tend to disappear. This behaviour is well described by the theory we have developed. Currently this information is used only to visually determine the approximate and relative depth location of the causative bodies. The next step in our research will be to obtain a quantitative depth estimate from the evolution of the egdes at different scale.

CONCLUSIONS

We presented an algorithm able to detect the main features in potential field images and recover an approximated location of the causative geological bodies. The main advantage of this approach is that it formulates an inversion strategy in a framework ('worm diagram') that is in common use for geoscientists and consequently is easily interpretable from a geological point of view. It also allows a fast, fine resolution analysis of maps many order of magnitude larger than what is possible for traditional, voxel based, inversion algorithms. The algorithm will form the basis of both an interactive visualisation environment designed for hands-on use by field geologists and geophysicists and a 3-D full inversion procedure.

REFERENCES

Mallat S., Zhong S., 1992, Characterisation of signals from multiscale edges, *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 14, 710-732.

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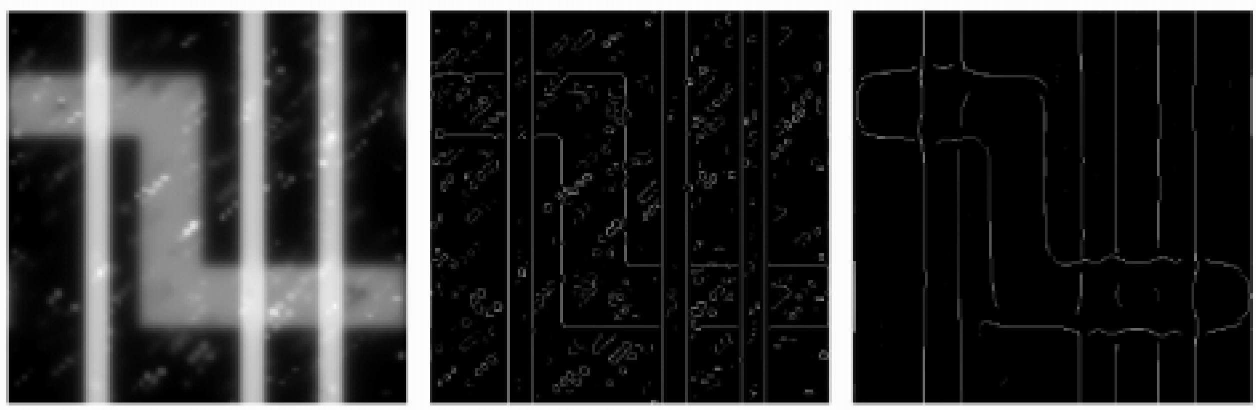

Figure 1a 1b 1c