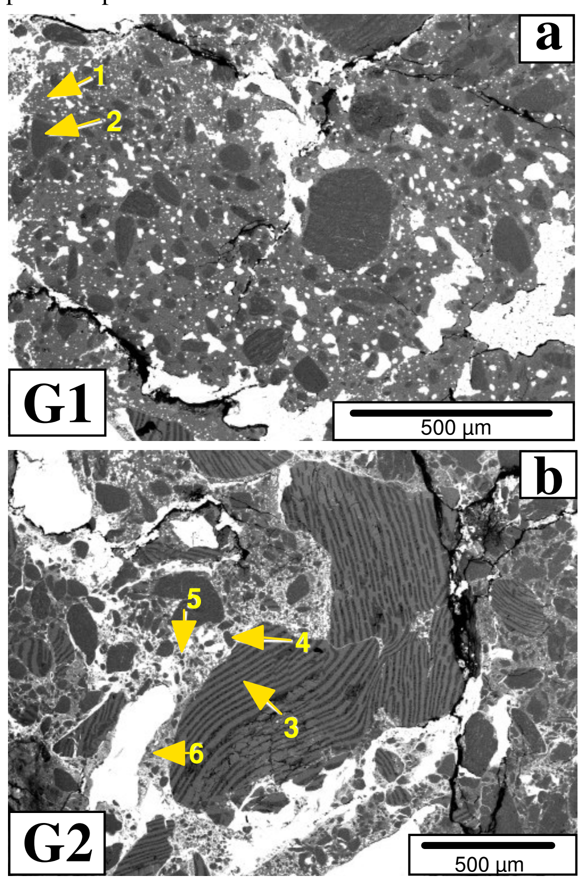
PETROLOGY AND RAMAN SPECTROSCOPY OF SHOCK PHASES IN THE GUJBA CB CHONDRITE AND THE SHOCK HISTORY OF THE CB PARENT BODY.

M. K. Weisberg[1,2] and M. Kimura[3], [1]Dept. Physical Sciences, Kingsborough College, City University of New York, Brooklyn, NY 11235. (mweisberg@kbcc.cuny.edu). [2]Dept. Earth and Planetary Sciences, American Museum of Natural History, NY, NY 10024, [3]Faculty of Science, Ibaraki University, Mito 310-8512, Japan.

Introduction: The CB chondrites are metal-rich chondritic meteorites having characteristics that sharply distinguish them from other chondrites [1], including (1) high metal abundances (60-80 vol.% metal), (2) most chondrules have cryptocrystalline or barred textures, (3) moderately volatile lithophile elements are highly depleted and (4) nitrogen is enriched in the heavy isotope. Similarities in mineral composition, as well as oxygen and nitrogen isotopic compositions of the CB to CR and CH chondrites are consistent with derivation of these chondrite groups from a common nebular reservoir, hence their grouping in the CR clan [1, 2, 3, 4]. CB chondrites have been divided into CB_a (Gujba, Bencubbin, Weatherford) and CB_b (Hammadah al Hamra 237 and QUE 94411) subgroups based on petrologic characteristics [1]. The CB_a chondrites contain ~60 vol. % metal, chondrules are cm-size, FeNi metal ranges 5-8 % Ni, and $\delta^{15}N$ is up to ~1000‰, whereas, the CB_b contain >70 vol. % metal, chondrules are mm-size, FeNi metal ranges 4-15 % Ni, and $\delta^{15}N$ is ~200‰. The origin and significance of the CB chondrites have generated much controversy. They have been interpreted to be highly primitive nebular materials containing metal that condensed directly from the nascent nebular gas [e.g., 1-7]. Others have contended that they formed in a vapor cloud produced during an impact event on a chondritic planetesimal [e.g., 8, 9]. Metal in the CB_b have trace element compositions consistent with condensation under nebular conditions, whereas the metal in the CB_a chondrites have trace element compositions interpreted to require condensation from a dense metal-rich gas, possibly generated by a protoplanetary impact [9]. An intriguing characteristic of CB chondrites is that they all contain impact melt areas between the metal and silicate chondrules [1- 5]. The silicate in some impact melt areas in QUE 94411 is richer in Fe than the chondrules, suggesting that these areas are the remains of an Fe-rich chondrite matrix material that was once present in the CB chondrites, and was preferentially melted during impact heating [11]. In this study we focused on areas in Gujba that contain shock melt, using a combination of petrology and Raman Spectroscopy. Our goals are to understand the nature of interstitial material in CB chondrites, determine the presence of high-pressure phases and constrain the thermal history of the CB chondrites.

Results: We studied three areas interstitial to the large metal and silicate chondrules in Gujba. These areas consist of small (10μm to 1mm) barred olivine fragments, texturally and compositionally similar to the large chondrules, surrounded by a fine (sub-micrometer) matrix of silicate dotted with tiny (2-30μm-size) blebs of FeNi metal (Fig. 1). Metal also occurs as veins and at boundaries between fragments and the matrix (Fig. 1), suggesting that it was remobilized. We used Raman Spectroscopy to determine the presence of high-pressure phases in the matrix and fragments in the regions shown in Fig. 1. The arrows in Fig. 1 show the points in which spectra were collected. We found majorite garnet, a phase that forms by high-pressure transformation of low-Ca pyroxene (low-Ca Pyx) and wadsleyite, a high-pressure product of olivine.



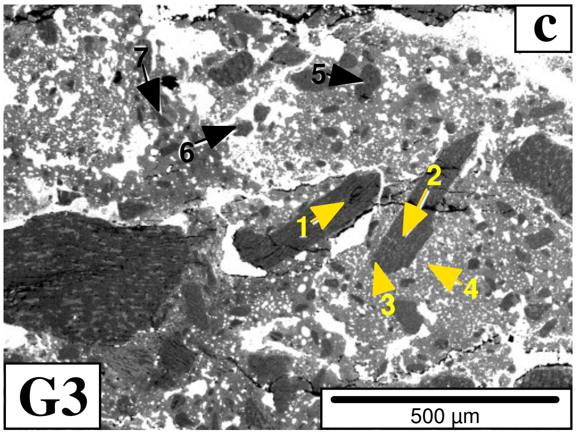


Figure 1. BSE images of shocked areas in Gujba AMNH-PS-3 showing (a) G1 consisting of barred olivine fragments surrounded by matrix. (b) G2 containing a large (~1mm), deformed barred olivine fragment surrounded by smaller fragments and matrix. (c) G3 showing barred olivine fragments surrounded by matrix. Arrows show areas that were analyzed with Raman Spectroscopy.

Compositions of some majorite suggest that it is majorite - pyrope solid solution. In region G1 (Fig. 1a), the matrix (point 1) and a barred olivine fragment (point 2) both have Raman spectra consistent with the presence of olivine (Fa_{15}) and majorite. In region G3 (Fig. 1c) one barred fragment contains olivine and low-Ca pyx coexisting with majorite-pyrope$_{ss}$ and wadsleyite (point 1) and, another barred fragment is similar (point 2 and 3) with a majorite-pyrope$_{ss}$ composition (in wt. %) of 56.6 SiO_2, 1.0 Al_2O_3, 0.8 Cr_2O_3, 37.0 MgO, 1.2 CaO, 0.4 MnO, 2.3 FeO. Other barred olivine fragments in region G3 contain wadsleyite and majorite-pyrope$_{ss}$ (point 5) and olivine and majorite or majorite-pyrope$_{ss}$ (point 6). The matrix of region G3 (point 4) contains olivine, low-Ca-pyx and majorite or majorite-pyrope$_{ss}$. In the region G2 (Fig 1b), the fragments and matrix contain olivine and low-Ca pyx and no high-pressure phases. The large barred olivine in G3 consists of olivine (Fa_2), Mg-Al spinel and a glassy mesostasis with fine crystals of Ca-pyx. This fragment is highly fractured and the olivine bars have bends suggesting plastic deformation.

Discussion and Conclusions: High-pressure phases majorite or majorite-pyrope$_{ss}$ and wadsleyite are present in the matrix and in barred olivine fragments in the Gujba CB chondrite. This is the first discovery of high-pressure phases in a carbonaceous chondrite. Majorite has been reported in shock veins in ordinary chondrites [e.g., 12,13,14] and as dendritic crystals intergrown with interstitial glass in the Tenham ordinary chondrite [15]. The only natural occurrence of wadsleyite is in shocked ordinary chondrites [e.g., 16]. The presence of these phases in Gujba suggests that carbonaceous chondrites also experienced heavy impact events, like those of ordinary chondrites. Majorite occurring with wadsleyite is an equilibrium assemblage at high pressure. However, many fragments in Gujba contain fine mixtures of olivine, low-Ca pyx, majorite and wadsleyite, and others contain olivine and majorite, suggesting disequilibrium and possibly back transformation of wadsleyite to olivine upon cooling [14, 17]. Within Gujba, the occurrence of high-pressure phases is variable from one area to another, on the scale of millimeters or less, suggesting heterogeneous distribution of shock or back transformation throughout the meteorite. The CB chondrite parent body clearly experienced a violent shock event that resulted in brecciation, melting, plastic deformation, high-pressure transformation of low-Ca pyx to majorite and conversion of olivine to wadsleyite. The phase assemblage in the fragments and matrix areas suggest maximum shock pressures and temperatures of ~19 GPa and ~2000ºC [17]. All of the CB chondrites contain impact melt areas throughout, suggesting a planetesimal scale collision. Other CB chondrites may also contain high-pressure minerals but this needs to be confirmed. The shock event recorded in the CB chondrites is superimposed onto the chondrules and metal. Shock melted areas in the Weatherford CB chondrite were determined to be relatively young (3.6 Ga), whereas the chondrules are 4.5Ga [18]. The barred chondrules and metal in the CB chondrites are primary materials formed prior to the impact event either generated in an earlier impact event or more likely in the nebula.

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