Electrical conductivity of metasomatized lithology in subcontinental lithosphere

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Abstract

A plausible origin of the seismically observed mid-lithospheric discontinuity (MLD) in the subcontinental lithosphere is mantle metasomatism. The metasomatized mantle is likely to stabilize hydrous phases such as amphiboles. The existing electrical conductivity data on amphiboles vary significantly. The electrical conductivity of hornblendite is much higher than that of tremolite. Thus, if hornblendite truly represents the amphibole varieties in MLD regions, then it is likely that amphibole will cause high electrical conductivity anomalies at MLD depths. However, this is inconsistent with the magnetotelluric observations across MLD depths. Hence, to better understand this discrepancy in electrical conductivity data of amphiboles and to evaluate whether MLD could be caused by metasomatism, we determined the electrical conductivity of a natural metasomatized rock sample. The metasomatized rock sample consists of ~87% diopside pyroxene, ~9% sodium-bearing tremolite amphibole, and ~3% albite feldspar. We collected the electrical conductivity data at ~3.0 GPa, i.e., the depth relevant to MLD. We also spanned a temperature range between 400 to 1000 K. We found that the electrical conductivity of this metasomatized rock sample increases with temperature. The temperature dependence of the electrical conductivity exhibits two distinct regimes. At low temperatures <700 K, the electrical conductivity is dominated by the conduction in the solid state. At temperatures >775 K, the conductivity increases, and it is likely to be dominated by the conduction of aqueous fluids due to partial dehydration. The main distinction between the current study and the prior studies on the electrical conductivity of amphiboles or amphibole-bearing rocks is the sodium (Na) content in amphiboles of the assemblage. Moreover, it is likely that the higher Na content in amphiboles leads to higher electrical conductivity. Pargasite and edenite amphiboles are the most common amphibole varieties in the metasomatized mantle, and our study on Na-bearing tremolite is the closest analog of these amphiboles. Comparison of the electrical conductivity results with the magnetotelluric observations constrains the amphibole abundance at MLD depths to <1.5%. Such a low-modal proportion of amphiboles could only reduce the seismic shear wave velocity by 0.4–0.5%, which is significantly lower than the observed velocity reduction of 2–6%. Thus, it might be challenging to explain both seismic and magnetotelluric observations at MLD simultaneously.

Keywords: Mid-lithospheric discontinuity (MLD), electrical conductivity, metasomatized rock, diopside, amphibole

Introduction

Recent high-frequency seismic data have revealed a seismic discontinuity in the subcontinental lithosphere at a depth range of 60–160 km. This is often referred to as the mid-lithospheric discontinuity (MLD) and is characterized by a 2–6% reduction in the seismic shear wave velocity (Rychert and Shearer 2009; Romanowicz 2009; Abt et al. 2010; Fischer et al. 2010). The thickness of the discontinuity typically varies between 10–20 km (Fischer et al. 2010).

Although MLDs are found across all cratons, their origin is poorly understood. A variety of mechanisms have been proposed to explain the observed shear wave velocity anomaly at MLD depths (Selway et al. 2015; Karato et al. 2015). The most plausible mechanisms include: the presence of partial melts (Thybo 2006), elastically accommodated grain boundary sliding (Karato et al. 2015; Karato and Park 2019), seismic anisotropy (Yuan and Romanowicz 2010; Sodoudi et al. 2013; Wirth and Long 2014; Ford et al. 2016), and mantle metasomatism or frozen-in melts (Savage and Silver 2008; Sodoudi et al. 2013; Hansen et al. 2015; Rader et al. 2015; Selway et al. 2015; Saha et al. 2018, 2021; Peng and Mookherjee 2020).

Mantle metasomatism alters the “dry” mantle lithology and often stabilizes carbonates and hydrous minerals such as amphiboles and phlogopite. The xenoliths formed at pressures associated with MLD depths indicate that at least ~25% of them are amphibole-bearing, ~90% are phlogopite-bearing, and less contain carbonates (Rader et al. 2015). While the presence of amphiboles in MLD tends to lower the seismic shear wave velocity (Selway et al. 2015; Peng and Mookherjee 2020; Saha et al. 2021), it may also lead to anomalously high electrical conductivity based on the measurement of hornblendeite (Wang et