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A wet mantle conductor?

Arising from: X. Huang, Y. Xu & S. Karato *Nature* 434, 746–749 (2005)

The suggestion that the transition zone of Earth's mantle (410–670 km in depth) is enriched in water is of great possible significance to the geodynamics and geochemistry of Earth's interior, as well as for the role of the mantle in the global water cycle¹. Huang *et al.*² compare the effect of water on electrical conductivities of transition-zone phases to electromagnetic and magnetotelluric soundings of the mantle beneath the North Pacific³ and conclude that the transition zone contains between 1,000 and 2,000 p.p.m. of water, which is considerably more than the 50–200 p.p.m. present in the upper mantle^{4–6}. This conclusion is predicated on the assumption that the transition zone is relatively oxidized, but in fact fairly reduced conditions are more likely^{7,8}. Here I show that if the transition zone is reduced, high conductivities can be explained without the requirement for large enrichments of water.

The experiments of Huang *et al.*² were done in the presence of metallic molybdenum (Mo), meaning that the oxygen fugacity was at or below the buffer defined by coexistence of Mo and MoO₃, which produces an oxygen fugacity similar to that defined by the coexistence of iron metal and wüstite (Fe_{1-x}O). However, Huang *et al.*² recognize that the electrical conductivity of mantle minerals may be critically dependent on oxygen state and assume that the oxygen fugacity of the transition zone of the Earth is similar to conditions imposed by the coexistence of nickel metal and NiO, which

is about four orders of magnitude more oxidizing than their experiments. Accordingly, they correct their measurements to account for this difference, using a plausible but unverified model for the relation between conductivity and oxygen fugacity in hydrous wadsleyite and ringwoodite. In contrast, the high propensity of transition-zone silicates, wadsleyite, ringwoodite and majorite to incorporate Fe³⁺ suggests that Earth's transition zone is quite reduced, with oxygen fugacities similar to or lower than the iron–wüstite buffer^{7,8}. Therefore, it is plausible that the conductivity measurements made by Huang *et al.*² may be applied to the transition zone without significant correction for oxygen fugacity.

Figure 1 compares inverted conductivity profiles for the North Pacific³ with model profiles constructed from equation (1) of Huang *et al.*², which is derived from uncorrected measurements. Reasonable matches to the inverted profiles are found for 100–300 p.p.m. of water. Such values for the water content are comparable to those in the upper mantle that have been deduced from the geochemistry of mid-ocean-ridge basalts^{4–6}.

The conductivity models in Fig. 1 and in Huang *et al.*² are not corrected for the effects of

grain size or secondary phases. Consequently, some uncertainty remains in relating laboratory measurements to the inverted conductivity structure of the mantle transition zone. But if the measurements of Huang *et al.*² give a good approximation of the effect of water on the conductivity in Earth's transition zone, and unless oxygen fugacity at these depths^{7,8} has been grossly underestimated, the available data do not appear to require significant enrichment of water in the transition zone.

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Huang *et al.* reply

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Inference of the spatial distribution of water content in the mantle is critical to our understanding of the dynamics of Earth's interior. A model¹ has been described that indicates there may be a jump in water content at the 410-km discontinuity in the Earth's mantle. From the electrical conductivity, we have inferred² the water content in the transition zone and concluded that it is significantly larger than that of the upper mantle. Hirschmann³ questions our conclusion on the grounds of the trade-off between water content and oxygen fugacity.

We² and Hirschmann³ compare the water content of the upper mantle with that of the transition zone but estimate these by different methods, which introduces errors that are difficult to evaluate. We can also use an alternative approach, in which the water content of the upper mantle and of the transition zone is estimated using the same method. Experimental data on electrical conductivity in

olivine⁴ and wadsleyite are compared with geophysical measurements of the electrical-conductivity jump at 410 km depth (ref. 5). Using the model of Huang *et al.*², a jump in electrical conductivity at 410 km can be expressed in terms of a jump in oxygen fugacity and water content as

$$\frac{\sigma^{410+}}{\sigma^{410-}} = \left(\frac{\sigma_{\text{wd}}}{\sigma_{\text{ol}}} \right)_0 \left(\frac{f_{\text{O}_2}^{410+}}{f_{\text{O}_2}^{410-}} \right)^{-1/8} \left(\frac{C_{\text{W}}^{410+}}{C_{\text{W}}^{410-}} \right)^{3/4}$$

where $\sigma^{410+}/\sigma^{410-}$ is the conductivity ratio (below and above 410 km, which is about 10; ref. 5), $(\sigma_{\text{wd}}/\sigma_{\text{ol}})_0$ is the conductivity ratio of wadsleyite and olivine compared at the same condition, $f_{\text{O}_2}^{410+}/f_{\text{O}_2}^{410-}$ is the oxygen fugacity ratio, and $C_{\text{W}}^{410+}/C_{\text{W}}^{410-}$ is the water-content ratio. On the basis of our results² and a re-analysis of those on olivine⁴, we can now place tight constraints on $(\sigma_{\text{wd}}/\sigma_{\text{ol}})_0$.

Figure 1 | Electrical conductivity versus depth in Earth's transition zone. Lines are for wadsleyite (410–520 km) and ringwoodite (520–670 km) calculated from equation (1) and the parameters in Table 1 of Huang *et al.*² for 100, 200 and 300 parts per million (p.p.m.) H₂O. The temperature is assumed to increase from 1,825 to 1,900 K between 410 and 670 km. The grey shaded region represents the range of conductivities deduced from three different inversions of conductivity profiles of geoelectrical sounding and magnetotelluric response function data for the North Pacific³. The conductivity profiles derived from experimental data are appropriate for oxygen fugacities similar to the Fe–Fe_{1-x}O buffer.