minsky (1948) has reported the mineral from Falls Church, Virginia. Fleischer and Faust (1963) report the mineral in Virginia but give no specific localities.

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THE AMERICAN MINERALOGIST, VOL. 52, SEPTEMBER–OCTOBER, 1967

OLIVINE IN ENSTATITE CHONDRITES

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Although abundant in chondritic meteorites belonging to the more common classes, olivine has hitherto been considered absent from enstatite chondrites. In a recent review of the mineralogy, chemistry, and structure of this latter group Mason (1966) noted that many stones, having orthorhombic enstatite and sodic plagioclase as their main silicate constituents, possess granular recrystallized textures. He also drew attention to the slight excess of silica over magnesia and other basic oxides revealed by chemical analyses. A new investigation of thoroughly recrystallized enstatite chondrites represented in the British Museum (Natural History) collection, London, has shown that all but one contain accessory tridymite. The exception, *Blithfield,* has small amounts of cristobalite. Under these circumstances, olivine would not be expected to occur had equilibrium been attained during recrystallization.

Three enstatite chondrites in the British Museum collection may be classified texturally as Primitive Group (Binns, 1967) or Type 4 (Van

Schmus and Wood, 1967) chondrites. They differ from the others by having well-developed chondritic textures with little or no evidence of recrystallization. Their dominant pyroxene is clinoenstatite (probably inverted protoenstatite, see legend to Fig. 1), most chondrules being composed almost entirely of this mineral. Two of the three contain small amounts of pale violet-brown chondrule glass. Forsteritic olivine has

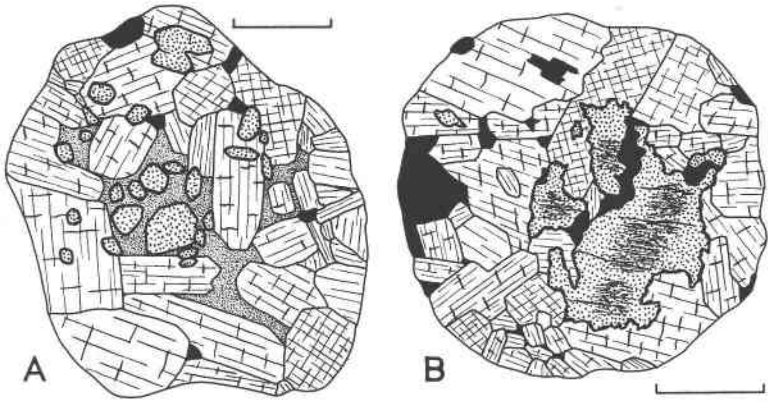

FIG. 1. Sketches from thin sections of two olivine-bearing chondrules in the Kota Kota meteorite (BM1905, 355)

A. Pale violet-brown glass (finely stippled) forms a groundmass to subhedral or rounded olivines (heavily outlined and stippled) and prismatic clinoenstatites (showing cleavage and partings). Opaque particles include kamacite and troilite. Olivine also occurs as inclusions within clinoenstatite (left). Its polysynthetic twinning, subhedral orthorhombic morphology (commonly with concave terminal faces, *cf.* Dallwitz, Green and Thompson, 1966), and irregular parting normal to *c* axes, suggest that the clinoenstatite has inverted from protoenstatite. The scale bar is 0.1 mm long.

B. Olivine grains with very fritted margins and cloudy cores, surrounded by clinoenstatite in a large chondrule. All the olivine, including the shred at the far upper left, has parallel orientation. The opaque grains are mainly kamacite. The scale bar is 0.5 mm long.

been identified optically in all three and by electron probe in two. It occurs most abundantly in *Kota Kota* (roughly 0.1 percent of the stone), but is scarce in *South Oman* and very rare in *Indarch*. Each stone also contains small amounts of one or more of the silica polymorphs. *Kota Kota* and *South Oman* both possess quartz, tridymite, and cristobalite (identified optically and by X-ray powder photography in low density fractions separated from crushed samples), but only tridymite was recognized in Indarch. A detailed investigation of the distribution of these polymorphs has yet to be undertaken, but a preliminary study showed that cristobalite occurs mainly in opaque-rich chondrules, tridymite is associated with clinoenstatite in barred or radiating rather than microporphyritic chondrules, and quartz is largely restricted to the interchondrule mesostases.

Four independent lines of mineralogical evidence denote the overall disequilibrium character of these three enstatite chondrites as compared with their recrystallized analogues; (1) the unstable coexistence of olivine

TABLE 1. ELECTRON PROBE ANALYSES OF OLIVINE IN TWO ENSTATITE CHONDRITES

	Wt. %				Mol. % fayalite
	SiO_2	MgO	FeO	Total	
Indarch (BM 86948)					
1	44.1	57.7	0.4	102.2	0.4
2	42.6	58.7	0.3	101.6	0.3
3	43.9	58.7	0.5	103.1	0.5
Average	43.5	58.4	0.4	102.3	0.4
Kota Kota (BM 1905, 355)					
1	42.4	55.8	0.9	99.1	0.9
2	43.2	58.5	0.9	102.6	0.9
3	44.3	57.9	1.0	103.2	1.0
4	44.4	57.2	0.9	102.5	0.9
5	44.2	55.2	0.9	100.3	0.9
6	43.8	55.8	0.9	100.5	0.9
7	44.7	55.7	0.7	101.1	0.7
8	44.4	55.3	1.0	100.7	1.0
9	41.8	56.1	0.3	98.2	0.3
10	41.8	54.4	1.9	98.1	1.9
11	41.7	55.6	0.2	97.5	0.2
12	42.7	57.0	0.3	100.0	0.3
Average	43.3	56.2	0.8	100.3	0.8

Electron probe analyses by S. J. B. Reed and R. A. Binns, using analysed olivine standards. Imperfect totals probably arise from variable surface and coating effects.

with silica polymorphs (2) the association of three different polymorphs of silica in *Kota Kota* and *South Oman*, (3) the compositionally zoned character of their constituent olivines, as revealed by electron probe microanalyses for *Kota Kota* and *Indarch* (Table 1), and (4) an anomalous distribution of ferrous iron between coexisting olivine and pyroxene (see below). A corresponding relationship between disequilibrium character and lack of recrystallization is now well established for the olivine-bronzite and olivine-hypersthene chondrite classes (Dodd and Van Schmus, 1965; Dodd, Van Schmus and Koffman, 1967).

In the three enstatite chondrites under discussion olivine mostly occurs as small anhedral grains (up to 20 μ in size) surrounded by clinoenstatite, in chondrules composed largely of prismatic pyroxene. Separate grains, even within different clinoenstatites from the one chondrule, commonly have the same optical orientation, suggesting that larger olivine crystals were almost completely resorbed before becoming enclosed by clinoenstatite. In *Kota Kota* and *South Oman* olivine also occurs in microporphyritic clinoenstatite-bearing chondrules that contain fresh, pale violet-brown glass or finely devitrified glass. Here the glass forms a groundmass to subhedral or embayed olivine grains (5 to 200 microns across) towards the centre of the chondrule, while the chondrule margins are marked by closely-packed clinoenstatites (Fig. 1A). A third mode of occurrence, observed only in *Kota Kota*, is as larger, highly resorbed grains entirely surrounded by clinoenstatite crystals (*cf.* Fig. 1B, which illustrates the largest such olivine grain encountered). Finally, a rare type of olivine-bearing chondrule, also seen only in *Kota Kota*, contains as much as 40 percent of small to moderately-sized olivine grains (up to 0.3 mm) with very fritted margins. These are surrounded by fibrous aggregates of clinoenstatite rather than by stout pyroxene prisms. The cores of larger olivine grains in the two latter kinds of chondrule are commonly clouded by tiny rod-like inclusions (of glass?).

The textural and mineralogical relationships in these olivine-bearing chondrules are readily explained in terms of experimental crystallization studies in the system MgO-SiO_2 (Bowen and Andersen, 1914), thereby favouring a molten droplet origin for the chondrules. Each chondrule represents a separate system with approximately metasilicate composition, although some are slightly oversaturated and others slightly undersaturated in silica with respect to enstatite (*i.e.*, oversilicated or undersilicated in the sense of Bowen and Schairer, 1935). Except in the case of substantial oversaturation olivine will be the first precipitant from a liquid of such composition, but as crystallization proceeds it will react with the liquid, becoming resorbed while pyroxene (protoenstatite) is formed. Olivine will be retained in the final product either if the cooling rate was sufficiently rapid to prevent its complete resorption, as may be the case in the glass-bearing chondrules, or if the initial liquid was undersilicated, as seems more likely in the majority of chondrules composed only of olivine and clinoenstatite.

Were cooling sufficiently rapid to prevent reaction of early-formed forsterite with the liquid, chondrules of overall metasilicate composition could crystallize to an unstable assemblage of olivine, pyroxene, and cristobalite. Several chondrules in *South Oman* and *Kota Kota* contain olivine, clinoenstatite, and a little colorless material showing low refractive indices and birefringence. However the identity of the latter constituent was not definitely established; it might be sodic plagioclase or roedderite (*q.v.* Fuchs, Frondel and Klein, 1966) rather than cristobalite or tridymite.

The ferrosilite and fayalite contents of the pyroxenes and olivines in enstatite chondrites are so small that the above chondrule crystallization behaviours will not be substantially affected by presence of iron. In the relevant portion of the system MgO-FeO-SiO_2, experimental studies by Bowen and Schairer (1935) demonstrated that early-formed olivines are more magnesian than the melts from which they separate but that, if equilibrium is maintained throughout, their fayalite contents steadily increase so that when the liquid enters the field of olivine resorption they are more iron-rich than the pyroxenes with which they coexist. An electron probe study of clinoenstatite phenocrysts in olivine-bearing chondrules from *Kota Kota* revealed an average ferrosilite content of 1.1 mole percent, with little variation. Most clinoenstatites in Indarch contain 1.5 mole percent ferrosilite, but a few range between 0.4 and 2.5 mole percent ferrosilite. On the whole, the pyroxenes are richer in iron than the olivines, which average 0.8 and 0.4 mole percent fayalite respectively in the two stones (Table 1), so the two minerals do not represent an equilibrium assemblage. The compositional differences, however, are compatible with textural indications that in most chondrules the olivines crystallized first, but were incompletely resorbed, probably as a consequence of rapid cooling, when pyroxenes commenced to form.

No information is available on the composition of primary chondrule glass in enstatite chondrites, but comparison with data on *Chainpur* glass (Fredriksson and Reid, 1965) suggests that normative albite might form a substantial component. Investigation of the synthetic system albiteforsterite-silica (Schairer and Yoder, 1960) shows that, for the likely composition of olivine-bearing chondrules containing fresh or devitrified glass in *Kota Kota* and *South Oman*, olivine will continue to be the first precipitating phase and will retain a reaction relationship with the liquid. In chondrules of the kind illustrated in Fig. 1A, such reaction is suggested by the rounded or embayed olivine inclusions in marginal clinoenstatites, but is not so apparent at the chondrule centres. This is perhaps an indication of a peculiar cooling history.

Olivine was tentatively identified in the early descriptions of two enstatite chondrites, *Adhi Kot* (Hobson, 1927) and *St. Marks* (Klein, in Cohen, 1906). The former is a chondrule-poor clinoenstatite-bearing chondrite of unrecrystallized aspect and in terms of the above discussion could conceivably possess forsterite, but the latter contains quartz and has suffered sufficient recrystallization to convert its pyroxene to the orthorhombic variety, so that forsterite would be unexpected. Olivine was not recognized by the writer in either stone during microscopic examination of material in the United States National Museum and the British Museum.

ACKNOWLEDGEMENTS

This work was carried out in the Department of Mineralogy, British Museum (Natural History), London. Thanks are extended to Dr. S. J. B. Reed for his assistance with electron probe analyses, to Dr. S. O. Agrell, who kindly provided material from the South Oman meteorite, and to Dr. Brian Mason who read the manuscript.

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THE AMERICAN MINERALOGIST, VOL. 52, SEPTEMBER-OCTOBER, 1967

GROWTH OF BERYL FROM MOLTEN SALT SOLUTIONS

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INTRODUCTION

Single crystals of beryl, $Be_3Al_2Si_6O_{18}$ are of interest for physical and optical studies, microwave maser devices, gemstones and other applications. A variety of techniques have been described for the growth of beryl