Garnets from the Eilat area, southern Israel

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[Taken as read 3 June 1965]

Summary. Garnets from twenty-eight pegmatites, schists, and gneisses from the crystalline massif of Eilat have been examined. Refractive index, unit-cell edge, MnO and FeO content were determined in 19 samples. Three chemical analyses are given. The garnets fall into two distinct groups, the pegmatite garnets (spessartine-rich, almandine to spessartine) and metamorphic garnets (nearly pure almandine). Garnets occurring in pegmatite-like granitoid veins cutting through the schists are shown to belong to the second (metamorphic) group. The pegmatite garnets again fall into two groups of different spessartine content.

THE Precambrian of Israel, outcropping near the Gulf of Eilat, has been reviewed by Bentor (1961). It consists of three petrographic complexes: the metamorphic complex, the intrusive complex, and the volcano-conglomeratic complex. Garnets are encountered in various schists, gneisses, and pegmatites associated with the metamorphic and the intrusive complexes.

Techniques. The rocks were crushed to pass a 0·5 mm sieve, and the heavy fraction was recovered by decantation using tetrabromethane (sp. gr. 2·95). In a few samples of pegmatites containing a large amount of apatite the concentrate was further passed through a Franz isodynamic separator. All samples were handpicked under a binocular microscope and further crushed to free them from inclusions, then decanted again with tetrabromethane. Some minute black undetermined needles still remained in a few cases.

Indices of refraction were measured in sodium light by the immersion method. Magnetic susceptibility was measured using a Franz separator (Frost, 1960). X-ray powder photographs were taken with a Nonius quadruple semi-focusing camera. Filtered Cu-radiation was used throughout with an additional Mn filter on the film; a small amount of KCl was mixed with each sample prior to exposure and the KCl lines were used for calibration. The unit-cell length was calculated as an average of the line values. No extrapolation method was considered

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justified as the camera gives lines only for $2\theta < 90°$. Specific gravity was measured with a pycnometer.

Partial chemical analysis for MnO and FeO content was carried out by dissolving the powdered mineral in boiling $HF–H_2SO_4$ solution followed by the colorimetric[1] determination of MnO and the volumetric determination of FeO.

TABLE I. Chemical compositions and physical properties of garnets from the Eilat area, Israel. M, garnets from metamorphic rocks; P, from pegmatites; G. from granitoid veins

Sample number		MnO (wt. %)	FeO (wt. %)	a	n	Sp. Gr. gr/cm³	Magnetic Susceptibility $\times 10^6$, e.m.u.
1	M	0·10	28·45	11·518 Å	1·799	—	—
2	M	2·06	29·84	11·518	1·801	—	—
3	M	1·73	30·11	11·518	1·801	—	—
4	G	3·88	30·63	11·539	1·805	—	—
5	M	2·09	27·40	11·568	1·805	—	—
6	G	4·17	28·17	11·537	1·805	—	—
7	M	1·64	30·21	11·512	1·803	—	—
8	M	2·50	31·93	11·531	1·802	—	—
9	P	11·98	25·24	11·540	1·806	—	—
10	M	2·84	29·29	11·544	1·800	—	—
11	M	2·48	30·62	11·533	1·800	4·19	53·8
12	P	n. d.	23·72	11·522	1·805	—	—
13	P	9·44	n. d.	11·546	1·804	—	—
14	P	n. d.	n. d.	11·570	1·810	—	—
15	P	22·73	18·75	11·572	1·803	4·22	73·3
16	M	6·13	29·22	11·545	1·805	—	—
17	P	17·83	21·94	11·558	1·802	4·17	70·9
18	M	n. d.	n. d.	11·556	1·799	—	—
19	P	13·32	25·04	11·560	1·813	—	—
20	M	4·21	34·20	11·568	1·805	3·96	53·9
21	M	3·61	29·47	11·543	1·799	—	—
22	P	17·22	22·20	11·560	1·807	—	—
23	P	16·90	21·10	11·562	1·807	—	—
24	P	19·17	n. d.	11·570	1·803	—	59·7
25	P	40·52	n. d.	11·590	1·802	—	71·3
26	P	40·82	n. d.	11·590	1·802	—	79·2
27	P	41·84	n. d.	11·590	1·802	—	78·1
28	P	42·17	n. d.	11·590	1·802	—	84·0

Three complete chemical analyses were performed, fusing the mineral with NaOH (Katz, in press).

Results and discussion. In table I, the contents of MnO, FeO, unit-cell length, refractive index, specific gravity, and magnetic susceptibility of the garnets are given.

[1] The volumetric method was used for particularly high MnO contents.

There are three distinct garnetiferous rock groups to be considered: the metamorphic rocks; the 'granitoid veins' cutting these; and the pegmatites.

Only four determinations of the specific gravity were carried out since these are of only restricted value: partly because of the numerous

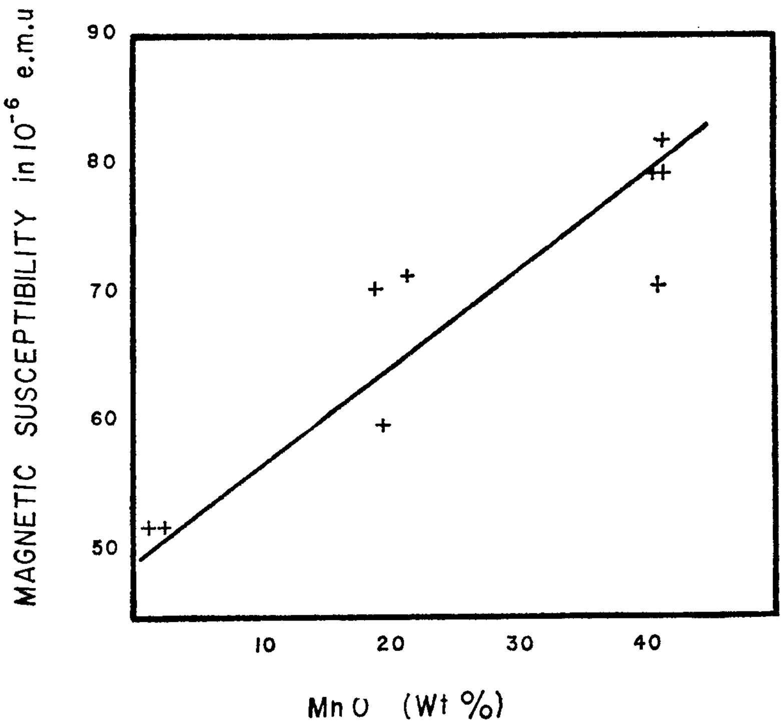

FIG. 1. A plot of magnetic susceptibility against MnO content for garnets from the Eilat area.

inclusions occurring in the garnets and partly because of the difficulty of performing satisfactory specific gravity measurements on a fine powder (Deer, Howie, and Zussman, 1962, vol. I, p. 81).

Good agreement exists between the physical properties and the chemical composition of the garnets. The magnetic susceptibility is the most sensitive physical property to serve as a measure of the spessartine content (fig. 1). However, it has two disadvantages: a much larger amount of the garnet is required for this method than for any other physical determination; and the volt-meter attached to the Franz separator does not allow any precise measurement. Three garnet samples were chosen for a complete major-element chemical analysis, the results appearing in table II.

The concentrations of TiO_2, P_2O_5, and alkalies were below the limits of determination. Molecular percentages were calculated from the chemical analyses on the basis of 24 oxygen atoms.

TABLE II. Chemical analyses and atomic ratios to 24 oxygen of garnets from the Eilat area, Israel

Sample	11		15		17	
SiO_2	38·39		36·76		37·21	
Al_2O_3	21·24		22·22		19·45	
Fe_2O_3	2·01		0·93		1·48	
FeO	31·17		18·68		21·94	
MnO	2·36		20·38		17·83	
CaO	1·16		0·84		1·71	
MgO	3·38		tr.		$\leqslant$0·40	
Total	99·71		99·81		100·02	
Si	6·104	6·10	5·977	6·00	6·099	6·10
Al	3·982	4·22	4·257	4·35	3·763	3·95
Fe^{3+}	0·240		0·113		0·185	
Fe^{2+}	4·144	5·46	2·536	5·49	3·008	5·88
Mn	0·317		2·807		2·475	
Ca	0·197		0·145		0·298	
Mg	0·799		—		0·098	
End-member percentages						
Almandine	77·0		46·2		51·1	
Andradite	2·2		2·6		5·1	
Pyrope	14·9		—		1·7	
Spessartine	5·9		51·2		42·1	

The results of the three full analyses confirm that a partial chemical analysis of FeO and MnO combined with a determination of the physical properties are sufficient to render a fair picture of the garnet composition. In addition, the analyses indicate the presence of more impurities in the garnets from metamorphic rocks (e.g. sample 11) than in the garnets from pegmatites (e.g. sample 17), the latter having an almost ideal garnet formula.

The chemical compositions are shown plotted in a triangular diagram (fig. 2) in which the almandine and spessartine are two co-ordinates, the third co-ordinate representing the 'remainder'. This third co-ordinate will, of course, have a different significance in each case, but for garnets of the metamorphic rocks it is close to pyrope.

Three compositional fields may be distinguished in the diagram: that near the spessartine pole (field 1, fig. 2); that almost equidistant between almandine and spessartine (field 2); and an almandine-rich, pyrope-bearing field (field 3).

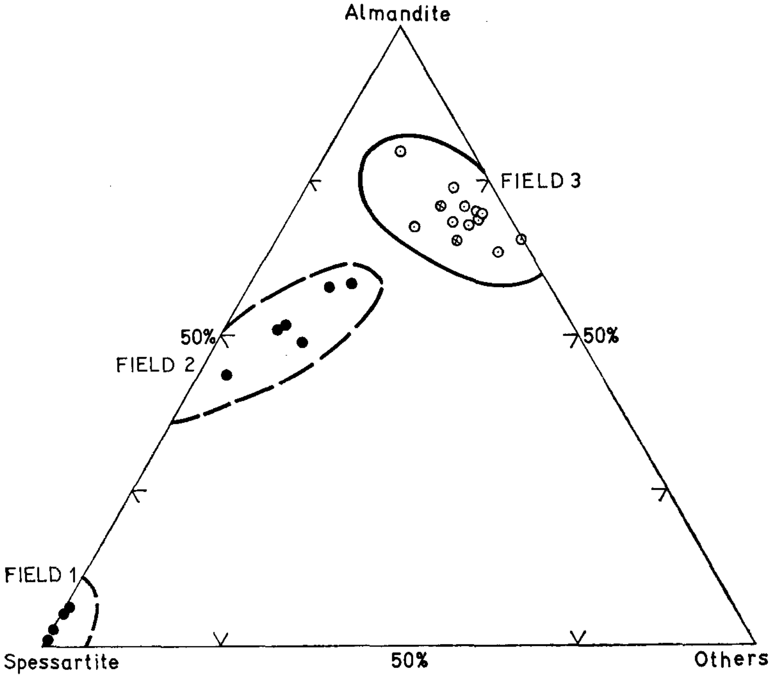

FIG. 2. Compositions of garnets from the Eilat area: ⊙ garnets from metamorphic rocks; ⊗ garnets from 'granitoid veins'; ● garnets from pegmatites.

Garnets from the metamorphic rocks and granitoid veins are restricted to field 3. Most of them may be assigned to Tröger's group XIV (Tröger, E., 1959). Garnets from the pegmatites are divided between fields 1 and 2 and correspond to Tröger's group I.

Samples 4 and 6 were taken from 'granitoid veins'. A large number of similar bodies are found cutting through the metamorphic rocks, and in places are garnet-bearing. Since the two sampled garnets fall so clearly into field 3, these 'veins' should be genetically related to the schists rather than to any other group. The veins are regarded as material that separated out of the sediments during their metamorphism; this view is supported by examination of the thin sections, for quartz shows a clearly metamorphic texture.

The division of the pegmatite garnets into two separate fields points to the existence of at least two pegmatite phases. This is in agreement with previous field and mineralogical work on the Eilat pegmatites (Bahat, 1963).

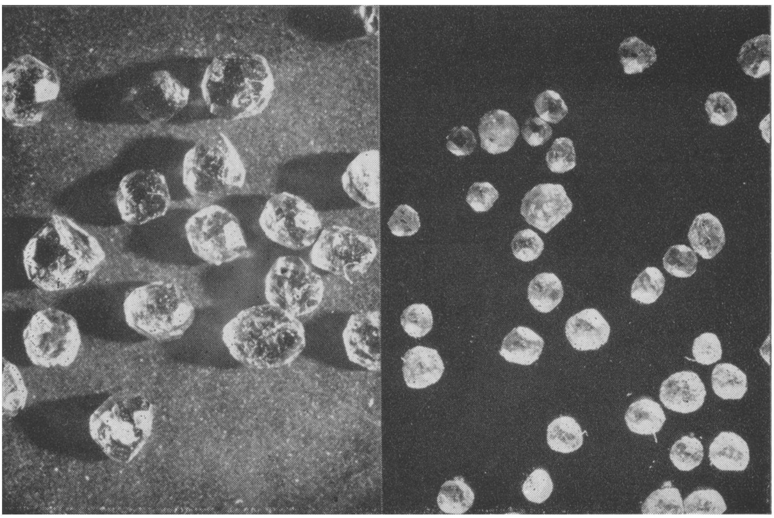

FIG. 3. Garnets from the Eilat area, Israel. *a* (left) from a mica-schist. *b* (right) from a pegmatite.

Morphological differences exist between the pegmatite garnets and the metamorphic garnets (see fig. 3). The pegmatite garnets are relatively small, ranging in size from 0·5 to 1 mm; one pegmatite exceptionally shows garnets up to 3 cm across. Most of them are transparent and pinkish-brown, and have well-developed crystal forms. In contrast, the schist garnets are bigger, usually ranging in size from 1 to 6 mm. They are mainly opaque, brown coloured, and less well crystallized. Some of them are twinned on (111).

The MnO content in the garnets is related to the grain size. Small crystals contain relatively high amounts of MnO. This is in agreement with previous observations in metamorphic rocks (Chinner, 1960; Lee *et al.*, 1963). The present study finds this to be true within the range of pegmatite garnets also.

Acknowledgements. The authors wish to express their thanks to their colleague Dr. M. J. Oppenheim for his help in preparing the manuscript. They also wish to thank Mr. Kennedy and Mr. Khoury from the Medical School of the Hebrew University, for kindly preparing the photographs.

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[*Manuscript received 18 August 1964*]