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Evaluation of Curie-point depths, geothermal gradients and near-surface heat flow from high-resolution aeromagnetic (HRAM) data of the entire Sokoto Basin, Nigeria

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ABSTRACT

An evaluation of Curie-point depths, geothermal gradients and near-surface heat flow has been carried out from the spectral analysis of the recently acquired high resolution aeromagnetic (HRAM) data of the entire Sokoto Basin in northwestern Nigeria. The HRAM data was divided into twenty two (22) overlapping blocks and each block analyzed using the spectral centroid method to obtain depth to the top, centroid and bottom of magnetic sources. The depth values were subsequently used to evaluate the Curie-point depth (CPD), geothermal gradient and near-surface heat flow in the study area. The result shows that the CPD varies between 11.13 and 27.83 km with an average of 18.57 km, the geothermal gradient varies between 20.84 and 52.11 °C/km with an average of 33.99 °C/km, and the resulting heat flow varies between 52.11 and 130.28 mW m^{-2} with an average of 84.97 mW m^{-2}. Such heat flow values are suggestive of anomalous geothermal conditions and are recommended for detailed geothermal exploration in the basin.

1. Introduction

Recently, a nationwide regional high resolution aeromagnetic (HRAM) data were acquired in Nigeria by Fugro Airborne Survey Limited for the Nigerian Geological Survey Agency (NGSA) for the period between 2004 and 2009. The acquisition, processing and compilation of the new data were jointly financed by the Federal Government of Nigeria and the World Bank as part of the Sustainable Management for Mineral Resources Project (SMMRP). The airborne magnetic surveys, using 3× Scintrex CS3 cesium vapour magnetometers with data recording interval of 0.1 s, were carried out by means of fixed-wing aircrafts flown at mean terrain clearance of 80 m with 500 m line spacing and nominal tie-line spacing of 2 km. The flight line and tie-line trends were 135 and 45° respectively. Unlike the preceding surveys that were done in the 1970s from a flight height of 152 m with line spacing of 2 km and nominal tie-line spacing of 20 km (Shehu et al., 2004; Adetona et al., 2007; Bonde et al., 2014; Nwankwo, 2015); this new HRAM data is adjudged by the NGSA to be better and it is therefore assumed that its analysis would provide better and improved geoscientific outcomes.

HRAM surveys have a resolution in the sub-nanotesla scale such that in addition to adequately mapping magnetic rocks, they can also be used to map intra-sedimentary faults with elevated magnetite concentrations that generate small anomalies (Pipan, 2009; Ochieng, 2013). The analyses of HRAM data are similarly useful in the study of regional volcanism and volcanic rocks of an area (e.g., Paoletti et al., 2005a,b). The magnetic susceptibility of a rock and the temperature at which it disappears (also regarded as Curie-temperature) depend on the rock components (Bansal et al., 2011, 2013; Gabriel et al., 2011, 2012). Demagnetized rocks confirm the existence of a hot rock mass in the crust that can be harnessed for geothermal energy utilization and regional tectonic studies. Consequently, adequate information of the thermal structure of the earth's interior is important in geothermal and geodynamic investigations (Chapman and Furlong, 1992; Ross et al., 2006). These thermal configurations could be estimated directly from near-surface heat flow measurements where possible. The primary objective of heat flow measurements is to estimate the amount of heat energy being lost by natural process. High heat loss anomalies usually coincide with the structural trend or areas with thermal manifestations (Ochieng, 2013). Oftentimes, direct crustal temperature measurements may not be too significant for regional studies; hence the depth to Curie-temperature suffices for estimating temperature at depth (Ross et al., 2006; Bansal and Anand, 2012; Bansal et al., 2013). This Curie-temperature corresponds to the temperature at which magnetic minerals lose their ferromagnetic properties, and for regional scale studies the depth at which it occurs can be inferred as the bottom of magnetic sources. Several studies (Spector and Grant, 1970; Bhattacharyya and Leu, 1975; 1977; Okubo et al., 1985; Blakely, 1995; Maus et al., 1997; Tanaka et al., 1999; Ross

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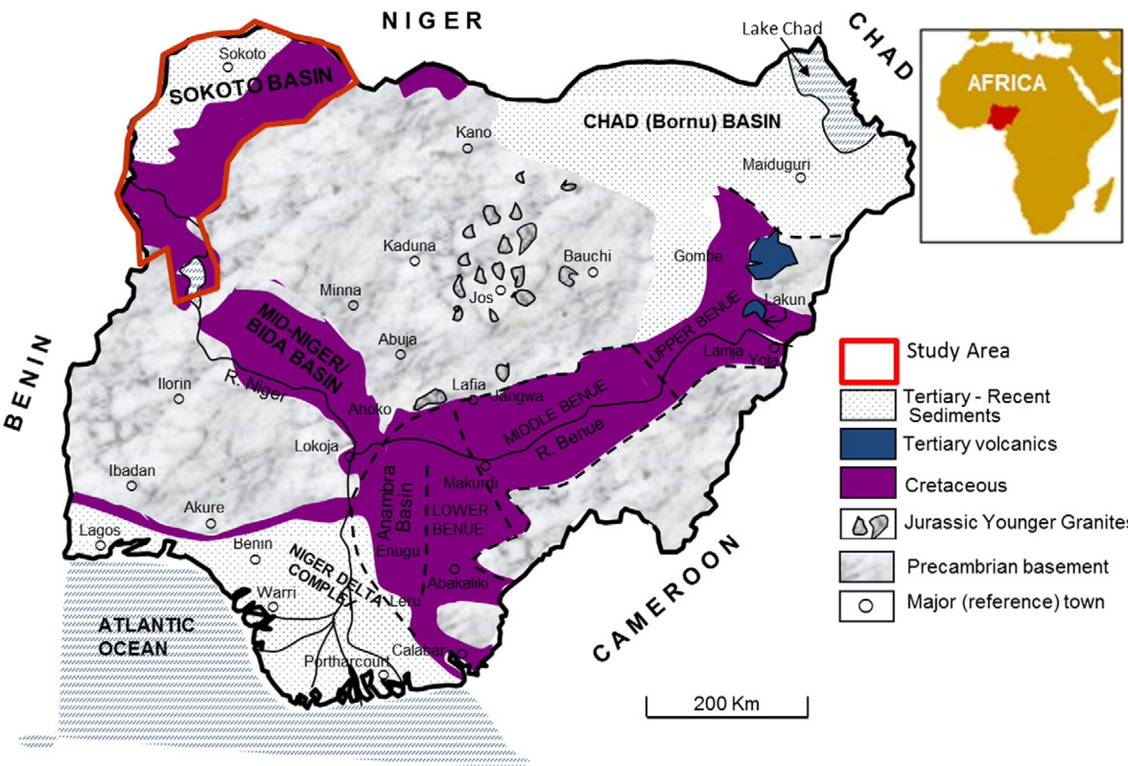

Fig. 1. Geological sketch map of Nigeria showing Sokoto Basin.
After Obaje (2009).

et al., 2006; Ravat et al., 2007; Bouligand et al., 2009; Bansal et al., 2011, 2013; Gabriel et al., 2011; Nwankwo et al., 2011; Bansal and Anand, 2012; Gabriel et al., 2012; Kasidi and Nur, 2012, 2013a,b; Guimaraes et al., 2013; Nwankwo, 2015) have shown that the depth to the bottom of magnetic sources, which is also regarded as the Curie-point depth (CPD), could be estimated from the analysis of regional magnetic data.

This paper, therefore, presents a regional estimation of Curie-point depths (CPD), resulting geothermal gradients and heat flow values in the entire Sokoto Basin, north-west Nigeria from the recently acquired HRAM data by means of spectral centroid method. No record of previous work done using the HRAM data exists on the basin. However, there is an earlier study covering only the upper part (about 21%) of the basin and utilizing the old low resolution data that showed that the CPD varies between 11.37 and 28.18 km, while the ensuing geothermal gradients and heat flow vary between 20.58 and 51.02 °C/km and 51.45 and 127.55 mW m^{-2} respectively (Nwankwo, 2015). Other researchers using the same low resolution magnetic data did not probe up to the basal depth but revealed that the depth to the top of magnetic sources

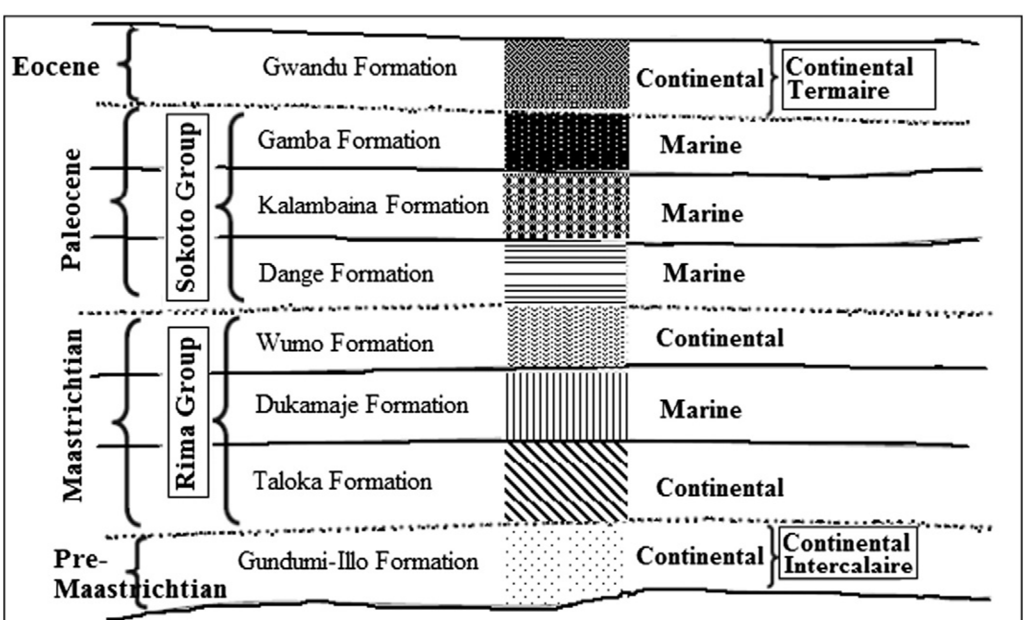

Fig. 2. Stratigraphic sequence of the Sokoto Basin.
After Obaje (2009).