BASALTIC ACHONDRITE POLYMICT BRECCIAS: AN INTERPRETATION
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Other investigators (1–7) have identified several similarities among brecciated pyroxene-plagioclase achondrites (howardites), brecciated chondrites, and lunar regolith breccias. This report summarizes the results of an extensive petrographic and compositional study of 10 howardites and 1 eucrite-rich mesosiderite, which characterizes these meteorites as lithified parent body regolith material. Petrographic observations define a wide range of textural features that indicate multiple impact and mixing processes of surface rocks. These features include cataclasis and comminution, mixing of clasts, multiple brecciation events, mechanical and thermal shock effects, recrystallization, annealing, formation of impact melt rocks and partial to complete melting with the production of glass spherules and fragments, agglutinates and glassy matrix breccias. A provisional textural classification of component clasts and glasses is given in Table 1. Subsequent compositional data from microprobe analyses are consistent with the textural parameters.

Many varieties of igneous rocks are present in howardites. Considerable uncertainty exists as to whether these rocks are the result of magmatic crystallization or impact melt products. Many of the ophitic-subophitic clasts (Table 1) are similar to eucrite meteorites in bulk composition, but are dissimilar in appearance; the clasts are commonly fresh, whereas eucrites have numerous bleb-like inclusions in plagioclase and degraded pyroxenes. In addition, many granoblastic clasts are present which are compositionally similar to either type IA or IB (Table 1). Granular basalts and microgabbros (not found as meteorites) are more numerous than the basaltic types. Defocused beam analyses show that these are compositionally distinct from basaltic types in higher amounts of FeO and MgO and lower amounts of Na2O, K2O, Al2O3 and CaO (Figs. 1 and 2). The [FeO/(FeO + MgO)]/CaO ratios are consistent with eucrites (8). Mafic rocks are pyroxene-rich and are either gabbroic or show apparent cumulate textures. Al-rich rocks are plagioclase-rich and are similar in composition to Serra de Mage (Fig. 2) which has anorthositic affinities (1). Several of the igneous clasts are very similar in major element composition to specific lunar basalts and ANT group rocks.

Breccia clasts are variable in texture and are similar to lunar breccias in complexity and mode of formation. Low to high metamorphic grade breccias are most common, with poikilitic varieties subordinate in frequency and variety. Glass matrix breccia glass is similar in composition to either basaltic clasts or howardite meteorites (8). Numerous breccias with angular rock and mineral fragments are embodied in a FeS-melt matrix. Impact melt rocks are also common and are very similar in appearance to lunar varieties. Glass spherules, fragments and devitrified products are compositionally similar to either igneous or breccia clasts. Hypersthene achondrite and carbonaceous chondrite clasts are present also. Very coarse (0.5–8 mm) fragments of bronzite (meteorite hypersthene) and plagioclase are the most abundant mineral clasts. Mineralogy of igneous clasts is similar to that described by Duke and Silver (1) for eucrites, although major minerals have more extensive compositional ranges. Particles 0.031–2 mm are equivalent in distribution frequency to lunar metabreccias (2).
Summary and Conclusions

Howardites are parent body surface breccias that contain varying proportions of igneous rocks, mainly hypersthene achondrites (orthopyroxenites) and eucrites (basalts). In addition, rock types have been identified that are not known as meteorites, thus, howardites are not simple two component mixtures. Howardites are very similar in overall characteristic to lunar breccias in mode of origin, although they are probably less mature in mixing and reflect somewhat less intense shock and thermal histories.

Petrographic and compositional data strongly imply large-scale planetary differentiation, magma generation, formation of cumulate and gabbroic rocks, and surface regolith breccias, which together argue for a sublunar-size parent body. The presence of feldspathic, basaltic, and mafic rocks may suggest an early period of surface melting and differentiation with later episodes of partial melting and basalt generation analogous to the Moon. The relative young radiogenic ages (between 4.0 and 3.5 AE) for basaltic clasts in Kamoeta imply an active geologic period for the parent body of at least 1 AE, although these clasts may have been impact melt rocks and not igneous.

References


**Fig. 1.** FeO and Na₂O+K₂O relationship among howardite igneous clasts. Dashed field is range for eucrites.

**Fig. 2.** MgO and CaO relationship among howardite igneous clasts and Serra de Mage. Best fit line from Ahrens and Von Michaelis (11).
Table 1. Petrographic and Compositional Classification of Howardite Components.

I. Igneous and Metagneous Clasts

A. Ophitic and subophitic (basaltic); includes intersertal and variolitic textures
   < 50% plagioclase
   > 40% pyroxene
   normative and modal SiO₂
   [FeO/(FeO + MgO)]/CaO ratios similar to eucrites
   Na₂O(0.5-0.7); K₂O(0.08-0.27); FeO(12.3-16.7)

B. Granular basalts and microgabbros
   < 50% plagioclase
   > 40% pyroxene
   normative and modal SiO₂
   [FeO/(FeO + MgO)]CaO ratios similar to eucrites
   Na₂O(0.2-0.5); K₂O(< 0.02-0.08); FeO(17.3-22.9)

C. Mafic rocks
   < 25% plagioclase
   > 70% pyroxene
   olivine normative; No SiO₂
   [FeO/(FeO + MgO)]/CaO ratios dissimilar to meteorites

D. Al-rich rocks
   > 60% plagioclase
   < 40% pyroxene
   normative and modal SiO₂
   [FeO/(FeO + MgO)]/CaO ratios similar to meteorites
   Al₂O₃(22.3-34.4); Na₂O(0.2-1.4)

II. Breccia Clasts

A. Crystalline matrix
   a) low metamorphic grade-cataclastic,
      no glass
   b) high metamorphic grade
      1. mosaic-polygonal-recrystallized;
         no glass
      2. poikilitic

B. Glassy matrix

C. Sulfide matrix

III. Impact Melt Rock Clasts

A. Melt matrix-quench crystals

B. Melt matrix-partly melted minerals

C. Melt matrix-basaltic texture

IV. Glasses

A. Spheroids compositions similar to

B. Irregular igneous or breccia clasts

C. Devitrified

V. Meteorite Clasts

A. Hypersthene achondrites

B. Carbonaceous chondrites, Type II

VI. Mineral Clasts (in order of abundance)

Bronzite, plagioclase, low Ca-pyroxene
opales, chromite, olivine