

and an oceanic geotherm. The temperature uncertainties are now based on the estimated error in our σ data. Implied in the results in Figures 5 and 6 is the requirement that the σ of the earth's mantle at these depths is controlled by olivine. Olivine with a composition near Fo 90 is believed to undergo a phase change to spinel, perhaps via an intermediate phase, at a depth near 380 km, the transformation being likely to be complete by about 450 km [Fujisawa, 1968; Ringwood and Major, 1970; Ringwood, 1972]. Other assumptions in the calculations are that there is no further change in conduction mechanism in olivine above 1660°C and that the pressure effect at higher temperatures is similar to that observed below 1440°C. Furthermore, the temperatures calculated from the present data are correct only if the oxygen fugacity in the mantle is near the values indicated at the top of Figure 3. Comparison of Figures 5 and 6 indicates clearly that although the uncertainty in σ due to the maximum possible pressure effect is large, it is at most only 25% of the total uncertainty due to lack of resolution of σ with depth for the earth at depths to 400 km. Thus improvements must be made in the resolution of the σ -depth data in order to improve the temperature profiles shown in Figures 5 and 6. It would also be helpful to be able to set realistic limits on the oxygen fugacity in the mantle.

Figure 3 demonstrates that the oxygen fugacity in the experimental atmosphere affects the electrical conductivity of olivine. Other structure-sensitive properties (i.e., elastic constants, creep properties, diffusion, optical absorption, thermal diffusivity) may also be affected at high temperatures by the atmosphere in which they are measured. We suggest therefore that more care be exercised in specifying the experimental conditions at which these properties are determined.

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REFERENCES

- Banks, R. J., Geomagnetic variations and the electrical conductivity of the upper mantle, *Geophys. J. Roy. Astron. Soc.*, **17**, 457-487, 1969.
- Bradley, R. S., A. K. Jamil, and D. C. Munro, The electrical conductivity of olivine at high temperatures and pressures, *Geochim. Cosmochim. Acta*, **28**, 1669-1678, 1964.
- Buening, D. K., and P. R. Buseck, Fe-Mg lattice diffusion in olivine, *J. Geophys. Res.*, **78**, 6852-6862, 1973.
- Condit, R. H., and Y. Hashimoto, Self-diffusion of beryllium in polycrystalline beryllium oxide, *J. Amer. Ceram. Soc.*, **50**, 425-432, 1967.
- Davis, B. T. C., and J. L. England, The melting of forsterite up to 50 kilobars, *J. Geophys. Res.*, **69**, 1113-1116, 1964.
- Dreyfus, R. W., and A. S. Nowick, Ionic conductivity of doped NaCl crystals, *Phys. Rev.*, **126**, 1367-1377, 1962.
- Duba, A., The electrical conductivity of olivine, *J. Geophys. Res.*, **77**, 2483-2495, 1972.
- Duba, A., and F. E. M. Lilley, Effect of an ocean ridge model on geomagnetic variations, *J. Geophys. Res.*, **77**, 7100-7105, 1972.
- Duba, A., and I. A. Nicholls, The influence of oxidation state on the electrical conductivity of olivine, *Earth Planet. Sci. Lett.*, **18**, 59-64, 1973.
- Duba, A., H. C. Heard, and R. N. Schock, The lunar temperature profile, *Earth Planet. Sci. Lett.*, **15**, 301-304, 1972.
- Duba, A., J. C. Jamieson, and J. Ito, The effect of ferric iron on the electrical conductivity of olivine, *Earth Planet. Sci. Lett.*, **18**, 279-284, 1973.
- Duba, A., J. N. Boland, and A. E. Ringwood, Electrical conductivity of pyroxene, *J. Geol.*, in press, 1974.
- Fujisawa, H., Temperature and discontinuities in the transition layer within the earth's mantle: Geophysical application of the olivine-spinel transition in the Mg_2SiO_4 - $FeSiO_4$ system, *J. Geophys. Res.*, **73**, 3281-3294, 1968.
- Getting, I. C., and G. C. Kennedy, The effect of pressure on the E. M. F. of chromel-alumel and platinum-platinum 10% rhodium thermocouples, *J. Appl. Phys.*, **41**, 4552-4562, 1970.
- Griggs, D. T., The sinking lithosphere and the focal mechanism of deep earthquakes, in *The Nature of the Solid Earth*, edited by E. C. Robertson, pp. 361-384, McGraw-Hill, New York, 1972.
- Hamilton, R. M., Temperature variation at constant pressures of the electrical conductivity of periclase and olivine, *J. Geophys. Res.*, **70**, 5679-5692, 1965.
- Hanneman, R. E., H. M. Strong, and F. P. Bundy, A critical review of the effect of pressure on thermocouple emf's, in *Proceedings of a Symposium on the Accurate Characterization of the High Pressure Environment*, pp. 53-62, National Bureau of Standards, Washington, D. C., 1971.
- Hughes, H., The electrical conductivity of the earth's interior, Ph.D. thesis, 131 pp., Univ. of Cambridge, Cambridge, England, 1953.
- Hughes, H., The pressure effect on the electrical conductivity of peridot, *J. Geophys. Res.*, **60**, 187-191, 1955.
- Ito, K., and G. C. Kennedy, Melting and phase relations in a natural peridotite to 40 kilobars, *Amer. J. Sci.*, **265**, 519-538, 1967.
- Lazarus, D., R. N. Jeffery, and J. D. Weiss, Relative pressure dependence of chromel/alumel and platinum/platinum-10% rhodium thermocouples, *Appl. Phys. Lett.*, **19**, 371-373, 1971.
- Lidiard, A. B., Ionic conductivity, in *Handbuch der Physik*, edited by S. W. Flugge, pp. 246-349, Springer, New York, 1957.
- Osburn, C. M., and R. W. Vest, Electrical properties of single crystals, bicrystals, and polycrystals of MgO, *J. Amer. Ceram. Soc.*, **54**, 428-435, 1971.
- Parker, R. L., The inverse problem of electrical conductivity in the mantle, *Geophys. J. Roy. Astron. Soc.*, **22**, 121-138, 1970.
- Ringwood, A. E., Mineralogy of the mantle, in *Advances in Earth Sciences*, edited by P. M. Hurley, pp. 357-399, MIT Press, Cambridge, Mass., 1966.
- Ringwood, A. E., Mineralogy of the deep mantle: Current status and future developments, in *The Nature of the Solid Earth*, edited by E. C. Robertson, pp. 67-92, McGraw-Hill, New York, 1972.
- Ringwood, A. E., and A. Major, The system Mg_2SiO_4 - Fe_2SiO_4 at high pressures and temperatures, *Phys. Earth Planet. Interiors*, **3**, 89-108, 1970.
- Robie, R. A., and D. R. Waldbaum, Thermodynamic properties of minerals and related substances at 298.15°K (25.0°C) and one atmosphere (1.013 bars) pressure and at higher temperatures, *U.S. Geol. Surv. Bull.*, **1259**, 214, 1968.
- Schober, M., The electrical conductivity of some samples of natural olivine at high temperatures and pressures, *Z. Geophys.*, **37**, 283-292, 1971.
- Shankland, T. J., Transport properties of olivine, in *The Application of Modern Physics to the Earth and Planetary Interiors*, edited by S. K. Runcorn, pp. 175-190, Interscience, New York, 1969.
- Virgo, D., and S. S. Hafner, Temperature-dependent Mg, Fe distribution in a lunar olivine, *Earth Planet. Sci. Lett.*, **14**, 305-312, 1972.

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