An exceptionally large chondrule in the Parnallee meteorite

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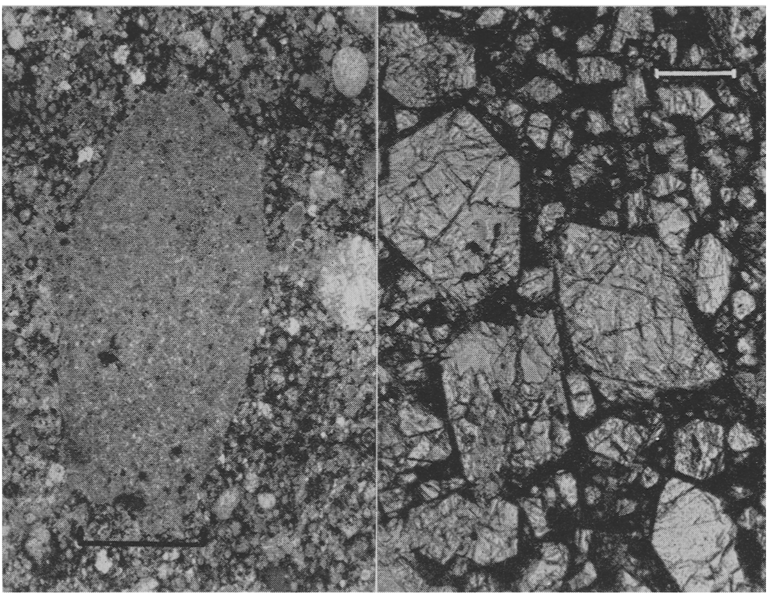
Summary. A giant chondrule, nearly 4 cm in diameter, has been found in the Parnallee meteorite, and is described, with analysis. An estimate of the composition of the partly devitrified groundmass falls within the known compositional range of chondrule glasses. The bulk composition of the chondrule is very close to the bulk composition of the meteorite excluding metal and sulphide.

SECTIONS sawn across the 134-lb. Parnallee meteorite (B.M. 34792) have disclosed an ellipsoidal stony object some $4{\cdot}0 \times 3{\cdot}6 \times 1{\cdot}6$ cm in size. This was initially interpreted as a foreign inclusion or xenolith, but further study has shown it to be a giant equivalent of certain normal-sized chondrules commonly encountered in the stone. As such, it is one of the largest chondrules known, and its exceptional size has permitted the first chemical analysis of a chondrule by conventional methods (table I).

The over-all colour of this chondrule is medium grey, but with a speckled appearance arising from the presence of abundant light-grey olivine crystals (fig. 1). On a megascopic scale its sharply defined margin is well rounded, except at one end where there is a small subangular projection. Microscopically it shows a porphyritic texture of distinctly igneous aspect, with stout euhedral olivine crystals, from 0·5 to 0·02 mm in length, set in a groundmass of pale-brown isotropic glass (fig. 2). The glass also contains subhedral chromite granules about 10 μ across, and tiny acicular crystallites of clinopyroxene with 45° maximum extinction angles. A few irregularly shaped particles of a fine spongy intergrowth between troilite and taenite or kamacite, ranging from 0·05 to 2 mm in size, are scattered throughout the chondrule. The latter are possibly replacement products rather than original constituents.

An electron-microprobe study established that the larger olivine phenocrysts in this chondrule are compositionally zoned, from cores containing 16–20 mol % fayalite to rims with 22–25 mol % fayalite. The smallest olivine crystals are relatively homogeneous, containing between 27 and 30 mol % fayalite, and intermediate-sized phenocrysts are zoned with compositions part way between the above extremes. These data, which are consistent with the gradually increasing iron



FIGS. 1 and 2: FIG. 1 (left). Photograph of a sawn surface on the Parnallee meteorite, showing the exceptionally large chondrule. Scale bar 1 cm. FIG. 2 (right). Photomicrograph of portion of the large chondrule, showing variously sized euhedral olivine phenocrysts set in a partly devitrified glassy groundmass. The scale bar is 0·1 mm long.

content expected during crystallization of olivine from a melt with the composition of the Parnallee chondrule, under conditions where cooling was sufficiently rapid to prevent continuous reaction between liquid and precipitant, tend to endorse the igneous character of this body. The higher iron contents of the smallest olivine crystals, by comparison with the rims on large phenocrysts, suggest increasing undercooling and nucleation as crystallization proceeded, the undercooling evidently becoming so severe that the final liquid residuum chilled to a glass.

A preliminary estimate for the composition of the residual liquid—now represented by the chondrule groundmass—was obtained by subtracting all normative olivine from the bulk analysis of the chondrule, assuming this to occur modally as phenocrysts. The resulting calculation (column 4 of table I) indicates high normative plagioclase and clinopyroxene contents, with a little normative orthoclase and nepheline. However, electron-probe determinations of Si, Fe, and Mg in portions of the glass free from clinopyroxene microlites revealed SiO_2 contents varying from 54 to 63 wt. % (average 57 %), FeO from 9 to 5 % (average 6·5 %), and MgO from 10 to 3 % (average 5·5 %). It therefore appears that some normative iron-rich olivine is actually contained in the glass. An appropriately corrected composition for the partly devitrified chondrule groundmass is given in column 4*a* of table I. This falls within the known compositional range of fresh and devitrified chondrule glasses, which are characteristically rich in normative plagioclase (Fredriksson and Reid, 1965; Reid and Fredriksson, 1967).

The high calcium content of the groundmass in the Parnallee chondrule presumably accounts for the abundance of clinopyroxene microlites in the glass. These have the appearance of quench products, but may alternatively have formed by devitrification during a later phase of very mild recrystallization (which, however, was not of sufficient intensity to wholly equilibrate this stone, cf. Dodd, Van Schmus, and Koffman, 1967). Although it might arise from a minor analytical error (e.g. in Na_2O), the small normative nepheline content of the Parnallee groundmass is noteworthy in so far as this mineral is not a known crystalline phase in meteorites. Nepheline-normative chondrule glasses have been reported from the Chainpur meteorite (Reid and Fredriksson, 1967), and may also occur in other primitive or unequilibrated chondrites, but it is probable that in recrystallized or equilibrated chondrites any former undersaturated glass would have reacted with lime-poor pyroxene from adjacent chondrules to form, *inter alia*, olivine and sodic plagioclase rather than nepheline.

Within the large Parnallee chondrule there is no chilled zone or other textural abnormality near its border, although in places it is surrounded by a narrow glassy selvage, indented by adjacent chondrules, or by a rim of spongy troilite, clearly added to the large chondrule *after* it originally formed. Euhedral olivine phenocrysts are abruptly broken away at the chondrule margin, which in thin section is somewhat jagged. Numerous smaller chondrules, with similar mineralogy, texture, and compositional variation in their olivine phenocrysts, occur in the main portion of the stone. These are typically more irregular in outline than chondrules with excentro-radial, fibrous, barred, or hyaline textures, i.e. than

TABLE I. Chemical composition of a large chondrule in the Parnallee meteorite (BM 34792), compared with the bulk of the meteorite; also calculated composition of the residual liquid represented by the glassy groundmass of the chondrule

	1
Fe	0·90
Ni	0·11
Co	0·007
FeS	0·5
$(Fe, Ni)_3P$	0·1
SiO_2	40·8
TiO_2	0·13
Al_2O_3	3·60
Cr_2O_3	0·23
FeO	20·0
MnO	0·39
MgO	28·4
CaO	2·40
Na_2O	1·31
K_2O	0·18
P_2O_5	0·12
C	0·1
Total	99·3
Sp. gr.	3·35

	1*a*
Metal	1·0
Troilite	0·5
Schreibersite	0·1
Graphite	0·1
Feldspar Or	1·1
Feldspar Ab	8·8
Feldspar An	3·4
Nepheline	1·3
Diopside (ferroan)	6·3
Olivine Fo	48·7
Olivine Fa	27·2
Ilmenite	0·2
Chromite	0·3
Apatite	0·3
Total	99·3
Fe/(Fe+Mg+Mn) in normative femics	27·9 %
An in normative plagioclase	26·9 %

	2	3
SiO_2	41·9	45·7
TiO_2	0·1	0·2
Al_2O_3	3·7	2·9
Cr_2O_3	0·2	0·7
FeO	20·5	17·6
MnO	0·4	0·4
MgO	29·1	29·3
CaO	2·5	1·8
Na_2O	1·3	1·0
K_2O	0·2	0·1
P_2O_5	0·1	0·3
	100·0	100·0

	4	4*a*
SiO_2	58·0	55·9
Al_2O_3	17·3	15·8
FeO	2·7	6·5
MgO	3·9	5·5
CaO	10·8	9·8
Na_2O	6·3	5·7
K_2O	0·9	0·8
	99·9	100·0
Norm		
Or	5·1	4·6
Ab	42·2	38·4
An	16·5	15·0
Ne	6·0	5·5
Di	30·2	27·5
Ol	—	9·0
	100·0	100·0

Analyst: A. J. Easton, British Museum (Natural History).

Metal, sulphide, and phosphide were separated by the chlorination technique (Moss, Hey, Elliott, and Easton, 1967). Schreibersite assumed to contain 20 % Ni. Sulphide portion includes 390 ppm Ca, 30 ppm Ti.

1. Analysis, and 1*a*, norm of the large chondrule.

2. Lithophile constituents of the large chondrule, recalculated to 100 %.

3. Lithophile constituents of the Parnallee chondrite, recalculated to 100 % from a bulk analysis of the stone (Dodd, Van Schmus, and Koffman, 1967).

4. Composition of the residual liquid, calculated by excluding olivine from normative silicates in the chondrule, and assigning chromium and phosphorus to chromite and apatite.

4*a*. Recalculated from 4, adding 9·0 % normative olivine (Fa_{55}) to bring the composition into conformity with electron-probe data.

chondrules of the kind thought to have crystallized rapidly from independent liquid droplets. It seems that the microporphyritic chondrules are fragments from some larger body, which crystallized from a molten state before being disrupted and mixed with other kinds of chondrule, and with metal and troilite, to form the stone. In this respect it may be argued that the large fragment described here should not be called a chondrule, although there is certain justification for doing so in the precedent set by other meteorite petrographers, who almost unanimously describe as chondrules the smaller microporphyritic bodies with phenocrysts of olivine or pyroxene or both. Broken chondrules with excentro-radial, etc., textures are by no means uncommon in chondrites, a feature which suggests that fragmentation, possibly accompanied by attrition, was an integral part of the process or processes responsible for chondrule formation and accumulation. Furthermore, a close genetic relationship between microporphyritic bodies and other types of chondrule is implied by the well-known chondrule-within-chondrule structures, for example the barred olivine chondrule enclosed by a larger microporphyritic olivine chondrule in the Dhurmsala meteorite (Tschermak, 1885, Tafel VIII, Fig. 1). Provided due attention is paid to their fragmental nature, there appears no necessity to discontinue applying the term 'chondrule' to these microporphyritic particles.

The bulk composition of the large Parnallee chondrule, neglecting its small metal and troilite content, is remarkably similar to that of the lithophile constituents (silicate, phosphate, and oxide) in the stone as a whole (table I). The most significant difference is in silica content, which is higher in the stone due to the presence of calcium-poor pyroxene in other chondrules. Nevertheless, the comparison is sufficiently close to suggest the possibility of this chondrule crystallizing from a liquid representing approximately the lithophile material that might have been mixed with metal and troilite from elsewhere to form the Parnallee meteorite. However, any hypothesis involving accumulation of material from two or more different sources fails to explain a number of fundamental chemical relationships in chondritic meteorites as a whole, for instance, the comparatively uniform oxidation state and abundance of iron within particular classes, and Prior's rules governing the grosser aspects of chemical variation between different classes. Moreover, if the large chondrule did form from a liquid that was parental to the lithophile portion of Parnallee, one is confronted by the problem of deriving from it by some differentiation process the many other kinds of chondrule found in the meteorite. Until further information is available on the compositional differences between the various textural kinds of chondrule in this and other stones, it is perhaps most wise to regard as fortuitous the chemical similarity discussed above.

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