
INTRODUCTION. Mineral chemistry of basaltic clasts from 12 howardites have been used to examine their relationships to one another, and to basaltic eucrites, cumulate eucrites and mesosiderite mafic clasts. The low-Ca pyroxene (px) range is En70-En31 and average feldspar varies from An92 to An75 (Fig. 1). Although most clasts are equilibrated [1] a few show px variations similar to the unequilibrated Pasamonte and many polymict eucrite clasts [2,3,4].

Two groups are distinguished: (a) PERITECTIC BASALTS have low-Ca px (En 35-40) and plag. (An87-92), compositions similar to most monomict basaltic eucrites [5], (b) EVOLVED BASALTS have low-Ca px compositions from En60 to En31 and plag. with Ab9-25 (Fig. 1). These latter overlap a trend defined by Stannern [1], Chervony Kut [6] and by individual clasts from the Pasamonte eucrite. All the unequilibrated and many equilibrated clasts fall in this group. A tiny basalt clast from Bununu, which plots at En69, An90 (Fig. 1), contains very rapidly cooled, chain olivines ~Fo68-70 [7] and glass. This clast lies on the Mg extension of the observed trend but is interpreted as an impact melt and will not be treated in detail. Some howardites (ALHA-78006, Bholgati, Bialystok) sample only one group while others (Bununu, Frankfort, Malvern, Pavlovka, Petersburg) sample both. Clasts in both groups have either granular or subophitic to ophitic textures.

(a) PERITECTIC BASALTS have low Ca px and plag. compositions very similar to most eucrites [5] and form a tight cluster. Several of these clasts differ from the eucrites however; because they contain discrete, often unexsolved, augite (Wo30-40) as well as the exsolved pigeonite (Wo7-12) typical of the eucrites. Two-px basalts have previously been recognized, only as mesosiderite mafic clasts [8]. The two-px basalts must have crystallized under different conditions than the majority of the eucrites. Oxide minerals in this group are dominantly ilmenite (ilm)+chromite (cm). The cm usually has constant Mg/(Mg+Mn+Fe) but coexisting ilm. may vary from 0.01 to 0.04 even though the clasts have essentially constant mg in pyroxene. The oxides are intimately intergrown and cm analyses often have ilm. contamination. Chromite is always much less Ti-rich than the unusual Ti-chromite of the Ibitira eucrite [9]. Plag. in this group is often much less variable than in the eucrites (Fig. 1) suggesting that it cooled more slowly or underwent more prolonged metamorphism than the eucrites. Tridymite may be either lathy or interstitial and has similar modal abundances in these clasts and in the eucrites (0-8%) [11]. The absolute abundance may however be sensitive to grain size/clast size ratio for the smaller clasts. Troilite is a ubiquitous accessory mineral and Fe metal, often with EDS detectable Ni, may be present.

(b) EVOLVED BASALTS are compositionally more diverse than the peritectic group and are as numerous in the samples studied. These clasts show no overlap with the peritectic basalts but instead define a trend (or trends) of increasing Na with increasing Fe (Fig. 1). Although not shown in Fig. 1, pyroxenes in the most iron rich clasts tend to be augitic rather than pigeonitic (from microprobe, modal and broad beam analyses) so that the group varies from Mg-rich, Ca-Na-poor basalts toward Mg-poor Ca-Na-rich clasts. Extension of the trend towards more magnesian compositions passes through Binda, the pyroxene cumulate eucrite [12] and the px-rich Yamato 75032 [13]. The lack of feldspar in most diogenites and in orthopyroxenite clasts in howardites [14] prevents further extrapolation. The overlap of these clasts with the trend defined by Pasamonte clasts [1] and at the Fe-rich end with the eucrites.
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Stannern and Chervony Kut (both of which are more fractionated than the majority of eucrites [15]) is perhaps indicative of a common origin. Neither ilm. nor cm from each group, in their overlapping ranges (En35-40), is considered characteristic of the group, but both oxides in the evolved basalt group have mg variations related to px composition. The clear differences between the two groups require explanation. The tight clustering of the peritectic basalts and their general similarity to most basaltic eucrites suggests a very similar source, probably by peritectic controlled, partial melting [16]. The two-pyroxene nature of several peritectic basalts may reflect Ca enrichment in the source rock, relative to that of the eucrites, which caused precipitation of pigeonite + augite after partial melting. The trend of increasing Fe/Mg in the px and oxides with increasing Na/Ca of the plag. in the evolved basalts may be explained by a fractionation sequence from Fe-Na-poor to Fe-Na-rich compositions. The similarity of this trend to that defined by individual clasts in Pasamonte [1] suggests that they evolved from a liquid like Pasamonte. Since most of the clasts have little mineral zoning, they may have cooled at sufficient depth for homogenization to occur. One clast from Kapoeta has exsolution textures strikingly similar to those in cumulate eucrites [13,17], having formed under very similar, cooling magma chamber conditions. This clast has px in the cumulate eucrite range (En56) but its plag. is much more sodic (An87 instead of An93-95) and is therefore distinct from the well defined group of 5 cumulate eucrites (Fig. 1). These clasts may be linked by fractionation of Mg-rich px and Ca-rich plag. causing progressive Fe, Na (+K) enrichment in the evolved liquid. The increasing alkalis in the liquid result in crystallization of more albitic feldspar so that Ca must increasingly enter pyroxene as magma evolution proceeds. The earliest cumulates would be px rich, like Binda, the pyroxene cumulate eucrite [12] and plag. bearing pyroxenite Yamato-75032 [18].

DISCUSSION. The howardite basalt clasts represent one of 4 basaltic suites. The others are, the basaltic eucrites, the feldspar cumulate eucrites and the mesosiderite mafic clasts. The cumulate eucrites (Moore Co., Moama, Medanitos, Nagaria, Serra de Magé) show a very clear trend of increasing Na with Fe and may be linked by fractionation, although REE problems [19] may require the involvement of an Fe-bearing phase such as an oxide or Fe-Ni metal. Similarly, the mesosiderite mafic clasts show increasing Na with Fe and are linked by a fractionation sequence [8]. The basaltic eucrites have a smaller range of px composition but have inhomogeneous plag. The majority however, have mean plag. compositions ~An90 and form a tight cluster around the peritectic group of howardite basalts (Fig. 1). Only three eucrites fall outside this cluster (Chervony Kut, Stannern and Pasamonte). The distinct differences between the two groups of howardite basalts suggest that two populations were sampled, both of which are represented in basaltic eucrites but in different proportions.

Modelling of a howardite parent body requires that three distinct regions be present. (A) Deep magma chambers in which orthopyroxenites/diogenites accumulate. (B) In addition sufficient mafic magma must accumulate to form a fractionated series of basalts, the Evolved Basalts. Pasamonte and the unequilibrated basalt clasts are probably surface lavas, erupted at the time of emplacement of this magma body. Finally (C) a region must exist where 5-15% partial melting [20] can occur with only minor fractionation to produce the Peritectic Basalts and most basaltic eucrites [16]. This region must be relatively undifferentiated, perhaps H-chondritic [21]. Direct evidence of this chondritic material is not seen in the howardites perhaps because of burial at greater depths than are sampled by brecciation. Clearly, the howardite parent body is not a simple homogeneous body. If the mesosider-
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Mafic clasts and the cumulate eucrites, which show evidence of having evolved, by fractionation in a more alkali depleted region than most howardite basalts, are also considered to be part of the same body then the "basaltic achondrite parent" (BAP) becomes extremely complex. Several related, but different, subsurface processes taking place simultaneously, must produce variations in the bulk chemistry of magmas if all were derived from a common parent. It is not clear that the observed diversity of basalts could have evolved on a single asteroid sized body. Instead it may be more realistic to consider BAP to be several bodies sampling different parts of an almost homogeneous nebular reservoir.

FIGURE 1: Opx lamellae (En%) composition vs plag. (An%). Fields are: -1- Basaltic eucrites except Pasamonte, Chervony Kut, Stannern; -2- Feld. cumulate eucrites; -3a- Trend for clasts from Pasamonte [1]; -3b- Chervony Kut, Stannern; -4- Mesosiderite mafic clasts. Dashed fields are the howardite basalt groups: -5- Peritectic basalts; -6- Evolved basalts. Symbols for individual howardite clasts are ○ Bholgati, ▲ Bununu, △ Bialystok, ○ Frankfort, ○ Kapoeta, ▲ Malvern, ○ Pavlovka, ○ Petersburg.