Electrical conductivity of mudstone (before and after dehydration at high P-T) and a test of high conductivity layers in the crust

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ABSTRACT

The electrical conductivity of mudstone before and after dehydration was measured using complex impedance spectroscopy in the frequency range of 10⁻¹ to 10⁶ Hz, and the experiments were carried out at 0.5–2.5 GPa and 623–973 K. Before and after dehydration, the electrical conductivity of mudstone and temperature followed an Arrhenius relation. The influence of pressure on electrical conductivity was weaker than that of temperature. The conductivity slightly increased with increasing pressure. Dehydration at 760–800 K dramatically enhanced the electrical conductivity of mudstone; the dehydration temperature decreased slightly with increasing pressure. Hydrogen-related lattice defects (e.g., H⁺ or H⁺) are proposed to be the main charge carriers in the mudstone sample before dehydration, whereas H⁺ and OH⁻ are suggested to be the main charge carriers in the dehydration product of mudstone. Finally, the electrical conductivity of the dehydration product of mudstone can be used to interpret high-conductivity layers (HCLs) associated with the Hope and Porters Pass fault zones in Marlborough, New Zealand.

Keywords: Electrical conductivity, mudstone, high pressure, dehydration, conduction mechanism, high-conductivity layer

INTRODUCTION

Electrical conductivity is an important parameter that can be used to infer the material composition and physical conditions of the interior of the Earth and other planets. Previous researchers have studied the electrical conductivities of most minerals and rocks in the Earth’s crust and mantle (Huebner and Dillenburg 1995; Dai et al. 2008; Yoshino et al. 2009; Yang et al. 2011; Yang and McCammon 2012; Hu et al. 2013, 2014; Dai and Karato 2014a; Li et al. 2016), and the magnetotelluric (MT) and geomagnetic depth sounding (GDS) results have provided significant constraints (Zhu et al. 2001; Maumus et al. 2005; Yang 2012; Dai et al. 2016; Manthilake et al. 2016). The dehydration of hydrous minerals and rocks (e.g., chlorite, lawsonite, and serpentine) can generate high-conductivity layers (HCLs) in the Earth’s interior (Zhu et al. 1999; Manthilake et al. 2015, 2016), but the electrical conductivity of pelite containing a large amount of water is unknown.

Pelite is widely distributed in the shallow crust, and as the main sedimentary rock that enters subduction zones, it also occurs in the Earth’s interior (Li et al. 2005; Song et al. 2015). At high temperatures and high pressures, pelite is metamorphosed, and the dehydration of rock-forming hydrous minerals (e.g., kaolinite, montmorillonite, sericite, and illite) occurs during the subduction of pelite. Song et al. (2009) studied the tectonic evolution of early Palaeozoic high-pressure metamorphic rocks in the North Qilian Mountains of China and obtained peak metamorphic conditions of 2.6 GPa and 813 K for metapelite. Tsuno et al. (2012) suggested that the subduction depths and slab-surface temperatures of pelitic sediments are >100 km and ~1073 K, respectively. The metamorphic grade of pelite differs under various conditions. Some regional metamorphic rocks (e.g., gneiss, schist, and granulite) can form by the metamorphism of mudstone, and the electrical properties of natural gneiss and granulite have been studied previously (Fuji-ta et al. 2004, 2007). Li et al. (2005) studied the dehydration temperature of pelite using high-pressure differential thermal analysis (HP-DTA); however, it might be better to determine the dehydration temperature directly using the inflection point between the electrical conductivity and temperature based on the Arrhenius relation (Song et al. 1996; Li et al. 2005).

In the present studies, we measured the electrical conductivity of mudstone under in situ conditions of 0.5–2.5 GPa and 623–973 K. The inflection point of the Arrhenius relation between electrical conductivity and temperature was applied to determine the dehydration temperature of mudstone. The conduction mechanisms before and after the dehydration of mudstone were explored in detail. Furthermore, the results are used to explain HCLs in Marlborough, New Zealand.

EXPERIMENTAL PROCEDURES

Sample preparation

Fresh mudstone samples were collected from the Tangjiawu Group of the Middle Devonian in Hangzhou, Zhejiang, China. To accurately determine the minerals in the samples, we used optical microscopy, scanning electron microscopy (SEM), and micro-focused X-ray diffraction (XRD) at the State Key Laboratory

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