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Further data on an 'eclogite' from the Sittampundi Complex, India

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SUMMARY. New analyses of a garnet–clinopyroxene rock ('eclogite') and its constituent minerals from the Sittampundi complex of India are presented. The rock has a composition comparable with an alkali-poor tholeiite and this composition, as well as the garnet (Py 51·5 %; Alm 32·7 %) and pyroxene (Jd 7·4 %; Ts 10·8 %) are very similar to those from South Harris.

The apparent distribution coefficient ($K'_{Fe/Mg}$) for the garnet–clinopyroxene pair suggests a temperature of equilibration near 850 °C. Projection of the experimental data of Green and Ringwood (1967) down to this temperature suggests a pressure of about 7–8 kb. This is well below the pressure of the granulite–eclogite transition.

THE chemical data on coexisting garnet and clinopyroxene in eclogites of various types have recently been used to estimate relative formation temperatures (Coleman *et al.*, 1965; Banno and Matsui, 1965). Combination of these data with the results of experiments on eclogite formation from basaltic compositions (Green and Ringwood, 1967) has also led to estimates of pressure of formation. The conditions of formation of certain sodium-poor eclogitic rocks, particularly those containing plagioclase as well as a pyrope-rich garnet, are still debatable. Livingstone (1967) recently presented new information on the eclogitic rocks of South Harris previously described by Davidson (1943); on the basis of the field association with garnet peridotites and the composition of the pyroxenes he suggested that the 'eclogite facies status' of these rocks must be reconsidered. In an account of the Sittampundi Complex in the Salem district of Madras, Subramaniam (1956) described eclogitic rocks with the assemblage garnet (pyrope–almandine)+clinopyroxene+orthopyroxene±plagioclase±amphibole, sometimes with scapolite and minor quartz or spinel. These 'eclogites' not only occur in a similar environment but also have many mineralogical and chemical characteristics in common with those from South Harris; many authors (e.g. O'Hara, 1960) have also expressed doubts about the eclogite-facies status of the Sittampundi rocks.

One of the rocks (ANU 3269) from the Sittampundi 'eclogite–gabbro series', kindly presented to the Australian National University by Dr. Subramaniam, was found to consist almost entirely of garnet and clinopyroxene. An analysis of this rock and its coexisting garnet and clinopyroxene are presented and probable conditions of formation of the Sittampundi eclogitic rocks are discussed.

Description and rock chemistry. The specimen consists of about equal proportions of bright pink garnet and pale green clinopyroxene each averaging 1·5–2 mm across. In

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thin section narrow rims of secondary amphibole with a very pale bluish-green colour are seen to surround many of the clinopyroxenes and this amphibole, along with plagioclase, forms strings of tiny granules along almost all grain boundaries. Small amounts of opaque mineral, green spinel, and sphene are confined to these intergrain aggregates. Chemical analysis (table I) shows that it is a basic rock with a relatively

TABLE I. *Analyses of Sittampundi 'eclogite' (3269) and its constituent garnet and clinopyroxene*

	1	2	3		4		5	
SiO_2	44·95	40·52	52·14	Si	2·981	3·000	1·892	2·000
TiO_2	0·47	0·02	0·08	Al^{iv}	0·019		0·108	
Al_2O_3	16·37	22·78	5·93	Al^{vi}	1·956		0·146	
Fe_2O_3	2·43	1·33	0·57	Ti	0·001	2·031	0·002	
FeO	9·45	15·72	3·94	Fe^{3+}	0·074		0·016	
MnO	0·18	0·29	0·04	Fe^{2+}	0·967		0·120	
MgO	13·94	13·80	14·92	Mn	0·018	2·962	0·001	2·017
CaO	11·50	5·72	21·46	Mg	1·526		0·807	
Na_2O	0·68	0·05	1·28	Ca	0·451		0·834	
K_2O	0·09	0·03	0·03	Na	—		0·090	
P_2O_5	0·01	0·01	0·02	K	—		0·001	
H_2O^+	0·30	—	—	*Garnet components* (mol %)				
H_2O^-	0·07	—	—					
CO_2	0·03	—	—	Pyrope	51·5			
				Almandine	32·7			
Total	100·47	100·27	100·41	Grossular	11·6			
				Andradite	3·6			
				Spessartite	0·6			

1. Garnet–clinopyroxene rock ('eclogite') from Sittampundi (A.N.U. Rock No. 3269).

2. Garnet from Sittampundi 'eclogite' (3269). The garnet has: Refractive index: measured $1·756\pm0·002$; calculated from Skinner's (1956) data 1·761. Cell edge: measured 11·547 Å; calculated 11·549.

3. Clinopyroxene from Sittampundi 'eclogite' (3269). α 1·679, β 1·683, γ 1·697; $2V_\gamma = 58\pm1°$. Dispersion $r > v$ moderate.

4 and 5. Structural formulae of garnet and pyroxene calculated on the basis of 12 and 6 oxygens respectively.

high Mg/Fe ratio and with exceptionally low alkali content. This is comparable with the South Harris data and consistent with Subramaniam's (1956) hypothesis that the Sittampundi eclogitic rocks are derived from metamorphosed cumulates (containing large amounts of olivine+calcic plagioclase) from a stratified basic complex.

All elements (except Na_2O, FeO, and H_2O) both in this rock and the minerals were determined by X-ray fluorescence spectrometry using the methods described by Norrish and Hutton (1969). Sodium was determined by flame photometry and water and ferrous iron by conventional methods.

Garnet. An analysis of garnet from the Sittampundi 'eclogite' is also given in table I. It is very rich in the pyrope component (51 %) and almost identical to the two previously analysed garnets from Sittampundi 'eclogites' (46 % and 55 % pyrope: Subramaniam, 1956).

Clinopyroxene. In thin section the pyroxene is colourless and resembles diopside in optical properties except for a characteristic dispersion ($r > v$, moderate). There is a fine schiller structure and parting parallel to (100), which appear to result from exsolution of both opaque rods and orthopyroxene. The analysis (table I) shows that it is high in aluminium compared with diopside but low in sodium compared with omphacite. Tschermak's component measured by aluminium in fourfold co-ordination (10·8 %) exceeds the amount of jadeite component (Na minus Fe^{3+} = 7·4 %). The corresponding values for the South Harris clinopyroxene are remarkably similar (Ts = 10·7 % and Jd = 8·6 % respectively).

Discussion

Garnet compositions in eclogites and granulites. It was chiefly the high pyrope content of the garnet that led Subramaniam (1956) to classify the Sittampundi rocks as eclogites. More recent work (e.g. O'Hara, 1961) showed that high-pyrope garnets may also occur in certain granulite facies rocks. A new compilation of garnet compositions from rocks of metamorphic granulite terrains (White, 1969) is graphically compared with compilations of garnet analyses from various eclogite types (from Lovering and White, 1969) in fig. 1. There is clearly a considerable overlap of the pyrope contents of garnets from granulites with those from eclogites. If the term eclogite is restricted to rocks of the eclogite facies, defined as a group of assemblages (clinopyroxene+garnet+quartz, clinopyroxene+garnet+kyanite, etc.) in which the clinopyroxene has a Jd/Ts ratio greater than 1, then this overlap is even greater since the eclogitic inclusions in basaltic breccias shown as group 4 in fig. 1 (garnet pyroxenites of Green, 1966, and fassaite eclogites of Lovering and White, 1969) have more in common with granulite-facies assemblages.

Clinopyroxene composition. White (1964) pointed out that the jadeite/Tschermak's-component ratio was greater than unity in clinopyroxenes of the eclogite facies but less than unity in granulite facies clinopyroxenes irrespective of the sodium content of the host rock. Both the Sittampundi and South Harris clinopyroxenes have Jd/Ts ratios just less than unity indicating that both crystallized at lower pressures than, but perhaps close to, the granulite–eclogite facies transition as defined by Green and Ringwood (1967) on the basis of the disappearance of plagioclase in a rock of quartz tholeiite composition.

The apparent distribution coefficient of iron and magnesium between garnet and clinopyroxene in eclogites has been shown (Banno and Matsui, 1965) to decrease from $K' = 14$ (average)[1] for garnet–clinopyroxene pairs from eclogites associated with glaucophane schists to $K' = 9$ for pairs from eclogites associated with amphibolites and $K' = 4{\cdot}2$ for clinopyroxene–garnet pairs from kimberlite eclogites. Although Banno and Matsui (1965) stated that both pressure and composition could have some effect

[1] New data indicate that this value is too low.

on the value of K', they pointed out that a theoretical decrease in K' with increasing temperature of equilibration was consistent with geological arguments for expected temperatures in these eclogite groups. Lovering and White (1969) also showed that

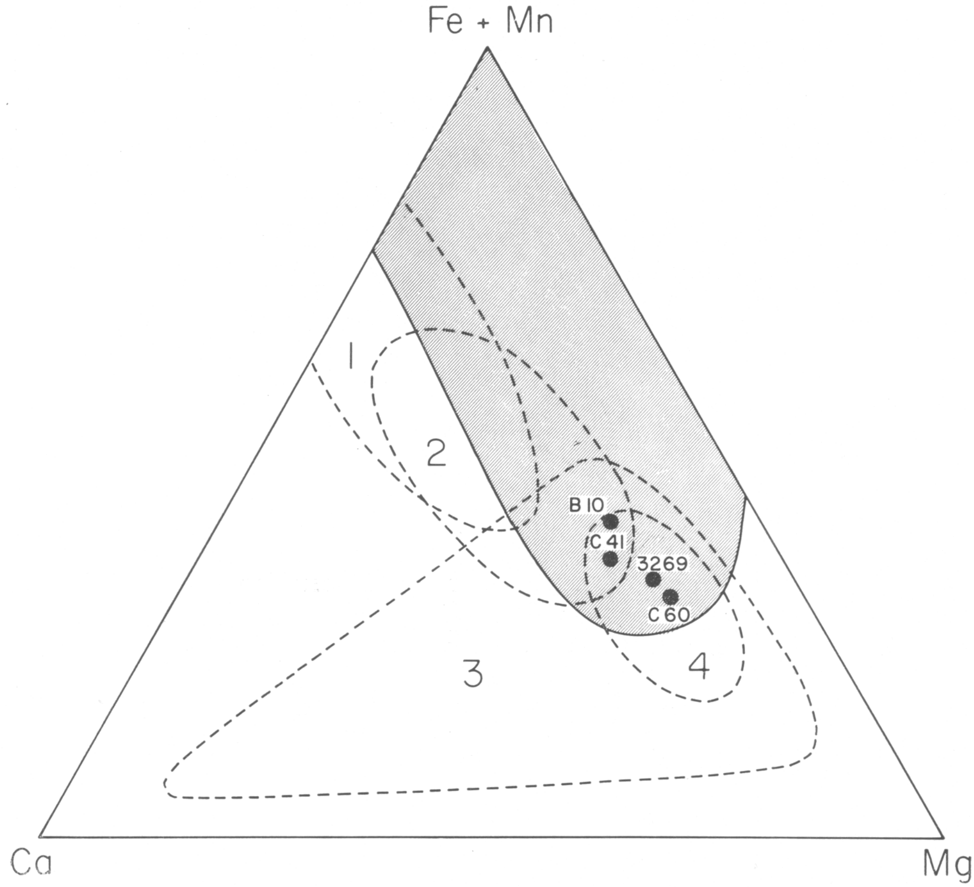

FIG. 1. Composition of garnets from the Sittampundi (3269, C41, C60) and South Harris (B10) 'eclogitic' rocks compared with the composition fields of garnets from eclogites and granulites shown in terms of atomic proportions of Fe+Mn (almandine+spessartine), Ca (grossular+andradite), and Mg (pyrope). Shaded area is the field of granulites of White (1969). Field 1, eclogites associated with glaucophane schists; field 2, eclogites from amphibolite facies terrains; field 3, eclogites from kimberlite pipes; field 4, eclogitic rocks (fassaite eclogites) from Delegate (Australia) and Salt Lake Crater (Hawaii) basaltic breccia pipes. Eclogite data from Lovering and White (1969).

the garnet–clinopyroxene pairs from eclogitic inclusions in basaltic breccias have even lower K' values ($K' < 2{\cdot}7$) consistent with a geological occurrence that suggests very high temperatures of equilibration; from this and other arguments they considered that both the Delegate (Australia) and Salt Lake Crater (Hawaii) inclusions crystallized at about 1100 °C. Garnet–clinopyroxene pairs from granulite-facies terrains showing gradations to amphibolites (Binns, 1962; Buddington, 1952; Kranck, 1961; Warnaars, 1967) have K' values between 6·0 and 7·8 (fig. 2). The temperature of equilibration for these granulites is at or above the estimated temperature for the

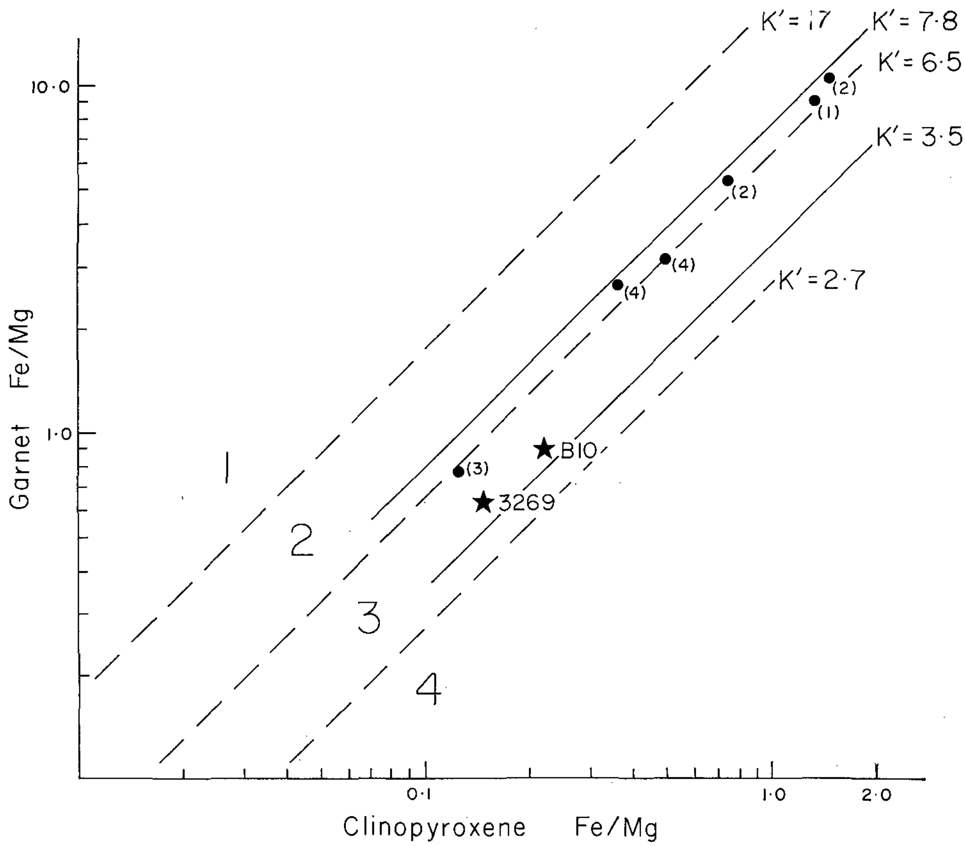

FIG. 2. Distribution of iron and magnesium between coexisting garnet and clinopyroxene for the Sittampundi 'eclogite' (3269) and South Harris 'eclogite' (B10). Fields bounded by dashed lines are: 1, eclogites associated with glaucophane schists; 2, eclogites from amphibolite terrains; 3, eclogites from kimberlites; 4, eclogitic rocks (fassaite eclogites) from basaltic breccias (Lovering and White, 1969). The field bounded by full lines is for granulites from metamorphic complexes (White, 1969). Small dots represent garnet–clinopyroxene pairs from granulites showing gradations to amphibolites. (1) Binns (1962), (2) Buddington (1952), (3) Kranck (1961), (4) Warnaars (1967).

upper limit of the amphibolite facies according to both geological occurrence and the K' values of eclogites associated with amphibolites. Turner (1968) estimates this temperature to be close on 700 °C.

The distribution relationships for coexisting garnet and clinopyroxene in the Sittampundi rock ($K' = 4{\cdot}3$) and the South Harris rock ($K' = 4{\cdot}0$) suggest that these have crystallized at temperatures between 700 and 1100 °C (fig. 2). A reasonable estimate is 850 °C.

Application of experimental data. Green and Ringwood (1967) showed experimentally that plagioclase disappeared at the expense of garnet and clinopyroxene at 1100 °C and 20 kb in a rock of quartz tholeiite composition, whereas in runs at 1100 °C on an alkali-poor olivine tholeiite with a composition similar to the Sittampundi rock plagioclase is very much reduced at 11·3 kb and could not be detected at 15·8 kb. If their data are projected down to about 850 °C plagioclase would be absent at about 7 or 8 kb. Since plagioclase is present in other Sittampundi eclogitic rocks this pressure estimate is considered to be close to the actual pressure of crystallization. At 850 °C, the pressure of the sillimanite–kyanite inversion is close to 11 kb (Richardson *et al.*, 1968) and hence our *P-T* estimate is consistent with the presence of sillimanite rather than kyanite in a pelitic xenolith in the Sittampundi complex.

The new data confirm the suggestion of Green and Ringwood (1967) that the Sittampundi 'eclogites' crystallized in their 'intermediate pressure' granulite field.

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