Northwest Africa 1232—a CO3 carbonaceous chondrite with two lithologies

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Northwest Africa 1232 (NWA 1232) is a carbonaceous chondrite consisting of two lithologies (A and B) that are separated by a sharp boundary. A petrographic and mineralogical study indicates that both lithologies can be classified as type CO3. However, olivine in lithology B chondrules is more enriched in Fe than in lithology A, whereas olivine in lithology B matrix is more depleted in Fe than in lithology A. Chondrules and Ca-Al-rich inclusions (CAIs) in lithology B show a higher degree of nephelinization than those in lithology A. These differences can be explained by that lithology B has gone through a higher degree of thermal metamorphism than lithology A. These two lithologies probably represent rocks that have been thermally metamorphosed at different locations within a single CO parent body and later mixed to form the present combined rock during a brecciation process.

Keywords: Carbonaceous chondrites, CO chondrites, Thermal metamorphism, Breccia, Nepheline

INTRODUCTION

A well-preserved carbonaceous chondrite weighing 1900 g was found by a French team in Morocco in 2001, although the original finder and the recovery site are unknown. This meteorite was named as Northwest Africa 1232 (NWA 1232) by the Nomenclature Committee of the Meteoritical Society. NWA 1232 was tentatively classified as a CO3 carbonaceous chondrite. A striking feature of NWA 1232 is that it consists of two different lithologies. In a hand specimen, one lithology appears dark gray, and the other appears light gray. NWA 1232 may therefore be a polymict breccia. If this is the case, this meteorite may provide new insight into the carbonaceous chondrite parent body and its formation history. We present here the results of our mineralogical and petrographic study of NWA 1232. Our goal was to determine the chemical and petrologic types of the two lithologies and how these are related to each other.

MATERIAL AND METHODS

A polished thin section of NWA 1232 with a total area of ~1670 mm² was studied using an optical microscope, a scanning electron microscope (JEOL JSM-6480LVII) equipped with an energy-dispersive X-ray spectrometer (EDS), and an electron probe microanalyzer (JEOL JXA-8900) equipped with wavelength-dispersive X-ray spectrometers (WDS). The data corrections were made by the ZAF method for the EDS analysis and by the Bence-Albee method for the WDS analysis. The EDS analysis was carried out at 15 kV and 0.6 nA, and the WDS analysis at 15 kV and 12 nA. Well-characterized natural and synthetic minerals and glasses were used as standards. The backscattered electron (BSE) images were used to determine the modal abundances of chondrules, amoeboid-olivine inclusions (AOIs), and CAIs. These objects were colored on the BSE images, and the colored areas were calculated as a percentage of the whole image using the Adobe Photoshop software package. The weathering level of NWA 1232 corresponds to W1-2.

RESULTS

General petrography

The thin section is divided into two areas by a sharp boundary (Fig. 1a). One area of ~720 mm², which is dark gray, is obscurely translucent in transmitted light, whereas the contrasting area of ~950 mm², which is light gray, is
distinctly more transparent. We refer to these two areas as lithology A and lithology B, respectively.

Both lithologies contain well defined chondrules set in a fine-grained matrix. The modal analysis indicates that lithology A consists of ~ 53 vol% chondrules including mineral fragments, ~ 2 vol% CAIs, and ~ 7 vol% AOIs, whereas lithology B consists of ~ 50 vol% chondrules, ~ 3 vol% CAIs, and ~ 5 vol% AOIs. Chondrules in lithology A range in apparent diameter from 50–510 µm with an average of ~ 128 µm, whereas those in lithology B range from 50–500 µm with an average of ~ 147 µm. The modal abundances and the average diameters of chondrules in both lithologies are consistent with those of the CO type carbonaceous chondrites [cf., 48 vol% and 150 µm, from Brearley and Jones (1998)].
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Lithology A

Chondrules. Both type I and type II chondrules occur, but the latter are very minor in abundance. Their textural types are mostly porphyritic olivine-pyroxene, porphyritic olivine, porphyritic pyroxene, and barred olivine. They mainly consist of phenocrysts of olivine and enstatite, with minor amounts of diopside, and mesostasis. Most chondrules contain opaque nodules (10–30 µm in diameter) that consist of Fe-Ni metal (both kamacite and taenite), troilite, and minor amounts of magnetite.

Olivine phenocrysts in type I chondrules are mostly Mg-rich (Fa_{41-59}) (Table 1 and Fig. 2a), but many of them show weak to moderate zoning of magnesian cores with ferroan rims (Fig. 3a), indicating that this lithology has been affected by a minor degree of thermal metamorphism. Mesostases of the chondrules consist mainly of plagioclase and glass. In some chondrules, plagioclase contains minor amounts of nepheline as thin lamellar intergrowths (Fig. 3a). Glass has been partially replaced by nepheline. These characteristics are similar to those of the CO3.2–3.5 chondrites (Tomeoka and Itoh, 2004).

CAIs and AOIs. Lithology A contains abundant round to irregularly shaped CAIs (30–270 µm in diameter) and AOIs (50–300 µm). Most CAIs are rimmed objects, with their interiors composed mainly of melilit, spinel, and minor amounts of anorthite and hibonite, enclosed by diopside rims 2–10 µm in thickness (Fig. 4a). Spinel commonly contains 2–5 µm diameter perovskite grains. In addition to these primary minerals, nepheline has been formed by replacing melilit (Fig. 4a) and anorthite. The average modal abundance of nepheline in the 15 CAIs that we studied is ~ 21 vol%. Spinel shows a wide range of Fe/(Mg + Fe) ratio between 0.2 and 58 mol% FeAl_{2}O_{4} (Table 2). The mineralogy and texture of these CAIs are similar to those typical in CO3 chondrites (Tomeoka et al., 1992; Kojima et al., 1995; Russell et al., 1998). AOIs consist mainly of olivine, diopside, anorthite, and minor amounts of nepheline. Olivine grains in most AOIs show Fe-Mg zoning and range in fayalite content from Fa_{0-40}.

Matrix. The matrix consists of fine grains (< 5 µm in diameter) of mainly olivine and minor Fe-Ni metal, Fe sulfide, and magnetite. Focused-beam analyses of relatively large olivine grains (3–5 µm in diameter) show that they have a wide range of fayalite content (Fa_{41-59}) (Table 1).

Lithology B

Chondrules. They have texture and mineralogy generally similar to those in lithology A. However, there are some differences. Olivine phenocrysts in type I chondrules are more Fe-rich than those in lithology A (Table 1 and Fig. 2b); most of the relatively large phenocrysts (> 20 µm in diameter) exhibit strong Fe-Mg zoning, and those < 20 µm in diameter are homogeneous, with approximately Fa_{35} (Fig. 3b). Mesostases have been more extensively replaced by nepheline than those in lithology A.

CAIs and AOIs. The size and texture of CAIs and AOIs in lithology B are also generally similar to those in lithology A. However, in the CAIs, melilit is absent, and anorthite is rare. Ilmenite is present, but perovskite is absent. Spinel is more Fe-rich and homogeneous in Fe/(Mg + Fe) ratio, with the range of 43–53 mol% FeAl_{2}O_{4} (Table 2).

Table 1. Average compositions of olivine in type I chondrules and matrix

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<tr>
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<th>Type I chondrules</th>
<th>Matrix</th>
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<tr>
<td>Lithology A</td>
<td>10.6 (±6.38)*</td>
<td>49.1 (±5.56)</td>
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<tr>
<td></td>
<td>(N=48)</td>
<td>(N=31)</td>
</tr>
<tr>
<td>Lithology B</td>
<td>29.5 (#9.06)</td>
<td>40.2 (#1.31)</td>
</tr>
<tr>
<td></td>
<td>(N=66)</td>
<td>(N=44)</td>
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The compositions were determined for each olivine phenocryst by analyzing the core and rim, following the method of Scott and Jones (1990).

* Standard deviation.
N, number of analyses.

Figure 2. Analyses of randomly selected olivine phenocrysts in type I chondrules in lithology A (a) and lithology B (b). The procedure to determine the compositions is described in the footnote of Table 1.
than that in lithology A. Nepheline is much more abundant (Fig. 4b). The average modal abundance of nepheline in the 19 CAIs that we studied is ~ 40 vol%. Olivine grains in AOIs are more Fe-rich and homogeneous, with approximately Fa_{40}, than those in lithology A.

**Matrix.** The matrix in lithology B consists of minerals similar to those in lithology A matrix. However, olivine grains are relatively more Fe-poor and homogenous, with Fa_{38-44}, than those in lithology A (Table 1); the difference in Fe content can also be observed in Figure 1b.

**DISCUSSION**

The modal abundances and sizes of chondrules in lithology A and lithology B are similar, and all these features point to a CO classification (e.g., Brearley and Jones, 1998). The mineralogy of the chondrules, CAIs, AOIs, and matrix are also consistent with this classification (e.g., Scott and Jones, 1990; Kojima et al., 1995; Rubin, 1998; Tomeoka and Itoh, 2004).

However, lithology A and lithology B show minor, but significant differences in mineralogy. Olivine in the chondrules in lithology B is more enriched in Fe (and depleted in Mg) than that in lithology A (Figs. 2a, 2b and Table 1), whereas olivine in the matrix in lithology B is more depleted in Fe (and enriched in Mg) than that in lithology A (Fig. 1b and Table 1). These differences in Fe distribution can be explained by the deduction that lithology B has gone through a higher degree of thermal metamorphism than lithology A such that Fe atoms in the Fe-rich matrix diffused into Fe-poor chondrules (and Mg atoms diffused out from chondrules to the matrix) during
thermal metamorphism, and the overall Fe distribution became more homogenized in lithology B than in lithology A.

Chondrules and CAIs in lithology B show a higher degree of nephelinization than those in lithology A. Previous studies showed that the amount of nepheline in chondrules and CAIs in CO3 chondrites systematically increases with an increase in the petrologic subtype of the host chondrites, and thus suggested that nephelinization in these objects is correlated with thermal metamorphism of their host chondrites (Kojima et al., 1995; Russell et al., 1998; Tomeoka and Itoh, 2004). We therefore conclude that the differences in Fe/Mg distribution and degree of nephelinization between lithology A and lithology B are related to the difference in degree of thermal metamorphism. Based on the olivine compositions (Table 1) and the criteria given by Scott and Jones (1990), we suggest that the subtypes for lithology A and lithology B are 3.4 and 3.7, respectively.

From the study of dark inclusions in CO3 chondrites, Itoh and Tomeoka (2003) showed that brecciation occurred actively in the CO parent body. Lithology A and lithology B probably represent rocks that have been thermally metamorphosed at different locations within a single CO parent body and then mixed to form the present combined rock during a brecciation process. Our results thus suggest that the CO parent body has undergone a heterogeneous distribution of its metamorphic condition, and a brecciation process has subsequently (or simultaneously) occurred in the parent body. The results further suggest that the CO3 chondrites of different subtypes from 3.0 to 3.8 (Chizmadia et al., 2002) constituted the same, single parent body.

**ACKNOWLEDGMENTS**

The meteorite sample was obtained through B. Fectay and C. Bidaut (The Earth’s Memory). The electron microprobe analysis was performed at the Venture Business Laboratory, Kobe University. This work was supported by a Grant-in-Aid (No. 16204042) and “The 21st Century COE Program of Origin and Evolution of Planetary Systems” of the Japan Ministry of Education, Culture, Sports, Science and Technology.

**REFERENCES**


*Manuscript received October 18, 2007*
*Manuscript accepted February 13, 2008*

*Manuscript handled by Hirokazu Fujimaki*