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MINERALOGY OF THE IBITIRA EUCRITE AND COMPARISON
WITH OTHER EUCRITES AND LUNAR SAMPLES

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Ibitira meteorite is interpreted as a strongly metamorphosed, unbrecciated, vicular eucrite with a primary variolitic and secondary hornfelsic texture dominated by 64% pyroxene (bulk composition En$_{37}$Fs$_{33}$Wo$_{30}$), exsolved into lamellae several micrometers wide of augite En$_{32}$Fs$_{37}$Wo$_{31}$ and pigeonite En$_{50}$Fs$_{50}$Wo$_{10}$, and 30% plagioclase An$_{14}$ (mosaic extinction and variable structural state). Minor phases are 5% tridymite plates one-quarter occupied by plagioclase (An$_{14}$) inclusions; several % intergrowths of ilmenite and Ti-chromite with trace kamacite Fe$_{99}$Co$_{0.5}$Ni$_{0.2}$ and narrow olivine (Fa$_{93}$) rims; one grain of low-Ti-chromite enclosed in tridymite; trace tetrata with kamacite Fe$_{99}$Co$_{0.5}$Ni$_{0.2}$; euhedral ilmenite, Ti-chromite, plagioclase and merrillite in vesicles indicate vapor deposition. These properties can be explained by a series of processes including at least the following: (a) igneous crystallization under pressure low enough to allow vaporization, (b) prolonged metamorphism, perhaps associated with vapor deposition and recondensation, to produce the coarse exsolution of the pyroxene and the coarse ilmenite-chromite intergrowths, (c) strong shock which perhaps melted the plagioclase and tridymite but not the pyroxene,

(d) sufficient annealing to allow crystallization of the plagioclase and tridymite, and partial conversion to the low structural state of the former.

1. Introduction

Because the Ibitira eucrite, unlike other eucrites and howardites, is unbrecciated and has an apparently vesicular texture [1], it promises to provide particularly valuable clues for the parent body or bodies of these achondrites. Because of the similarity between these achondrites and samples from the lunar surface, as noted frequently (e.g. [2], [3]), experience from the latter can be applied to the former. Wilkening and Anders [1] briefly described the mineralogy and track history of Ibitira, and concluded that it originated from a basalt flow 2.5-20 meters thick. Using single crystal X-ray and energy-dispersive electron-probe techniques, we continued their study.

2. General Description and Texture

Two types of samples were available: a) a polished thin-section (area ~ 1 cm$^2$) previously used by Wilkening and Anders [1] and b) small fragments (~ 2 mm) and single mineral grains.

Fig. 1

Fig. 1a shows some general features in the thin section. Equant (0.1-0.2mm) grains of pale-brown pyroxene showing ~ 3-5µm exsolution lamellae (Fig. 2a) comprise ~ 60% of the area and are set in an irregular matrix of plagioclase (30%). Sub-rounded holes up to 1mm across comprise about 7% of the area. All have jagged margins bounded mainly by pyroxene "teeth", and some deviate

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substantially from a circular shape (e.g., middle hole in Fig. 1a). Some plagioclase occurs as irregular, near-rectangular regions up to 2 mm long containing pyroxene inclusions and having a jagged outline against bounding pyroxene grains (Fig. 1b). When the entire thin section is viewed at one time in a binocular microscope, these irregular regions give the impression of a ghostly variolitic texture. Under crossed polars at high magnification, the plagioclase lath-like regions are seen to consist of an intimate mosaic of small interlocking grains (Fig. 1c; see also [1] for an excellent illustration of the largest area of plagioclase). Other plagioclase grains occur interstitially to pyroxene grains as shown by the small white areas in Fig. 1a. Tridymite occurs as laths up to 2 mm long peppered with small drops of plagioclase which based on electron microprobe scanning analyses comprise one-quarter of the volume (Fig. 2a). The laths are commonly associated with holes as in Fig. 1a. Some tridymite laths occur as pairs lying in a straight line on opposite sides of a hole (Fig. 1a), and the obvious interpretation is that the pairs are portions of a hexagonal plate penetrated by the hole. Other tridymite grains are tangential to cavities as though bubbles had stuck to tridymite plates during growth. Each tridymite lath actually consists of a mosaic of small interlocking grains with texture somewhat similar to that of the plagioclase mosaic.

The remaining 5% of the mode is composed of ilmenite—Ti-chromite intergrowths (Fig. 2d,e) sometimes showing subhedral boundaries suggesting sections through octahedral forms (Fig. 2e); a minor occurrence is as small laths. Typically the opaque assemblage has pyroxene inclusions giving a "Swiss-cheese" texture. Trace phases include iron-troilite micrometer assemblages and iron associated with the opaque intergrowths. Several opaque intergrowths are rimmed by olivine. No additional phases were found in thin section, either optically or with the electron probe.

Careful examination of the small chips produced four additional mineral types or morphologies. Ilmenite, unlike that present in the thin-section, was found as thin, fragile tablets with mirror-like surfaces growing into two cavities; other similar grains were found among the single mineral grains. Ti-chromite showing stepped growth-faces was found in another cavity. Among the chips, three pale brown grains similar to pyroxene but without exsolution lamellae proved to be merrillite; although not observed in the cavities, the planar growth faces suggest uninhibited growth into cavities. Associated in a cavity with the Ti-chromite was a clear plagioclase grain with a subhedral form; one other similar occurrence was noted. All the above identifications were made from Gandolfi X-ray patterns and qualitative microprobe analysis.

Before going into details of the mineralogy it is obvious that the above textural features are very strange indeed, and cannot be explained by any single mechanism. Some coarse features (holes, indication of variolitic texture, platy and lathy overall shape of tridymite and plagioclase) are consistent with igneous crystallization, whereas some finer features, especially the chunky shape and coarse exsolution lamellae of the pyroxene grains, indicate a prolonged...
metamorphic history. In addition, the mosaic extinction of the
plagioclase and tridymite indicates yet a third process. The remainder
of the description of the mineralogy is directed to obtaining
information on the possible processes which transformed a presumed
igneous texture into a more complex one.

3. Detailed Mineralogy

Quantitative energy dispersive (ED) analyses were obtained using
a focused beam and on-line data reduction methods as described by
Reed and Ware [4]. Minor elements were determined with crystal
spectrometers using Albee-Ray correction factors. All analyses were
referred to synthetic minerals of known compositions, and the
analyses in Tables 1 and 2 have a detection level of 0.01 wt.\% and
an accuracy for major elements between 1 and 5\% of the amount
present. Single-crystal X-ray data were obtained from proctorial
cameras.

Pyroxene. The exsolution lamellae are straight in most grains and
range in width only two-fold. Very rare grains have curved lamellae
as in Fig. 2a. Many grains are fractured.

Zero-layer precession photographs about the $b$-axis showed
diffractions only from pigeonite ($\text{P}2_1/\text{c}$; $a = 9.69 \pm 0.57\%$ $b = 5.22$
$\pm 108.75^\circ$) and augite ($\text{C}2/\text{c}$; $a = 9.69 \pm 0.97 \pm 5.26$ $\pm 106.17^\circ$) with
common (001).

X-ray scanning images showed clear lamellae with widths near
Table 1. Microprobe ED analyses (Table 1), obtained by maximizing or
minimizing the Ca signal with a crystal spectrometer, cluster tightly

Table 2

| Intergrowth | Composition | Two Analyzed
|-------------|-------------|-------------|
| Intergrowth to another (Table 2, Figs. 4 and 5) | Although there is no equilibrium over the entire thin section, local equilibrium is demonstrated by the constant partition of Mg between coexisting chromite and ilmenite. The MgO content of the ilmenite is low ($<1.6\%$) consistent with the high bulk Fe/Mg of Etta II. Although most Ti-chromites have high TiO$_2$ ($\sim 15-25\%$), one analysis ($\#4a$, Table 2)
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- 7 -

is unusually low (TiO₂ = 5.7%) and has high Cr₂O₃ (30.6); this grain is also unusual because it is not equidimensional, but lath shaped and included within tridymite. Fe-metal is common at grain boundaries within the ilmenite—Ti-chromite intergrowths. The one grain of Ti-chromite and those of ilmenite picked from cavities had compositions similar to the common matrix equivalents. Scanning X-ray images of a typical intergrowth are shown in Fig. 3d and e. Although some intergrowths show straight boundaries, most are curved. Spectrometer analyses of Zr showed strong partitioning into ilmenite. Values in the spinel phase ranged from <0.01 to 0.03 wt.% ZrO₂ and those in ilmenite from 0.08 and 0.18 wt.% ZrO₂, lower values being associated with spinel of lower TiO₂ content.

**Fe-metal** - This phase contains different Co and Ni depending on associated phases. Metal associated with taenite has Co ranging from 0.80 to 1.10 wt.% and Ni ~ 0.88 wt.%. Metal associated with ilmenite—Ti-chromite has slightly lower Co (0.40 – 0.60 wt.%) and much lower Ni (0.10 – 0.35 wt.%). Gandolfi patterns indicated kamacite.

**Tridymite** - Gandolfi X-ray patterns were like the Powder Diffraction File pattern 16-1170 for synthetic tridymite. Spectrometer data for minor elements were: FeO 0.31 MgO 0.27 CaO 0.20 K₂O 0.1 Na₂O 0.1 MgO < 0.01 wt.%

**Merrillite** - Identification was made both by Gandolfi and precession photographs. Cell constants are a = 10.4 and c = 37.3 Å. Compositional data, obtained only from unpolished grains gave: ED analysis;

MgO 3.5 A₂O₃ 1.2 Fe₂O₃ 4.4 CaO 4.4; spectrometer analysis SiO₂ 0.5 FeO 1.89 La₂O₃ 0.36 CaO 0.26 MgO 0.53 Sm₂O₃ 0.19 Dy₂O₃ 0.31 Dy₂O₃ 0.08, other REE <0.05 wt.% each, F and C₁ not detected, E 97.36. The low sum probably results from lack of polish. The term merrillite is used rather than whitlockite following the recommendations of Prewitt and Rothbard [8] as referred to the anhydrous nature of Ibitira and other eucrites.

**Olivine** - Narrow rims (~ 10μm) on some ilmenite—Ti-chromite intergrowths analyzed as Fe-rich olivine (Table 1, #8). The high TiO₂ and Cr₂O₃ may result from secondary fluorescence but because an analysis adjacent to ilmenite showed high Cr₂O₃ the olivine may really contain chromium.

4. **Discussion**

The above mineralogical features of the Ibitira eucrite, when examined in the context of data for other eucrites and howardites and for lunar samples, lead to a complex history. Perhaps the following sequence provides the simplest explanation:

(a) crystallisation of the Ibitira eucrite in a lava flow producing a variolitic texture between pyroxene and plagioclase, chromite grains, and vesicles associated with plates of tridymite, (b) prolonged annealing which yielded a hornfelsic texture, coarse exsolution of the pyroxene (but not inversion of pigeonite to hypersthene) and ordering of the plagioclase; the coarse intergrowths of ilmenite and chromite with minor Fe-metal and Fe-rich olivine probably result from reduction of primary spinel during this period; vapor deposition
probably also occurred at this time, (c) strong shock sufficient to pressure the texture of the plagioclase grains (perhaps involving local melting), but not sufficient to do more than bend or crack pyroxene grains, and (d) sufficient annealing to allow crystallization of the plagioclase as a sub-parallel mosaic and partial conversion to the low structural state. In the discussion, the evidence for this sequence will be examined in detail, especially in relation to the general features of eucrites, howardites and mesosiderites, ably summarized by Duke and Silver [7].

The simplest way to produce the rounded cavities is by presence of a gas phase, and the arguments of Wilkening and Anders [1] for CO are adopted. Shrinking during metamorphism of a glassy, porous breccia might produce holes, but does not easily explain the associated plates of tridymite. Distortion of some of the holes and tridymite plates is easily explained by deformation. Perhaps the two plates in Fig. 1a were once one continuous plate, which was broken during deformation of the central cavity from an original spherical shape. If the holes are accepted as vesicles, restrictions are placed on the solidification regime of the parent magma. Although accurate modeling is impossible, one argument by Wilkening and Anders [1] for crystallization of the Itbitira eucrite in a thin flow some meters thick seems plausible: however, particle-track data should be inapplicable because of the prolonged metamorphism. By analogy with lunar mare basalts, a surface lava flow is most obvious, but a sub-surface dyke or sill cannot be ruled out because the parent body may be small with a low gravitational gradient ($\frac{dP}{dr} = \frac{Gm}{r^2}$ at the surface where $P$ is gravitational pressure, $r$ is radius, $G$ gravitational constant, $M$ mass).

The evidence for prolonged metamorphism is overwhelming, but it is difficult to quantify the conditions. No chemical zoning was found in the pyroxenes, and the compositions of the coexisting augite and plagioclase suggest equilibration halted near 950°C based on the data of Ishii et al. [8]. Evidence presented by Takeda et al. [9] indicated that Apollo 12 and 15 mare basalts cooled in lava flows up to 10 m thick, but none of their pyroxenes show optically-visible exsolution in contrast to the relatively coarse exsolution of Itbitira pyroxenes. Unfortunately there is no evidence on the conditions under which metamorphism occurred. Perhaps the parent lava flow of the Itbitira eucrite was disrupted by impact, and the Itbitira eucrite was buried in a thick hot ejecta blanket. This would be consistent with the general evidence from howardites and eucrites [7] for brecciation and recrystallization, and indeed fragments with hornfelsic or granoblastic texture set in a fine-grained matrix occur frequently in these meteorite groups. Another possibility might be intrusion as a dyke or sill well below the surface in a planetesimal, but not too deep to prevent vesiculation. If magma near 1200°C were injected into impact breccia at (say) 950°C, rapid crystallization would occur followed by annealing from ~ 1050°C downward.

Under equilibrium, tridymite should invert to high quartz upon cooling to 880°C [10], and preservation of tridymite might be taken to imply sufficiently rapid cooling below this temperature. Quartz
was reported in six eucrites, in two of which it occurred with
troilite and one with cristobalite, whereas tridymite was reported
to occur alone in six others [summary in 7]. If this evidence were
taken to indicate that transformation of tridymite to quartz is not
kinetically inhibited, the presence of tridymite in the Ibitira eucrite
would indicate rapid cooling through 850°C. The ferro-pigeonite in
the Ibitira eucrite has not inverted to the orthorhombic variety,
again suggesting absence of prolonged metamorphism at low temperature
such as occurs in some regionally-metamorphosed rocks on Earth.
Thus it might be suggested that the Ibitira eucrite cooled slowly
down to ~ 950°C and then cooled more rapidly. However, there are
many uncertainties behind this suggestion including lack of knowledge
of kinetic factors and the possibility of inversion of tridymite
to quartz in stage (s) followed by shock melting and recrystallisation
of tridymite in stages (c) and (d). Experimental data on kinetics
of reactions in silica minerals and pyroxenes might allow quantification
of the cooling conditions for the Ibitira eucrite. In the meantime,
meaningful estimates of the physical conditions, such as the depth
or burial in a possible ejecta blanket are impossible, though one
might guess a depth nearer to 1km than 1m. The compositional and
dimensional data of Ibitira pyroxenes are almost identical to rare
pigeonite augite pairs in 14310 [11,12] suggesting some similarity
of thermal history. Furthermore the extent of exsolution in pyroxenes
from all eucrites is roughly similar (Fig. 3; [8]).

The ilmenite-Ti-chromite-metal assemblage is similar to lunar
examples where reduction or late stage re-equilibration has partially
transformed a Ti-rich spinel to a Ti-poorer spinel + ilmenite +
metal [13]. Probably the reduction occurred during the metamorphism.
Crystallisation of minerals inside the vesicles probably occurred
during the metamorphism because individual grains of chromite and
ilmenite were found in the vesicles.

The third episode, that of shock, is inferred from the relative
mineralogy of the pyroxene and plagioclase. During the prolonged
metamorphism to about 950°C revealed by the pyroxene, the
plagioclase should have transformed to a low structural state based
on extrapolation of the kinetic data summarised by Smith [14]. The
only feasible way to obtain the strange texture and the erratic
structural disorder is by shock metamorphism followed by annealing.
Pyroxene is much more resistant to shock than feldspar [15], as
evidenced by lunar fragments consisting of maskelynite and crystalline
pyroxene. Fig. 2b illustrates an extreme example of shocked
plagioclase (now maskelynite) in lunar sample 79482,5-A-15,
illustrating the preservation of a metamorphic texture although highly
shocked. Whether the Ibitira plagioclase was completely melted to
maskelynite, or only partly converted from the crystalline to glassy
state/undetermined, because a further episode of annealing occurred
to provide crystallisation or recrystallisation of the plagioclase
thereby obscuring the earlier state. This episode of annealing
must be much less pronounced than the one invoked for the exsolution
of the pyroxene. Because silica minerals and feldspar undergo
shock melting at similar pressures, the present tridymite probably
results from crystallisation of shocked silica and is not the
original tridymite even though the original platy shape is fairly well preserved. The pyroxene underwent only fracturing and rare bending without any evidence of melting or reaction with the plagioclase. Shock melting of plagioclase and bending of pyroxene suggest that the Hugoniot pressure reached about 500kbar (3 x 10^11 Pa).

How and when the shock metamorphism and subsequent annealing occurred is quite speculative. Of course, some event must be responsible for perturbation of the Ibitira meteorite into Earth-impacting orbit. However, once ejected into orbit the meteorite should cool rapidly to a very low temperature (< 100°C) by radiation loss, thereby precluding annealing in the temperature range for silicate reaction (over 800°C). This suggests that the Ibitira meteorite was shocked during an earlier event, and perhaps was annealed near the surface of a planetesimal prior to ejection into Earth orbit by a relatively mild event.

Whatever the actual details there can be no question that the Ibitira eucrite underwent a complex sequence of events, and that only a fortunate combination of such events allowed them to be disentangled from comparative mineralogy. Whether all these events occurred on one body, and whether all eucrites, howardites and mesosiderites derive from the same body is uncertain. We shall now compare the available mineralogical data to test the possibility of co-genesis, as suggested by Duke and Silver [7].

The Ibitira plagioclase is very calcic (An₂₅). This is at the calcic end of the range An₂₀₋₉₅ quoted by Duke and Silver, mainly from optical data, and is the same composition as the plagioclase in the Hoima eucrite for which detailed mineralogical data were given by Lovering [16]. The high Fe/Mg ratio in Ibitira anorthite (0.22/0.04) matches the high Fe/Mg ratio of the pyroxene (22/7) and contrasts with the more magnesian compositions of the Hoima minerals (anorthite 0.09/0.08; pyroxene 19/11). The Fe and Mg contents of both anorthites are lower than for anorthite from lunar basalts; thus for plagioclase from Apollo 15 mare basalts [17], the Fe content is ~ 0.9 wt.% vs. 0.22 and 0.09 wt.%, respectively, for Ibitira and Hoima anorthites. The obvious explanation for both eucrites is that metamorphic equilibration reduced the minor elements inferred to have been incorporated in the anorthites during original crystallization from a melt.

The Ibitira tridymite contains 25 wt.% inclusions of anorthite. This is much too high to be accounted for by exsolution, because Longhi and Hays [18] reported a maximum of 5 wt.% solution of anorthite molecule in silica minerals. Simultaneous crystallization of anorthite and tridymite followed by metamorphism provides a reasonable explanation [Longhi, pers. comm.]. Neither Duke and Silver nor Lovering reported inclusions of plagioclase in tridymite, but a systematic study would be worth-while in silica minerals from eucrites and howardites.

Fig. 4 summarizes the major elements in spinel-type phases from eucrites, and compares them with spinels from Apollo 15 basalts [19]. All the spinels from eucrites and mesosiderites lie close to a single trend from Ti-poor to Ti-rich compositions [20]. Lovering [16] reported that the chromite from Hoima eucrite is very uniform, and
Bunch and Kell [20] reported only the mean composition for chromites in eucrites and mesosiderites, but mentioned up to 86% variation (mostly in Ti) of major elements from grain to grain in the eucrites and up to 13% in the mesosiderites. Bunch and Kell also reported composition variation within single grains, and coexistence with rutile and rarely ilmenite. Reexamination of the specimens is desirable to check whether all the chemical and mineralogical variations can be ascribed to different degrees of reduction of primary single-phase spinels (which would move the composition away from ulvöspinel) or whether the compositional range is the result mainly of primary crystallization. In Ibitira, the spinel with the least Ti occurs as a bladed crystal associated with ilmenite and enclosed in tridymite, and it has the same composition as the uniform spinel in Noma; however, the pyroxenes and plagioclases are distinctly different for these two eucrites as shown earlier. Whatever the details, the spinels from all the eucrites and mesosiderites fall into a single trend with all the spinels from mesosiderites lying at the Ti-poor region of the trend. Compared to the trend for Apollo 15 basalts, the eucrite-mesosiderite trend is poorer in A\textsuperscript{3} and richer in Cr.

For Ibitira spinels, the distribution of Mg between coexisting ilmenite and spinel is monotonic and linear within experimental error. Analyses obtained by Bunch and Kell [20] for eucrites tend to lie around the trend for Ibitira, and the scatter results from averaging for grains which do not touch each other. Only one point for the four mesosiderites lies near the trend. No ilmenite was reported in the Noana eucrite, suggesting that the spinel phase had not been reduced.

The Ibitira pyroxenes fall neatly in the trend for pyroxenes from eucrites collected by Takeda et al. [21], and the Noana eucrite [16], and the trend of bulk compositions tends to lie parallel to but with lower Ca than the trend for Apollo 15 pyroxene-phric basalts [22].

Merrillite has apparently not been reported from eucrites but the occurrence in Ibitira is compositionally similar to that of whitlockite in lunar rock 14310 [23]. The vesicular texture of Ibitira and the planar growth faces on merrillite strongly suggest vapor deposits similar to those found in lunar rocks [e.g., 24]. Other indications of vapor deposits are the euhedral crystals of ilmenite, ulvöspinel and plagioclase found in rinds. These were not seen in thin-section probably because they are too fragile. Compositionally these phases do not differ from those in the bulk rock which suggests equilibration between the vapor and the bulk rock.

A remarkable feature of the Ibitira eucrite is the absence of a late-stage KREEPy residuum such as is typically found in lunar basalts. Whether this feature is common to all eucrites and howardites is not clear from the literature, but should be checked carefully. It is consistent with the low content of large-ion-lithophile elements reported in bulk analyses of eucrites, and is one argument in favor of derivation of eucrites from an environment other than the Moon. The compositions of the metal and sulphide in the Ibitira and Noana eucrites fall in the range of those in
lunar basalts, and are consistent with presence of a late-stage, 
3-bearing, reducing vapor in all specimens.

There is a general tendency in the literature to explain the 
eucrite, howardite, diogenite and mesosiderite meteorites in terms 
of processes occurring in only one parent body. This is certainly 
the simplest assumption, but may be unwarranted. Furthermore there 
is a tendency to attempt interpretation of the mineralogy and 
petrology in terms of one trend of crystal-liquid differentiation 
(e.g. [25,26]), and the chemistry in terms of one sequence of 
separation processes (e.g. [27]). These approaches are undoubtedly 
stimulating, but require some critical examination in the context of 
detailed mineralogical, petrological and chemical studies of all 
the above groups of meteorites on the level of examination of lunar 
samples. To raise just one question: why is there no significant 
Eu anomaly for the Ibitira and Juvinas eucrites [1] when the Fe-rich 
nature of their pyroxenes would indicate that they originated late 
in a crystal-liquid fractionation series after substantial amounts of 
plagioclase should have crystallized? There is no sense in an exhaustive 
discussion here of all the possible alternatives, and we conclude by 
re-emphasizing the problems with respect to interpretation of the 
petrogenesis, chemistry and particle tr.m.s when there is so much 
evidence for complex, prolonged metamorphism associated with volatile 
movement and reduction.

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### TABLE 1. Ibitira pyroxene and olivine analyses

<table>
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<tr>
<th>Low-Ca Pyroxene</th>
<th>High-Ca Pyroxene</th>
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\*Values high due to secondary fluorescence of Cr-ulvöspinel.

### TABLE 2. Ibitira Ti-chromite and ilmenite analyses.

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<th>Ti-chromite</th>
<th>(1a)</th>
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\*a and b denote coexistence in same intergrowths. Analyses 7 and 8 are from separate grains. Analyses 9 is average chromite in Naam [16]; total includes 0.57 V₂O₃.
FIGURE CAPTIONS

Fig. 1  Textures in Ibitira eucrite.
(a) This 8 x 1.5mm montage taken in plain light shows three cavities now filled with epoxy. The texture is dominated by pyroxene (grey) with fine exsolution lamellae just at the limit of optical resolution. White areas are plagioclase and the black area at lower left is chromite-ilmenite intergrowth with pyroxene inclusions. Particularly emphasized are four laths with irregular boundaries outlined in ink for clarity. These are interpreted as sections of two plates of tridymite with plagioclase inclusions; see text for suggestion that they once formed one plate.
(b) Plagioclase "lath" with pyroxene inclusions and irregular boundary with pyroxene grains. Black areas are chromite-ilmenite intergrowths. The speckled irregular lath pointing NW from the middle of the right-hand edge is tridymite with plagioclase inclusions. Plain light, 1.1mm wide.
(c) Central part of plagioclase "lath" at high magnification and under crossed polars. 0.15mm wide.

Fig. 2  Textures in Ibitira eucrite and lunar soil fragment.
(a) The speckled lath is tridymite containing drop-like inclusions of anorthite. Grey grains with lamellae are pyroxene: note curvature of some lamellae especially near the arrow. Clear grains are anorthite. Plain light, 0.4mm wide.
(b) Lunar soil fragment 76482,5-A-15 showing euhedral maskelynite (light grey with speckling from epoxy in thin section), pyroxene (dark grey) and opaque phases. Plain light, 0.5mm wide.

Fig. 2 (continued)
(c) Intergrowth of Ti-chromite and ilmenite (both light grey) showing subhedral outline against pyroxene (dark grey) and containing pyroxene inclusions. Reflected light, 0.5mm wide.
(d) and (e) Cr and Ti X-ray scanning images (Kα radiation) of intergrown Ti-chromite and ilmenite. Absence of both Cr and Ti identifies areas of sub-rounded pyroxene inclusions, while absence of just Cr identifies ilmenite. 0.25mm wide.

Fig. 3  Pyroxene compositions for representative eucrites. Bulk compositions are shown by solid symbols and exsolved phases by open symbols. Actual samples usually showed some variation and low-Ca compositions may be too high in Ca because of overlap and fluorescence. Samples labeled by (1) and (3) are from [21], and (2) from [16]. General crystallization trend of Apollo 15 pyroxene-phyric basalts [22] is shown for comparison.

Fig. 4  Mg in ilmenite vs. Mg in coexisting Ti-chromite calculated for 12 oxygen units. Data for other eucrites and mesosiderites from [20].

Fig. 5  Spinel-phase compositions in Ibitira compared to those in other eucrites and mesosiderites, and from compositionally similar Apollo 15 basalts. Meteoric and lunar data define similar near-linear trends with nearly constant Cr/AI. Note tendency for most meteoritic specimens to have low Ti. Data for Mauna from [16], other meteorites from [20], and lunar trend from [19].