MINERALOGICAL STUDY OF LEW88774: NOT SO UNUSUAL UREILITE;
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LEW88774 is a Cr-rich ureilite and has been proposed to be quite different in mineralogy from all previously known ureilites. It mainly consists of pyroxene, olivine, picrochromite, and carbon. Our mineralogical study indicate that pyroxene is rich in Ca (Bulk Wo: 15-20) and now consists of coarse augite and low-Ca pyroxene lamellae intergrowth each up to 50 \( \mu \text{m} \) in width. The diffusion profiles of CaO across the lamellae indicate that pyroxene cooled slowly (0.01°C/year) down to 1160°C, corresponding to the depth of 1 km in a parent body. Below this temperature it would have cooled down quickly possibly due to quenching by excavation. This is not contradictory to a formation history of ureilites so far believed, although the lamellae show coarse exsolution features. Unlike other meteorites, chromite in LEW88774 is very rich in Al and poor in Fe, and belongs to the category of picrochromite. High ZnO in chromites is similar to that in chondrites and primitive achondrites. LEW88774 will be the first ureilite including abundant Ca, Al-rich phases generally missing in normal ureilites, which would supports the possibility that ureilites are not so differentiated meteorites from primitive materials presumably a kind of carbonaceous chondrite.

INTRODUCTION

Ureilites are one class of achondrites which have two quite different characters. O-isotope anomaly and high noble gas contents show remnant of chondritic properties, while the texture of coarse-grained mafic silicates is characteristic of differentiated meteorites. Thus, ureilites have offered a subject to controversy for their origin [1]. The discovery of LEW88774 ureilite in the Antarctic has been believed to give new aspects for ureilite origin, because typically ureilite does not include abundant chromite and coarse exsolution lamellae in pyroxene indicating slow cooling [2]. Prinz et al. [3] suggested that it would require extremely slow cooling (millions of years) to form coarse exsolution features in pyroxene and equilibrated the texture. Warren and Kallemeyn [4] also pointed out that original crystallization deep in mantle of the ureilite parent body(s) is preferred. To give the better explanation of their formation process and petrogenesis of this meteorite, we performed a detailed mineralogical study especially on exsolution and zoning profiles of pyroxene and chromite.

RESULTS

Our microprobe analysis gave high CaO bulk composition of pyroxenes. Initial 100 x molar Ca/(Ca+Mg+Fe) is estimated to be 15-20. Exsolved augite has composition Ca\(_{33.7}\)Mg\(_{52.9}\)Fe\(_{13.3}\) and low-Ca pyroxene Ca\(_{4.4}\)Mg\(_{87.5}\)Fe\(_{20.8}\). Each of the lamellae has almost same widths (up to 50 \( \mu \text{m} \)) and its boundary is irregular. Ca diffusion profiles intersecting the lamellae (Fig.1) show nearly flat chemical compositions for both augite and low-Ca pyroxene. This implies that the pyroxene cooled slowly enough to permit homogenization of the composition of each phase. According to the calculation of the cooling rate by a method similar to [5], exsolution began at 1278°C and cooled 0.01°C/year until 1160°C [6]. This cooling rate corresponds to the depth about 1 km covered with the solid rock.

LEW88774 has abundant chromites which show segregate distribution in the section we studied (LEW88774,4). Prinz et al. [3] reported chemical zoning ranging from FeCr\(_2\)O\(_4\) to MgCr\(_2\)O\(_4\), then to MgAl\(_2\)O\(_4\) due to reduction, but according to our analysis most chromites have poor Fe content unlike any other meteorites and can be classified as picrochromite. This might be caused by heterogeneous distribution of chromite suggested by [3] and [4], but our analysis rather indicates enrichment of Cr\(_2\)O\(_3\) at the rim in picrochromite. Our ZnO analysis shows that up to 0.5 wt% ZnO are present in FeO-rich chromite. Picrochromites also include ~0.2 wt% ZnO. Although one picrochromite which we analyzed are zoned in Al\(_2\)O\(_3\) and Cr\(_2\)O\(_3\), we can not detect zoning for ZnO.

DISCUSSION

From Ca diffusion profiles of pyroxene lamellae, we found that these coarse lamella formation does not necessarily need extremely slow cooling. Rather short duration (ca. ten thousands of years) will be required for the lamella to grow because they have high Ca content, locating at near top of solvis at high temperature where diffusion rate is fast. The irregular boundaries are different from regular exsolution and support slow cooling or annealing. The termination temperature estimated from this exsolution (1160°C) is almost identical to those inferred from coexisting pyroxenes of other ureilites [7,8], and would correspond to a break up temperature of the previously proposed
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model. After all this is not an odd member of ureilites.

Picrochromite is also a key to consider the petrogenesis of this meteorite. Enrichment of MgO may be due to reduction process as observed reduction rim of olivine [3]. The rim includes lower Al$_2$O$_3$ than the core. Furthermore, it is unusually rich in ZnO (~0.5 wt%) for the standard of differentiated meteorites. FeO and ZnO are positively related and maybe due to reduction (Fig.2). In spite of the volatile nature of Zn, chromites in equilibrated chondrites, lodranites, and acapulcoites are known to contain significant Zn [9]. High abundance of ZnO in LEW88774 chromite will indicate that the melt from which chromite crystallized included normal level of ZnO which would not be so largely differentiated from the chondritic composition.

The presence of picrochromite displays another important aspect for ureilite formation. From modal abundances, we computed rough bulk composition of this meteorite. In conformity with the high CaO in pyroxenes and high Al$_2$O$_3$ in chromites, bulk CaO and Al$_2$O$_3$ are high (CaO: 5 wt%, Al$_2$O$_3$ 2 wt%). Typically, ureilites include less than 2 wt% CaO and 1 wt% Al$_2$O$_3$. Bulk chemical analysis [10] also shows high bulk compositions of CaO (3.34 wt%) and Al$_2$O$_3$ (1.3 wt%). The enrichment of these component, generally missing in ureilites will link the relationship between ureilites and carbonaceous chondrite. A model of spinel formation [11] has been proposed to explain reaction between olivine and Cr$_2$O$_3$ to form chromite and pyroxene in primitive achondrites. In this ureilite, similar reaction including CaO and Al$_2$O$_3$ in a melt can be considered. The fact is in line with the low modal abundance of olivine.

CONCLUSION

Presence of coarse exsolution lamellae in pyroxene might puzzle us to solve the petrogenesis of this unique ureilite by comparing with other known ureilites. However, it is not surprising that initially Ca-rich pyroxene can exsolved coarse lamellae in short period and the termination temperature is within the range inferred from coexisting pyroxene in other ureilites. In this sense, this is not an "anomalous" ureilite which forced us to reconsider general ureilte formation process [12]. High Ca, Al content of bulk composition and enrichment of ZnO in chromites will support the possibility that this meteorite is a missing link between carbonaceous chondrite and ureilite, and ureilite is not so differentiated from primitive materials although it has an igneous texture.

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Fig.1: Ca diffusion profile intersecting pyroxene exsolution lamellae of augite and low-Ca pyroxene. Note that each phase is almost homogeneous, and roughly calculated initial bulk Wo is about 15-20.

Fig.2: Wt% ZnO vs. Molar Fe/(Fe+Mg) in chromites. LEW88774 chromites contain significant ZnO never seen in normal achondritic chromites. ZnO and Fe# is positively related.

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