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Twinning and intergrowth of olivine crystals in chondritic meteorites

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SUMMARY. The angular relationships among sets of olivine plates in barred chondrules were investigated on the universal stage to test a suggestion that such chondrules represent exsolution and inversion from a pre-existing jadeitic pyroxene. In one of sixty-seven cases studied, adjacent plates represent olivine twinning on (100); the others vary randomly and correspond to neither olivine nor pyroxene twinning. On this basis and from other evidence, we conclude that the mineralogy and texture of barred chondrules are primary and due to rapid crystallization of ultrabasic magma in a low-pressure environment.

OF the many and varied types of chondrules found in chondritic meteorites, the most bizarre are those that consist of optically parallel plates of olivine separated by a glassy, microcrystalline, or (in the more severely metamorphosed stones) crystalline groundmass. In some cases (fig. 1) a single set of plates is present; in others (fig. 2), two or more sets are present. Intergrowths of five or more sets are by no means rare.

Chondrules of this type, variously termed 'barred' or 'graticulate', comprise roughly a tenth of the chondrules in a given ordinary chondrite (Dodd and Teleky, 1967). Although they are usually discussed as a distinct class, two lines of evidence suggest that they are genetically related to the microporphyritic chondrules: they commonly occur as inclusions in such chondrules, and the phenocrysts in such chondrules occasionally have barred forms (fig. 3).

The common occurrence of two or more sets of olivine plates in barred chondrules raises the question: What governs the orientation of these plates? Twinning is one possibility. A second is that the different sets of plates simply represent skeletal growth from several nucleii. Both of these possibilities are consistent with rapid crystallization of the chondrules, which is also suggested by the small sizes of crystals, the presence of a fine-grained to glassy mesostasis, and the Fe–Mg zoning and high calcium contents of the olivine crystals (Dodd, 1968 and 1969).

LeBas (1966) has suggested a third interpretation of barred chondrules, namely that they represent a complex sequence of inversion and exsolution from a pre-existing jadeitic pyroxene. The basis for this suggestion is the resemblance of some complex barred chondrules to hourglass and herringbone-twinned clinopyroxenes, and a major implication is that some or all chondritic material experienced very high pressures early in its development. A high-pressure history has been suggested before

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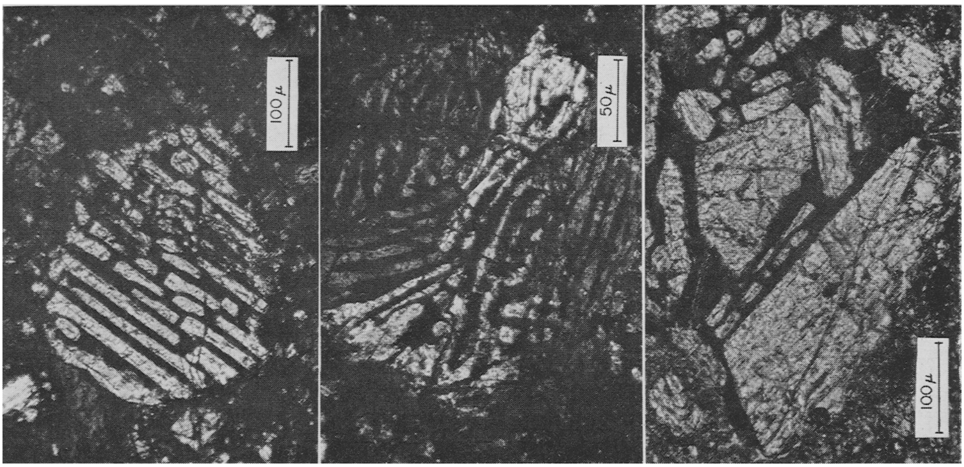
(Fermor, 1913) but does not appear in recent discussions of chondrule origin. It is therefore important to seek evidence to support or discourage LeBas's view.

Twinning of either olivine or a pre-existing clinopyroxene should be manifest in the orientations of plates in complexly barred chondrules. The authors therefore performed universal stage measurements on sixty-seven pairs of olivine plates in



FIGS. 1 to 3: FIG. 1 (left). Photomicrograph (crossed nicols) of a barred olivine chondrule in the Barratta chondrite (type 4). The groundmass is glassy. FIG. 2 (middle). Photomicrograph (crossed nicols) of a barred olivine chondrule in the Yonozu chondrite (type 4, 5). FIG. 3 (right). Platy microphenocrysts in a microporphyritic chondrule of the Khohar (type 3) meteorite (ordinary light).

twenty-five barred chondrules.[1] As a control, we also sought twinned olivine crystals in fifty microporphyritic chondrules. Measurements were made on a Leitz 5-axis universal stage, using hemispheres with a refractive index of 1·516 to simplify tilt corrections (Munro, 1963) and the procedure of Emmons (1943) to make these corrections. Stereographic plots were used to determine the angular relations among intergrown olivine crystals.

Because olivine crystals in the chondrites are commonly fractured and display mosaic extinction, the universal stage measurements are less precise than one might wish. However, repeated measurements of the orientation of a single crystal suggest a precision of ± 2 to 3° for all but the least favourable cases.

The angular relations for types of twinning known to occur in terrestrial olivines are summarized in fig. 4. Diligent search in fifty microporphyritic chondrules revealed only eight twins: two according to (011), three according to (012), and three according to (100). The rare (031) twin (Burri, 1935) was not observed. Inasmuch as the chondrules examined contain collectively several thousand crystals, it must be concluded that twinning is uncommon among chondritic olivines.

The results of our examination of sixty-seven pairs of plates in barred chondrules

[1] Chondrites examined include Arriba (L–5), Barratta (L–4), Selma (H–4), Khohar (L–3), Taiban (L–5), McKinney (L–4), and Yonozu (H–4, 5).

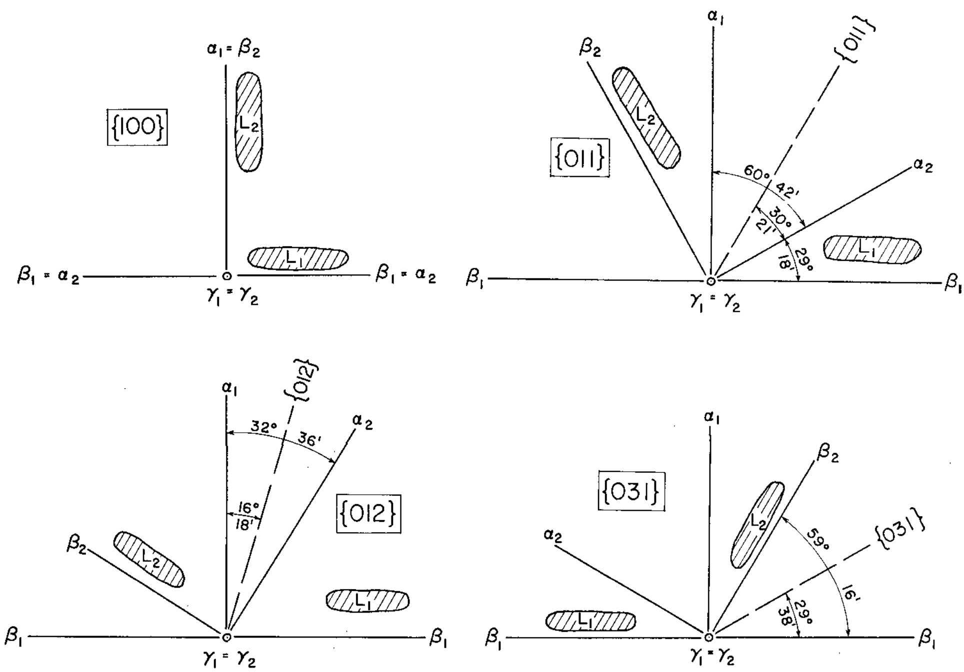


FIG. 4. Angular relationships for olivine (Fa_{20}) twinned according to the four known olivine twin laws. α, β, and γ refer to crystallographic directions, and L refers to the shape orientation of olivine plates in each set. Subscripts identify the two sets of plates in each diagram.

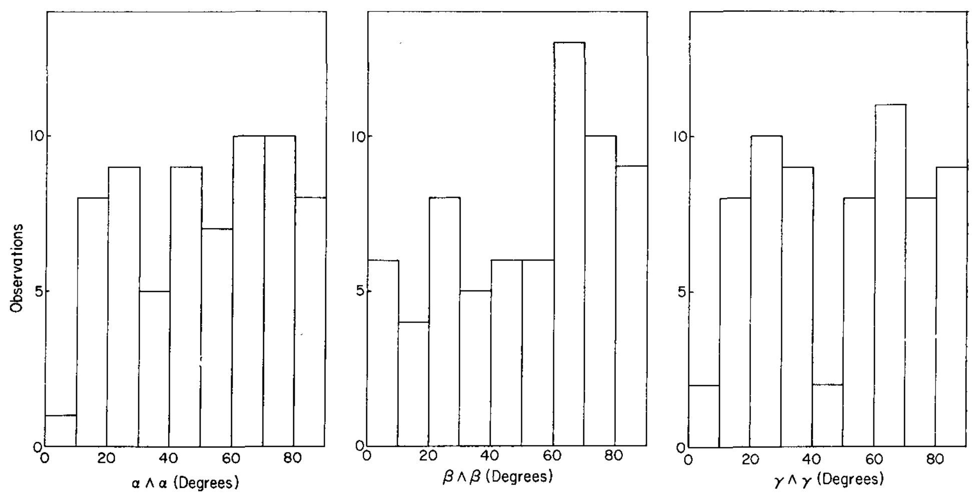


FIG. 5. Inter-axial angles between associated sets of olivine plates in barred chondrules.

are summarized in fig. 5. Although all known olivine twin laws have γ as a common axis, only one of the pairs studied shows this relationship. The angular relations of the other axes in this pair are appropriate to twinning on (100). In the other sixty-six pairs, the γ axes do not coincide, nor is there any consistent angular relationship between these axes or the others. It is clear that plates in complex barred chondrules are but rarely related by olivine twinning.

The case for twinning in a pre-existing pyroxene is also weakened by fig. 5. Although it is not clear exactly what angular relations would result from the series of transformations needed to form barred olivines from twinned jadeitic pyroxenes, it is reasonable to expect consistency rather than the essentially random variation observed here. Our data do not support the thesis that barred chondrules have developed from jadeitic pyroxene, and in view of the lack of experimental or empirical verification of the process suggested by LeBas (1966), we prefer the view that barred chondrules are due to directed growth of olivine during rapid crystallization of ultrabasic magma, and that the occurrence of more than one set of olivine plates reflects growth from more than one nucleus or, in rare cases, twinning. This interpretation is consistent with the fact that olivine similar in form to that in barred chondrules is commonly found both in the margins of hypabyssal basic to ultrabasic sheets and in rapidly crystallized experimental melts (Drever and Johnston, 1957).

The remaining evidence suggestive of high pressures during the formation of chondrules—namely Fermor's observation that excentroradial pyroxene chondrules commonly appear to be faceted and thus somewhat resemble garnets (Fermor, 1913; LeBas, 1966)—is questionable. In our experience, faceting of such chondrules occurs only in those chondrites that have experienced appreciable recrystallization (petrologic types 4 to 6 in the classification of Van Schmus and Wood, 1967). Similar chondrules in the weakly metamorphosed type 3 chondrites are spherical, sometimes with rounded indentations suggestive of impact while they were still plastic. It appears that faceting of radial chondrules is due to recrystallization and says nothing about the pre-metamorphic history of chondrules.

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REFERENCES

BURRI (C.), 1935. *Min. Petr. Mitt.* **15**, 160.
DODD (R. T.), 1968. *Geochimica Acta*, **32**, 1111.
—— 1969. Ibid. **33**, 161.
—— and TELEKY (L. S.), 1967. *Icarus*, **6**, 407.
DREVER (H. I.) and JOHNSTON (R.), 1957. *Trans. Roy. Soc. Edinburgh*, **63**, 289.
EMMONS (R. C.), 1943. *The Universal Stage. Geol. Soc. Amer. Mem.* **8**.
FERMOR (L. L.), 1913. *Journ. Proc. Asiatic Soc. Bengal*, **8**, 315.
LEBAS (M. J.), 1966. *Nature*, **211**, 1355.
MUNRO (M.), 1963. *Amer. Min.* **48**, 308.
VAN SCHMUS (W. R.) and WOOD (J. A.), 1967. *Geochimica Acta*, **31**, 747.

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