QUE97416 AND A-88882094, TWO CO3 BRECCIAS: EVIDENCE FROM PETROLOGIC SUBTYPES DETERMINED FROM AMOEBOID OLIVINE INCLUSIONS

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Introduction: [1] first recognized that the type 3 CO chondrites form a metamorphic sequence; he defined three stages (I-III) based on the degree of textural recrystallization, decreasing heterogeneity in mafic mineral compositions and increasing FeO enrichment in the mafic minerals. Afterwards, [2] subdivided the CO3 chondrites into petrologic subtypes from 3.0 (least altered) to 3.7 (thermally altered) based on igneous zoning in chondrules phenocrysts and increasing FeO concentration at the edges and cracks of these phenocrysts, redefining [1] metamorphic series. Other techniques such as peak TL temperatures of whole rock samples, the structural grade of organic matter trapped in the matrix, and amount of Na-metasomatism have also been used to classify the amout of hydrothermal alteration displayed by the CO3 chnodrites [3-5]. The most sensitive technique that spans the entire range of metamorphism is the systematic Fe-enrichment shown by amoeboid olivine inclusions (AOIs) as subtype increases from 3.0 to 3.8 [6].

AOIs span the whole range of petrologic subtypes. Due to their high-surface-area/volume ratios, AOIs are affected in the early stages of secondary alteration [1] and are sensitive indicators of such alteration [5]. According to [5], as petrologic subtype increases from 3.0 to 3.8 due to hydrothermal alteration the following systematic changes occur: the olivine is initially small forsteritic grains, with practically no ferroan olivine (subtype 3.0), narrow veins of FeO-rich olivine form along cracks and grain boundaries (subtype 3.2), as alteration continues the veins thicken, and by subtypes 3.7 there is almost no Mg-rich olivine remaining and none has been observed in the AOIs in CO3.8 chondrites. In this paper the systematic changes described by [5] are used to develop a semi-quantitative classification of CO3 chondrites. With the right tools, this semi-quantitive classification should serve as a cost- and time-efficient way of classifying CO3 chondrites. In addition, the carbonaceous chondrite classification described by [6] was used to verify that samples classified as CO chondrites actually belong to that group.

Analytical methods: Images of 21 CO3 chondrites (12 previously studied and 9 unclassified) were captured by [6,7-8] using the LEO 1430VP scanning electron microscope (SEM) at UCLA and the and the JEOL JSM5900 LV SEM at the Hawaii Institute for Geophysics and Planetology at the University of Hawaii. The percentages of Mg-olivine, Fe-olivine, anorthite-diopside-spinel (An-Di-Sp) assemblages, and Fe-Ni metal within each of the AOIs were estimated using a random grid in JMicroVision© point counting software. The dimensions of the AOIs and thicknesses of their veins were also measured. The sample size of each image consisted of 500 points, which were randomly selected. Points in the matrix or within voids in the AOIs were excluded. The compositions of the 9 samples with previously assigned subtypes [6] were used to create a classification scheme. The 12 CO3 chondrites were assigned subtypes based on the abundance of Fe-rich olivine in the AOIs in comparison with the .

Results: Using the obtained point count data of the chondrites with known subtypes, which corroborated the systematic decrease in Mg-ol and enrichment in Fe-ol as subtype changed from 3.0 to 3.8 discussed by [5], a range (Table 1) for the classification of CO3 chondrites was developed and the subtype of 9 previously unstudied samples were estimated (Table 2). This range is solely based on the amount of Mg-olivine versus Fe-olivine in the AOIs of each chondrite. An-Di-Sp assemblages and Fe-Ni metal grains were not used in the classification because they do not show any systematic changes as subtype changed from 3.0 to 3.8. The vein thicknesses, which were previously determined by [5], were used to refine the estimation of the subtype.

Discussion. Typically, AOIs in a given CO3 show uniform levels of replacement of the primary forsteritic olivine with Fe-rich olivine [6], with as little as 5 wt% in overall ranges. AOIs in QUE97416 and Asuka -882094 have differing ratios of Fe:Mg olivine which seems to indicate a range of subtypes from ~3.2 to 3.6 (Fig. 1), as much as 20 wt% difference in range . This has not been documented in the CO3 chondrites before and can be best explained if these meteorites are brecciated representatives of the CO3 parent body asteroid.

References: [1] McSween H. Y., Jr. (1977) *Geochimica et Cosmochimica Acta 41* 483-491. [2] Scott E. R. D. and Jones R. H. (1990) *Geochimica et Cosmochimica Acta 54,* 2485-2502. [3] Keck and Sears (1997) *Geochimica et Cosmochimica Acta 51,* 303-3021. [4] Bonal L. et al. (2007) *Geochimica et Cosmochimica Acta 71,* 1605-1623. [5] Tomeoka and Itoh (2004) *Meteoritics & Planetary Science* 39, 1359-1373. [6] Chizmadia L. J. et al. (2002) *Meteoritics & Planetary Science* 37, 1781-1796. [7] Bendersky C. N.

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Subtype	Mg-ol (%)	Vein thickness (µm)
3.0	100	n/a
3.1	99.9-99.5	<2
3.2	99.5-75	≈2.5
3.3	75-55	≈4
3.4	55-35	≈6
3.5	35-15	10 to 15
3.6	15-0.5	20 to 30
3.7	0.5-.01	n/a
3.8	0	n/a

Table 1. Proposed classification scheme for the CO3 chondrites based on point count data of 9 previously studied CO3 chondrites and the thicknesses of Fe-rich olivine veins. The width of the interval of the classification in Table 1 is not the same for each subtype. Subtypes 3.1 and 3.7 have a smaller interval width due to the fact that few CO3.1 and CO3.7 chondrites exist, and that the amount of Fe-ol in subtype 3.1 is very small (0.1%), and in CO3.7 Warrenton not even an Mg-ol core was found.

Meteorite	Subtype
Alan Hills-77307	3.0
Yamato-81020	3.0
Kainsaz	3.2
Felix	3.3
Ornans	3.4
Lance	3.5
Alan Hills-77003	3.6
Warrenton	3.7
Isna	3.8
	Estimated subtype
Asuka-881632	3.1
Yamato-82050	3.25
Yamato-82094	3.25
Asuka-882094	n/a
Dominion Hills-03238	3.1
Queen Alexandra Range -97416	n/a
Meteorite Hills-00694	3.8
Meteorite Hills-00711	3.8
Meteorite Hills-00737	3.8
Alan Hills-83108	3.8
Alan Hills-82101B	3.5
Dar al Gani-055	n/a

Table 2. The CO3 chondrites. The chondrites with defined subtype were previously studied by [5]. The samples that their subtype was estimated were the focus of this investigation (n/a= did not fit in the classification).

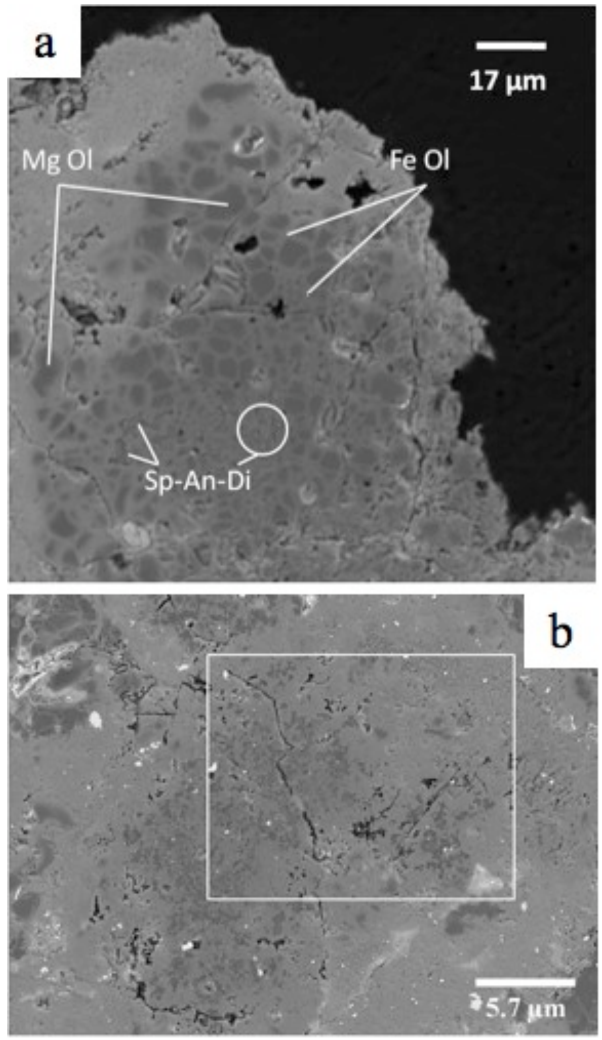

Figure 1. Backscattered electron images of two typical AOIs in QUE97416 which show the range of subtypes exhibited by AOIs in this CO3 chondrite.