

Electromagnetism of ultramafic rocks from the Luobusa ophiolite studied at room temperatures and pressures

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Abstract—It is generally accepted that a major phase of the Earth's upper mantle is represented by ultramafic rocks, including olivine pyroxenites, dunites, and peridotites. Studies on the electrical conductivity of ultramafic rocks continue to attract a great deal of interest, and much progress in the study of the electrical conductivity of rocks and minerals at high temperatures and pressures has been achieved recently. However, publications that consider the electromagnetism of ultramafic rocks at room temperatures and pressures are few and far between. In this paper, we present a study of the complex impedance properties of ultramafic samples from the Luobusa ophiolite, and their relationship to petrography. Samples were regularized and were not processed (e.g., fluid extraction, including soaking) before they were measured, and an impedance/gain-phase analyzer was used for complex impedance measurements across a frequency range, 0.005~1000 Hz. Density, susceptibility, major minerals, and trace element contents for most of samples were measured for comprehensive analysis, but just density features and weight content of serpentine are discussed in this paper. Results show that chromite exhibits complex resistivity, far lower than harzburgite, but larger than dunite. Chromite also has more complex phases than dunite at frequencies lower than 0.02 Hz, while at the same time exhibiting less phases at frequencies ranging from 0.02 to 1000 Hz. In terms of resistivity, serpentine content, and sample density, resistivity increases alongside density, and serpentine content decreases. Given that serpentine content and density have a clear relationship with petrography and the degree of metamorphism of the Ophiolite complex, our study opens up new possibilities for understanding the inner structure and phases of ultramafic complexes, as well as their relationships to geological processes, using ground-based geo-electrical methods.

Keywords—*Electromagnetism; Ultramafic rocks; Luobusa ophiolite ;Room conditions*

I. INTRODUCTION

Electrical conductivity is one physical property that can be estimated using geophysical remote sensing, and is also one of the most important for study of the Earth's interior^[1]. It is generally accepted that ultramafic rocks, including olivine pyroxenites, dunites, and peridotites, represent the major phase in formation of the Earth's upper mantle^[2]. As a result, research on the electrical conductivity of ultramafic rocks is of

great interest to geologists and geophysicists, especially in recent years. Most experimental investigations to date of the electrical properties ultramafic rocks have been conducted under high temperatures, and pressures to simulate the crust and relevant portions of the upper mantle. Understanding of the electrical conductivity of rocks and minerals, including fundamentals^[1,3], effects of temperature^[2,4,5], and pressure^[6], impurity and oxygen fugacity^[5,7], and hydrogen (water) content^[7], and their relationships with conductivity have been refined recently.

However, understanding of electromagnetic properties at room temperatures and pressures are important to the study of outcrop scale, and shallow-buried (i.e., less than 2 km) ultramafic rocks. On the one hand, these data will provide fundamental insights to geo-electrical studies and for the exploration of these ultramafic rocks, while on the other, results from natural samples tested under room temperatures and pressures can be used as references for other studies in higher temperatures and pressures. In this paper, we present laboratory measurements of the electrical properties of ultramafic rocks sampled from the Luobusa ophiolite, southern Tibet. We also discuss the relationship between the electrical properties and petrography of these samples.

II. GEOLOGICAL SETTING AND SAMPLING

The Luobusa ophiolite, southern Tibet, is located in the eastern portion of the Yarlung Zangbo ophiolite complex, controlled by the Indus-Yarlung Zangbo suture zone. Our study area (Fig.1) is a small, but vitally important, part of a major tectonic contact within the Yarlung Zangbo ophiolite belt, one of the best known and most extensively studied ophiolites in China^[8,9]. The Luobusa ophiolite has a length of about 40 km, a width that ranges from 0.7 to 4 km, and an area of about 70 km² with a general west-east trend. To the north of the Luobusa ophiolite, a suite of island-arc volcanic rock sequences are discordantly overlain by the Tertiary Luobusa group that consist of polymictic and sandy conglomerates^[9]. While the southern region of the Luobusa ophiolite is in faulted contact with Upper Triassic turbidites, available outcrop and drilling results show that its major lithotypes are harzburgite and dunite (Fig.1). The contact zone between the

harzburgite and dunite is characterized as a central ore-bearing zone; most of the chromite occurs within, or close, to this zone. The age of the ophiolite is 130 Ma, based on the results of Wu et al.^[8]. All of our samples were collected from the main

body of the Luobusa ophiolite; 90% of them were sampled from the drill core, while 10% were taken from typical outcrops.

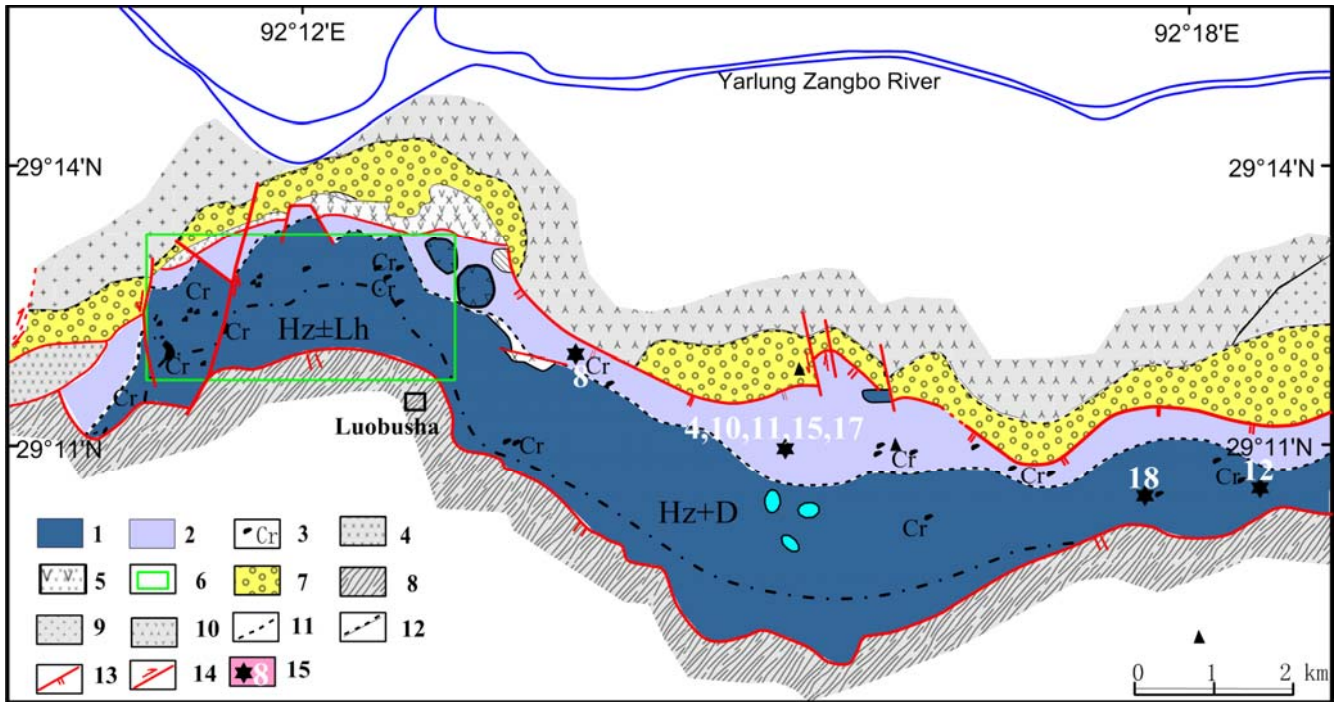


Fig.1 Schematic geological map of the Luobusa ophiolite (from He et al., 2014, modified after Li et al., 2012). Legends are as follows: 1, harzburgite (containing dunite and lherzolite); 2, dunite; 3, chromite ore; 4, cumulus bojjite; 5, cumulus of bojjite and wehrlite; 6, scope of the surface magnetic survey; 7, Luobusa group conglomerates; 8, Upper Triassic formation; 9, quartz diorite and monzonite; 10, biotite granite; 11, lithostratigraphic boundary; 12, unconformable contact; 13, reverse fault; 14, strike-slip fault; 15, sample number and position.

III. METHODS

A. Sample Preparation

We prepared our samples by cutting them into regular cuboids (i.e., length, 10-15 cm; width, 5-10 cm; height, 5-10 cm) depending on the state of cores. All rock cores were cut to cylinders, and the remainder of each sample, after cutting, was divided into several sub-samples for thin-sectioning, major mineral and trace element testing, and scanning electron microscopy (SEM). In order to retain the original nature of rock samples for our complex resistivity measurements, no other processing, including the extraction of fluids from fissures and pores, or soaking, was carried out.

B. Complex Impedance Measurements

Complex impedance measurements (i.e., impedance spectroscopy) were taken from prepared samples under room temperatures and pressures. All samples were measured using a four-pole electrode configuration, with two outer current electrodes, and two inner potential electrodes. Two polymethyl methacrylate boxes, filled with wet flour dough mixed with copper sulfate, were used to contact the non-polarizing electrode pairs (Fig.2). Because the current, and

potential electrodes, were made of copperplate, in some cases, the reference electrode pair were used to measure the inner potential. Complex resistivity measurements were carried out using a Solartron-1260A impedance/gain-phase analyzer, while the frequency range used for impedance spectroscopy was 0.005~1000 Hz.



Fig.2 The complex impedance measurement system including the Solartron-1260A (on the desk), and wet flour dough mixed with copper sulfate to contact the non-polarizing electrode pair.

IV. RESULTS AND DISCUSSION

In total, we measured 75 samples from the Luobusa ophiolite. Results show that the resistivity of samples varies from 10 to 10 M Ω ·m around a mean of 0.85 M Ω ·m. Of the total sample, 20% had a resistivity less than 10 k Ω ·m, 45% exhibited a value between 10 and 1000 k Ω ·m, and 35% had a

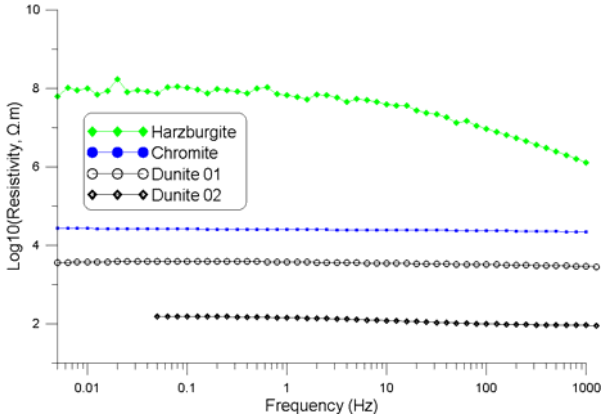


Fig.3 Complex resistivity of harzburgite, chromite, and dunite samples from the Luobusa ophiolite.

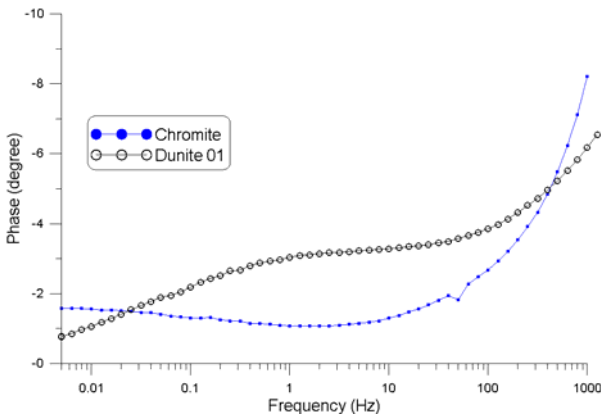


Fig. 4 Complex resistivity of chromite and dunite samples from the Luobusa ophiolite.

resistivity greater than 1000 k Ω ·m. Complex resistivity results measured from harzburgite, chromite, and dunite samples are shown in Fig. 3. The resistivity of harzburgite is around 100 M Ω ·m across a frequency range from 0.005 to 10 Hz; resistivity decreases sharply with increasing frequencies greater than 10 Hz. In contrast, while the resistivity of harzburgite is around 100 M Ω ·m at frequencies ranging from 0.005 to 10 Hz, it decreases sharply as frequency increases

greater than 10 Hz. Although the resistivity of the chromite sample is 30 k Ω ·m across the whole range of frequency measurements, from 0.005 to 1000 Hz, it decreases slowly as frequency increases. In contrast, the values for the two dunite samples are 3 k Ω ·m and 150 k Ω ·m.

These data show that chromite exhibits a complex resistivity that is far lower than that of harzburgite, yet greater than that of dunite. Measured complex phase results for chromite and dunite samples are shown in Figure 4; note that because the impedance of harzburgite is too high to beyond the reach of 1260A, its complex phase is highly variable, and is thus not comparable. The phase value (in Unit of minus degree) decreases sharply as frequency changes from 1000 to 10 Hz, then decreases slowly from 10 to 2 Hz, and finally increases gradually at decreasing frequencies less than 2 Hz.

Phase values for dunite decrease as the measurement frequency changes from 1000 to 0.005 Hz. These results also show that chromite has a lower phase than dunite at a frequency range between 0.02 and 1000 Hz, while it has a greater phase than dunite at frequencies less than 0.02 Hz. These data indicate that very high frequencies should be used to acquire induced polarization (IP) information of chromite from a complex consisting of harzburgite, chromite, and dunite.

Most of the samples with resistivity greater than 1000 k Ω ·m are 40% or less serpentine by weight, while, in contrast, most samples that have a resistivity lower than 10 k Ω ·m are more than 50% serpentine. Controlled by oxygen fugacity, fresh harzburgite, dunite, and olivine contain little serpentine; however, via metamorphism, more and more serpentinization occurs in ultramafic rocks. Thus, serpentine content is an indicator of degree of metamorphism related to geological processes, and the ultramafic rock electromagnetism can be employed for analysis of the processes related to the ophiolite complex. Regarding the relationship between resistivity and sample density (Fig.5b), results show that resistivity increases generally in line with increasing density. Half of the samples with a resistivity greater than 1000 k Ω ·m also have densities greater than 3.0 g/cm³, while all samples with a resistivity lower than 100 k Ω ·m have densities lower than 2.8 g/cm³. Because the density of rock samples from the ophiolite complex reflect both their petrography and degree of metamorphism^[10], the relationship between density and resistivity provides a new opportunity to evaluate the inner petrography and makeup of such complexes using ground-based geo-electrical methods.

V. CONCLUSIONS

We report the results of a study on the electromagnetism at room temperatures and pressures of ultramafic rocks from the Luobusa ophiolite. We measured and analyzed correlations between the complex impedance of samples and their petrography features, taking the density and content by weight of serpentine as an example. The resistivity of our 75 samples varies from 10 Ω ·m, to 10 M Ω ·m, around a mean value of 0.85

MΩ·m. The harzburgite samples had a resistivity of around 100 MΩ·m, chromite of about 30 kΩ·m, and dunite in the range of several hundred to several thousand Ω·m at frequency ranges from, or less than, 0.005 to 10 Hz. The complex phase of chromite increases to greater than that of the dunite at low frequencies, ranging from 0.02 Hz. Resistivity increases as density increases, and a reduction in serpentine content generally varies according to these results. Finally, our study shows that it is possible to apply ground-based geoelectrical methods to the analysis of the inner structures and phases of ultramafic complexes to understand the geological processes they have experienced.

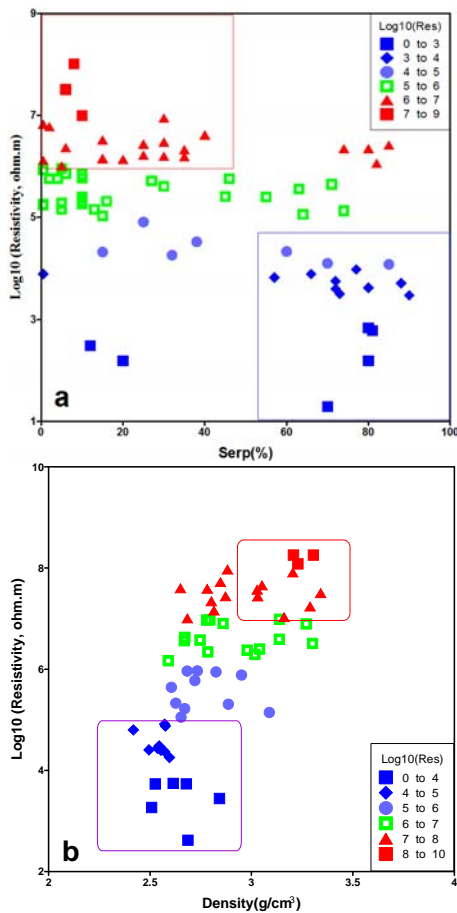


Fig.5 Relationships between resistivity, serpentine content (a), and sample density (b).

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