

Mineralization of the Bayankhongor Metal Belt and the South Hangai suture zone, Mongolia: insights from 3-D electrical resistivity models

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Summary

The South Hangai fault system, located between the uplifted Hangai Dome and the Gobi-Altai Mountains in central Mongolia, represents an ancient suture zone and terrane boundary, which is possibly an extension of the Mongol–Okhotsk suture that resulted from the closure of the Mongol–Okhotsk Ocean. The adjacent obducted Bayankhongor Ophiolite Belt is possibly the longest continuous ophiolite belt in the world. This area is important because it is associated with the Bayankhongor Metal Belt, which is an economically significant zone for ore extraction in Mongolia, including important sources of gold and copper.

Electrical resistivity is a key parameter for mineral exploration. Because faults and suture zones are regions of fractured, weakened crust they often have circulating fluids that act to increase their electrical conductivity. Additionally, economic mineralization is commonly associated with a conductive signature from associated sulfide mineralogy.

We present magnetotelluric data acquired in an array across the southern Hangai region, Valley of Lakes, Mongolia. The magnetotelluric data were used to generate 3-D electrical resistivity models of the shallow crustal structure. Because the cratonic upper crust is highly resistive ($> 1000 \Omega\text{m}$), the low-resistivity ($< 30 \Omega\text{m}$) South Hangai fault system is easily detected. It is revealed to be a major crustal-scale structure. A clear transition in crustal electrical properties was observed across the suture zone and may reflect both the rheological and petrological differences across accreted terranes. Furthermore, anomalous, low-resistivity zones in the crust are spatially associated with the surface expressions of known mineralization and resource extraction projects. By combining our electrical resistivity results with other geological and petrological data we attempt to gain insights into the potential mineral resources of this unique region, and their origin.

1 Introduction

South of the Hangai Dome and at the northern margin of the Valley of Lakes, central Mongolia, a series of fault segments are seen, known as the South Hangai fault zone (Walker et al., 2007; Calais et al., 2003). This zone is believed to be a large suture zone, and thus an important terrane boundary (Buchan, et al., 2001; Badarch et al., 2002; Osozawaa et al., 2008). It is possibly the western-most extension of the Mongol–Okhotsk suture zone, that was created from the scissor-like closure of the Mongol–Okhotsk Ocean approximately 140 million years ago (e.g., Van der Voo et al., 2015; Figure 1).

Later, the pre-Cambrian cratonic blocks of the Hangai and Baydrag (to the north) acted as a nucleus for Paleozoic accreted terranes from the south (Badarch et al., 2002). As a consequence of the ocean closure, an ophiolite belt was exposed at the surface, the Bayankhongor Ophiolite Belt, which is possibly the longest continuous ophiolite belt in the world (Buchan et al., 2001). Other belts of metamorphosed material are also seen at the surface (Osozawaa et al., 2008). Furthermore, this region hosts the Bayankhongor Metal Belt, an economically significant mineralized zone that contains important sources of copper, iron, and gold (e.g., Buchan et al., 2001).

Seismic studies indicated that the crust below central Mongolia is thick (~50 km) and that the lithosphere is anomalously thin (60 - 80 km), compared to its surroundings (> 150 km) (Petit et al., 2008). However, the detailed 3-D structure of the central Mongolia, including the shallow crust, is poorly understood. Moreover, no dedicated geophysical survey has been conducted across the fault and mineral zones of central Mongolia. Magnetotelluric (MT) data measure the electrical resistivity of the subsurface, using natural electromagnetic signals (see Unsworth and Rondenay, 2012). The MT method can provide insights on the structure of the fault zones and mineral zones of central Mongolia. Here we present MT data acquired across this region.

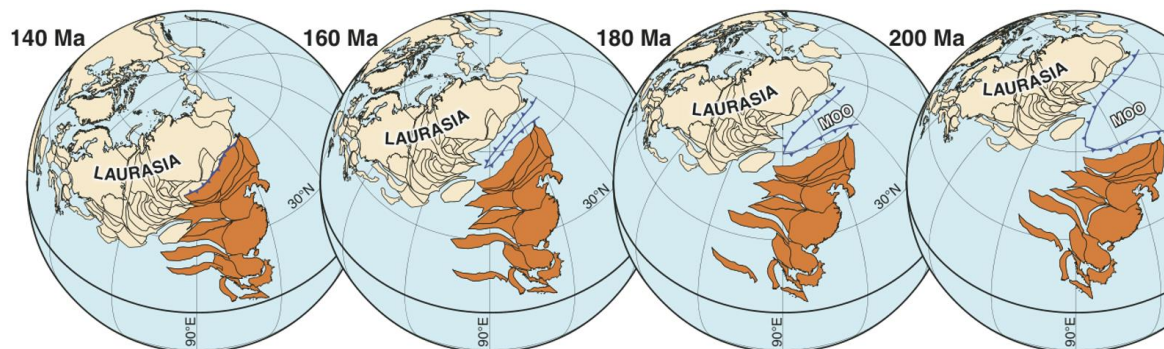


Figure 1: The Mongol–Okhotsk Ocean (MOO) closure created a large suture zone across Asia (modified from Van der Voo et al., 2015). The South Hangai fault system in central Mongolia is believed to be the western-most extension of that suture.

2 Magnetotelluric measurements

Here we focus on a subset of an extensive MT data set (~330 sites) collected across central Mongolia (2016 - 2018; Käüfl et al., 2019; Comeau et al., 2018). We use three profiles, roughly ~120 km long and each separated by ~100 km (Figure 2). These profiles (L2000, L4000, and L6000) have 6, 7, and 9 km average site spacing, and 18, 16, and 13 sites, respectively. We deployed both telluric-only data-loggers (EDEs), developed by the University of Münster, and full MT sites (SPAMs), provided by the Geophysical Instrument Pool Potsdam (GIPP). Combining deployment in this way ensured fast and efficient data acquisition (see Käüfl et al., 2019). Data collection at each site was typically 1 – 6 days, with data recorded from 512 Hz to 4,200 s. The MT data are generally high quality and have a very low noise level. This is primarily due to the remote location and lack of cultural noise.

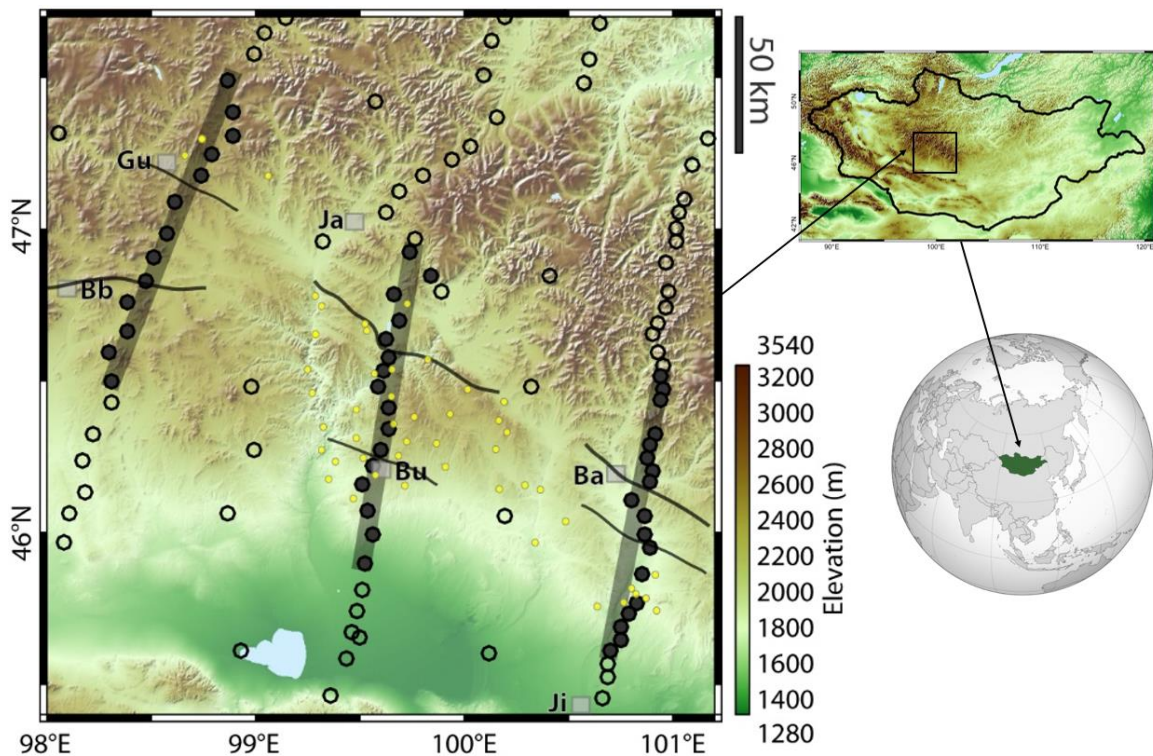


Figure 2: Map of the study area across the Bayankhongor Metal Belt and the South Hangai suture zone, south-central Mongolia. Inset map shows location within Mongolia and within Asia. The location of MT measurement sites are indicating with circles. The Bayankhongor Metal Belt (gold deposits are yellow circles; black lines are limits; Buchan et al., 2001) lies south of the South Hangai fault system (bold black lines; Walker et al., 2007). Villages are grey boxes (Gu = Gurvanbulag; Bb = Bayan Bulag; Ja = Jargalant; Bu = Bumbugur; Ba = Bayankhongor; Ji = Jinst).

3 Electrical resistivity model

The MT data along all three profiles were inverted with the MODEM inversion algorithm (Kelbert et al., 2014). The three-dimensional (3-D) electrical resistivity model is shown in Figure 3. No topography was included in the models. The terrain in this region is not particularly rough, although the elevation does decrease by an average of 1000 m from north to south over the modelled area, and some contribution from the topography may be present (Käufel et al., 2018). All model depths are below the average surface elevation, which is defined as 2000 m. Only data from 128 Hz to 1000 s were included. The impedance components were assigned an error floor of 5%. The inversion algorithm reduced the root-mean-square (RMS) misfit from 33.16 to 1.86 after 108 iterations. This indicates that the 3-D model fits the measured MT data.

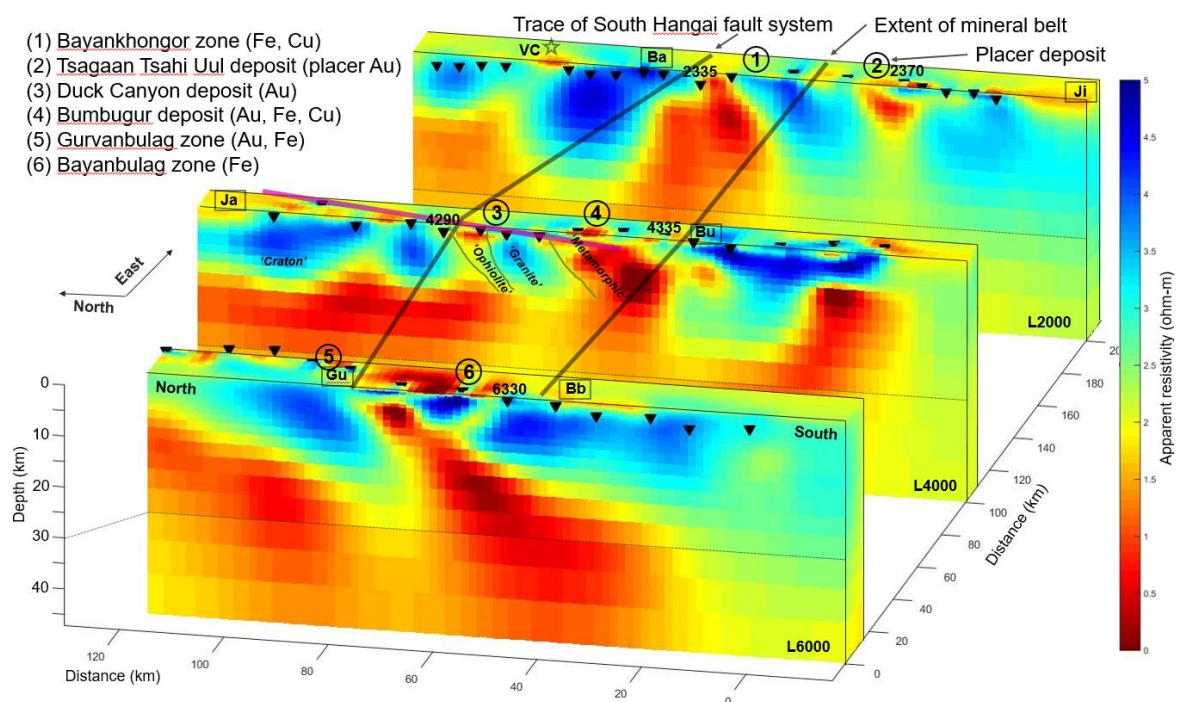


Figure 3: The 3-D electrical resistivity models reveal mineralization zones and fault zones in the upper crust, along the Bayankhongor Metallogenic Belt and South Hangai suture zone, central Mongolia. Three profiles (L2000, L4000, and L6000) contain 18, 16, and 13 MT sites, respectively. The location of several well-known mineral deposits (circled numbers) and the minerals found in these deposits (legend in upper left) are indicated (Buchan et al., 2001; Tseesuren, 2001). The locations of mineral deposits are coincident with low-resistivity anomalies. The South Hangai fault system and the extent of the mineral belt is indicated (black line; Walker et al., 2007; Buchan et al., 2001). The location of a geological cross-section from Osozawa et al. (2008) (pink line) along profile L4000 and geological units are indicated. A volcanic zone is also indicated (VC, star; Ancuta et al., 2018; Barry et al., 2003). Villages are labelled in boxes (Gu = Gurvanbulag; Bb = Bayan Bulag; Ja = Jargalant; Bu = Bumbergur; Ba = Bayankhongor; Ji = Jinst). Model resolution is reduced in the lower crust, below a depth of 30 km.

4 Model features

In the 3-D resistivity models, in general, the upper crust appears highly resistive ($> 1000 \Omega\text{m}$). This can be explained by the pre-Cambrian cratonic Baydrag and Hangai micro-continent blocks (Cunningham, 2001). However, this is interrupted by anomalous, strongly conductive features ($20 - 40 \Omega\text{m}$) that stretch nearly vertically from the surface to mid-crustal depths.

The surface trace of the South Hangai fault and suture system (Walker et al., 2007; Calais et al., 2003; Van der Voo et al., 2015) is coincident with strong conductive anomalies ($< 30 \Omega\text{m}$). This can be explained by the fact that fault zones are regions of fractured and weakened crust and often have circulating fluids that act to increase their electrical conductivity (e.g., Unsworth and Rondenay, 2012; Unsworth and Bedrosian, 2004).

The locations of other localized conductive anomalies match with well-known mineral deposits (Buchan et al., 2001; Tseesuren, 2001; see Figure 3). Mineralization in this region includes porphyry copper, iron ore, and both hard and placer gold deposits of economic significance (Buchan et al., 2001). Mineralization zones commonly have conductive signatures from associated sulfide mineralogy, and corresponding metamorphic processes. This can potential explain the conductive anomalies observed.

Profile L4000 crosses the Bumbugur mineral district, a known deposit of gold, iron ore, and porphyry copper (Au, Fe, Cu), and it crosses the zone of Duck Canyon, which hosts an active gold deposit (Buchan et al., 2001). A geological cross section across Darvsin Nuur and Duck Canyon from Osozawa et al. (2008) is roughly coincident with this profile (Figure 4). It shows several south-dipping units, including the South Hangai Fault Zone (see Figure 5), the Bayankhongor Ophiolite Belt, and several metamorphosed and mineralized units to the south.

The Valley of the Lakes is an internal drainage basin so placer type deposits may also be found outside the fault zone and mineral belt. For example, profile L2000 crosses first the Bayankhongor mineral zone, which contains sources of iron and copper, and 30 km further (downslope) the Tsagaan Tsahi Uul (TTU) mining zone, which contains placer gold (Buchan et al., 2001; see also Comeau et al., 2019).

Further to the west, along profile L6000, the Gurvanbulag mineral district is crossed (Buchan et al., 2001). Deeper in the crust, the same conductive signature associated with the ophiolite belt is detected here too. This is potential evidence that the ophiolite belt, and possibly the suture zone, extends as far west as 98° longitude. Note the main fault zone bends south towards Bayan Bulag, where it is spectacularly exposed (e.g., Walker et al., 2007), whereas the ophiolite belt continues north-west towards Gurvanbulag.

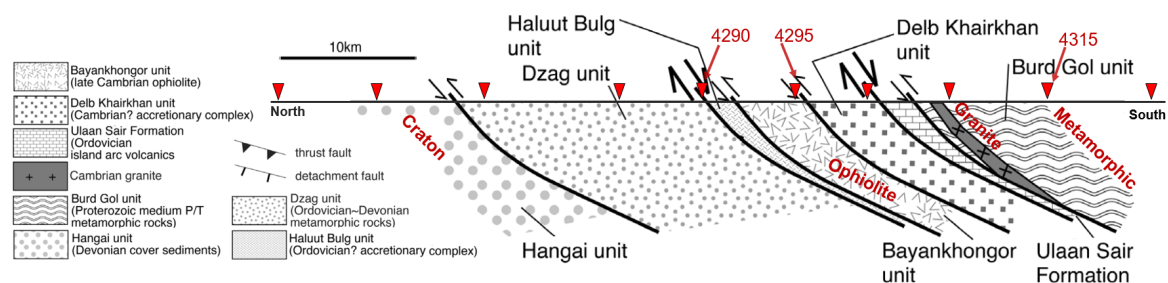


Figure 4: A geological cross section across Darvsin Nuur and Duck Canyon (modified from Osozawa et al., 2008). The section is roughly coincident with MT profile L400. It crosses the South Hangai Fault Zone, the Bayankhongor Ophiolite Belt, and several metamorphosed and mineralized zones. MT measurement sites along the section are indicated in red.



Figure 5: The South Hangai fault zone from Duck Canyon, central Mongolia. Photograph looking North.

5 Conclusions

The 3-D electrical resistivity model presented here provides new insights into the electrical resistivity structure of the Bayankhongor Metal Belt and the South Hangai suture zone. Low-resistivity anomalies in an otherwise highly-resistive cratonic crust are found to be coincident with the location of the South Hangai suture zone and with several known mineral deposits in the Bayankhongor Metal Belt.

The Bayankhongor Metal Belt is a region with significant economic mineralization. Broad-scale electrical resistivity models, as shown here, can help to locate potential mineral resources. Future work may shed light on their origin and emplacement. Future detailed follow-up studies can pinpoint precise deposit locations (e.g., dense CSAMT, DC, TEM, drone surveys). Ultimately, the focused, localized, extraction of minerals from precisely-located deposits, compared to indiscriminate land-stripping, can limit environmental and societal harm and increase economic potential.

Acknowledgements

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