BILANGA: A UNIQUE DIOGENITE.

S. E. Kolar[1], K. J. Domanik[2], D. S. Musslewhite[3], and M. J. Drake[2], [1]Canyon Del Oro High School, Tucson AZ., 85737, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092. [3]NASA Johnson Space Center, Houston, TX, 77586.

Introduction: Diogenites are a part of the howardite, eucrite, diogenite (HED) association. This group of meteorites is believed to originate from the large asteroid, 4-Vesta [1]. These meteorites are typically very highly brecciated and contain 84–100 vol% orthopyroxene [2]. Other common minerals include chromite as well as highly variable amounts of troilite and olivine [3]. Silicate phases such as Ca-pyroxene, plagioclase, and silica are typically present in minor amounts and occur as small breccia fragments, exsolution lamella, or small single inclusions in orthopyroxene. As a result, few chemical analyses are available for these phases and their original textural relationship to orthopyroxene is poorly known [3].

We have studied the Bilanga meteorite, a diogenitic breccia fall that was recovered in Burkina Faso on October 27, 1999. Although Ca-pyroxene, plagioclase, and silica are not abundant in the Bilanga samples we examined, the size of these phases appear to be unusually large. Several areas in the breccia contain aggregates of diopside and in some cases plagioclase that are 10s - 100s of µm in size. These aggregates are typically in contact with orthopyroxene and large grains of chromite and/or troilite. Smaller inclusions (2-20µm) of Ca-pyroxene, plagioclase, and silica also occur completely enclosed within large crystals of orthopyroxene. Thus, the Bilanga sample offers a unique opportunity to study the composition, equilibration temperature, and mode of occurrence, of the minor silicate phases in diogenites. This would help to provide a better understanding of the igneous crystallization and later metamorphic histories of these meteorites.

Observations: The Bilanga meteorite is highly brecciated orthopyroxenite with an average grain size of 1.5mm x 1.5mm. However some fragments of orthopyroxene up to 11mm x 5mm are observed. Phases present include orthopyroxene (mg# 80; En_{78}, Fs_{21}, Wo_2), chromite (mg# 19, cr# 78), troilite, diopside (mg# 89; En_{47}, Fs_6, Wo_{47}), plagioclase (typically An_{87} but ranging down to An_{50}), silica, and very minor Fe,Ni metal. Olivine appears to be absent. The orthopyroxene in Bilanga (En_{78}) is somewhat more magnesian than is common in most diogenites (typically En_{74}). X-ray mapping shows that the orthopyroxene contains diffuse, calcium-rich, exsolution bands oriented parallel to the (001) direction of the host orthopyroxene. These bands tend that die out near fractures, inclusion trails, and grain boundaries. Individual augite lamella are not observed in these bands, but may occur on a scale too small to be resolved by electron microprobe The average composition of these phases are given in Table 1.

	Orthopyroxene	Diopside	Plagioclase	Chromite
SiO2	55.21	54.29	45.87	0.08
TiO2	0.10	0.10	0.01	0.48
Cr2O3	0.40	0.40	0.12	55.26
Al2O3	0.81	0.48	35.32	10.31
FeO	13.21	3.97	0.21	27.54
MnO	0.44	0.18	0.01	0.81
MgO	29.15	17.13	0.01	3.55
CaO	0.72	23.53	17.82	0.10
Na2O	0.01	0.12	1.38	0.01
K2O	0.00	0.00	0.04	0.01
NiO	0.02	0.01	0.02	0.03
Total	100.08	100.25	100.83	98.23
#analyses	73	121	26	43

Table 1: Composition of selected minerals in the Bilanga meteorite. Compositions for plagioclase are for Type 1 inclusions only.

Three distinct modes of occurrence of diopside, plagioclase, and silica are observed in the Bilanga sample. Type 1 consists of coarse grained aggregates of diopside + chromite + troilite +/- plagioclase +/- silica that are associated with or partially enclosed by moderately sized breccia fragments of orthopyroxene. These diopside aggregates range from 10 to 200µm in size. Plagioclase is typically also present in varying amounts and can range from 1µm grains to 200µm aggregates. The composition of plagioclase in Type 1 inclusions is $An_{87 +/- 2}$. Silica occurs as small µm-sized inclusions in diopside. In all cases, the diopside +/- plagioclase assemblages are closely associated with large (20–200µm) chromite and troilite grains that typically to occur near the boundaries with adjacent orthopyroxene. Chemical zoning in these assemblages has not been observed. A typical Type 1 assemblage is shown in Fig. 1.

Type 2 assemblages consist of fine grained diopside and silica inclusions associated with inclusion "curtains" within orthopyroxene grains. These "curtains" consist of blebbly chromite, minor troilite, and abundant non-opaque particles <1 - 2µm in size. These are typically randomly distributed on the surfaces of healed and open fractures and, in a few cases,

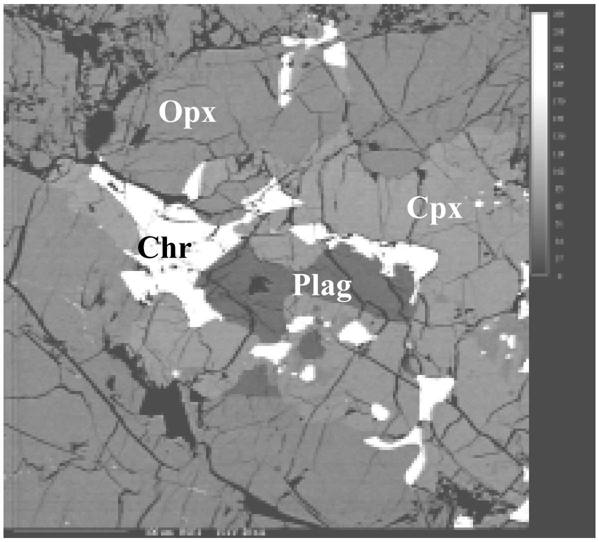

Fig 1: BSE photo showing "Chromite man" A typical Type 1 diopside-plagioclase-chromite assemblage in the Bilanga diogenite. Area: 450 x 450 µm.

crystallographic planes. In some areas, these grains are aligned to form parallel columns on the fracture surfaces that appear to be oriented roughly perpendicular to the (001) direction of the host orthopyroxene. Similar inclusion "curtains" consisting of troilite, metal, and a minor silica phase have previously been described [4, 5]. Larger diopside grains (2–10µm) and µm-sized silica grains are distributed at irregular intervals along the length of the inclusion curtains. The composition of diopside is similar to that observed in Type 1 inclusions. Plagioclase (An_{89}) occurs in one coarse grained, deformed chromite inclusion trail. However, the unusual nature of this trial suggests that it might be a trapped melt vein.

Type 3 inclusions appears to consist of recrystallized melt inclusions within orthopyroxene grains. These are fine grained multi-phase (2-20µm) patches that consist primarily of intergrown diopside and silica. Plagioclase is usually also present, (and in a few cases abundant), and displays an extremely variable composition even within a single inclusion. Chromite and troilite are also invariably present. Based on their textures and compositions these melt inclusions appear to mainly consist of rapidly cooled disequilibrium assemblages.

Discussion: The Type 1 inclusions in the Bilanga breccia matrix appear to be relatively well preserved samples of intercumulus melt that was present during the late stages of the crystallization. The constant composition of the phases and the lack of chemical zoning, and the well defined contacts between diopside and orthopyroxene suggest that these assemblages crystallized in equilibrium with the surrounding orthopyroxene and (in many cases) retain their original igneous contacts. In order to determine the temperature at which the inclusions last equilibrated, we applied the clinopyroxene-orthopyroxene QUILF geothermometer of Andersen et al. [6], and the orthopyroxene-chromite geothermometer of Liermann and Ganguly [7] to selected pairs of analyses assuming a pressure of 1 kbar. The average temperatures obtained from these models were 823˚C and 720˚C respectively. Given the large difference in diffusion rates for these two equilibria, these temperatures are considered to be in relatively good agreement and appear to record a late stage metamorphic event, followed by a long period of slow cooling.

Type 2 diopside inclusions appear to be similar to the few descriptions of Ca-rich clinopyroxene in diogenites previously reported in the literature (e.g. [8]). These assemblages appear to be the result heterogeneous nucleation of exsolved diopside along fractures and other defects. Concentration of Ca into these grains may account for the absence of diffuse exsolution bands in the vicinity of these features. Conversely, the diffuse bands are interpreted as having formed later, by much slower homogeneous exsolution processes during slow cooling.

The high Al content of the orthopyroxene (0.04 cations per 6 oxygen formula unit) suggests that the sample is the product of relatively late stage crystal fractionation in comparison with other diogenites [9]. This can also be inferred from presence of plagioclase and silica in both the intercumulus melt and in melt inclusions in orthopyroxene which must have been trapped earlier in the crystallization history of the sample. Thus the Bilanga sample appears to provide a unique opportunity to characterize the nature of the melt phase during the late stages of diogenite crystallization.

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