On Gem Orthopyroxenes: Enstatite and Bronzite

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Introduction

Enstatite and hypersthene are members of an isomorphous series of orthorhombic pyroxenes. The pure end members of the series are enstatite, $MgSiO_3$ and orthoferrosilite, $Fe^{+2}SiO_3$. Iron and magnesium substitute mutually between $Mg_{100}Fe^{+2}{}_0$ and about $Mg_{10}Fe^{+2}{}_{90}$ (Deer *et al.*, 1963). Although petrologists have subdivided this series into 6 subspecies *(Table I)*, the practicing gemologist is primarily concerned with only the magnesium-rich members which yield some attractive gems. Adopting the classification used by Deer *et al.* (1963), enstatite is designated as a member of the series having 88% to

TABLE I
NOMENCLATURE OF THE ORTHOPYROXENES

enstatite	$En_{100}Fs_0$	to	$En_{88}Fs_{12}$	FeO $<$ 6.50%
bronzite	$En_{88}Fs_{12}$	to	$En_{70}Fs_{30}$	FeO $>$ 6.50%
hypersthene	$En_{70}Fs_{30}$	to	$En_{50}Fs_{50}$	FeO $>$ 16.32%
ferrohypersthene	$En_{50}Fs_{50}$	to	$En_{30}Fs_{70}$	FeO $>$ 27.23%
eolite	$En_{30}Fs_{70}$	to	$En_{12}Fs_{88}$	FeO $>$ 38.12%
orthoferrosilite	$En_{12}Fs_{88}$	to	En_0Fs_{100}	FeO $>$ 47.92%

En—Enstatite member
Fs—Orthoferrosilite member

100% of the magnesium end member; bronzite having 70% to 88% of the magnesium end member and hypersthene between 50% and 70% of the magnesium end member. Members of the series with Fe > Mg are usually opaque and of little gemological interest. It should be noted that meteoriticists use a slightly different classification wherein the enstatite-bronzite border is at 10% of the iron end member and the bronzite-hypersthene border is at 30% of the iron end member (Mason, 1962). Although this system aids in the classification of the chondrule meteorites, gem enstatites are best designated by the petrological classification in *Table I.*

The recent emergence, in the gem market, of a number of gem grade faceted "hypersthenes" prompted the author's investigation into this gem group. The present study of gem quality enstatite was initiated to determine the iron content, and hence the correct nomenclature, of these purported "hypersthenes," and gem enstatites in general.

Three faceted gems in the U.S. National Gem Collection, weighing 7.77, 8.07, and 10.93 carats each were examined. Eight other gemmy orthopyroxenes were also examined, including the Indian material originally noted by the American gemologist, John Sinkankas (1955), and donated by him to the Smithsonian Institution. Five samples from Brazil were donated by Miss Tomiko Butler, F.G.A. of Silver Spring, Maryland, U.S.A., who generously and thoughtfully donated fragments of the rough for this study before cutting the gems. Other occurrences include the noted Ceylon greenish enstatite, and the dark green material from the San Carlos Indian Reservation in Arizona (Sinkankas, 1959).

All numbered specimens are from the U.S. National Mineral Collection at the Smithsonian Institution, Washington, D.C. 20560. Specimens with numbers prefixed by "G" are faceted gems on exhibit.

Previous Work

For discussions of asterism and inclusions in star enstatite, the reader is referred to the work of Eppler (1967) and (1971). Early work on gem enstatite was done by Mitchell (1953) (1954) and Trumper (1954). Tanzanian enstatite was recently noted by Bank (1974).

Chemistry

All the samples were analyzed on an ARL-SEMQ electron microprobe utilizing an operating voltage of 15KV and a sample current of 0.15Mu. Wet-chemically analyzed enstatite and hypersthene microprobe standards of high reliability were used. The analyses are presented as *Table II,* in order of increasing iron content, together with their densities, color, and localities.

The examined gems are all magnesium-rich with the FeO content varying from 2% to 11% by weight. It is quite obvious that gem enstatites and bronzites vary little in composition for a given locality. None of the samples, including six offered for sale as hypersthene, contained sufficient iron to be considered hypersthene. The Tanzanian enstatites were the purest of those examined and the Ceylon gems next in relative purity.

TABLE II. ANALYSES OF GEM ORTHOPYROXENES

	NMNH	SiO_2	Al_2O_3	FeO	MgO	MnO	CaO	K_2O	Na_2O	TiO_2	Total	D	Locality	Color	Percent Enstatite End-Member
ENSTATITE	G-5459	58.79	1.33	1.89	38.29	0.08	0.08	0.00	0.05	0.03	100.54	3.25	Tanzania	Brown	95
ENSTATITE	126031	59.55	1.33	2.00	37.78	0.09	0.06	0.00	0.04	0.02	100.87	3.24	Tanzania	Brown	94
ENSTATITE	G-2294	58.04	0.78	5.17	35.26	0.16	0.53	0.02	0.02	0.03	100.01	3.31	Ceylon	Brownish green	88
ENSTATITE	G-3638	58.24	0.84	5.23	35.44	0.15	0.51	0.03	0.03	0.01	100.48	3.31	Ceylon	Brownish green	88
ENSTATITE	134302	56.60	3.27	5.67	33.68	0.15	1.10	0.00	0.07	0.14	100.68	3.31	Arizona	Dark green	84
ENSTATITE	134309	56.28	3.18	5.77	33.24	0.16	0.83	0.01	0.09	0.06	99.62	3.32	Arizona	Dark green	83
BRONZITE	134303	56.23	3.51	6.80	33.17	0.14	0.99	0.00	0.15	0.20	101.19	3.32	Arizona	Dark green	83
BRONZITE	BUTLER	57.01	0.53	8.97	33.50	0.20	0.22	0.01	0.02	0.03	100.49	3.32	Brazil	Brown	84
BRONZITE	134001	55.93	0.63	9.78	31.91	0.24	0.26	0.00	0.03	0.03	98.81	3.34	India	Greenish brown	79
BRONZITE	134002	58.03	0.60	10.02	32.53	0.24	0.25	0.01	0.03	0.04	101.75	3.32	India	Brown	81
BRONZITE	BUTLER	56.99	0.54	10.43	32.45	0.20	0.24	0.00	0.02	0.02	100.89	3.32	Brazil	Brown	80
BRONZITE	BUTLER	56.45	0.62	10.50	32.33	0.20	0.24	0.02	0.02	0.00	100.38	3.32	Brazil	Brown	80
BRONZITE	BUTLER	57.01	0.56	10.73	32.47	0.22	0.25	0.01	0.03	0.01	101.29	3.32	Brazil	Brown	80
BRONZITE	BUTLER	56.15	0.65	10.77	32.12	0.25	0.27	0.03	0.02	0.03	100.29	3.32	Brazil	Brown	80
BRONZITE	134003	57.35	0.55	11.08	32.32	0.25	0.26	0.01	0.03	0.05	101.90	3.35	India	Brown	80

Although the density of the orthopyroxenes varies from 3.21 to 3.95, the densities of the gemmy enstatites and bronzites examined in this study varied from 3.24 to 3.35. Gems with high iron content have the higher densities. Members of this series with densities less than 3.30 may be considered enstatite, and those with densities between 3.30 and 3.44 may be designated as bronzite.

Optical Properties

The refractive indices of the orthopyroxenes have been studied in great detail and several excellent graphs relating the optical constants to composition have been prepared (Deer *et al.*, 1963).

The indices and birefringence increase with increasing iron content. Values for gemmy enstatites and bronzites vary as follows: α = 1.650–1.665, β = 1.655–1.676, and γ = 1.665–1.690. Birefringence values vary from 0.015 to 0.025. The optic sign changes from positive to negative at about $En_{88}Fs_{12}$. This change in optic sign was taken as the demarcation point between enstatite and bronzite and may be used with reliability in determining the correct designation for a gem.

The color of enstatite and bronzite is not related to the FeO content; both the low-iron Tanzanian enstatite, the relatively high-iron Indian bronzite, and the Brazilian bronzite are a medium brown color.

Pleochroism in orthopyroxenes has not been explained in terms of chemical composition. Several investigators (Howie, 1955; Parras, 1958) have suggested that the pleochroism might be due to oriented intergrowths of diopside lamellae but no such lamellae were observed in the visible pleochroic Tanzanian and Ceylon enstatites. Although rock-forming enstatites are not usually pleochroic, the Tanzanian enstatites exhibit very strong pleochroism and the Ceylon enstatites moderate to weak pleochroism. The bronzite from India also exhibited strong pleochroism.

Optical data for the enstatite from Tanzania (G-5459), the one nearest to the enstatite end of the series, is given as *Table III*. None of the examined gems were luminescent in either long or short-wave ultraviolet or in CuKα x-radiation.

Enstatite occurs as prismatic crystals, with a blocky habit. The rough is ideally suited to emerald and rectangular cuts. The gems are usually oriented with the table parallel to $\{100\}$ to obtain maximum yield, and sometimes with a table parallel to $\{010\}$ as these directions provide the most pleasing color. This preferred orientation in cutting aids the gemologist for gems with tables cut parallel to $\{100\}$ permit the direct measurement of true α and β and gems with tables parallel to $\{010\}$ will permit the measurement of true β and γ.

An interference figure, with $2V = 90°$ is a helpful determination as it indicates that the gem's composition lies on the enstatite-bronzite border. This is only applicable in the case of a gem with a density between 3.25 and 3.35 as 2V also approaches 90° at the eulyite-orthoferrosilite border in the iron-rich end of the series.

Absorption Spectra

Although enstatites are known to always have a strong absorption line at 5060 Å, other spectral lines were observed and recorded. All samples exhibited the 5060 Å line, and it was the dominant line in each case. In addition to this dominant line, Tanzanian gems also had diffuse lines at 4550, 4880 and 5550 Å, Ceylon gems had one diffuse line at 5550 Å, Indian and Brazilian material had diffuse lines at 4880 and 5550 Å, and Arizona, U.S.A., gems had one diffuse line at 4880 Å.

TABLE III
OPTICAL DATA FOR TANZANIA ENSTATITE
($En_{95}Fs_5$)

α = 1.653 (±0.002) Optic sign +
β = 1.655 (±0.002) Birefringence 0.010
γ = 1.663 (±0.002)

PLEOCHROISM

X = *b*	Light brown
Y = *a*	Brown
Z = *c*	Green

Although an uncommon gem material, and one whose low hardness (5½ - 6) and perfect easy cleavage in two directions restrict its use in jewelry, enstatite and bronzite do provide very attractive gems. This material is also quite useful in teaching gemology inasmuch as it is a biaxial gem mineral with noticeable pleochroism; a material in which the optical constants and optic sign determination can provide a correct nomenclature designation, and one in which correct orientation is essential to the lapidary.

Inclusions in the studied enstatites were uncommon. Several of the Arizona bronzites had exsolution lamellae of diopside. Inclusions in the Tanzanian enstatite will be the subject of a subsequent investigation.

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