Interactive comment on "Effect of chemical composition on the electrical conductivity of gneiss at high temperatures and pressures" by Lidong Dai et al.

Response to Professor Fabrice Gaillard:

The electrical conductivity of gneiss samples is measured using multi-anvil presses at high-pressure high-temperature. Impedance spectroscopy is used but the paper focuses on the DC results only. The purpose of the paper is to complete a database on the conductivity of crustal rocks with the broad purpose of discussing electrical anomalies in continental crust. Several experimental surveys have been conducted by the same group on different crustal materials, including single crystals. A more specific purpose consists in explaining the Dabie-Sulu ultrahigh-pressure metamorphic belt, in China. This region might be better presented: both the geology and the geophysical observations deserve a thorough explanation as the reader of Solid Earth is mostly not aware of this area. Regarding the data, we need more information on the run products and on the results: what is the phase proportion? What is (are) the interconnected phase(s) as this is defining the electrical path? Shall we suspect impurities such as carbon or hydrogen to contribute to the DC flow? How these measurements on a multi-phased system compare with the conductivity of individual crystals? How the conductivity compare with other works on, for example, sedimentary gneisses, such as Hashim et al. or Ferri et al? Could the conductivity anomaly in the Dabie-Sulu ultrahigh pressure metamorphic belt be explained by crustal melting or brines as beneath the Tibetan plateau, on which a vast literature that is ignored here exists? I am looking forward to seeing a ms addressing this issue.

Thanks for your positive comments. I am very appreciated that Professor Fabrice Gaillard for very constructive and enlightened comments and suggestions in the reviewing process, which helped us greatly in improving the manuscript. In this revised paper, we conscientiously read through all comments from the valuable suggestions of Professor Fabrice Gaillard, and revised each one points by points, sentences by sentences. All of detailed revisions and responses are listed as follows.

1. *Regarding the data, we need more information on the run products and on the results: what is the phase proportion?*

As shown in table 2, the phase proportion of natural gneiss sample has been provided in detail. The rock-forming minerals of three gneiss samples are feldspar, quartz and biotite, and the contents of the same mineral in each samples are different. Hashim et al. (2013) shows that the dehydration-melting of muscovite starts at 923 K at 0.3 GPa, and biotite is formed in this process. It implies that the mineralogical assemblage of our gneiss samples is stable at a certain range of high temperatures and pressures. Furthermore, it has been confirmed that feldspar, quartz and biotite occur a reaction when T exceeds 1272 K (Ferri et al. 2013). It indicates that the mineralogical assemblage of gneiss is stable at our experimental temperatures and pressures. Therefore, the phase proportion of the natural sample is same with that of the sample after experiment.

2. *What is (are) the interconnected phase(s) as this is defining the electrical path?*

In the present studies, the rock-forming minerals of our three gneiss samples are feldspar, quartz and biotite, and the volume percentage for each correspondent rock-forming mineral in each gneiss samples were various (Fig.1 and Table 1). The dominant charge carriers of gneiss were proposed to be K^+, Na^+ and Ca^{2+}. Feldspar is the main mineral with the major elements of K^+, Na^+ and Ca^{2+}, quartz may contain the impurity ions of K^+, Na^+ and Ca^{2+}, and biotite contains a certain amount of K^+. Therefore, all rock-forming minerals contribute to the conductivities of gneiss.

As for the conduction mechanisms for each compositional minerals (feldspar, quartz and biotite) in gneiss, they have been already reported in the previously published work. As pointed by Hu et al. (2011, 2013, 2014, 2015), the main conduction mechanism of feldspar is the alkali- and alkali-Earth ions (e.g. K^+, Na^+, Ca^{2+}, etc.) by virtue of electrical conductivity measurements and the calculated diffusion coefficient from Nernst–Einstein equation at high temperature and high pressure. The alkali- and alkali-Earth ions, as the dominant charge carriers were

transferred between normal lattice alkali positions and adjacent interstitial sites along thermally activated electric fields. Some representative defect reactions for synthetic albite, K-feldspar and anorthite were put forward as follows,

$$\mathrm{Na}_{A1}^{\times} + V_i = Na_i^{\bullet} + V_{A1}' \qquad (1)$$

$$K_{A1}^{\times} + V_i = K_i^{\bullet} + V_{A1}' \qquad (2)$$

$$Ca_{A2}^{\times} + V_i = Ca_i^{\bullet} + V_{A2}' \qquad (3)$$

The main conduction mechanism in quartz has been investigated in detail by Wang et al., (2010), e.g. the alkali ion moving in channels of crystalline lattice. One typical defect reaction was described as,

$$(\mathrm{Al}^{3+} - \mathrm{M}^{+}) \Leftrightarrow \mathrm{Al_S} + \mathrm{M_i} \qquad (4)$$

According to previously published conductivity results for phlogopite single crystal by Li et al. (2016), they extrapolated that the main charge carriers are probably K^+ and F^-.

So, in the present work, we think that some intrinsic defects (e.g. K^+, Na^+, Ca^{2+}, etc.) in gneiss controlled the main electrical migration path of sample at high temperature and high pressure.

3. *Shall we suspect impurities such as carbon or hydrogen to contribute to the DC flow?*

The conduction mechanism for gneiss sample at high temperature region was proposed to be intrinsic conduction, but the conduction mechanism at low temperature region was impurity conduction (possible charge carriers: K^+, Na^+, Ca^{2+}, H^+, et al.). It's really possible that carbon or hydrogen contribute to the DC flow.

4. *How these measurements on a multi-phased system compare with the conductivity of individual crystals?*

The mineralogical assemblage of gneiss sample is complicated, and the rock-forming minerals are feldspar, quartz and biotite. Dai et al. (2014) measured the

electrical conductivity of granite at 0.5–1.5 GPa and 623–1173 K, and the main rock-forming minerals are also quartz, feldspar, and biotite. It was found that the content of calcium and alkali ions significantly influences the electrical conductivities of gneiss. Electrical conductivities of granite and gneiss increase with increasing content of calcium and alkali ions. However, the electrical conductivities of granite were much lower than those of gneiss (Fig. 8). The discrepancy may be caused by the various chemical compositions and rock structure of granite and gneiss. Feldspars are important rock-forming minerals of gneiss, and thus it is important to compare the electrical conductivities of feldspars. The electrical conductivities of alkali feldspars are much higher than the values of the gneiss samples (Hu et al., 2013). It may be due to that the concentrations of alkali ions of alkali feldspars were higher than those of gneisses. In addition, the electrical conductivities of quartz at 1.0 GPa were slightly lower than the values of the gneiss with X_A = 7.27% at 1.5 GPa, and the slope of the linear relation between the logarithm of electrical conductivity and the reciprocal of temperature for quartz is close to that for gneiss at lower temperature range (Wang et al. 2010). The conductivities of phlogopite were higher than those of the gneiss with X_A = 7.64% at higher temperatures (above 773 K), and lower than those of the gneiss samples at lower temperatures (below 773 K). Furthermore, the slope of the linear relation between the logarithm of electrical conductivity for the phlogopite sample and the reciprocal of temperature is much higher than the slopes for the gneiss samples (Li et al., 2016).

5. *How the conductivity compare with other works on, for example, sedimentary gneisses, such as Hashim et al. or Ferri et al?*

It's important to compare the conductivities of gneiss with the relevant results of previous studies. As shown in the Fig. 1, the conductivities of the garnet–biotite–sillimanite residual enclave JOY2-X4 are close to the values of gneiss sample DS14 and DS13 at low temperature region and high temperature region, respectively. The conductivities of JOY2-X4 are slightly lower than those of DS12

(Ferri et al. 2013). In addition, the conductivities of natural metapelite PP216 are close to the values of gneiss DS12 at low temperature region, and the slope of relationship between logarithmic conductivities and reciprocal temperature for the metapelite PP216 is higher than those for the gneiss samples at high temperature region (Hashim et al. 2013).

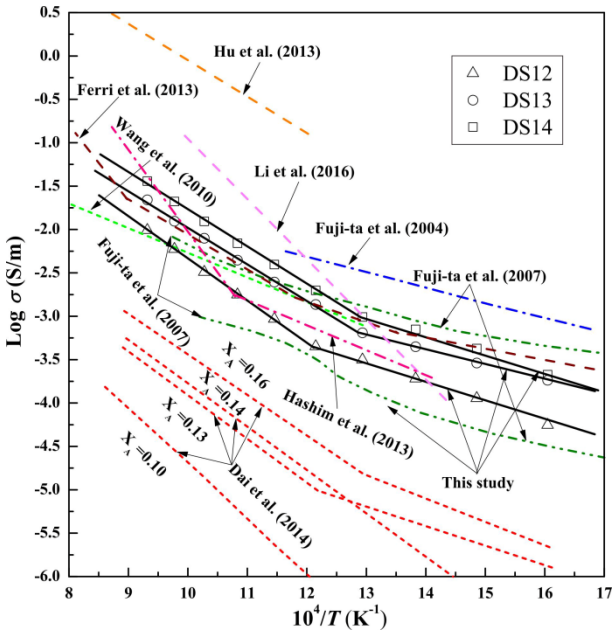

Fig. 1 Comparisons of the electrical conductivities of the gneiss samples measured at 1.5 GPa in this study and in previous studies.

6. *Could the conductivity anomaly in the Dabie-Sulu ultrahigh pressure metamorphic belt be explained by crustal melting or brines as beneath the Tibetan plateau, on which a vast literature that is ignored here exists?*

Thanks for the constructive and enlightened comments and suggestions. Although the conductivities of gneiss samples can't be used to interpret the conductivity anomaly in the Dabie-Sulu ultrahigh pressure metamorphic belt, the conductivity anomaly is probably caused by crustal melting or brines as beneath the Tibetan plateau (Ferri et al. 2013; Hashim et al. 2013). Actually, the geological environment of Dabie-Sulu ultrahigh pressure metamorphic belt is similar to that of the Tibetan plateau. Therefore, the causes for HCLs of two geological units might be similar. Besides, gneiss is widely distributed in the Dabie-Sulu ultrahigh pressure

metamorphic belt and Tibetan plateau. Consequently, the conductivity-depth profiles for the gneiss samples with various chemical compositions may provide important constraints on the interpretation of the magnetotelluric results for some regions where the conductivities is close to those of gneiss at high temperatures and pressures.

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