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Mapping subtrappean sediments and delineating structure with the aid of heliborne time domain electromagnetics: Case study from Kaladgi Basin, Karnataka

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ABSTRACT

Mapping of subtrappean sediments is a complex geological problem attempted by many interpreters applying different geophysical techniques. Variations in thickness and resistivity of traps and underlying sediments, respectively, results in considerable uncertainty in the interpretation of geophysical data. It is proposed that the transient electromagnetic technique is an effective geophysical tool for delineation of the sub-trappean sediments, due to marked resistivity contrast between the Deccan trap, and underlying sediments and/or basement. The northern margin of the Kaladgi basin is covered under trap.

A heliborne time domain electromagnetic survey was conducted to demarcate the basin extent and map the subtrappean sediments.

Conductivity depth transformations were used to map the interface between conductive trap and resistive 'basement'. Two resistivity contrast boundaries are picked: the first corresponds to the bottom of the shallow conductive unit interpreted as the base of the Deccan Volcanics and the second - picked at the base of a deeper subsurface conductive zone – is interpreted as the weathered paleo-surface of the crystalline basement.

This second boundary can only be seen in areas where the volcanics are thin or absent, suggesting that the volcanics are masking the EM signal preventing deeper penetration. An interesting feature, which shows prominently in the EM data but less clearly imaged in the magnetic data, is observed in the vicinity of Mudhol. The surface geology interpreted from satellite imagery show Deccan trap cover around Mudhol. Modelling of TDEM data suggest the presence of synclinal basin structure. The depth of penetration of the heliborne TDEM data is estimated to be approximately 350 m for the study area. This suggests that heliborne TDEM could penetrate significant thicknesses of conductive Deccan trap cover to delineate structure below in the Bagalkot Group.

1. Introduction

There are large prospective areas of the world sedimentary basins that remain unexplored/under-explored beneath flood basalts. So far, many exploration programs have been carried out on in sub-basalt sedimentary basins in the North Atlantic Volcanic Province, the Deccan Traps in India, the Columbia River basalts in the North-West USA, the Parana Basin in South America and the Siberian Traps (Feinstein and Joshi, 2010). These programs have validated the existence of sedimentary basins underneath the flood basalt cover.

In peninsular India, Deccan traps form a vast flood basalt province. The basalts are the product of eruptions at the close of the Cretaceous, around 65 (±4) Ma when the Indian continent moved over the Reunion hotspot during its northward journey following its separation from Madagascar (Morgan, 1981; Duncan and Pyle, 1988; Allegre et al., 1999). Geochronological studies have shown that the eruption of these massive amounts of lavas occurred rapidly over a period of only 1–4 million years (Courtillot et al., 1986, 1988; Duncan and Pyle, 1988; Baksi, 1994). The Deccan traps occupy an area of nearly 500,000 km^2, which makes this formation the second most extensive geological formation in Peninsular India, next only to the Archean igneous and metamorphic complexes. The traps occupy large tracts in Saurashtra and Kutch in the west and northwest, extending to Belgaum in the south, Sarguja and Jashpur in the east and as far as Rajahmundry in the SE, covering parts of the states of Gujarat, Maharashtra, Madhya Pradesh and Karnataka. Expansive, thick tabular sheets typically characterize the lava flows. They are mostly horizontal and form flat-topped hills with step-like terraces that have been produced by differential weathering and erosion. Dips are southward from the northern end of the section to Kohlapur, where there is a dip-reversal (Watts and Cox, 1989). The thickness of individual flows may vary from a few meters to as much as 40 m. The Deccan trap column also shows significant variations in thickness from 100 m to 1500 m (Kaila, 1988).

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To determine the thickness variations of the traps and acquiring insights into the nature of the subtrappean lithology and structure, constitute an important data input that will facilitate the understanding of the geology, structure and tectonics of the Deccan trap region. If the continuation of older rock sequences is assumed beneath the Deccan Traps, then a variety of rock types – including granitic rocks, sedimentary rocks, and metamorphic rocks of Achaean to Jurassic age – can be presumed to underlie the volcanics (Tiwari et al., 2001; Ray et al., 2008).

The Proterozoic basins are known to host a significant share of the world's uranium reserves. Hence, it is of great interest to map the subtrappean proterozoic sediments and their extent in the trap covered regions. Numerous uranium occurrences have been located within the environs of Kaladgi basin, and the first sizable sub-surface uranium mineralisation was intercepted at Deshnur within Badami arenites, close to the unconformity contact along the southern margin of the basin to host uranium mineralisation (Sridhar et al., 2014). Exploration efforts to locate suitable zones for uranium mineralization are undertaken by Atomic Minerals Directorate for Exploration and Research (AMD) for different types of uranium mineralisation. A good part of the northerly and westerly extension of basin is covered by basaltic lava flows comprising the Deccan Traps. The inliers around Ajra in the west and Mamdapur in the north have provided unequivocal evidence of the presence of Kaladgi sediments under the volcanic rocks. There have been a few attempts to estimate the thickness of the traps using conventional geophysical methods, such as gravity, magnetics seismics and magnetotellurics (Negi et al., 1983; Tiwari et al., 2001; Kaila et al., 1981a, 1981b; Patro and Sarma, 2007). These studies have a number of limitations in terms of determining the trap thicknesses and the nature of the subtrappean lithology. Electrical methods in general and heliborne transient electromagnetic (TEM) technique in particular, have been proven to be a cost effective tools for exploration. However, their application over trap-covered areas to map sub-trappean sediments has not been rigorously tested. The present study show results of the effective use of heliborne TEM data to map sub-trappean sediment and estimate trap thickness.

2. Geology of the study area

The irregular E–W trending Kaladgi basin is a peri-cratonic Meso to Neoproterozoic basin located on the north-western fringe of the Western Dharwar Craton covering an area of approximately 8000 km^2. The Kaladgi Supergroup sediments unconformably overlie the Archaean basement Peninsular Gneiss and Dharwar Supergroup units in the south of the study area and in the north and westerly extensions, the sediment package is concealed under Cretaceous-Eocene Deccan Traps (Jayaprakash et al., 1987).

The Kaladgi basin comprises thick cyclic piles of quartzite and arenite with minor shale and carbonate facies. The NNW trending Mesoarchaean to Neoarchaean Peninsular Gneiss, greenstone belts and Closepet Granite form the basement for the Kaladgi Supergroup (Fig. 1). The Peninsular Gneiss is tonalite–trondhjemite–granodiorite (TTG) in composition and the greenstone belt comprises of metabasalts with subordinate felsic volcanics, BIF, meta-ultramafics, metapelites and meta greywacke. The Closepet Granite compositionally varies from K- and LREE-rich granodiorite to granites (Jayananda et al., 2006). The Kaladgi Supergroup is divided along an angular unconformity surface into two groups: the lower Bagalkot Group, and the overlying Badami Group. At the centre of the basin, the Bagalkot Group is highly deformed, displaying WNW–ESE plunging anticlines and synclines (Jayaprakash et al., 1987). Peninsular gneisses with younger intrusive granites and Chitradurga metasediments form the basement rocks for Bagalkot Group.

Bagalkot Group and the undeformed Badami sediments. In general, steeply dipping folded rocks of Bagalkot form basement to Badami Group, however at places they directly overlie the granitoids and schists. The Bagalkot Group is further subdivided into two subgroups viz. Lokapur and Simikeri separated by a disconformity and consists mainly of quartzite, shale and limestone with extensive development of stromatolitic dolomite and chert breccias. The Badami Group comprises of horizontal to gently dipping beds of arenite, shale and limestone.

3. Methodology

The transient electromagnetic (TEM) geophysical surveying technique relies on the premise that changes in the primary magnetic field produced in the transmitting loop will result in eddy currents being generated in any conductors in the ground. The eddy currents then decay to produce a secondary magnetic field, which may be sensed in the receiver coil. Theoretically, the electromagnetic method assume in an entirely homogeneous half-space, a conductive value can be calculated for the subsurface by knowing the primary induced field and measuring the response of secondary field at specific locations. However, homogeneity within the subsurface is very rare and induced current will follow the path of least resistance, concentrating in areas of conductive material and avoiding areas of resistive material (West and Macnae, 1991).

A fundamental problem with all AEM systems is that there are practical limits to the lowest transmitter base frequency that can be used, therefore penetration with AEM surveys in areas of very conductive overburden and high conductance discrimination remains a problem. In TEM systems, which measure the derivative of time varying B field during the on-time of the transmitter pulse, the effect of relatively conductive host rocks or overburden (as low as 10 to 1 Ω-m) can be minimized. This allows extremely conductive bodies to be detected within geological “conductivity” noise (King, 2007). The on-time measurements are much more difficult in practice, because the primary field has to be accurately calculated and subtracted from the total field on-time reading that includes both primary and secondary fields. This requires geometric control of the primary field to the same level that recording accuracy is desired. For this reason most time domain EM systems, particularly towed bird AEM systems generally do not measure the on-time response.

A new generation of high power airborne TEM systems provide various combinations of capabilities to measure derivative of time varying B field, partial “on time” at low transmitter base frequency with high power into the transmitter loop. These systems have experienced dramatic improvements in transmitter power and system noise reduction, such that signal to noise has improved to a level that inductively induced polarization (airborne IP) and superparamagetic effects are detectable (Graham et al., 2016). The Fugro (now CGG) Geotem systems measures dB/dt and integrate to produce reliable calculated B field measurements (Smith and Annan, 1998). Fugro has modified the geometry to improve overall data quality and the time-domain helicopter electromagnetic system (HELITEM®) uses the same high-speed digital EM receiver that is used in the GEOTEM® and MEGATEM® systems. The significantly higher peak moment of the HELITEM system provides an increased ability to penetrate thicker conductive overburden which is of specific relevance (Mulè et al., 2012).

4. Data acquisition and processing

Heliborne geophysical surveys were carried with the Fugro HELITEM system in the western part of the basin from Kadgaon to Ramdurg to acquire time domain electromagnetic, magnetic and radiometric data. The HELITEM transmitter loop is towed 35 m above the ground, by a helicopter with a 45 meter tow cable. The receiver is positioned 23.0 m above and 10.7 m forward of the transmitter loop centre. The TDEM data were acquired at a line spacing of 200 m along N–S flight lines at a speed of 80 km/h (sample spacing of ~2.5 m along the line). Tie lines were flown E–W perpendicular to flight lines at a 5000 m interval.