H044

Depth Extent - An Overlooked Parameter in Magnetic Depth Estimation

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SUMMARY

Magnetic depth estimation has been an essential component of geophysical interpretation since its earliest days. Virtually all depth estimation techniques are based in some measure on determining curve characteristics of relatively simple body geometries such as infinite dikes, contacts and thin plates.

Such techniques worked reasonably well in continental areas of thick crust and relatively shallow basins. However, as exploration has moved into the offshore and other remote areas where basins are extremely deep and correspondingly the crust is significantly thinner, these methods tend to break down and yield depth estimates which are generally much too shallow because the assumed infinite thickness model doesn't fit the geology.

We present modeled results to demonstrate the thickness effect, develop corrections to account for these effects and demonstrate the value of these corrections in improving the results on simple models.

Introduction

Magnetic depth estimation has been an essential component of geophysical interpretation since its earliest days. Virtually all depth estimation techniques are based in some measure on determining curve characteristics of relatively simple body geometries such as infinite dikes, and contacts. Vacquier et.al. (1951) and Steenland (1970) recognized the need for an additional model based on a thin plate to account for basement structure which resulted in steeper gradients that gave rise to depth estimates which were too shallow by 30% or more.

Such techniques worked reasonably well in continental areas of thick crust and relatively shallow basins such as the mid-continent areas of North America. However, as exploration has moved into the offshore and other remote areas where basins are extremely deep and correspondingly the crust is significantly thinner, these methods tend to break down and yield depth estimates which are generally much too shallow because the assumed model doesn't fit the geology.

Figure 1 illustrates the classic model used in depth estimation with terms defined: D – depth to basement, t – thickness of basement structure (thin plate model), T - thickness of magnetic basement (generally assumed very large or infinite) giving rise to a thickness to depth (T/D) ratio of 9 or higher, W – width of thin sheet or dike and S1, S2 etc. representing various susceptibilities or magnetizations of the basement rocks.

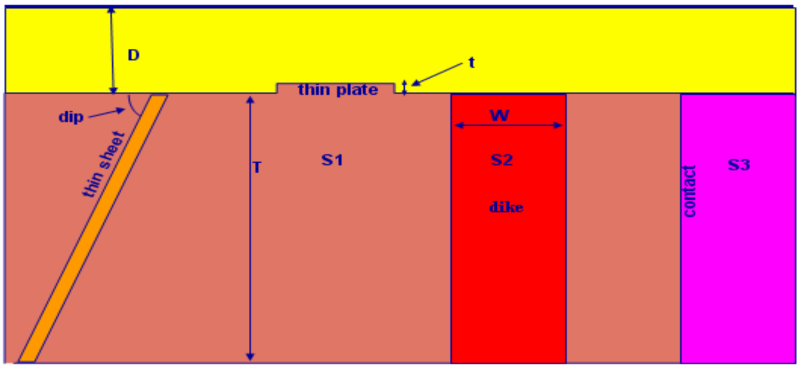

***Figure 1** Simple 2D basement model with terms defined.*

Figure 2 illustrates a revised model that may be more appropriate for example in a passive margin setting. Here the thickness of the crust and therefore our assumed magnetic layer varies dramatically from very thick on the right (T/D of 9 or higher) to very thin on the left (T/D of 1 or less). In such an environment most techniques break down without the application of appropriate corrections.

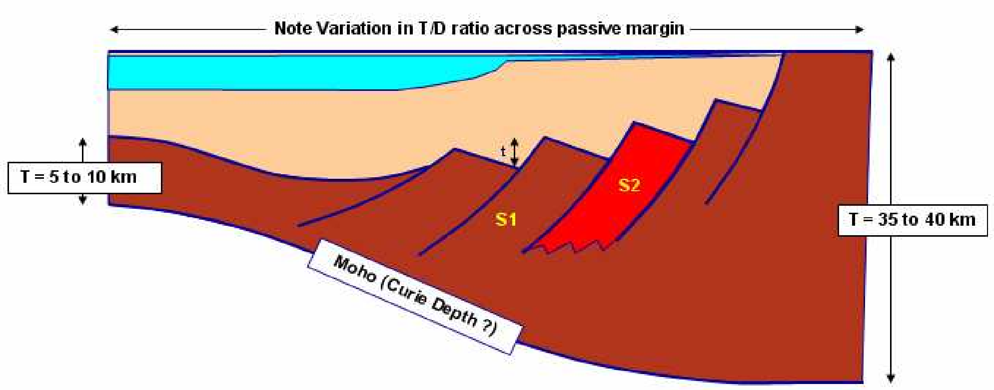

***Figure 2** Passive margin model.*

Methodology

We assume that the thickness "T" of the layer of interest is equivalent to the isopach between top magnetic basement and base of the magnetic layer, for which we use Moho as a first approximation.

Additionally we have focused on empirical methods as well as the tilt-depth method which work on individual anomalies rather than the more automated methods such as Werner and Euler. As Salem et.al. (2010) point out these methods have the advantage of producing depth estimates that relate directly to individual sections of anomalies, unlike most automated methods that use overlapping windows and generate multiple solutions of varying quality.

A number of authors (deRidder, 1972; Litinsky, per. comm. 1981; Bean, per. comm. 1990, Skilbrei, 1993; and Reeves, 2005) have recognized the depth extent (thickness of magnetic body) issue but often have dismissed it for any number of reasons such as: "it is usually not possible to interpret depth extent of magnetic bodies within the basement" (Skilbrei, 1993), "as long as the depth to the bottom of the dike is at least several times greater than the depth to top, the effect as a whole is minimal" (Reeves, 2005), "the assumption of infinite depth extent should be extended to mean that the body is thicker than the depth of burial of its upper surface" (Vacquier, et.al. 1951), or the effects have been ascribed to anomaly interference. Bean and Litinsky should be recognized for understanding its significance but in neither case, as far as we are aware, was the result published.

We show that depth extent is much more significant then generally recognized. For example in current offshore petroleum exploration a thickness vs. depth ratio (T/D) of 2 or less (for example, from depths to basement of 5 to 10+ km and crustal thicknesses of 5 to 15 km) are the norm rather than the exception.

Examples

As an example we use the tilt-depth method (Salem, et.al., 2007). The published tilt-depth divisor calculated theoretically for a dike is 2.0. However, calculations show that even for a T/D ratio as high as 9 or 10 (the maximum applicable to most oil prone basinal settings, with basement depth minimally 3 to 5 km and crustal thickness of 35 to 50 km) the appropriate divisor is 1.85 or less. Thus prior to any complications due to interference, anomaly source shape etc. the estimate is likely to be 7.5% too shallow using the theoretical divisor of 2. Taken to the extreme, for example in areas of the Vøring Basin where T/D is 1 or less (basement depth 10+ km and crustal thickness of 5 to 10 km) or applied inappropriately to supra-basement anomalies, the divisor may be 1 or less resulting in a depth error of 30% or more (Figure 3).

We have generated nomographs combining the width to depth (W/D) effects documented so well by Åm, 1972 as well as many others and T/D effects for many of the common methods (Peters, tilt-depth, Sokolov, Tiberg, Bean, Haanel, Demi-Pentes, Pyatnitsky, etc.) and see similar effects in all cases. The tilt-depth method (Figure 3) shows some promise as a first pass technique in that it is easy to calculate even in a mapped or gridded view and seems significantly less affected by width than other methods.

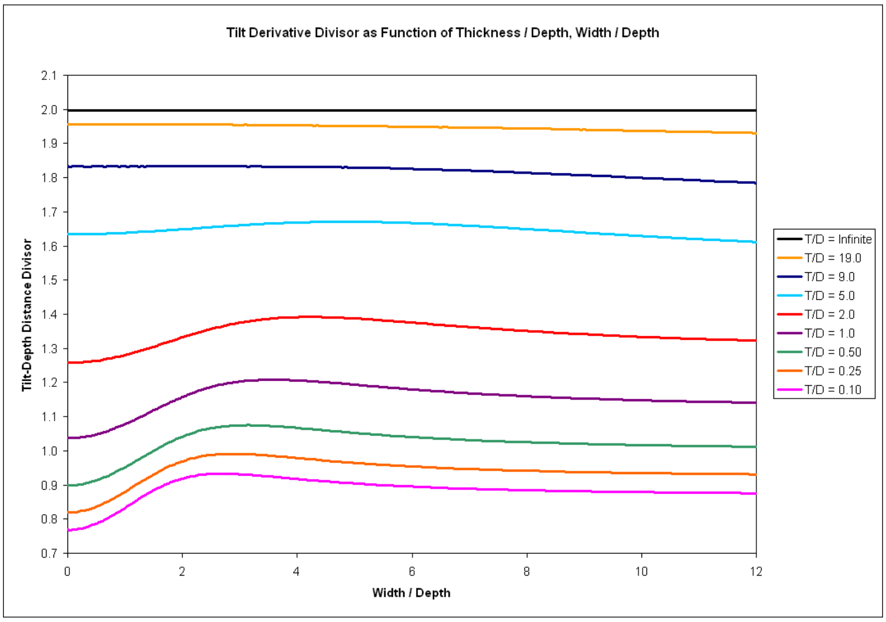

Figure 3 *Tilt-depth nomograph relating W/D and T/D to divisor.*

Applying the divisor taken from the nomograph (Figure 3) to the example dikes in Figure 3 we get the results shown in Figure 4.

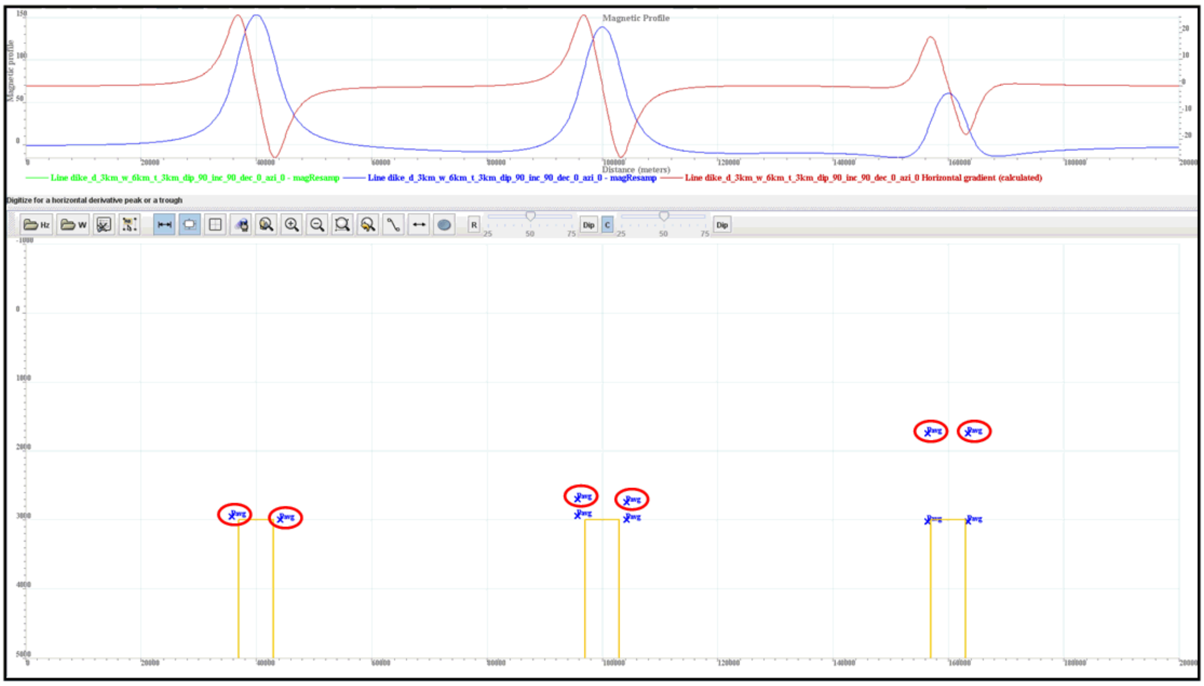

Figure 4 *Tilt-depth results for dikes of depth 3000m and varying T/D using divisors from tilt-depth nomograph. Body on left has T/D of infinity, center body has T/D of 10, body on right has T/D of 1. Depths are respectively, 2975 m, 2725 m, and 1750 m using the default tilt-depth divisor of 2(red circles) and 2975 m, 2975 m, and 3025 m using the divisor from the nomograph in Figure 3.*

Conclusions

We have developed nomographs to account for both depth extent and width extent of simple dike and contact models. Incorporating these corrections has been shown to improve estimated magnetic depths from simple models by 30% or more.

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