Magnetic mentor

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Depth interpretation part 2: Automated methods

Automated depth interpretation methods have been in use since the first computers were available to geophysicists. Numerous techniques have been published, but not many are available for widespread use. In the days before interactive modelling and geological concept testing, I worked with the Werner deconvolution and Peter's length methods. It was a frustrating time, because it was very difficult to apply geological principles and defend my interpretations. The line spacing was generally too wide for imaging, and the normal products were contour and stacked profile maps. These limitations drove a lifetime passion to develop software that produced geological models that could quickly explain the geophysical measurements and create practical geological models.

In the June issue of the *Magnetic mentor* I introduced the underlying geological principles that support recovery of magnetic source depths. I used the Peter's length method to illustrate that the estimated depth could be in error by over 40% to 70% unless you applied an appropriate geological style.

If you want to create defensible interpretations, you cannot ignore geology. The difference could be as simple as deciding on geological grounds, that a particular anomaly is caused by a pipe rather than an IOCG style source. Others might be the difference between the edge of a complex structure or a semi-linear formation.

Depth methods

Depth estimation methods split into pure automated, modelling with inversion and hybrid methods. The input data may be gridded or original flight line data depending on the method. I favour using the line data and gridding to provide information on cross-gradients and shape information for automatic estimation of the geometry of the target anomaly.

In Australia, we have the luxury of open access to high-quality data with line separations from 100 to 400 m. This quality makes it feasible to use automated and integrated inversion methods. So, is there room for automated methods in defensible interpretation? The answer is yes if the method also provides an analysis of the anomaly shape that helps to differentiate between different geological styles and assigns a confidence parameter.

Naudy (1971) published a method suitable for computer automation. This method operates only on semi linear magnetic anomalies from formations, dykes or geological boundaries and utilises the original line data. It is not suitable for semicircular anomalies related to pipe or IOCG style geology. Naudy used an early form of inversion with curve matching that can be applied to either anomalous magnetic intensity (AMI) or vertical derivative anomalies. The curve matching produces a correlation coefficient that is used to find the best fit for depth, width, dip and susceptibility. For her PhD, my colleague Zhiqun Shi further developed the Naudy method and introduced additional features. She called it AutoMag. Importantly, it works with the original line data and we added a capability to automatically apply strike corrections for depth, width and dip where the geology was not orthogonal to the flight lines. **Figure 1** shows an example from the Northern Territory where the automated results have been strike corrected and a solution confidence factor is used to modify the arrow symbol size. Importantly, each solution can be selected, converted into a solid model equivalent, a response computed for validation and optionally a subsequent inversion. That ability makes the interpretation defensible.

Structural Index, Euler and NSS

There is a lot of geological information present in a magnetic anomaly beyond the magnetic properties and depth. The spatial shape of the anomaly gradients and curvature hold another part of the geological story. A commonly used shape parameter is the structural index or SI which is derived from AMI, magnetic gradients and gravity anomalies. Clark's 2012 paper defines the structural index as $NSS = Cqr^{-n}$ (Eqn 32) where ***n*** is the structural index, ***C*** is a constant, ***q*** relates to the magnetic source geometry and r is the distance of the sensor from the source. Equation 32 is solved for n, C, q and z (at x=0) using the sensor position and tensor derived value for NSS. Equation (4) in Reid and Thurston (2014)

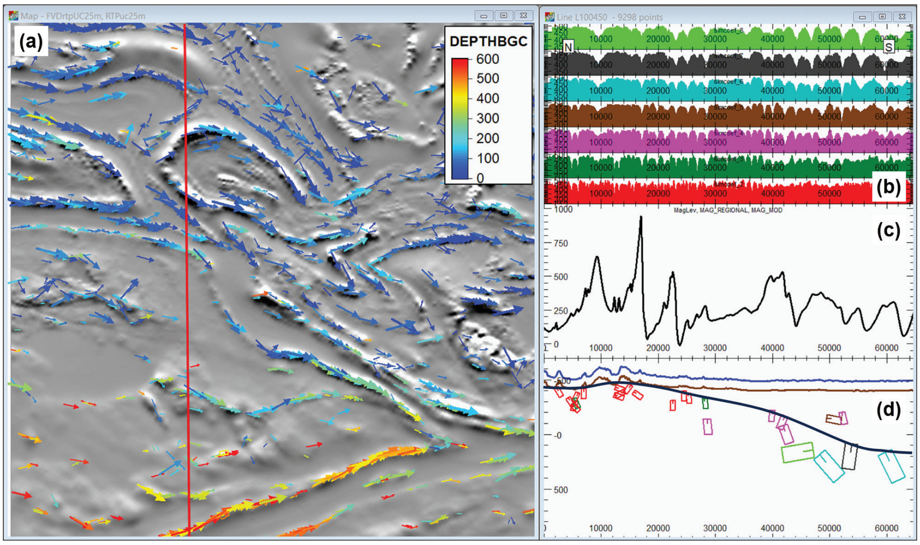

Figure 1. *An RTP map with Naudy results from a 400 m spaced NT survey (a) showing arrow symbols, coloured by depth, size encoded by confidence with depth corrected for the azimuth relative to the flight line. Inverted similarity coefficients (b) are shown above the cross-section view and AMI trace (c). Depth symbols (d) are shown on the section where colours match the similarity tracks.*

has the same form for the TMI derivatives, but the SI differences relate to the higher order derivatives used to calculate NSS. **Table 1** summarises the SI values.

Table 1. SI for the Euler and NSS methods

Geological source	Euler SI	NSS SI
Contact	0	1
Dyke / thin sheet	1	2
Pipe / cylinder	2	3
Sphere / dipole	3	4

Figure 2 provides a schematic view of the geological equivalence with SI (from NSS). Note there are some important caveats as expressed by Reid and Thurston where the optimum depth value requires an integer value of SI and compliance with the underlying mathematical shape.

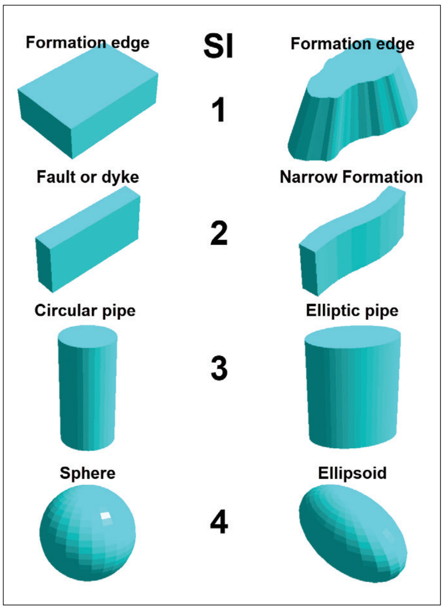

Figure 2. *Structural index concept diagram.*

A thin sheet is a mathematical concept that works reasonably well until the width of the sheet is equivalent to 50% of the sensor height above the formation. A similar argument is true for the circular and elliptic pipes. Geological edges and spheroids are valid geological shapes. A pure edge is difficult to extract due to the variability of susceptibility on the magnetised side of the edge and the extra width of edge anomalies. The sphere is mathematically equivalent to a point source and changes in radius do not change the anomaly shape.

Figure 3 shows a split image example from the Gawler Craton in South Australia showing SI and depth below the ground surface (DepthBG). I have computed SI from the NSS along the north-south flight lines using derived magnetic gradient tensor data. The use of the confidence parameter as symbol size makes it easy for our brains to focus on the geology as well as the best solutions while still having the ability to explore lower confidence anomalies.

To derive the NSS, I compute the magnetic gradient tensor from the total magnetic intensity survey grids using Fourier transformation and then resample the results back onto the flight lines. Once you have a tensor dataset, you can evaluate other useful tensor related parameters (Pratt et al., 2019). Importantly, the magnetic tensor contains cross-line gradient information and the strike direction of each magnetic anomaly.

Summary

- Geological shape interpretation is fundamental to good depth estimation, and the SI assists with inferring the probable geometry of the source.
- Using grid data and flight line data together provides the ability to deduce geology, correct for strike and estimate confidence for physical properties as well as depth.
- The SI value is nominally associated with integer values from 1 to 4, but in reality, the estimated numbers vary as a continuum.
- You can use the SI to highlight compact zones of magnetisation that could be associated with fracture zones at structural intersections.

See the Magnetic Mentor series link to download data and related information for this and previous editions.

References

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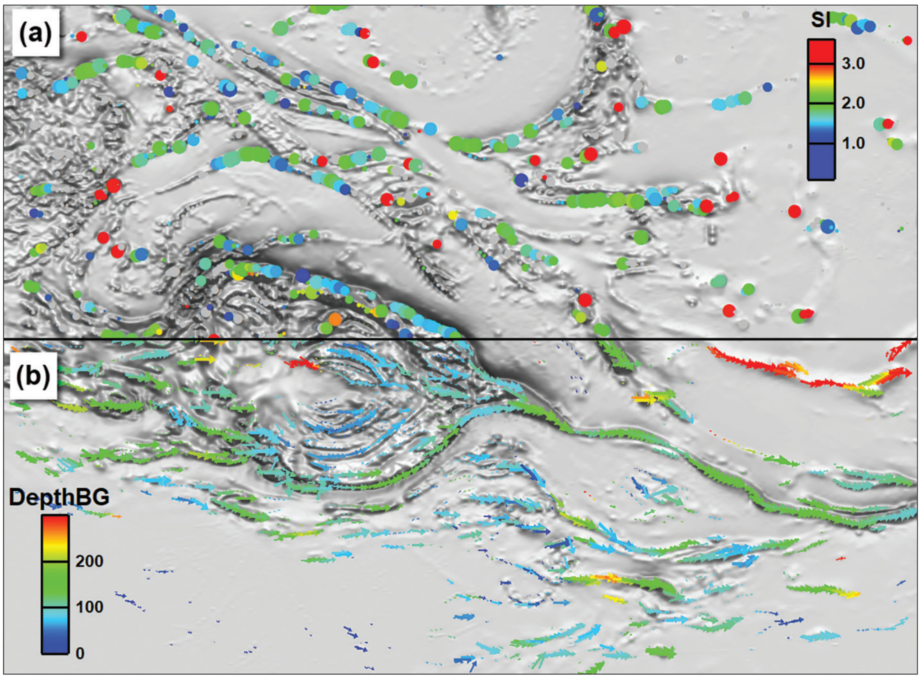

Figure 3. *An image of the 1VD overplotted with NSS derived values of SI (a) shown as dots and arrows showing computed trend and depth below the ground surface (b). The symbols are colour coded by value and size which is mapped to estimated confidence.*