The paragenesis of garnet in charnockite, enderbite, and related granulites

(With Plate XVIII.)

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Summary. The presence of garnet in acid rocks of the charnockite series south of Madras is reported. Petrographic descriptions of garnetiferous enderbites and related pyroxene-granulites, khondalites, and leptynites are accompanied by new chemical analyses of 6 rocks, 8 garnets, and 5 orthopyroxenes from the type area near Madras, and from Ceylon, Varberg, and Uganda. The garnets show a considerably higher FeO/MgO ratio than the coexisting orthopyroxenes and the host rocks. The presence or absence of garnet appears to be related to the bulk chemistry of the rocks. Basic garnetiferous granulites associated with these rocks are considered to represent an unstable mineral assemblage and may be genetically unrelated to the acid types. Attention is drawn to the prevalence of enderbitic rocks in the type area.

IN his memoir on the charnockite series of India Holland (1900) defined charnockite as 'a quartz–felspar–hypersthene–iron ore rock in the charnockite series', the latter being a name used to express the fact that he grouped together in the one petrographic province a number of petrological types which he considered to be genetically related to charnockite and to one another. Holland made no mention of garnet in his list of characteristic constituents or in the detailed petrography of charnockite although he briefly described the occurrence of garnet in some basic rocks of the series and in garnetiferous leptynite (light-coloured acidic granulite). The purpose of this paper is to record and emphasize the occurrence of garnet in the rocks of the type area south of Madras and to describe the mineralogy of these garnet-bearing charnockites and related rock types.

In general to avoid ambiguity the nomenclature of Holland will be used, but without any petrogenetic significance. In particular the name charnockite is confined to the normal dark orthopyroxene-bearing acid member of the series. Tilley (1936) has suggested the name enderbite for acid rocks of this series in which plagioclase is the predominant felspar rather than microcline or orthoclase, and in this restricted sense many of the garnetiferous rocks here described are enderbites rather than charnockites, although both felspars are present.

After the appearance of Holland's memoir very little work was done on the type area for forty years, although Washington (1916) published petrographic descriptions and analyses of a suite of rocks from the Madras charnockite series, none of which contained garnet. Rajagopalan (1946 and 1947), working on material from St. Thomas's Mount, Madras, again does not report any garnet in rocks of the series ranging from 49 to 75 % in SiO_2 content. Although Muthuswami (1953) described a basic garnetiferous diopside granulite from Pallavaram, in the various 'norites' of the district garnet is reported to be absent: an area marked 'garnetiferous charnockite' is, however, indicated on the sketch-map of the country south-east of Pallavaram. Naidu (1955) states that 'garnet occurs in the basic, intermediate, and acid charnockites', but in the 42 modal analyses presented the only acid rocks with garnet do not contain any orthopyroxene: similarly Narayanan *et al.* (1955), who re-examined the Pallavaram area, describe leptynite grading into garnetiferous charnockite at Cheri Hill: but the mode of their 'acid charnockite' shows no orthopyroxene to be present. Leelananda Rao (1955) described garnetiferous khondalites and leptynites from Pachaimalai, 2 miles south-west of Pallavaram, but reported that basic, intermediate, and acid members of the charnockite series bear no garnets.

In a recent chemical and mineralogical study by one of the present authors, working largely on material supplied by the Geological Survey of India, no garnets were found other than in the leptynite (Howie, 1955). Although various authors have described garnetiferous intermediate and acid members of the series from elsewhere in India and from other pre-Cambrian areas, the garnetiferous rocks of the Madras district have thus been largely overlooked.

One of us (A. P. S.) has recently had the opportunity to map and investigate the field relationships in the area of St. Thomas' Mount and Pallavaram, where numerous quarries have been opened in the last few years, and it is now apparent that garnetiferous charnockite or enderbite is of fairly common occurrence: indeed an examination of the paratype, the tombstone of Job Charnock in St. John's Churchyard, Calcutta, reveals that it itself contains easily discernible red garnets. Basic granulites containing garnet as well as orthopyroxene are abundant in the Madras area. The garnet-bearing leptynites and the khondalites (garnet–quartz–sillimanite rocks) will also be briefly considered as they are of importance in discussing the possible origin and relationship of the charnockites. Only brief details of the field occurrence of these garnetiferous rocks are given here, as the field and petrogenetic relationships in the type area will be discussed in a separate communication by one of us (A. P. S.).

Field occurrence and petrography.

For convenience of description the rocks may be divided into six groups: the acid garnetiferous charnockites or enderbites, the dark acid garnetiferous granulites without orthopyroxene, the rocks of intermediate composition, the basic garnetiferous 'norites', the light-coloured garnetiferous leptynites, and the sillimanite-bearing khondalites. The constant textural feature is the even-grained granular character of the constituents: the rocks are remarkably fresh and the orthopyroxene when it occurs is strongly pleochroic.

The garnetiferous enderbites. Rock Ch 113 from west of Hasanapuram quarry to the south of Pallavaram is typical of this group and has the almost greasy lustre and dark bluish-grey colour characteristic of charnockite, with grains of red garnet occasionally visible. In thin section the potash felspar is strongly perthitic with a slightly shadowy extinction: the refractive indices α 1·523, γ 1·530 (both $\pm$ 0·001) indicate a composition of Or_{55} ($\pm$ 7 % Or). The quartz shows evidence of strain, each grain consisting of several optically related individuals all showing wavy extinction, while the plagioclase is antiperthitic with the irregular blebs of potash felspar regularly oriented in the crystals: its composition from optics is An_{30}. The orthopyroxene occurs in ragged and embayed grains but is relatively fresh (pl. XVIII, fig. 1); it is strongly pleochroic. The pink garnet forms large masses of indeterminate shape with many quartzo-felspathic and iron ore inclusions: a small amount of iron ore is found, both magnetite and ilmenite being present; other accessories include a little reddish-brown biotite and rounded grains of zircon.

Specimen 56 from Pallavaram is rather coarser than the previous rock, and has a more olive-brown colour. In this rock it was noticed that on a freshly sliced surface the quartz was light greyish blue and the felspar yellow, although after a few months the colour gradually changed to the usual overall olive-brown hue. In thin section the mineralogy is rather similar to Ch 113 but the large grains of microperthite show a more noticeable undulatory extinction together with the faint suggestion of cross-hatching typical of incipient microclinization: the quartz contains some minute hair-like inclusions. The garnet and orthopyroxene tend to be roughly associated in clumps.

Acid garnetiferous granulites without orthopyroxene. Ch 219 from Tattan Kunnu quarry, between the two rifle ranges south of Minambakkam railway station, has the typical dark appearance in hand specimen with blue quartz and greenish-blue felspars together with rounded grains of red garnet and in the field forms a marginal facies of the normal non-garnetiferous charnockite. In thin section orthopyroxene is virtually absent though one grain was found in one of the 20 sections examined: it may therefore be classed as a garnetiferous granulite without orthopyroxene. Specimen Ch 44 is a fairly coarse alaskitic rock from the south-east face of knoll 150, west of Ottaiyambakkam, 8 miles south of Pallavaram, and is light-coloured but with parallel streaks of bluish-grey quartz and deep-brown garnets throughout the rock: its mineralogy is similar to Ch 219. Rock Ch 58 is a similar type found as a band in pyroxene granulites and khondalitic rocks in a knoll a mile south of Umamanchori, 3 miles south-east of Vandalur railway station: its strongly perthitic potash felspar has refractive indices α 1·522, γ 1·526 indicating a composition of Or_{65} ($\pm$ 7 % Or).

Garnetiferous pyroxene granulites of intermediate composition. No garnetiferous rocks of this type are reported from the Madras area; specimen S.347 is the rock described by Groves (1935, p. 164) as a quartz–hypersthene–diorite, from Mt. Wati (Ote), West Nile District, Uganda, falling in the intermediate division of the Uganda charnockite series. It is a fairly coarse-grained rock with plagioclase of composition An_{32} as the dominant light mineral: the quartz has undulose extinction and a few dusty inclusions, while the potash felspar is a microperthitic orthoclase. The dark minerals consist of approximately equal amounts of ferrohypersthene, greenish-yellow hornblende, sheaves and laths of brown biotite, and pink grains of garnet clouded with inclusions; the garnet generally occurs in association with iron ore and biotite and contains inclusions of biotite and quartz. The modal analysis of this rock as given in table I differs from that given by Groves (1935, p. 166) for material from the same hand specimen, the variation being accounted for by the inclusion of biotite in the new mode and also by the splitting up of the felspar into its components, which was facilitated by the sodium cobaltinitrite staining technique for potassium felspar (Chayes, 1952).

Rock V.2 from Fästningsberget, Varberg, Sweden, is from the rock mass described as 'intermediate charnockite' by Quensel (1951, pp.

247–51). It is a medium grained yellowish-brown rock, with traces of dark minerals in bands between the olive-green felspars. Strongly antiperthitic plagioclase of composition An_{25-28} is accompanied by almost non-perthitic intermediate microcline and lesser amounts of quartz. Moderately pleochroic iron-rich orthopyroxene (table VI) is the most abundant dark mineral and occurs with hornblende, clinopyroxene, ilmenite, and magnetite, together with minor zircon and fluor-apatite.

Specimen 68671 from the roadside at 21/5 culvert, Hatton, Ceylon (cf. Adams, 1929, p. 470), is a typical dark pyroxene granulite, with a few red garnets visible in hand specimen. Under the microscope quartz and antiperthite (sodic andesine) are abundant and are accompanied by moderately pleochroic ferrohypersthene and hornblende, weakly pleochroic augite, pink garnet, and lesser amounts of iron ore and apatite.

Basic garnetiferous granulites. Rock Ch 199 is a basic two-pyroxene granulite or garnetiferous 'norite' from Paravatta Hill, Pallavaram, and is a medium-grained dark rock showing occasional patches of red garnet and greenish-yellow felspar. In thin section the plagioclase is clear and fresh, the α index 1·565 $\pm$ 0·001 indicating a composition in the range An_{65-70}. Light green weakly pleochroic augite showing salite structure is the commoner pyroxene and has α 1·705, β 1·714, γ 1·735 (all $\pm$ 0·001), $2V_{\gamma}$ 49°$\pm$1°, absorption $\alpha < \beta < \gamma$: the less abundant ferrohypersthene (table VI) is only weakly pleochroic (α pale pink, β yellowish pink, γ light green). A yellowish-brown hornblende occurs in embayed grains often intimately associated with the pyroxenes: it is strongly pleochroic with α pale yellow, β pale brown, γ deep brown and has α 1·670, β 1·685, γ 1·693 (all $\pm$0·001). Garnet occurs in large pink grains of irregular outline poikiloblastically enclosing the other dark minerals (pl. XVIII, figs. 3 and 4) and sometimes also plagioclase: iron ore and reddish biotite are the accessories.

Specimen Ch 200 occurs as lenses and thin layers in the garnetiferous pyroxene granulite (Ch 199) and is light-coloured, with garnets and green pyroxene appearing in a carbonate base. The pyroxene is in the hedenbergite range α 1·714, γ 1·744 (both $\pm$0.001), $2V_{\gamma}$ 60°$\pm$1°, γ: [001] 44°$\pm$1°, absorption $\alpha < \beta < \gamma$, and in thin section other minerals visible are garnet, sphene, calcite, apatite, plagioclase (An_{75-90}), and scapolite: the latter has ϵ 1·561, ω 1·596 ($\pm$0·001) indicating a composition of Me_{80-85}.

Specimen V.1 from Högahalla quarry, Träslövsläge, Varberg, is described as a 'basic charnockite' by Quensel (1951, pp. 239–46), and is a massive fine-grained dark rock with a granular texture. The felspar is a moderately antiperthitic andesine, the composition of the plagioclase phase from optics being An_{35}, the most common composition in the charnockite series. The dark minerals include a green pleochroic clinopyroxene, strongly pleochroic hypersthene, pink garnet with inclusions of quartz and felspar, yellowish to green-brown hornblende, brown biotite, magnetite, and ilmenite; a few grains of apatite also occur.

Garnetiferous leptynite. Rock 3708 (G.S.I. 9·665), the garnetiferous leptynite from Pallavaram, has already been described by Holland (1900, p. 173, pl. XV) and by Howie (1955). In hand specimen it is greyish white in colour sprinkled with red garnets. In thin section strained quartz crystals can be seen to occur among small grains of microcline microperthite ($Or_{80\cdot7}Ab_{17\cdot9}An_{1\cdot4}$): orthopyroxene is absent, pink anhedral garnets being the main ferro-magnesian mineral; small amounts of both ilmenite and magnetite are also present. Holland considered this rock to represent a dynamically metamorphosed charnockite.

Khondalites. Specimen Ch 119 is a khondalite from the northern end of Pachaimalai hill 360, south-west of Chromepet railway station: it is buff-coloured and schistose with abundant brownish garnet and visible aggregates of sillimanite. In thin section quartz is seen to form more than half the rock, occurring in large grains with undulose extinction, hair-like inclusions, and sutured margins: the potash felspar is a microperthite. Garnet occurs as subhedral crystals and ragged grains occasionally forming 'atolls': inclusions of quartz, plagioclase, ores, green spinel, biotite, and sillimanite may be seen. Elsewhere the sillimanite forms elongated prisms with a preferred orientation and is closely associated with the garnets: green spinel is also found bordering the garnets.

Ch 121 is a recrystallized khondalite from a small knoll south of Oddapalaiyam, one mile south-west of Pallavaram railway station: it represents a recrystallized facies of the normal khondalite and occurs near typical charnockite. The rock is medium-grained and greyish with rose-coloured garnet porphyroblasts and in thin section shows a mosaic of granulated quartz and subordinate perthite in which irregular grains of garnet are scattered. The felspar shows incipient cross-hatching and its refractive indices α 1·521, γ 1·525 indicate a composition of Or_{80} (± 7 % Or): a small amount of plagioclase (An_{25}) sometimes rims the larger perthite plates. Sillimanite occurs as prismatic crystals, and other minerals include brown biotite, iron ores, and a minor amount of iron-rich amphibole.

The chemistry of the rocks.

Analyses of seven of the Madras rocks together with those of the Uganda and Varberg rocks are given in table I, where the C.I.P.W. norms and volume percentage modes are also listed. Modal analyses were carried out by the point-counting method, 15 000 points being determined for specimens Ch 113 and 219 which were rather variable in mineral composition, while 4 000 to 5 000 points were determined on the remaining rocks.

The garnetiferous enderbites are relatively poor in silica compared with normal charnockites, while alumina is fairly high, bringing in appreciable amounts of corundum to the norm. The enderbitic nature of these rocks is not very pronounced as the potash values remain above 2 %. The Fe_2O_3/FeO ratio is low, being less than 0·3 compared with an average value of 0·88 for 546 granites (Goldschmidt, 1954, p. 37); indeed this value is low throughout these Indian rocks, suggesting high temperature metamorphism (Goldschmidt, loc. cit.), or a magma deficient in water, allowing the reduction of ferric iron to ferrous iron to take place. In the basic garnetiferous pyroxene-granulite (Ch 199), although SiO_2 is low, both the FeO/MgO ratio and the CaO content are rather high. The khondalitic rocks (Ch 119 and 121) are both very high in SiO_2 with more than 50 % modal quartz, the greater alkali content of Ch 121 being reflected in the development of a considerable amount of potash felspar. Ch 119 is richer in FeO and also has a higher FeO/MgO ratio, and, as will be seen later, its garnet has a higher FeO/MgO ratio than that from Ch 121. The Uganda intermediate rock S.347 is rather similar chemically to V.2 from Varberg, and both could be compared with intermediate non-garnetiferous rocks from the Madras charnockite series (Howie, 1955): the Fe_2O_3/FeO ratio is particularly low in the Uganda rock. The basic granulite from Varberg (V.1) resembles chemically the Madras rock of this type (Ch 199), the greater amount of K_2O in the Varberg specimen being reflected in the noticeably antiperthitic plagioclase. In general all these rocks are rather high in alumina, and the iron oxides are also high with ferrous oxide greatly in excess of ferric oxide. Total alkalis are found in normal amounts in the charnockitic rocks, although they are low in the khondalites and leptynite. Soda is almost always in excess of potash in the orthopyroxene granulites.

Mineralogy.

The garnets and orthopyroxenes were initially concentrated to above 90 % purity with the aid of an isodynamic separator and final purification

TABLE I. Chemical analyses, CIPW norms, and modes of garnetiferous enderbites, pyroxene-granulites, and associated rocks.

	56.	Ch 113.	Ch 219.	Ch 199.	Ch 121.	Ch 119.	3708.	S.347.	V.2.	V.1.
SiO_2	64·18	65·95	67·49	47·71	81·08	75·88	77·93	60·45	60·12	45·00
TiO_2	1·12	0·99	0·54	0·97	0·52	0·58	0·31	1·50	0·95	2·40
Al_2O_3	16·40	15·27	16·13	15·57	9·88	11·03	10·65	17·56	16·63	16·62
Fe_2O_3	0·95	1·12	1·14	2·31	0·57	2·46	0·99	0·62	2·19	6·05
FeO	5·21	4·86	4·47	10·85	2·33	6·27	2·50	5·77	4·79	8·97
MnO	0·07	0·22	0·12	0·38	0·00	0·11	0·04	0·10	0·10	0·31
MgO	2·41	2·70	1·60	7·24	1·16	1·51	0·18	1·60	0·82	7·24
CaO	3·26	2·95	3·44	11·52	0·42	0·18	0·40	4·72	3·75	9·50
Na_2O	3·64	3·74	3·13	2·07	1·26	0·59	2·19	3·75	4·73	2·76
K_2O	2·52	2·06	1·47	0·42	2·22	0·11	4·54	2·45	4·25	0·96
H_2O+	0·14	0·25	0·27	1·11	0·49	0·85	0·08	0·75	0·25	0·16
H_2O-	0·28	0·20	0·40	0·07	0·14	0·17	0·16	0·53	—	0·06
P_2O_5	0·08	tr.	0·04	0·12	0·03	0·03	tr.	0·31	0·77	0·00
Total	100·26	100·31	100·24	100·34	100·10	99·77	99·97	100·36	99·56	100·03
					C.I.P.W. Norms.					
Q	19·74	22·92	30·97	—	61·68	65·28	45·48	13·88	7·26	—
or	14·85	12·23	8·67	2·2[illegible]	12·79	0·56	26·69	15·01	25·02	5·59
ab	30·79	31·44	26·46	17·82	10·48	5·24	18·34	31·44	39·82	22·25
an	15·71	14·73	16·76	31·97	1·95	1·11	1·95	21·78	11·68	30·07
C	1·92	1·53	3·24	—	4·79	9·38	1·43	0·64	—	(ne)·70
di	—	—	—	21·00	—	—	—	—	1·89	13·67
hy	13·05	13·53	10·60	8·89	5·80	12·38	4·28	11·66	6·68	—
ol	—	—	—	12·89	—	—	—	—	—	14·20
mt	1·37	1·62	1·64	3·25	0·93	3·71	1·39	0·93	3·25	8·77
il	2·14	1·98	1·03	1·98	0·91	1·22	0·61	2·89	1·82	4·56
ap	0·19	—	0·10	0·29	0·07	0·07	—	0·67	1·68	—
					Modes (vol. %).					
Quartz	20·6	23·8	39·4	—	52·9	53·7	53·4	14·3	14·7	—
K-felspar	20·8	16·3	16·5	—	24·3	7·4	40·5	21·3	23·4	—
Plagioclase	40·2	32·2	25·5	37·5	—	—	2·1	43·6	41·0	34·8
Orthopyroxene	9·7	12·3	—	6·4	—	—	—	3·9	6·8	9·1
Clinopyroxene	—	tr.	—	24·8	—	—	—	1·9	3·2	25·5
Garnet	5·8	12·6	16·1	8·6	13·5	27·6	2·9	4·0	2·8	13·2
Hornblende	—	—	—	20·0	—	—	—	4·3	3·0	7·5
Biotite	0·9	1·0	1·1	—	4·6	—	—	4·0	—	4·6
Sillimanite	—	—	—	—	4·2	8·9	—	—	—	—
Apatite & Zircon	0·3	0·7	0·3	—	—	—	—	0·4	0·9	0·1
Ores	1·7	1·1	1·1	2·7	0·5	0·6	1·1	2·3	4·2	5·2
Green Spinel	—	—	—	—	—	1·8	—	—	—	—
D	2·66	2·84	2·77	3·10	2·77	2·87	2·67	2·74	2·77	3·19

56 Garnetiferous enderbite, Pallavaram. Anal. R. A. Howie.

Ch 113 Garnetiferous enderbite, west of Hasanapuram quarry, south of Pallavaram, Madras. Anal: T. Katsura, Tokyo. (K_2O, Na_2O, H_2O+, and H_2O- by R. A. Howie.)

Ch 219 Garnetiferous granulite, Tattan Kunnu quarry, between the two rifle ranges, south of Minambakkam Railway station. Anal. R. A. Howie.

Ch 199 Basic granulite ('norite'), summit of Paravatta Hill, south of Mosque Hill, Pallavaram. Anal. T. Katsura, Tokyo.

Ch 121 Recrystallized khondalite, near contact with charnockite, south of Oddapalaiyam. Anal. T. Katsura, Tokyo.

Ch 119 Khondalite, northern end of Pachaimalai hill 360. Anal. T. Katsura, Tokyo.

3708 Garnetiferous leptynite (G.S.I. 9·665, Holland, 1900, p. 173), Pallavaram. Anal. R. A. Howie (Howie, 1955).

S. 347 'Quartz–hypersthene–diorite', Mt. Wati (Ote), West Nile district, Uganda. (Anal. also shows ZrO_2 0·01, BaO 0·18, S 0·09.) Anal. A. W. Groves (Groves, 1935).

V.2 'Intermediate charnockite', Fästningsberget, Varberg, Sweden (with BaO 0·21). Anal. R. Mauzelius (Quensel, 1951).

V.1 'Basic charnockite', Högahalla quarry, Träslövsläge, Varberg. Anal. N. Sahlbom (Quensel, 1951).

was accomplished by use of Clerici's solution. The garnets in many cases had to be ground to pass a 300-mesh sieve to release quartz or sillimanite inclusions. Refractive indices were measured in sodium light with an estimated accuracy of $\pm 0{\cdot}001$ for the orthopyroxenes and $\pm 0{\cdot}004$ for the garnets. Normal analytical techniques were used, special care being taken over the determination of FeO and MnO. For the estimation of ferrous iron in the garnets samples that had been particularly finely ground were taken, and using the normal Pratt method the acid attack was continued for up to 25 minutes, the operation being repeated until consistent results were obtained. Susceptibility to attack varied, some garnets going into solution relatively easily: but in the analysis of the garnet from the recrystallized khondalite (Ch 121) the FeO determination was repeated eight times before consistent values resulted. In the estimation of MnO, MnO was looked for in both the calcium and magnesium precipitates as well as in the R_2O_3 portion.

The cell sizes of the garnets were measured using a 9-cm. diameter powder camera with Mn-filtered Fe-$K\alpha$ radiation; the accuracy is estimated to be $\pm 0{\cdot}002$ Å. Specific gravities were determined in a pycnometer, the final reading being taken after several preliminary checks over 24 hours to eliminate trapped air bubbles: the accuracy is probably better than $\pm 0{\cdot}03$. In tables II and III the calculated physical properties are also given, using the values for synthetic end-member garnets (Skinner, 1956). The agreement for cell size and refractive index is generally fair, but the correlation for specific gravity is poor except in the two cases where more than about 2 g. of the purified mineral powder was used (3708 and S.347): otherwise the observed values are low with respect to the theoretical values, part of the reason being the small amount of material used for the determination and its more than usually fine grain size. The refractive indices and cell sizes of unanalysed garnets are given in table IV. The trace-element contents of the nine analysed garnets have been determined by Dr. S. R. Nockolds and Mr. R. S. Allen: their results are given in table V.

The garnets. In all the rocks the garnet is well crystallized in subhedral grains, faintly pink in thin section, fresh in appearance and often containing a few pools of quartz and occasionally felspar and biotite, or, in khondalite, inclusions of green spinel and sillimanite. In all the garnets now examined the dominant 'molecule' is almandine, though an analysis by Groves (1935) of a garnet from 'dynamo-metamorphosed charnockite' showed a very high proportion of pyrope (table III, G.79). Analyses of Madras garnets are presented in table II: their structural

TABLE II. Chemical analyses and physical properties of Madras garnets.

	Ch 113.	Ch 219.	Ch 199.	Ch 121.	Ch 119.	3708.	J.1.
SiO_2	38·02	38·35	37·65	39·21	38·51	37·20	36·20
TiO_2	0·03	0·08	0·04	0·11	0·03	0·07	1·04
Al_2O_3	21·02	21·10	20·87	22·42	22·10	21·75	26·26
Fe_2O_3	1·98	1·50	1·87	0·85	0·93	0·71	0·88
FeO	28·12	28·48	27·65	25·20	27·92	33·30	26·46
MnO	0·64	0·71	1·10	0·32	0·15	0·74	0·42
MgO	7·87	7·93	3·74	11·38	9·50	4·82	5·60
CaO	2·25	2·04	7·16	0·77	0·81	1·58	2·42
Na_2O	0·11	0·01	0·09	tr.	0·04	n.d.	0·06
K_2O	0·01	0·04	0·02	0·04	0·00	n.d.	0·41
H_2O+	n.d.	n.d.	n.d.	0·02	0·04	n.d.	0·18
H_2O-	0·09	0·02	0·02	0·03	0·05	0·09	0·01
Total	100·14	100·26	100·21	100·35	100·08	100·26	100·01
Percentage composition in terms of garnet end-member molecules							
Almandine	65·3	66·0	64·5	58·5	64·9	77·6	66·3
Andradite	6·6	4·8	5·7	2·7	2·6	2·5	—
Grossular	0·3	1·2	14·6	—	—	2·0	7·8
Pyrope	26·3	26·4	12·7	38·0	32·1	16·3	25·0
Spessartine	1·5	1·6	2·5	0·8	0·4	1·6	0·9
Observed physical properties							
n	1·796	1·800	1·800	1·788	1·794	1·806	1·795
a(Å.)	11·528	11·529	11·594	11·507	11·569	11·541	
D	3·99	4·02	4·01	3·99	4·02	4·17	4·14
Calculated physical properties using values for synthetic end-members							
n	1·801	1·801	1·804	1·786	1·795	1·810	1·792
a(Å.)	11·544	11·541	11·600	11·526	11·507	11·538	
D	4·09	4·09	4·09	4·02	4·04	4·17	4·08

Ch 113 Garnet from garnetiferous enderbite.
Ch 219 Garnet from garnetiferous granulite.
Ch 199 Garnet from basic orthopyroxene granulite.
Ch 121 Garnet from recrystallized khondalite.
Ch 119 Garnet from khondalite.
3708 Garnet from garnetiferous leptynite (Howie, 1955, table VI).
J.1 Garnet from 'leptite' (Naidu, 1955). Anal. H. Schwander. (Anal. includes 0·07 P_2O_5.)

All are from Pallavaram type area: for detailed localities see table I. Anal. except for J.1, R. A. Howie.

formulae on the basis of 12 oxygen ions (table VII) show that in general they conform fairly closely with the theoretical ratio of 3:2:3 for the R'', R''', and z groups in the garnet series, although the R''' group is always very slightly greater than 2, probably indicating that the ferric iron has been overestimated.

TABLE III. Chemical analyses and physical properties of granulite garnets from outside India.

	S.347.	G.79.	V.1.	V.2.	A.	9.	13.
SiO_2	38·10	39·55	37·85	37·33	36·70	36·35	37·19
TiO_2	0·19	0·21	0·03	0·02	0·00	1·72	0·38
Al_2O_3	20·76	17·67	21·06	20·96	16·58	22·97	21·02
Fe_2O_3	1·56	7·39	1·40	0·68	12·72	—	1·28
FeO	28·54	17·93	26·79	30·58	20·70	24·72	28·61
MnO	1·32	0·46	0·86	2·19	3·00	0·64	0·93
MgO	3·12	14·66	4·94	1·25	2·73	11·80	3·08
CaO	6·70	2·07	7·20	7·05	7·00	1·87	7·41
Na_2O	n.d.	n.d.	0·03	0·03	0·03	—	0·02
K_2O	n.d.	n.d.	0·00	0·00	0·11	—	0·09
H_2O+	n.d.	n.d.	n.d.	n.d.	0·68	—	0·16
H_2O-	0·03	n.d.	0·03	0·03	0·00	—	0·00
Total	100·32	99·94	100·19	100·12	100·25	100·07	100·17

Percentage composition in terms of garnet end-member molecules

	S.347.	G.79.	V.1.	V.2.	A.	9.	13.
Almandine	67·1	42·3	61·7	71·3		55·6	67·0
Andradite	6·2	6·6	4·5	2·0		—	4·1
Grossular	12·8	—	15·4	17·3		4·8	16·4
Pyrope	10·7	50·0	16·4	4·2		38·2	10·5
Spessartine	3·2	1·0	2·0	5·2		1·4	2·0

Observed physical properties

	S.347.	G.79.	V.1.	V.2.	A.	9.	13.
n	1·805		1·794	1·808	(1·808)	1·76	
a(Å.)	11·597		11·570	11·603			
D	4·12		3·98	4·13		3·80 ± 0·04	

Calculated physical properties using values for synthetic end-members

	S.347.	G.79.	V.1.	V.2.	A.	9.	13.
n	1·803		1·798	1·809			
a(Å.)	11·595		11·591	11·596			
D	4·11		4·06	4·14			

S.347 Almandine garnet from 'Quartz-hypersthene-diorite', Uganda. Anal. R. A. Howie.

G.79 Garnet from 'dynamo-metamorphosed charnockite', Bunyoro district, Uganda (after recalculation free from 21·6 % normative quartz). Anal. A. W. Groves (1935).

V.1 Almandine garnet from 'basic charnockite', Högahalla quarry, Varberg, Sweden. Anal. R. A. Howie.

V.2 Almandine garnet from 'intermediate charnockite', Fästningsberget, Varberg. Anal. R. A. Howie.

A Garnet from 'intermediate charnockite', Fästingsberget, Varberg (Quensel, 1951). Anal. N. Sahlbom.

9 Garnet from basic hypersthene granulite, Kevuavdshi, Kevujoki, Lapland (Eskola, 1952). Anal. A. Huhma.

13 Almandine garnet from garnet–pyroxene–oligoclase granulite, one mile W. of Elizabethtown, Adirondacks (Buddington, 1952). Anal. L. C. Peck.

The garnets from the dark acid granulites (Ch 113 and 219) and that from the basic granulite (Ch 199) are rather similar in FeO and Fe_2O_3 content, their main compositional difference lying in the greater pyrope component of Ch 113 and 219 while Ch 199 has more grossular. In the corresponding orthopyroxenes that from Ch 113 is also richer in MgO

TABLE IV. Refractive index and cell-size of unanalysed garnets.

	Rock.	*n.*	*a*(Å.).
Ch 44	Acidic granulite, south of Pallavaram	1·801	11·545
Ch 58	Acidic granulite, Pallavaram	1·800	11·518
56	Garnetiferous enderbite, Pallavaram	1·802	11·520
Ch 200	Calc-granulite lens in Ch 199	1·790	11·675
68671	Pyroxene granulite, Hatton, Ceylon	1·798	11·592

TABLE V. Trace elements in the garnets of garnetiferous granulites (in parts per million).

	r(Å.).	*s*.	V.1.	Ch 199.	V.2.	S.347.	Ch 113.	Ch 219.	3708.	Ch 119.	Ch 121.
Ga	0·62	1	10	10	12	50	10	15	40	15	10
Cr	0·63	2	45	450	*	25	450	450	*	*	*
Li	0·68	1	1	*	3	1	1	3	12	3	3
Mo	0·70	2	*	*	*	*	*	*	25	*	*
Co	0·72	5	30	45	*	15	30	30	5	5	5
V	0·74	5	40	220	*	65	140	220	*	*	*
Zr	0·79	10	40	50	125	30	60	50	120	120	120
Sc	0·81	10	100	40	10	200	100	150	*	*	*
Y	0·92	15	140	150	1000	60	1000	1000	600	350	450
Pb	1·20	10	*	*	*	*	*	*	40	*	*
Ba	1·34	10	*	*	*	20	*	*	*	*	*

For details and localities see foot of tables I–III.

An asterisk denotes that the element, if present, was in an amount below the limit of sensitivity (*s*). *r* = the ionic radius of the element for sixfold coordination. Ni (2), Sn (10), Sr (10), Rb (5), and La (50) below limits of sensitivity (given in brackets) in all cases. (The values for 3708 are from Howie, 1955, table VII.)

while the rock analyses show that the MgO/FeO ratio is lower in Ch 113. Thus the distribution of calcium appears to be a controlling factor: in the acid rock the CaO content of the rock is low while in Ch 199 it is higher and the CaO/MgO ratio is also higher, so that much of the MgO is taken into the high modal percentage of augite and hornblende.

The garnets from the khondalites (Ch 119 and 121) contain relatively little calcium, reflecting the composition of their parent rocks: the difference in the chemistry of the rocks is shown in the FeO/MgO ratios of the garnets, that of the garnet from the recrystallized khondalite (Ch 121) being the lower. S. V. L. N. Rao (1955) gives an analysis of a garnet from a garnetiferous gneiss (khondalite) from Vizagapatam district with 77 % almandine, and quotes another from Kondapalli with

65·7 % of the almandine molecule, while Fermor (1926) computed the composition of a khondalite garnet from Kalahandi, knowing the composition of the rock, and estimated it to be 78·8 % almandine (assuming all the iron to be in the ferrous condition). The garnet of the garnetiferous leptynite (3708) was the most iron-rich in the present investigation with 77·6 % of the almandine molecule, it being the only ferromagnesian mineral in the rock. Naidu (1955) reports a garnet from a 'leptite' at Pallavaram (table II, J.1) with 66·3 % almandine,[1] the modal composition of the rock showing almost four times as much iron ore as in 3708. Other analyses of garnets from leptynites are given by S. V. L. N. Rao (1955), showing lower iron contents, but as no details are given of the rocks themselves they will not be discussed here.

Three new analyses of garnets from orthopyroxene granulites from Uganda and Varberg are given in table III, together with earlier analyses from both these localities and from other granulite areas in Lapland and the Adirondacks. The garnet from the 'intermediate charnockite' of Groves (S.347) is again fairly rich in iron with 67 % of the almandine molecule: it has a FeO/MgO ratio greater than that of its parent rock (table I) and much greater than that of the coexisting orthopyroxene (table VI), clinopyroxene, hornblende, or biotite.[2] The garnet G.79 is much richer in MgO and is from a charnockite which Groves considered to have suffered subsequent dynamo-metamorphism, the garnet being considered to be derived directly from orthopyroxene with the setting free of the quartz, which occurs as inclusions. In the original description of this garnet (Groves, 1935, p. 160) the percentage composition is wrongly stated in terms of the end-member molecules, and has since been quoted thus elsewhere: the corrected values (Groves, 1952, personal communication) are as given in table III.

The garnets from the two Varberg rocks are again fairly rich in iron, and like the Uganda and Madras examples they have a considerably higher FeO/MgO ratio than either their parent rocks or their coexisting orthopyroxenes. That of V.2, the more acid rock, is richer in the almandine molecule, although for a rock with only 45 % SiO_2 the V.1 garnet with 61·7 % almandine is still very rich in iron. Analysis A (table III) is of a garnet described by Quensel (1951, p. 251) from the same mass at Fästningsberget as V.2; the essential difference is in the ferrous iron

[1] In table II Naidu's values for the standard molecules for this garnet are quoted, but on recalculation FeO and SiO_2 are in considerable excess.

[2] Analyses of the clinopyroxene and hornblende from this rock were given by Groves (1935); the biotite has an FeO/MgO ratio of 2·26 (Howie, unpublished data).

content: the high Fe_2O_3 of analysis A prohibits the recalculation into normal end-member garnet molecules, as there is insufficient CaO to form andradite. Analyses 9 and 13 are of garnets from garnetiferous pyroxene granulites from Lapland (Eskola, 1952) and from the Adirondack meta-gabbro area (Buddington, 1952) respectively: as before the FeO/MgO ratios of the garnets are very much greater than those of the parent rocks, and in the Lapland example greater than the FeO/MgO ratio for the orthopyroxene (Eskola, 1952, p. 152).

The trace-element contents of the nine analysed garnets are given in table V. Yttrium is almost certainly being captured by manganese rather than by calcium: in garnets V.1 and V.2, for example, the yttrium content is very much larger in V.2, while the calcium values are almost identical. Lithium is probably being concentrated with respect to magnesium: scandium is rather variable, and although nickel is not present in appreciable amounts cobalt does occur and is probably camouflaged by iron. Chromium and vanadium are noticeably low in those garnets low in ferric iron. In general the garnets from the three light-coloured acidic granulites, 3708, Ch 119, and Ch 121, can be seen to have a different trace-element assemblage. On the other hand the garnets from Ch 113 and Ch 219 have an almost identical major and trace-element composition, and although both rocks have a dark aspect in hand specimen only Ch 113 carries appreciable orthopyroxene.

The orthopyroxenes. The analyses and properties of five ortho-pyroxenes from garnetiferous charnockites and pyroxene granulites are given in table VI, and their structural formulae on the basis of 12 oxygen atoms are shown in table VII. They range from 50·5 to 25·2 % enstatite, the most magnesian being from the most acid rock, the Madras garnetiferous enderbite Ch 113. The content of alumina is moderate except in Ch 113, where it rises to 4·08 %, perhaps an expression of the aluminous nature of the parent rock which has over 1·5% normative corundum: this amount of alumina, however, is not much greater than that found in orthopyroxenes of non-garnetiferous rocks of the charnock-ite series (Howie, 1955, p. 754), and greater amounts are known from orthopyroxenes of other basic granulites (Eskola, 1952, p. 152, and Howie, unpublished data). The MnO content of the orthopyroxenes is always just less than half that of the coexisting garnets and is greatest in the most iron-rich orthopyroxene, the eulite from the Varberg garnetiferous pyroxene-granulite V.2. The optical properties of the orthopyroxene from the same rock mass as V.1 indicate a composition of 52 % enstatite (Quensel, 1951, p. 241); those for orthopyroxene from an 'intermediate charnockite' give a composition of 25 % enstatite, which compares well with the analytical result for V.2 orthopyroxene (26 % En). From analysis, the orthopyroxene coexisting with garnet 9 from Lapland has 62 % enstatite (Eskola, 1952). All the orthopyroxenes are very distinctly pleochroic, that from Ch 113 having the strongest

TABLE VI. Chemical analyses and physical properties of orthopyroxenes from garnetiferous granulites.

	Ch 113.	Ch 199.	68671.	S.347.	V.2.
SiO_2	50·05	49·28	49·73	49·48	47·33
TiO_2	0·30	0·17	0·11	0·13	0·29
Al_2O_3	4·08	2·09	1·96	1·77	1·37
Fe_2O_3	0·68	0·98	1·72	1·84	1·09
FeO	27·50	32·01	29·64	31·56	39·41
MnO	0·27	0·47	0·53	0·49	0·94
MgO	16·51	13·32	14·66	14·25	8·02
CaO	0·46	1·38	1·24	0·80	1·25
Na_2O	0·09	0·06	0·10	0·01	0·05
K_2O	0·03	0·01	0·01	tr.	0·01
H_2O+	0·02	n.d.	0·04	0·02	0·07
H_2O-	0·11	0·04	0·11	0·04	0·23
Total	100·10	99·81	99·85	100·39	100·06
		Atomic percentages.			
Fe	48·5	56·6	53·4	54·2	72·0
Mg	50·5	40·5	44·1	44·1	25·2
Ca	1·0	2·9	2·6	1·7	2·8
γ	1·728	1·734	1·732	1·733	1·758
$2V_\alpha$			52°	54°	66°
D	3·58	3·62	3·63	3·60	3·75

Anal. R. A. Howie.

Ch 113 Hypersthene from garnetiferous enderbite, Pallavaram.
Ch 199 Ferrohypersthene from basic granulite ('norite'), Pallavaram.
68671 Ferrohypersthene from pyroxene granulite, Hatton, Ceylon.
S.347 Ferrohypersthene from 'quartz–hypersthene–diorite', Mt. Wati, West Nile district, Uganda.
V.2 Eulite from basic granulite ('intermediate charnockite'). Fästningsberget, Varberg.

pleochroism with α pinkish red, β pink, γ light green: thus in these granulite-facies orthopyroxenes under discussion the most strongly pleochroic also has the lowest content of both ferrous and ferric iron, contrary to the widespread but fallacious belief that the degree of pleochroism can be equated with iron content in this mineral series. The orthopyroxenes of these rocks almost invariably show straight extinction, and often have well-developed 'schiller' or microplakite inclusions of thin reddish-brown plates of unknown composition.

TABLE VII. Garnet and orthopyroxene analyses recalculated to show number of metal ions per 12(O).

	Garnets								Orthopyroxenes				
	Ch 113.	Ch 219.	Ch 199.	Ch 121.	Ch 119.	S. 347.	V.1.	V.2.	Ch. 113.	Ch. 199.	68671.	S. 347	V.2.
Si	2·968	2·982	2·978	2·970	2·974	3·009	2·978	3·002	3·835	3·891	3·890	3·879	3·898
Al	0·032	0·018	0·022	0·030	0·026	—	0·022	—	0·165	0·109	0·110	0·121	0·102
Al	1·898	1·918	1·912	1·972	1·978	1·934	1·928	1·981	0·203	0·091	0·069	0·041	0·030
Fe^{3+}	0·120	0·088	0·111	0·048	0·046	0·085	0·085	0·038	0·037	0·057	0·103	0·108	0·069
Ti	0·004	0·005	0·002	0·006	0·001	0·012	0·002	0·003	0·018	0·009	0·004	0·008	0·020
Mg	0·913	0·920	0·443	1·286	1·091	0·371	0·578	0·148	1·885	1·565	1·708	1·674	0·984
Fe^{2+}	1·835	1·853	1·833	1·598	1·801	1·886	1·759	2·059	1·757	2·109	1·935	2·059	2·708
Mn	0·042	0·047	0·071	0·020	0·010	0·090	0·057	0·150	0·018	0·033	0·035	0·033	0·065
Na	0·018	0·002	0·016	—	0·005	—	0·004	0·004	0·018	0·010	0·019	0·002	0·008
Ca	0·187	0·170	0·608	0·063	0·067	0·570	0·609	0·609	0·037	0·114	0·103	0·068	0·111
K	0·001	0·003	0·003	0·004	—	—	—	—	0·003	0·001	0·001	—	0·001
Z	3·00	3·00	3·00	3·00	3·00	3·01	3·00	3·00	4·00	4·00	4·00	4·00	4·00
Y	2·02	2·01	2·02	2·03	2·02	2·03	2·01	2·02	3·98	3·99	3·98	3·99	4·00
X	2·99	3·00	2·97	2·97	2·97	2·92	3·01	2·97					

Petrogenesis and conclusions.

The compositions of the garnets under discussion in this paper together with the compositions of their host rocks are plotted in a ternary diagram (fig. 1) in which the molecular per cent. ratios (FeO+MnO), MgO, and CaO are represented at the corners. It can be seen that the

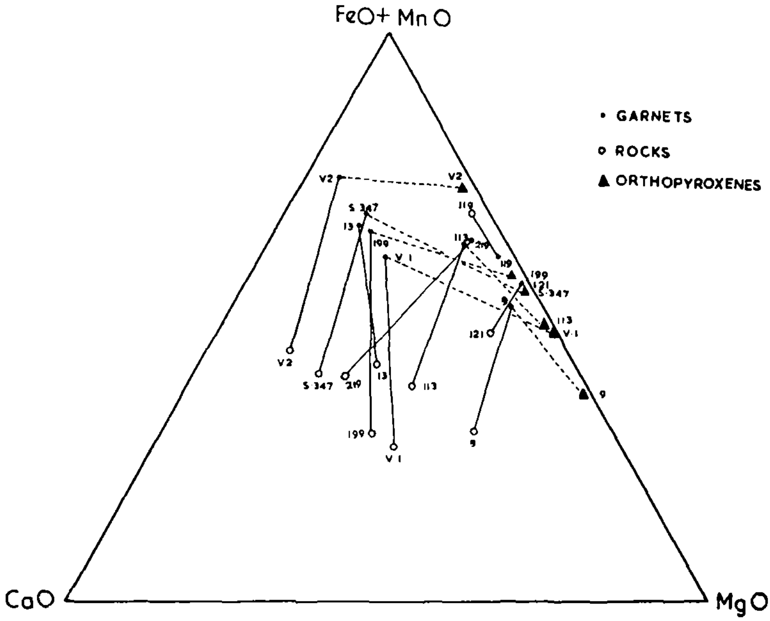

FIG. 1. (FeO+MnO), MgO, CaO molecular diagram showing the compositions of the orthopyroxenes, the garnets, and their host rocks.

(FeO+MnO)/MgO ratio in these garnets is considerably greater than in the equivalent host rocks: this relationship has previously been demonstrated by Buddington (1952) for the Adirondack gabbroic rocks, while Subramaniam (1956) has shown that a converse relationship holds good in the case of garnets in eclogites. The compositions of the coexisting orthopyroxenes are also plotted in fig. 1 and their (FeO+MnO)/MgO ratios are again seen to be considerably less than those of the garnets, being generally similar to the ratio for the host rocks. Many authors have suggested various chemical equations for the production of garnets in granulitic assemblages generally involving anorthite and spinel, corundum, or the ferromagnesian minerals (hornblende or augite or orthopyroxene). In these garnetiferous granulites, however, the (FeO+MnO)/

MgO ratio in the garnets is not only greater than that in the host rocks and the orthopyroxenes but also, as indicated by optics, greater than that in any other coexisting ferromagnesian mineral. Thus if the garnets did not form at the same time as the other minerals then their subsequent formation from pre-existing silicates must also have involved some iron-rich mineral such as magnetite or spinel, and have liberated a certain amount of silica. Evidence of the close relationship of the garnet with pyroxenes or spinel may be found in several of the rocks under discussion, although not in every section. In Ch 199, a basic pyroxene-granulite from Paravatta Hill, Pallavaram, in which both ortho- and clinopyroxenes occur together with garnet and iron ore (pl. XVIII, figs. 3 and 4), a crystal of garnet contiguous with clinopyroxene is seen enveloping magnetite. In the garnetiferous enderbites orthopyroxenes, garnets, and ore minerals are fairly closely associated (pl. XVIII, figs. 1 and 2), while in the khondalite garnet sometimes encloses green spinel. Pl. XVIII, fig. 5 is of a typically dark charnockite from the banks of the Kehelella Ela, 20 miles east-south-east of Kandy, Ceylon, with both ortho- and clinopyroxene, the latter being more abundant: here a rim of quartz can be seen between a large crystal of garnet and pyroxene. Ramanthan (1956, p. 149, sketch 4) also illustrates pyroxenes in contact with garnet, the latter containing quartz inclusions and also large grains of magnetite.

Eskola (1939) has defined the granulite facies as comprising rocks for which at basaltic bulk composition the association of hypersthene and plagioclase is typomorphic, while at granitic bulk composition quartz, felspars, and almandine-pyrope garnet occur. The garnetiferous granulites whose analyses are given here have been plotted on the appropriate ACF diagram (fig. 2), with the diopside–anorthite–orthopyroxene field extended slightly in its anorthite–orthopyroxene border to allow for the fairly considerable alumina content of the orthopyroxenes of this facies, indicated by the shaded area which covers the range 0 to 8 % Al_2O_3. The plots of the garnetiferous enderbites fall in the appropriate field for garnet and orthopyroxene-bearing rocks, while the non-garnetiferous charnockites plot in the anorthite–diopside–aluminous-orthopyroxene field close to the anorthite–orthopyroxene boundary (Howie, 1955, fig. 7). It has been suggested that garnet-free charnockites are unmetamorphosed igneous rocks whereas the presence of garnet in a charnockitic rock is an indication that the rock has been subjected to high-grade metamorphism. The chemical evidence given here indicates that the presence or absence of garnet in a charnockite is controlled only by the chemical composition of the rock, the garnetiferous charnockites and enderbites being richer in $Al_2O_3+(FeO+MgO)$.

The khondalites plot well out into the alumina-rich field as would be expected from their modal sillimanite, while the leptynite and Ch 219,

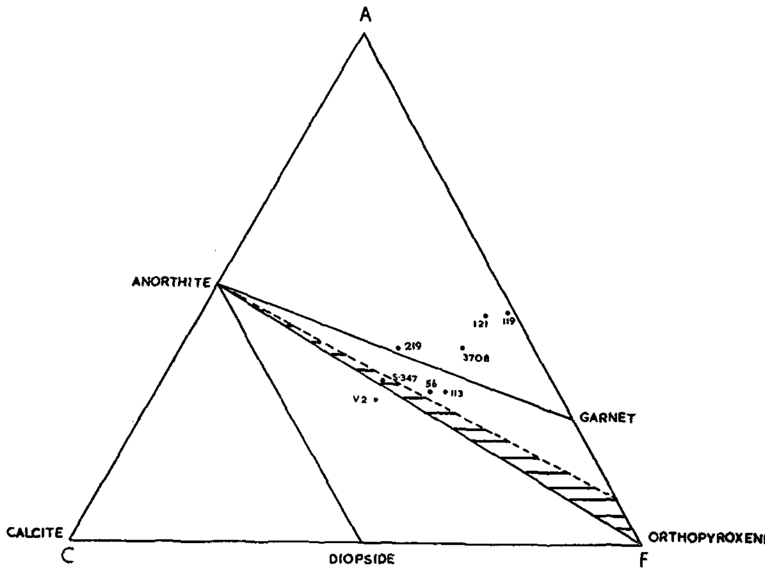

FIG. 2. ACF diagram for the garnetiferous granulites (granulite facies, with excess silica). 119, 121, 219, and 3708 are plots of garnetiferous granulites without orthopyroxene, 56 and 113 are of enderbites carrying garnet and orthopyroxene, while S.347 and V.2 are of more basic garnetiferous granulites containing both ortho- and clino-pyroxene.

the dark garnetiferous granulite without appreciable orthopyroxene, plot close to the garnet–anorthite border.

The intermediate rocks S.347 and V.2 have compositions lying in the anorthite–orthopyroxene–diopside field although both contain considerable garnet. That diopside and almandine-pyrope garnet cannot occur together in stable equilibrium in this facies is evident from the ACF diagram: thus these rocks, which contain free quartz and also both clinopyroxene and garnet in appreciable amounts (see table I), must be considered as being in a state of disequilibrium. The additional presence of hornblende in these rocks reaffirms this, as although there is evidence (Eskola, 1952) that brownish-green hornblende may exist alongside ortho- and clino-pyroxenes in the granulite facies, the assemblage hornblende–orthopyroxene–almandine is an unstable one. Thus while in the more acid granulites and charnockites the mineralogical assemblage sillimanite–garnet–plagioclase or orthopyroxene–garnet–plagioclase is a typically stable one, in the more basic garnetiferous pyroxene granulites such as S.347 and V.2 the assemblage found is unstable.

It is not intended here to make more than a passing reference to some aspects of the petrogenesis of charnockites and associated rock types, but the new data now available may be of some significance. Holland (1900) and several later observers have considered the charnockite series as representing a genetically related group of rocks varying from basic to acid types: this conclusion is inconsistent with recent work on the field relationship, mineralogy, petrography, and chemistry of these rocks from the type area. Leaving aside the question of whether the series is an igneous one or whether it was originally igneous and has recrystallized under granulite facies conditions, if these rocks represent what was originally a differentiated igneous series derived from a common magma we should expect this to be reflected in the mineralogy of the various members of the series. In the present instance, however, for rocks around Pallavaram, the basic granulite Ch 199 carries an orthopyroxene of composition $En_{40\cdot5}$, while the acid garnetiferous enderbite Ch 113 has an orthopyroxene of composition $En_{50\cdot5}$, which is inconsistent with the accepted facts of mineral variation in a differentiation series where the basic members carry a magnesian orthopyroxene and the more acid members a progressively more iron-rich orthopyroxene. The garnets from these two rocks behave in the same way, the more basic rock having the more iron-rich garnet.

New chemical analyses of charnockitic rocks from the type area (56, Ch 113 and Ch 219) show a dominance of soda over potash, suggesting them to be akin to enderbites. The presence of enderbite in the Pallavaram area has already been indicated by Tilley (1936) and a chemical analysis is given by Howie (1955): recent field studies by one of us have, however, shown that enderbite is more prevalent in the type area than charnockite *sensu stricto*, and any theory on the petrogenesis of these rocks must be able to account for this fact. These and related problems on the type area will be discussed in a later communication.

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Explanation of Plate XVIII. Photomicrographs of Madras and Ceylon granulites.

Fig. 1. Garnetiferous enderbite, Ch 113, Pallavaram, showing subhedral garnets (light) with small crystals of orthopyroxene (dark). ×6.

Fig. 2. Orthopyroxene–garnet–magnetite relationship in garnetiferous enderbite Ch 113. Note perthitic felspars also present. ×25.

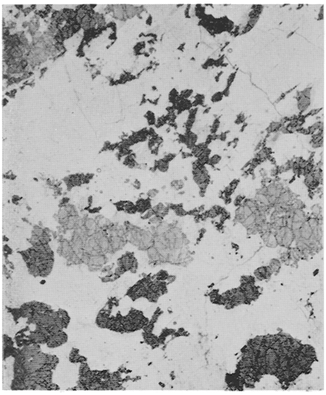
Fig. 3. Basic pyroxene granulite Ch 199, Paravatta Hill, Pallavaram, showing granular texture. The large crystals are garnet. ×6.

Fig. 4. Pyroxene–garnet–magnetite relationship in Ch 199. Note the opaque core of magnetite and the clinopyroxene closely associated with the garnet and

magnetite. $\times 25$ (nicols slightly moved from crossed position to distinguish between garnet and magnetite).

FIG. 5. Garnetiferous granulite, 20 miles east-south-east of Kandy, Ceylon, showing a rim of quartz in the north-west quadrant between a large crystal of garnet and crystals of ortho- and clinopyroxene: the orthopyroxene is slightly altered. $\times 20$.

FIG. 6. Garnetiferous granulite Ch 219, Tattan Kunnu quarry, Pallavaram, showing development of myrmekite against large grains of perthite. Crossed nicols. $\times 25$.



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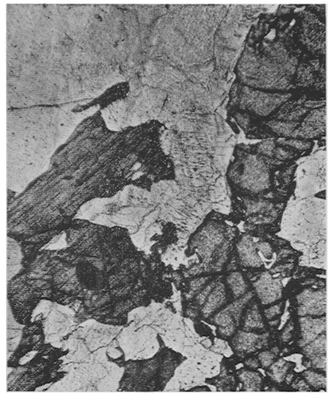

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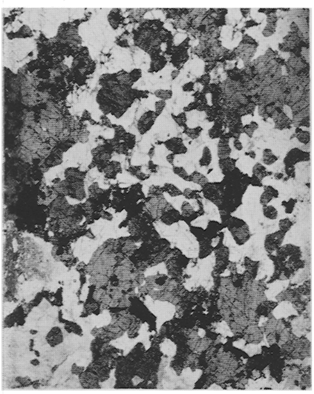

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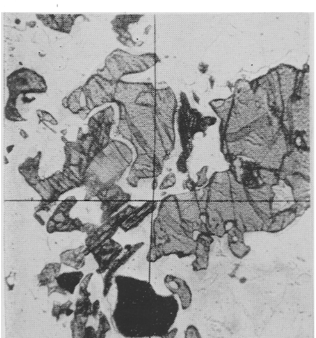

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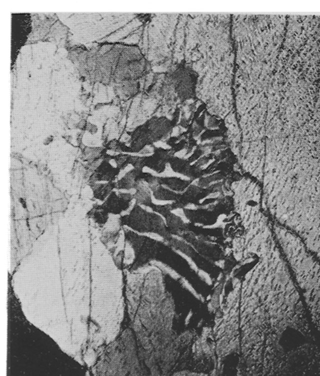

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HOWIE & SUBRAMANIAM: THE PARAGENESIS OF GARNET