Geothermal Energy
a SpringerOpen Journal

DEBATE Open Access

Reply to discussion on 'Spectral analysis of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring - Ekiti State, southwestern Nigeria'

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Abstract

In reply to Geothermal Energy 2:11 comments about possible errors in our recent paper Geothermal Energy 2:6, 1-21 with title 'Spectral analysis of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring - Ekiti State, southwestern Nigeria', we show that there are no errors in the published paper. Our choice of 55 × 55 km block dimension slide across the magnetic anomaly map is consistent with the derived Curie point depths. This choice was adopted because of complexity of the geology in the area and the need to sample more data points while preserving the spectral peak. All depth estimates were carefully and thoroughly performed and assessed using tectonic framework, geological and geophysical evidence, heat flow, seismicity, and other independent information.

Keywords: Data; Window; Spectra; Aeromagnetic; CPD

Background

The method used for basal or Curie point depth (CPD) calculations is very subjective, needs great caution, and has to be constrained by independent information for a particular region. The theoretical basis of estimating the depth from Fourier spectra has been explained by several authors such as Spector (1968), Spector and Grant (1970), and Hahn et al. (1976) among others. The algorithm given by Spector and Grant (1970) directly estimates the depth of the causative body from the relationship between the logarithmic power and frequencies. For a single ensemble, the natural log of the power spectrum density as a function of wave number would have a linear slope approximately twice the maximum depth (Rabeh et al. 2008). For multiple ensembles, one obtains a linear slope approximately twice the maximum depths to the various magnetic sources (Rabeh et al. 2008; Trifonova et al. 2009; Bansal et al. 2011; Abraham et al. 2014).

Often, only proxy data are available to derive an idea about the thermal structure of the crust. One important proxy data is the CPD (Bansal et al. 2011). A number of assumptions and limitations are associated with Curie depth estimation (Blakely 1995; Ross et al. 2006; Aboud et al. 2011). One of the assumptions is that deep magnetic sources have long wavelengths and low amplitudes, which makes them difficult to distinguish from anomalies caused by shallow sources. The dimension of the subregion must be sufficiently large to capture these long wavelengths, which forces a trade-off between accurately determining depth to the bottom (Z_b) within each subregion and resolving small changes in Z_b across subregions (Ross et al. 2006; Ravat et al. 2007; Aboud et al. 2011). However, the depths obtained for the bottom of the magnetized crust are assumed to correspond to the CPD where the magnetic layer loses its magnetization (Aboud et al. 2011; Abraham et al. 2014). The obtained CPD reflects the average value of the area. Therefore, the results may not delineate local shallow or deep CPD anomaly (Aboud et al. 2011; Abraham et al. 2014). In this debate, we scrutinize the assertion that given our data window of 55 × 55 km, the computed CPD was marked with errors. We shall also prove that re-computing our depths is not necessary as our assumed CPD is adequate for the window and method chosen.

Discussion

Connard et al. (1983) divided a magnetic data of Cascade Range, central Oregon into overlapping cells (77 × 77 km) and calculated the radially average power spectrum for each cell. Okubo et al. (1985) used a window (approximately 41 km) to determine CPDs of the island of Kyushu and surrounding areas, Japan. Blakely (1988) divided the U.S. state of Nevada into subregions (120 × 120 km) in terms of aeromagnetic data and mapped the Curie depth of the entire state. Tanaka et al. (1999) divided East and Southeast Asia into subregions (approximately 200 × 200 km) and estimated the power density spectra for each region from which they created the Curie depth map. Salem et al. (2000) applied spectral analysis of aeromagnetic data for the geothermal reconnaissance of Quseir area, northern Red Sea, Egypt, using a data window of 40 × 50 km. Trifonova et al. (2006) estimated the Curie point depth in Bulgaria using six blocks with dimensions of 300 × 300 km using the criteria of minimal size of the block that does not cut the spectral peak. Trifonova et al. (2009) investigated the CPDs of Bulgarian territory inferred from geomagnetic observations and its correlation with regional thermal structure and seismicity using overlapping block windows of 150 × 150 km. Nwankwo et al. (2009) attempted to estimate the Curie point isotherm depths in the Nupe Basin, West Central Nigeria using data windows of 45 × 45 km. Aboud et al. (2011) used windows of size 100 × 100 km to map the Curie depth isotherm surface for Sinai Peninsula, Egypt based on the spectral analysis of ground magnetic data. Bansal et al. (2011) used a selection of windows ranging 200 × 200 km and 100 × 100 km to estimate depth to the bottom of magnetic sources by a modified centroid method for fractal distribution of sources. Obande et al. (2014) conducted spectral analysis of aeromagnetic data for geothermal investigation of Wikki Warm Spring, northeast Nigeria using a data window of 55 × 55 km. Abraham et al. (2014) investigated the geothermal energy potential of Ikogosi Warm Spring, Nigeria using spectral analysis of aeromagnetic data from blocks of size 55 × 55 km. However, Ravat et al. (2007) concluded that no single technique worked on their model studies with complete reliability and at times produced completely erroneous depths to top and bottom.

Abraham et al. (2014) explicitly stated that the methods of Spector and Grant (1970), Okubo et al. (1985) and Trifonova et al. (2006), which examined the spectral knowledge included in subregions of magnetic data was used for their analysis. This algorithm (and all other magnetic methods) only computes the depth to the bottom of magnetization contrasts. Whether or not these depths represent Curie point transitions is an interpretation that must be supported by other independent evidence (Okubo et al. 1985; Trifonova et al. 2009). The choice of 55 × 55 km block dimension slide across the magnetic anomaly map was necessary because of the complexity of the geology of the area and the need to sample more data points while preserving the spectral peaks as suggested by Okubo et al. (1985). Because of the dimensions of aeromagnetic data of the study area (110 × 110 km), we could have applied spectral analysis to the main grid but given the geology of the region, we adopted the suggestion of Okubo et al. (1985) on the minimal block size to use.

Selecting windows over geologically/geophysically homogeneous regions rather than margins of provinces is another consideration that is very useful in the process of choosing window sizes to ascertain that one is not missing the spectral peaks (Ross et al. 2006; Ravat et al. 2007). Determination of the size of blocks to be used for calculations requires a compromise between the spatial resolution and preservation of the long-wavelength part of the spectrum (Trifonova et al. 2009). Even if the technique provides an accurate Z_b, there is no guarantee that Z_b represents the Curie temperature depth. A variety of geologic reasons exist for truncated magnetic sources that are unrelated to crustal temperatures (Trifonova et al. 2009). All depth estimates must be carefully performed and assessed using tectonic framework, geological and shallow as well as deep geophysical evidence, and heat flow modeling, especially in the cases where high values of heat flow are inferred based on magnetic bottoms lying within the upper and middle crust (Ravat et al. 2007). Abraham et al. (2014) took these precautions and suggestions into consideration, and efforts were thoroughly made to examine and compare results with independent data. They also added that their depth to the bottom of magnetic earth's crust was assumed CPD, placing our results within acceptable norms in magnetic depth study (e.g., Trifonova et al. 2009). In many cases, the approximation of the bottom depth of magnetic earth's crust, generally accepted to concur with the CPD, causes ambiguity, because it is unclear which particular value should be accepted as Curie point. Because of this uncertainty, Trifonova et al. (2009) compared the calculated magnetic bottom's depth to the results from geothermal modeling in depth and some paleomagnetic investigations. It would also be better to seek an external confirmation through other related geophysical results such as the various relevant parameters that contribute to the surface heat flow and seismic determinations of thickness and interpretations of tectonic setting (Ravat et al. 2007).

In light of these instances, we respectfully disagree with Nwankwo (2014) comments describing our computed CPD as erroneous, based solely on our choice of block size. We would advise consideration of the extensive comparison with independent data and information presented in the paper. Ross et al. (2006) applied a comparison of estimated basal depths with heat flow values and thickness of the seismogenic crust to draw conclusions that these parameters provided additional confidence in the basal depths they determined. Ultimately, the validity of the filter parameters will be judged by how well the resulting CPD map corresponds to independent data (Okubo et al. 1985). The depth to the bottom of magnetic sources (assumed CPD) in Abraham et al. (2014) from spectral analysis using 55 × 55 km block size is acceptable and far from being erroneous. While we had to acknowledge Shuey et al.'s (1977) suggestions regarding spectrum depth information as a guide when considering window lengths, nevertheless, great caution must be exercised in excoriating as erroneous depths obtained from various window sizes that may not entirely conform to this suggestion. Various examples can be seen in Okubo et al. (1985) whose CPD of up to 15 km is obtained from a 41 × 41 km data window (not 94 × 94 km), a CPD of up to 46 km using a data window of 222 × 222 km (Tanaka et al. 1999) and not from a 289 × 289 km data window, Salem et al. (2000) with CPD of 10 km obtained from a 40 × 50 km data window (not 63 × 63 km), Ross et al. (2006) with CPD of up to 30 km obtained from 130 × 130 km data window, not 180 × 180 km data window, and Nwankwo et al. (2009) whose CPD of 30 km is obtained from a data window of 45 × 45 km and not 189 × 189 km. Trifonova et al. (2009) whose CPD of up to 32 km obtained from a data window of 150 × 150 km, not 201 × 201 km. Other examples could be seen in CPD estimates from Aboud et al. (2011) and Bansal et al. (2011). The depths realized from these examples may not be erroneous given the context and perspective of the respective studies.

After recommending considerations in the usage of methods to successfully determine bottom depth on a really large synthetic layered and random magnetization models, Ravat et al. (2007) concluded that despite all precautions enunciated (including using windows with sufficient width to ascertain that the response of the deepest magnetic layer is captured, verifying the spectra and computing the depth estimates with the largest possible windows), in some cases, the results can still be erroneous and therefore recommended a critical evaluation of the results by modeling heat flow and taking into account the seismic information of the crustal and lithospheric thickness and seismic velocities wherever possible.

Summary

The CPDs obtained in Abraham et al. (2014) using window size of 55 × 55 km is correct in the context of the investigation. The window size coupled with the overlapping and spectral method chosen accommodated the geology of the area and also preserved the spectral peak. The resulting depth to the bottom of the magnetic crust in the paper was taken as assumed CPD. All depth estimates were carefully and thoroughly performed and assessed using tectonic framework, geological and geophysical evidence, heat flow, seismicity, and other independent data. In spite of agreement with several independent information, we speculate that other causes could impel the assumed CPD.

Abbreviation

CPD: Curie point depth.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors of this study made inputs in this debate. All authors read and approved the final manuscript.

Acknowledgements

We remain grateful to all the anonymous reviewers and editors whose comments contributed to improve our manuscript.

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Received: 15 August 2014 Accepted: 25 November 2014
Published online: 18 December 2014

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doi:10.1186/s40517-014-0018-9
Cite this article as: Abraham *et al.*: Reply to discussion on 'Spectral analysis of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring - Ekiti State, southwestern Nigeria'. *Geothermal Energy* 2014 **2**:18.