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Evidence for fluid and melt generation in response to an asthenospheric upwelling beneath the Hangai Dome, Mongolia

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ABSTRACT

The Hangai Dome, Mongolia, is an unusual high-elevation, intra-continental plateau characterized by dispersed, low-volume, intraplate volcanism. Its subsurface structure and its origin remains unexplained, due in part to a lack of high-resolution geophysical data. Magnetotelluric data along a ∼610 km profile crossing the Hangai Dome were used to generate electrical resistivity models of the crust and upper mantle. The crust is found to be unexpectedly heterogeneous. The upper crust is highly resistive but contains several features interpreted as ancient fluid pathways and fault zones, including the South Hangai fault system and ophiolite belt that is revealed to be a major crustal boundary. South of the Hangai Dome a clear transition in crustal properties is observed which reflects the rheological differences across accreted terranes. The lower crust contains discrete zones of low-resistivity material that indicate the presence of fluids and a weakened lower crust. The upper mantle contains a large low-resistivity zone that is consistent with the presence of partial melt within an asthenospheric upwelling, believed to be driving intraplate volcanism and supporting uplift.

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1. Introduction

The Hangai Dome in central Mongolia is an uplifted, intra-continental plateau with a large topographic bulge extending more than 2000 m above the regional elevation (Cunningham, 2001). The mechanism of uplift and support in the continental interior, away from active tectonic margins, is an open and important question. The Hangai region occupies a unique position in central Asia because it is a link between actively deforming regions. It is located between the rigid Siberian craton to the north, which is associated with an east-west extensional regime near the Baikal rift, and the North China and Tarim cratons to the south (see Fig. 1), which have a northward compressional regime to accommodate the movement of the Tibetan Plateau from the India–Asia collision (e.g., Calais et al., 2003). The Hangai region is believed to be underlain by a rigid pre-Cambrian crustal block (Cunningham, 2001). It is bounded by large, seismically active faults (Walker et al., 2007) that, along with the transpressional deformation of the Altai range, accommodate the northward compressional motion (Cunningham, 2001; Calais et al., 2003). Both the Bulnay fault system to the north and the Bogd fault system to the south have had intra-continental earthquakes larger than magnitude 8 within the last century (e.g., Calais et al., 2003, and references therein).

Magmatism is commonly associated with tectonic plate boundary processes, such as subduction and rifting. Enigmatically, intra-continental, intraplate volcanism occurs throughout the Hangai region. It is characterized by dispersed, low-volume, alkali basaltic volcanism, with ages from the Holocene to the Oligocene (2 ka to 33 Ma) (Barry et al., 2003). The onset of uplift and doming is believed to have been coincident with the beginning of volcanism (e.g., Cunningham, 2001; Walker et al., 2007; Sahagian et al., 2016), indicating that the processes may be linked. A mantle plume was originally favored to explain the origin of the high topography and associated volcanism far from active tectonic margins (Windley and Allen, 1993). However, some recent petrological evidence is inconsistent with a deep-rooted, high heat-flux mantle plume, including: dispersed volcanism that exhibits no definable spatial boundaries and lacks age progression, small erupted volumes that occurred sporadically, and a lack of xenolith evidence

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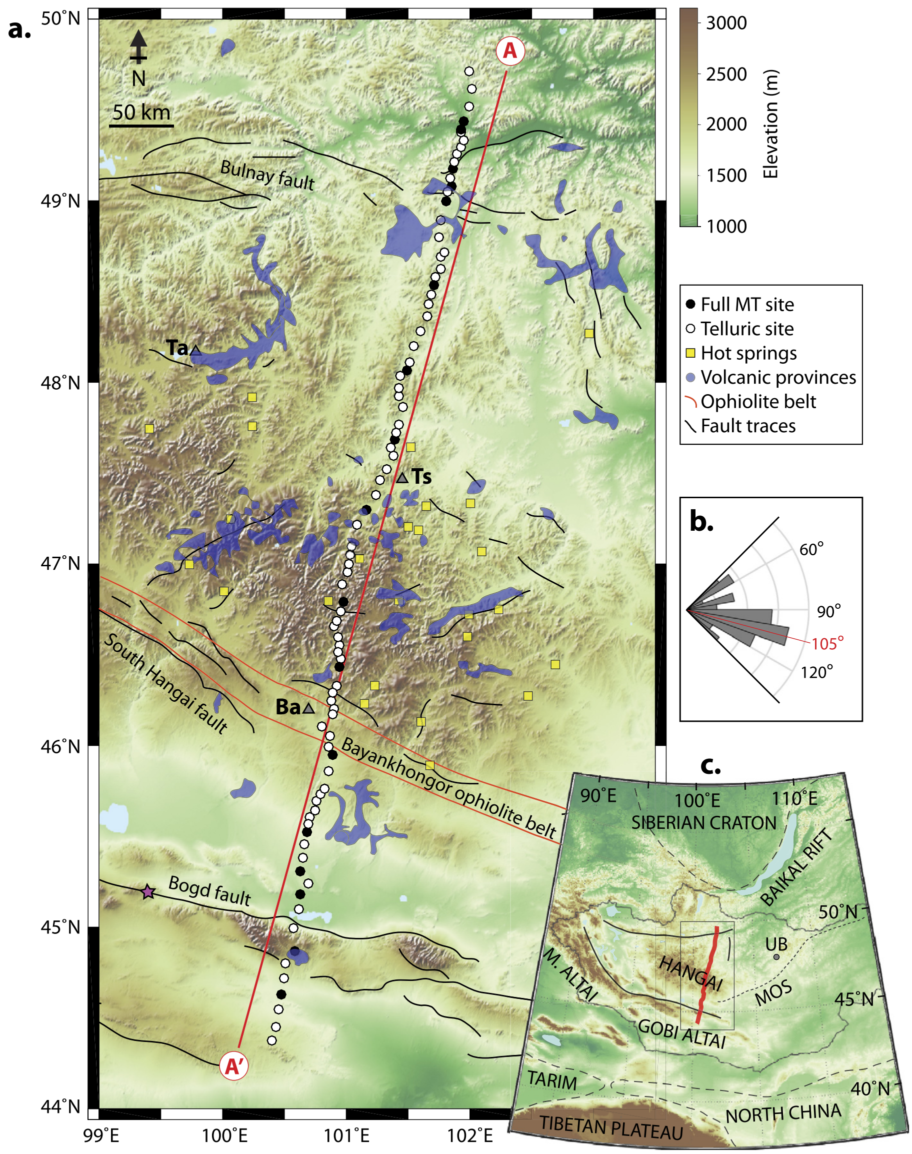

Fig. 1. (a) Topographic map of the study area. A total of 89 magnetotelluric (MT) sites (circles) were deployed along profile A–A′ (red line). Select towns are shown for reference: Ba = Bayankhongor, Ta = Tariat, Ts = Tsetserleg. Additional information includes: volcanic provinces (blue shapes) (adapted from Sahagian et al., 2016; Hunt et al., 2012, and Cunningham, 2001); hot springs (gold squares) (Ganbat and Demberel, 2010); fault traces (black lines) (adapted from Walker et al., 2007, 2008); ophiolite belt (orange lines) (Badarch et al., 2002); pink star marks the epicenter of the 1957 Bogd event (Calais et al., 2003). (b) Average 2-D geo-electric strike direction calculated from the MT data, for periods of 1–1000 s. (c) The Hangai region has a unique position between the Siberian craton and the North China and Tarim cratons (dashed gray lines) (Badarch et al., 2002). The survey location (box), MT sites (red dots), Mongolian Altai and Gobi Altai mountains, political boundary of Mongolia (thin black line), and the capital city, Ulaanbataar (UB), are indicated. Major fault systems (solid black lines) bound the Hangai region (Walker et al., 2007). The approximate location of the Mongol–Okhotsk suture zone (MOS; dotted gray line) is marked (Van der Voo et al., 2015).

for anomalously high lithospheric temperatures (Barry et al., 2003; Harris et al., 2010). Hence alternative explanations are sought.

Seismic studies, supported by analysis of xenoliths from surface lavas, estimated a surprisingly thin lithosphere (60–80 km) below the central Hangai region, in comparison to the surrounding area (120–225 km) (Petit et al., 2008; Ionov, 2002). In addition, they detected a thick crust (45–55 km) below the Hangai region which thins at the edges (∼35 km) (Petit et al., 2008). Other geophysical studies have determined that the lithosphere below the Hangai Dome has anomalously low seismic velocities (e.g., Chen et al., 2015), and is characterized by a very low negative Bouguer anomaly (<−250 mGal) compared to the surrounding region (Tiberi et al., 2008). However the lithospheric structure of the Hangai region is poorly understood and additional high-resolution geophysical data are needed to give detailed images of subsurface structures, specifically crustal features, and to gain further insights into its origin.

Magnetotelluric (MT) data map subsurface electrical resistivity using natural electromagnetic signals (e.g., Chave and Jones, 2012). The resistivity of a rock is highly sensitive to the quantity and composition of fluids, and hence the MT method is useful for investigating subsurface fluid and melt distribution. Therefore MT data have the potential to image intraplate volcanism throughout the lithospheric column and to restrict the mechanisms responsible for the uplift and support of the Hangai Dome. Moreover, MT data can help to provide constraints on lithospheric viscosity and mechanical strength, both of which are required for accurate modeling of lithosphere dynamics (Liu and Hasterok, 2016). Although the Hangai region is unique, its origin is relevant for other cases of continental uplift and intraplate volcanism worldwide, over diverse scales and settings, such as south-eastern Australia (e.g.,

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