

# Electrical Conductivity of Olivine Single Crystals at 1200 to 1600 oK

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## Electrical Conductivity of Olivine Single Crystals at 1200 to 1600°K

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**Abstract** The electrical conductivities of two olivine single crystals with 8.4 mole % fayalite content are measured in the temperature range of 1200 to 1600°K in the stability field of wüstite. In this temperature range, the conduction in olivine is presumably ionic mechanism with the activation energy of 1.8 eV. Combining the present results with previous data, it is concluded that the electrical conductivity increases by 1.7 orders of magnitude with increasing 10 mole % fayalite content at constant temperature.

### 1. Introduction

Recently, it has been pointed out that the electrical conductivity of olivine is controlled by the oxidation state of Fe ion (DUBA, 1972; DUBA *et al.*, 1973; DUBA and NICHOLLS, 1973). DUBA *et al.* (1973) have found that the major difference between olivines with the different electrical conductivities by several orders of magnitude is due to the oxidation state of Fe ion in the olivines below 1400°K. Further they presumed that a process with the activation energies less than 1 eV was associated with presence of  $\text{Fe}^{3+}$ , while the conduction mechanism with activation energies greater than 1 eV occurred for olivines without detectable amount of  $\text{Fe}^{3+}$ . Although DUBA *et al.* have asserted that the electric conduction was controlled by the oxidation state of Fe ion in olivine, KOBAYASHI and MARUYAMA (1971) have shown that the conductivity was strongly related to the fayalite contents for the conductivity mechanism with the activation energy of 0.8 eV.

In the present paper, we report the electrical conductivity data of olivines in the temperature range of 1200 to 1600°K in the atmosphere with controlled oxygen partial pressure, and intend to clarify the relationship between the electrical conductivity and the fayalite content in olivine which does not contain any detectable amount of ferric iron.

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## 2. Experiment

We used natural olivine single crystals as specimens for measurements. Brief descriptions of these specimens are shown in Table 1. Chemical compositions and localities are the same as those for one of the specimens used in our previous measurement (KOBAYASHI and MARUYAMA, 1971).

Table 1 The measured electrical conductivity of olivine from 1200 to 1600°K.

Specimen	Chemical composition (mole %)	Pre-exponential factor $\alpha$ ( $\Omega^{-1} \text{ cm}^{-1}$ )	Activation energy E (eV)
Olivine 1	Fa 8.4 Fo 91.6	15.3	1.81
Olivine 2	Ditto	12.9* 17.7**	1.81* 1.85**

\* the result in a run with increasing temperature.

\*\* the result in a run with decreasing temperature.

Since the anisotropy of conductivity in olivine is small according to KOBAYASHI and MARUYAMA (1971), the crystal orientations of these specimens were not determined. Each specimen was cut into a thin plate with a cross sectional area from 0.1 to 0.3 cm<sup>2</sup> and the thickness from 0.1 to 0.2 cm.

Electrodes were prepared by coating the platinum conductive paste on both flat ends of the specimen and curing the paste at high temperature in the controlled gas environment. Electrical resistivity was measured by the same method as that used by KOBAYASHI and MARUYAMA (1971). The temperature was measured with Pt-Pt 10% Rh thermocouples.

At high temperature, the ferrous iron in the specimen can easily be oxidized. In order to avoid the oxidation of specimens, the atmosphere must be controlled. We prepared the necessary oxygen partial pressure by mixing CO<sub>2</sub> and H<sub>2</sub> with an appropriate ratio by means of the apparatus developed by DARKEN and GURRY (1945). The electrical conductivities were measured in the stability field of wüstite (oxygen partial pressure  $P_{O_2} = 10^{-10}$  to  $10^{-15}$  atm) in which ferric iron will not involve in the electric property of olivine. The olivine sample after the measurement did not show any color change. In addition, the measured conductivity was quite reproducible. Therefore, the sample was assumed to be chemically unchanged.

## 3. Result and Discussion

The logarithm of electrical conductivity was plotted against the reciprocal of the absolute temperature in Fig. 1. The figure contains all the results obtained by different experimental runs at the controlled oxygen partial pressure. The values of activation

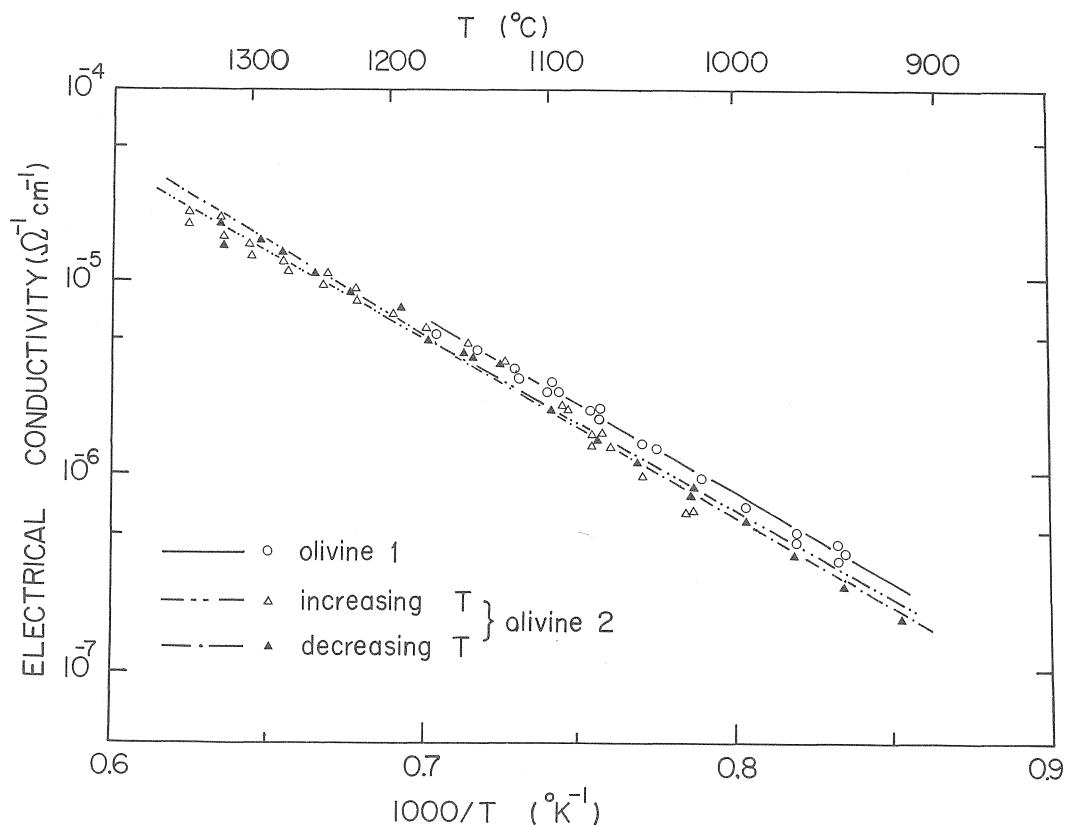


Fig. 1. Log  $\sigma$  versus  $10^3/T$  for olivines with 8.4 mole % fayalite content in the stability field of wüstite.

energies  $E$  and pre-exponential factors  $\sigma_0$  measured by different runs are about 1.8 eV and  $15 \Omega^{-1}\text{cm}^{-1}$ , respectively.

The electrical conductivity of olivine with 8.4 mole% fayalite content at 1200°K in the atmosphere with controlled oxygen partial pressure was by one order of magnitude less than that measured in argon or nitrogen gas (KOBAYASHI and MARUYAMA, 1971). As pointed out by DUBA *et al.* (1973) and DUBA and NICHOLLS (1973), the present authors also conclude that the electrical conductivity of olivines differs depending on the oxidation state of iron.

Fig. 2 shows that comparison of the present results with those of non-ferric olivines obtained at above 1200°K by DUBA (1972) and DUBA and NICHOLLS (1973). The present results (Fa 8.4) as well as those by DUBA (Fo 100) and DUBA and NICHOLLS (Fa 4.0 and Fa 8.2) show the conduction mechanism with the  $E$  of  $2.0 \pm 0.3$  eV at the temperature between 1200 and 1600°K. Judging from the experimental condition, the electric conduction with  $E = 2.0$  eV takes place in olivine without ferric iron.

MISENER (1972) has measured the interdiffusion of  $\text{Fe}^{2+}$  and Mg in olivine at 1200 to

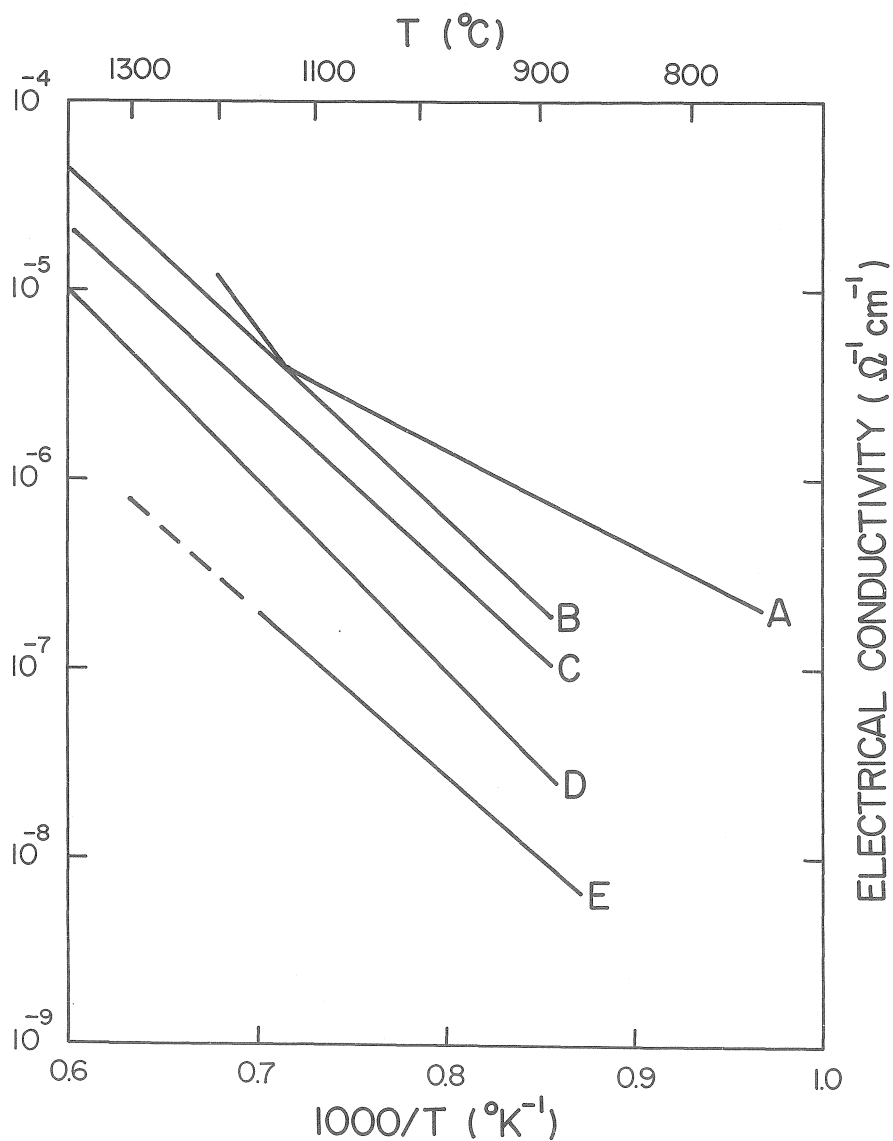


Fig. 2. Log  $\sigma$  versus  $10^3/T$  for non-ferric olivine single crystals.

A: 9.4 mole % fayalite by DUBA (1972).

B: 8.4 mole % fayalite. Present data.

C: 8.2 mole % fayalite by DUBA and NICHOLLS (1973).

D: 4.0 mole % fayalite by DUBA and NICHOLLS (1973).

E: 100 mole % forsterite by DUBA, (1972).

1450°K, and has shown the activation energy of 2 eV, which is approximately the same to 1.8 eV obtained by the present work. Although we have not sufficient knowledge of the quantitative relationship between the interdiffusion and the self-diffusion in olivine, it is suggested that olivine shows the ionic conduction with E of about 2 eV above 1200°K if

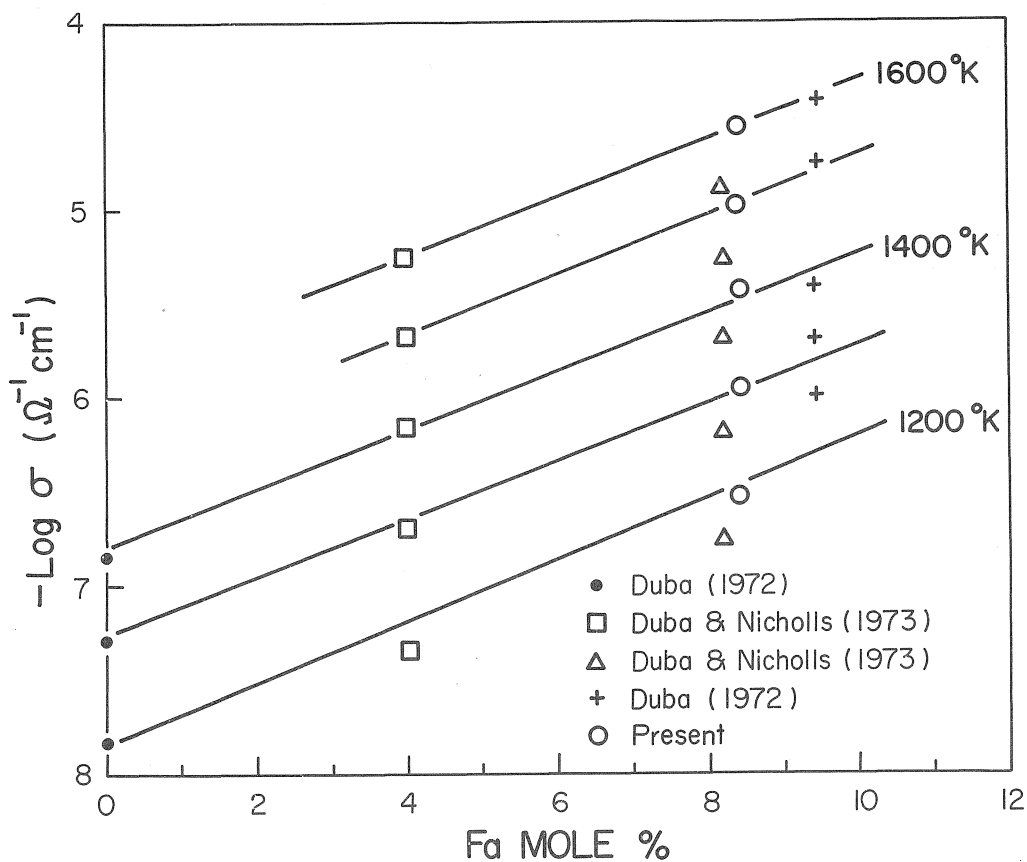


Fig. 3. Log  $\sigma$  for non-ferric olivine single crystals at constant temperature as a function of fayalite mole %.

we note the Nernst-Einstein equation which relates the electrical conductivity to the diffusion coefficient in ionic conduction.

The logarithm of the electrical conductivity  $\sigma$  at constant temperature is plotted against the fayalite mole % in olivine in Fig. 3. As shown in Fig. 3, the electrical conductivity increases by about 1.7 orders of magnitude with the increases of 10 mole % fayalite content at constant temperature. According to KOBAYASHI and MARUYAMA (1971), the relationship between the pre-exponential factor  $\sigma_0$  and the fayalite mole %  $C$  in olivine single crystals is represented by a formula :

$$\log \sigma_0 = -(3.13 \pm 0.4) + 0.14 C$$

for the mechanism with the  $E$  of 0.8 eV in the temperature range of 600 to 1200°K. We cannot clearly show the relationship between the pre-exponential factor  $\sigma_0$  and the fayalite content above 1200°K because of the small difference in the activation energy

among the different olivines. However, the similar type of the empirical relation between electrical conductivity  $\sigma$  and fayalite mole % C for the mechanism with the  $E = 2.0$  eV is given by :

$$\log \sigma = (0.49 - 8.82 \times 10^3/T) + 0.17 C$$

We are interested in this behavior, since the diffusion coefficient shows a similar dependence on the fayalite content in olivine (MISENER, 1972). It is noted that the nature of electrical conduction clarified here is very important, when we explain the cause of conductivity anomaly in the upper mantle.

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