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Discussion and Reply

On “Theta map: Edge detection in magnetic data” (C. Wijns, C. Perez, and P. Kowalczyk, 2005, GEOPHYSICS, 70, L39–L43)

Discussion by Xiong Li[1]

Wijns et al. (2005) may have presented an effective edge detector, but do not acknowledge several very relevant works (Hansen et al., 1987; Phillips, 2000; Keating et al., 2004). To some extent, the technique of Wijns et al. (2005) is just a variant of, but not necessarily better than, the technique of Miller and Singh (1994), which Wijns et al. (2005) have not referred to.

Wijns et al. (2005) define the theta angle as the arccosine of the ratio of the horizontal gradient amplitude (HGA) to the analytical signal amplitude (ASA), and contrast the cosine of theta with the HGA and ASA in edge detection. A combined use of the HGA and ASA for interpretation of contacts (or edges) has been well investigated by Hansen et al. (1987), Phillips (2000), and Keating et al. (2004). Figure 3 and its related text in Wijns et al. (2005) explain that a combined use can interpret the direction of a contact's dip. This was one of the key advantages already stated in Hansen et al. (1987).

Wijns et al. (2005) have referred to Verduzco et al. (2004) and pointed out Verduzco et al.'s use of second-order derivatives. Verduzco et al. (2004) have referred to and generalized the technique of Miller and Singh (1994). In theory, the theta angle of Wijns et al. (2005) is the same as the tilt angle of Miller and Singh (1994), and the local phase of the complex analytical signal [equation 4 of Thurston and Smith (1997)] if the local phase is defined for 3D.

Figure 1 of Miller and Singh (1994) explains all. The tilt angle is defined as the arctangent of the ratio of the vertical derivative to the HGA. One difference in use is that Miller and Singh (1994) interpret directly the tilt angle, which has a value between $-90°$ and $+90°$, whereas Wijns et al. (2005) interpret the cosine of the theta angle, which has a value between 0 and 1, because the theta angle itself is between $0°$ and $+90°$.

Miller and Singh (1994) compared in their examples the tilt angle with edge detection measures such as the HGA, the ASA, and the second vertical derivative, and explained clearly the advantage: “The tilt angle, however, resolves both [*shallow and deep*] bodies equally well since it is dependent only on the ratio of the two gradients, not their amplitudes, for resolution” (p. 215). Wijns et al. (2005) have conducted a similar comparison and reached the same conclusion, saying: “the theta map may also be thought of as a normalization of the horizontal gradient. This normalization introduces an effective gain control, such that amplitude information is lost, but low-amplitude features are highlighted in a manner similar to automatic gain control maps” (p. L39).

Wijns et al. (2005) write (p. L41): “The theta profile over a dike distinguishes two edges, and a central minimum is shared between the two peaks (Figure 4).” In exploration geophysics, dikes may be thin or thick depending on the ratio of the width to the top depth, and magnetic responses of a thin dike and a thick dike are different. The statement of Wijns et al. (2005) is valid for a thick dike. For a thin-enough dike, two peaks will merge into one, i.e., the central minimum will disappear.

In particular, use of the theta angle or its cosine by Wijns et al. (2005) may be less informative than using the tilt angle. Tilt angle responses vary from positive to negative: positive over the source, zero over or near the edge, and negative outside the body (Miller and Singh, 1994, p. 215). This sign variation is useful. For example, it may indicate the relative magnetization contrast. This sign information gets lost when Wijns et al. (2005) use the ratio of the HGA to the ASA.

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Reply to the discussion

Xiong Li

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First, we thank Xiong Li for drawing to the attention of readers our lapse in not referencing Miller and Singh (1994) as the originators of the tilt angle. He also correctly points out that Miller and Singh (1994) first stated the automatic gain control (AGC) nature of the tilt angle. Thurston and Smith (1997) introduce the local wavenumber, from Nabighian's (1972) complex analytic signal, as an edge detection and characterisation tool, and are also worthy of reference.

Although the works of Hansen et al. (1987), Phillips (2000), and Keating et al. (2004) are indeed relevant to our research, the authors have unfortunately not chosen to make these particular papers available in the scientific literature through publication in refereed journals. We must point out to Li that extended abstracts are not peer reviewed, and the general academic rule is that they are not suitable for referencing. Many journals reject abstract references outright. This example can only serve to emphasise the importance of publication as a means to validate and archive good research. Peer review, in the vast majority of cases, serves to improve the quality of academic research and presentation.

For the benefit of readers unfamiliar with the abstracts, Hansen et al. (1987) urge the use of the horizontal gradient amplitude and the analytic signal (amplitude) as two layers to be used in tandem for interpreting edges and dips in gravity data. Phillips (2000) does not contribute new methods or theories, but gives an overview of the methods of depth and edge location using the horizontal gradient, analytic signal, and local wavenumber, this last method being the one proposed by Thurston and Smith (1997). Perhaps to reinforce the points made about publicaton, we were unable to find the abstract of Keating et al. (2004) on any online publication search engine, and we did not attend the 66th EAGE conference and receive an abstract volume; we therefore remain ignorant of the content of this work.

We agree with Li's statement that our theta angle is, in theory, the same angle as the tilt angle. This has become obvious to us with further investigation, due in part, frankly, to Li's comments. We first developed our approach in-house nearly a decade ago, and, to our discredit, we were then unaware of the published work on the tilt angle (Miller and Singh, 1994). Our work was driven by the need to detect edges at the magnetic equator, and so we chose to map the cosine of the analytic signal angle, in order to have a maximum over any contact.

The tilt angle by itself does not highlight edges in magnetic data. For this reason, Verduzco et al. (2004) employ its horizontal derivative. The main difference with the theta map we use is that we can see two peaks for two edges of a dike, whether data are reduced to the equator or pole, whereas only one peak appears in the horizontal derivative of the tilt angle. Verduzco et al. (2004) cannot distinguish between a step (contact) and a dike (c.f. their Figure 1). While Li correctly points out that we lose the positive-to-negative range of the tilt angle, we gain the ability to discriminate between steps and dikes.

Li's assertion that a very thin dike will lose its double peak in the theta map is not correct, and again highlights the difference between the method of Verduzco et al. (2004) and ours. Any dike, free from the influence of neighbouring anomalies, will have the same pattern of zero crossover of the horizontal derivative above the dike, as drawn in our Figure 4. Therefore, the amplitude of the horizontal derivative will always have a double peak, and this translates directly into the double peak of the theta map. However, the distance between peaks in the theta map will be larger than the width of the thin dike, so this width would be overestimated.

The tilt angle, and/or its horizontal derivative, is a very useful interpretation tool. The superior edge detection of the theta map, or cosine of the tilt angle, may be contrasted with the simpler and cleaner image of the tilt angle or its horizontal derivative, and different interpreters may prefer one image or the other, or both, depending on the scale of interpretation. We use both. As stated in our original paper, any such derivative image needs to be interpreted within the context of the original magnetic intensity data, with as many other processed images as may be needed.

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