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Large mantle magma reservoir of Afar, Ethiopia

***Afroz Ahmad Shah* ***

Applied Geology, Curtin University Sarawak, Miri, Malaysia
**Correspondence: afroz.shah@curtin.edu.my*

Edited and reviewed by:
Jan H. Behrmann, GEOMAR Helmholtz Centre for Ocean Research, Germany

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A commentary on

A mantle magma reservoir beneath an incipient mid-ocean ridge in Afar, Ethiopia
by Desissa, M., Johnson, N. E., Whaler, K. A., Hautot, S., Fisseha, S., and Dawes, G. J. K. (2013). Nat. Geosci. 6, 861–865. doi: 10.1038/ngeo1925

Most of the Earth's crust is created at mid-oceanic ridges where two tectonic plates move away from each other, known as constructive plate boundary system and extends for ~60,000 km around the globe (Wright et al., 2006). It creates characteristic extensional structures, wherein tectonic stress is primarily released by rifting processes, which thus forms major system of normal faults and volcanoes. Such tectonic settings are dominated by vertical sheets of dyke systems, along which magma is injected into the crust. To understand the rifting process and the associated magmatism at these places a direct observation is often difficult, primarily, because on Earth only 2% of the mid-ocean ridge system is above sea level (Smith and Cann, 1999; Wright et al., 2006; Buck, 2013; Desissa et al., 2013). However, Afar (East Africa) and Iceland are the rare places where such observations can be directly examined on land (Buck, 2013; Desissa et al., 2013). Therefore, the past observations at these sites have suggested that they share a very similar driving mechanism (Wright et al., 2006). This usually follows a pattern wherein magma is sporadically stowed in the crust and there it is stored at numerous positions and levels. This is followed by injection through various dyke systems within the brittle upper crust (Wright et al., 2006).

Further, it is commonly believed that unavailability of magma in the crust results in the quiescence between different dyking episodes (MacGregor et al., 1998; Canales et al., 2000; Heinson et al., 2000; Singh et al., 2006; Key et al., 2013). For example, the historical record for the northern spreading segments of Iceland suggests 200–300 years of quiescence between dyke episodes; however, the southern segments have largely been quite for 1000 years (Buck, 2013).

The recent results of Desissa et al. (2013), and some previous findings at spreading centers (e.g., Carbotte et al., 2006) have questioned this widely accepted view. These studies argue that a large quantity of magma is probably always available in the mantle and shallow crust at many spreading centers, which suggests that some other mechanism is required to understand the control and frequency of dyking events. Desissa et al. (2013) have used magnetotelluric techniques, a geophysical method particularly sensitive to high conductivity (low resistivity) materials (non-organic) fluids, magmas and partial melts, to understand the dynamics of Dabbahu magmatic segment in Afar, Ethiopia. It is therefore a very useful procedure to image magma and partial melt in the crust and upper mantle (Tolstoy et al., 2006).

Since 2005, the Dabbahu magmatic segment was active, as demonstrated by repeated magma intrusions and is believed to suggest a late stage of continental rifting process (Wright et al., 2006; Buck, 2013; Desissa et al., 2013). Tectonically, the magmatic activity at the 60-km-long Dabbahu spreading segment is part of the Red Sea spreading process, which accommodates the separation between the Arabian and African plates (Buck, 2013). Magnetotelluric data of Desissa et al. (2013) in Afar shows a very high electrical conductivity region, which is 30-km-wide and 35 km deep. It is interpreted as an area, wherein a large of volume of magma (~500 km^3) extends well into the mantle with a 13% melt fraction. The large dimensions of the magma chamber allows these authors to argue that it must have stayed there for quite a while and probably for several tens of thousands of years, however, it remains unclear why it stayed at that depth within both the crust and mantle and for so long without coming out through dyking processes (Buck, 2013). Further, geochemical analyses of samples taken from the Dabbahu segment (Ferguson et al., 2013) suggest that melting of mantle rocks occurs at greater depths (>80 km). This allows to understand that large accumulations of melt should not occur at depth, primarily, because of the low density of the magma should force it to move upwards to percolate into the crust.

However, the study of Desissa et al. (2013) clearly suggests that a large quantity of magma is stored within the crust and mantle beneath the Dabbahu plate spreading segment without large dyking events. Such a large volume of melt could supply 100 typical magmatic dyking events and should aid plate rifting for tens of thousands of years to come. This is contrary to the observations (Buck, 2013), and clearly indicates that initiation of dyking is not controlled by the volume of magma but some other process, which needs to be investigated.

Further, the resolution of geophysical data (e.g., seismic, gravimetric, magnetotelluric methods) is not always enough to image accurately magma bodies and the limitation of available MT method offers uncertainties regarding the dynamics of mamgmatic dyking in hot-spot influenced crust and such estimates from Iceland are equally questionable (e.g., Björnsson et al., 2005). Thus, such data should be compared with temperature, pressure, geochemical, mineral, and seismic data to constrain the acquired parameters of a magma body efficiently. Such a data set will provide robust constraints and reliable results than does the use of one method only (e.g., MT only). Further, another array of MT data traverse could be acquired along the western portion of the study area, which should ideally map a similar anomaly at depth.

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