

*Feldspars and pyroxenes from the charnockite series of  
Visakhapatnam area, Andhra Pradesh, India<sup>1</sup>*

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*Summary.* A twin-law study of the plagioclase indicated metamorphic origin of the charnockites and volcanic origin of the basic members of the charnockite series. The original volcanic products have been influenced by the later metamorphism, resulting in the various basic members. The twinning in the plagioclase is considered to be primary. The perthite in the charnockite is of orthoclase variety and indicates a higher temperature of formation than the charnockites of other areas containing microcline. The orthopyroxene in the charnockite series is hypersthene and the clinopyroxene is sahlite. Hypersthene is inferred to have formed at the expense of sahlite, hornblende, biotite, and garnet.

AN area of about 190 square miles (between  $17^{\circ} 37\frac{1}{2}'$  and  $17^{\circ} 54'$  N. and between  $83^{\circ} 12'$  and  $83^{\circ} 29'$  E.) in the Visakhapatnam district has been geologically mapped. The charnockite series, khondalite series (garnet-sillimanite gneisses, garnet-biotite-sillimanite gneisses, quartzites, and garnetiferous quartzites), leptynites (quartz-feldspar-garnet-granulite), granites, and pegmatites are the various rock types noticed in the area. The garnet-sillimanite gneisses, quartzites, and garnetiferous quartzites cover about nine-tenths of the area and occupy mostly the hill ranges. The charnockite series of rocks, garnet-biotites, sillimanite gneisses, leptynites, granites, and pegmatites cover the rest of the area and occupy mostly the plains around Visakhapatnam. An interesting feature of the area is that the charnockite series of rocks are always closely associated with the leptynite and garnet-biotite-sillimanite gneiss.

The charnockite series include gabbro, norite, hornblende-norite, biotite-norite, and amphibolite in the basic division and charnockite (hypersthene-granulite) and garnetiferous charnockite in the acid division. Hereafter the rocks under the basic division are referred as basic members and the rocks under the acid division as charnockites. The basic members are black in colour, hard and compact and medium

<sup>1</sup> This forms a summary of part of the thesis accepted for the degree of Doctor of Science by the Andhra University, Waltair, in 1961.

to coarse-grained; the specific gravity varies from 2.95 to 3.3; they are characterized by the granulitic texture, and consist of ortho- and clinopyroxenes, plagioclase, hornblende, biotite, apatite, zircon, magnetite, ilmenite, chalcopyrite, and pyrite. The charnockites are dark grey in colour with greasy lustre and consist of quartz, perthite, plagioclase, and orthopyroxene as essentials and magnetite, apatite, zircon as the accessories, with or without garnet and sometimes monazite; both the feldspars and the quartz are grey.

The optical properties of the feldspars and pyroxenes were determined by the usual conventional methods on the Fedorov stage. The refractive indices were determined by the immersion method in sodium light and verified with the Abbe and Jelly refractometers. The  $2V$  and  $\gamma:[001]$  are within the accuracy range  $\pm 1^\circ$  and the indices are within the accuracy range  $\pm 0.001$ . The twin laws and anorthite content of the plagioclase were determined by Turner's method (1947). The alkalies of the pyroxenes were determined by the flame photometer and the rest of the constituents by the classical methods. Over 100 thin sections were examined out of which about 20 were chosen for the detailed study.

### *Feldspars*

The anorthite content of the *plagioclase* in the charnockites varies from 15 to 40 % and that in the basic members from 38 to 65 %. The distinction between the charnockites and the basic members is not based on the plagioclase composition, but on their field occurrence and on their appearance. Some of the grey greasy-coloured charnockites contain plagioclase of anorthite content as high as 40 %, whereas some of the black coloured basic members contain as little as 38 %.

The twin laws and compositions of the plagioclases are given in table I.

Albite twins are commonest and are present over the entire composition range, whereas the C twins are found in the andesine and labradorite range of the charnockite series. Coulson (1932), on the basis of statistical study, suggested that the occurrence of Albite-Ala twins is favoured in the plagioclase composition  $An_{30-35}$ , but in the charnockite series of Visakhapatnam, out of the four Albite-Ala twins recorded, two have  $An_{38}$ , one  $An_{40}$ , and one  $An_{53}$ .

Gorai (1951) divided the plagioclase grains from the petrological point of view into untwinned, A, and C twins. The twinned and untwinned plagioclase grains were counted separately on a mechanical

stage. In the charnockites, both potash feldspar and plagioclase are present, but the potash feldspar is always perthitic and so the plagioclase is easily recognized. Since only plagioclase is present in the basic members, the proportions of twinned and untwinned grains are determined without any difficulty.

Table I. Twin laws and compositions of the plagioclases  
(Twins bracketed are A type, the rest C type)

Twin laws	Anorthite content in %				Total
	15-25	26-35	36-50	51-65	
Manebach	1	—	—	—	1
(Albite)	3	6	10	3	22
(Pericline)	2	—	2	—	4
(Acline)	1	1	4	2	8
Ala	—	1	3	4	8
Carlsbad	—	1	4	2	7
Albite-Carlsbad	—	3	3	6	12
Albite-Ala	—	—	3	1	4
Total	7	12	29	18	66

TABLE II. Twins in the plagioclases of the charnockite series  
(U, Untwinned)

Twins	Charnockites		Basic members	
	Determined	in %	Determined	in %
U	21	30	8	20
A	20	37	14	34
C	13	24	19	46

On a triangular plot of U, A, and C (Gorai 1951), the plagioclase of the charnockites indicates metamorphic origin and that of the basic members volcanic origin. The position of the basic members on the plot, very close to the enclosed field, indicates that the original volcanic members were later influenced by the metamorphic process.

Twinning is well developed in the less granulated basic members. In the highly granulated charnockites, the lamellae are discontinuous, bent, broken, and less common, indicating that the twinning is not due to the external forces operating after crystallization. Hence the twinning is considered primary, that is, a function of crystal growth controlled by the geometry of the space lattice, as proposed by Donnay (1943).

*Perthite.* The potash feldspar in the charnockites is always perthitic. Over 90 % of the grains examined exhibit straight extinction; the rest, inclined extinction up to a maximum of 5° with the (010) cleavage trace.

Out of the 50 grains studied, 45 grains have  $2V_\alpha$  between  $54^\circ$  and  $70^\circ$  and the rest  $71^\circ$  to  $78^\circ$ . Spencer (1930) recorded a similar oblique extinction and  $2V_\alpha$  variation from  $68^\circ$  to  $73^\circ$  in orthoclase. Alling (1921) also observed oblique extinction up to  $3^\circ$  and attributed it to some soda in potash feldspar. Following Harker (1954), most of the potash feldspar grains examined are classed under orthoclase. This is confirmed by an X-ray diffraction pattern in which both the (130) and (131) reflections do not show resolution.

Following the nomenclature of Alling (1938), the blebs are classed into stringlets, strings, and rods; the average values of length and width of these blebs are 0.01 and 0.006 mm, 0.08 and 0.01 mm, and 0.05 and 0.02 mm respectively. Much coarser blebs (1 mm and 0.08 mm) are noticed in the perthites of some feldspathic segregations of the charnockites.

The plagioclase blebs are regularly oriented in the orthoclase host, and make an angle of  $73^\circ$  to  $84^\circ$  with the (010) cleavage. Most of the blebs have a higher refractive index than the host, whereas a few others are almost of the same index as the host. The blebs are never seen cutting across the margin of the host grain.

*Antiperthite.* Plagioclase forms the host for the potash feldspar in the antiperthite, which is very much minor in the charnockites as compared to perthites. The host is of oligoclase ( $An_{28}$ ) variety and is twinned on the albite law; and along the twin lamellae small blebs of orthoclase feldspar are present. In antiperthites also the blebs are always confined to the central portion of the body and are never found cutting across the margin of the host. The average proportion of the blebs is estimated at 25 % in perthite, and 10 % in antiperthite.

*Origin of perthitic texture.* Perthitic texture can originate by exsolution, by simultaneous crystallization, or by replacement. In the charnockites, the regular orientation and the absence of any cross-cutting relationship preclude the possibility of replacement origin; the gradational nature of the composition (inferred from varying index) of the blebs and the host (inferred from varying  $2V$ ) is more suggestive of exsolution rather than simultaneous crystallization (Alling, 1938).

*Significance of orthoclase perthite in the charnockites.* Holland (1900) and many others reported microcline in the charnockites of India. But the optical and X-ray studies of feldspars from the charnockites of Visakhapatnam show that the perthite is mostly of orthoclase type.

MacKenzie (1954) suggests that the ordering of Si and Al atoms depends on the chemical composition of the potash feldspar. If it contains

some soda, the ordering to microcline depends on the extent to which the exsolution of soda feldspar has proceeded. In some of the orthoclase perthite grains, the soda phase is in the form of blebs (about 20%) in the host. The X-ray study of a perthite shows that the host is monoclinic potash feldspar with about 3% soda phase in it. This indicates that the soda phase might not have any control in the ordering of Si and Al

TABLE III. Chemical analysis, atomic ratios to 6 oxygen, and physical properties of clinopyroxene

SiO <sub>2</sub>	48.93	Z	{ Si	1.876
Al <sub>2</sub> O <sub>3</sub>	3.69		{ Al	0.124
Fe <sub>2</sub> O <sub>3</sub>	2.58			
FeO	13.51		{ Al	0.042
MgO	9.18		{ Ti	0.009
CaO	21.48		{ Fe''	0.074
TiO <sub>2</sub>	0.34	WXY	{ Fe''	0.462
Na <sub>2</sub> O	0.29		{ Mg	0.528
			{ Ca	0.881
			{ Na	0.023
			{ K	—
	100.00		ΣWXY	2.019
α	1.693	Sp. gr.		3.38
β	1.698	En		28.3 %
γ	1.718	Fs		24.7
2V <sub>γ</sub>	58–62°	Wo		47.0
γ:[001]	38–44°			

atoms in the potash feldspar of charnockite of the Visakhapatnam area. Hence the presence of orthoclase perthite in these charnockites indicates that the temperature of the environment controlled its structural state; that is, the temperature was higher or the time allowed for ordering shorter than for the charnockites of areas containing mostly microcline.

*Pyroxenes* are the most important constituents of the charnockite series. Pleochroic orthopyroxene is present in both the charnockite and the basic members, whereas the clinopyroxene is mostly confined to the basic members.

Chemical analyses of the two orthopyroxenes together with optical data are reported elsewhere (Murty, 1964); they work out at  $En_{48.6}Fs_{48.3}Wo_{3.1}$  and  $En_{47.0}Fs_{42.8}Wo_{9.2}$ . The analysis of the clinopyroxene and its physical properties are reported in Table III.

The *orthopyroxene* from the charnockite falls in the hypersthene field and that from the norite in the pigeonites in the classification of Hess and Phillips (1940). The analysis of the pyroxene from the norite is comparable in its CaO content to the hypersthene inverted from pigeonites

(Bushveld type, Hess 1941), but is more ferri-ferous and aluminous than the Bushveld pyroxenes. Crookshank (1938) and Groves (1935) observed aluminous hypersthene in the charnockites from Eastern Ghats and Uganda respectively. It is probable that the hypersthene is inverted from the pigeonite.

In some of the hypersthene grains of the charnockites and more commonly in those of the basic members, fine lamellae are noticed; these are not as fine, as close, as those of the Bushveld orthopyroxenes.

The stronger pleochroism and higher refractive indices noticed in the orthopyroxene of the norite than in that of the charnockite are due to the higher amounts of  $\text{TiO}_2$  present in it (Murty, 1964).

*Anomalous extinction* has been noted by several investigators, but none seem to have given a very satisfactory explanation. Sriramadas (1956) reported pyroxenes with pleochroism  $\alpha$  pink,  $\beta$  colourless, and  $\gamma$  green, with  $\gamma$ : $[001]$  varying from  $1^\circ$  to  $22^\circ$  and negative sign and grouped them as a distinct division between the orthopyroxenes and the clinopyroxenes. In the present investigation also anomalous extinction up to  $24^\circ$  was noted. This extinction is considered to be due to the replacement of Mg by Ca. The entrance of Ca in the sites of Mg in the pyroxenes may affect their symmetry. The writer has arrived at this conclusion because the orthopyroxenes of both the rocks contain more CaO than is normally present in orthopyroxenes. This excess CaO cannot be attributed to impurity or analytical error as the purity of the material was tested under the microscope and repeated analyses gave consistent results. If the excess CaO is due to the fine lamellae present in the orthopyroxenes, the explanation of Hess and Phillips (1938) appears possible.

*Clinopyroxene.* The analytical and optical data of the clinopyroxene indicate that it is sahlite. Some lamellae are present, and are thicker than those present in the hypersthene.

*Coexisting ortho- and clinopyroxenes.* The tie line drawn between the composition of the orthopyroxene (from  $\gamma$  1.718) and the clinopyroxene ( $\beta$  1.695 and  $2V_\gamma$   $56^\circ$ ) meets the En-Wo line at 78% Wo, which is within the range of Hess' (1941) values of 70-80% Wo for the coexisting ortho- and clinopyroxenes formed by mafic magmas. Muir and Tilley (1958) have pointed out a similar relationship for the coexisting pyroxenes in the metamorphic assemblages. So, on the basis of tie-line values, a distinction of pyroxenes from mafic magmas from that of metamorphic pyroxenes may not be possible.

*Paragenesis.* In the amphibolite, hypersthene is found surrounding completely some of the hornblende grains, indicating its secondary

nature. In other basic members also, hypersthene is found to be secondary to sahlite and biotite. It has already been reported that the gabbro and the norites are derived from the amphibolite during the pro-grade metamorphism and this amphibolite is the result of the original basic volcanic rock (Murty, 1962). In the amphibolite, the formation of sahlite and hornblende have the effect of reducing the calcium content in the residuum, with result that the later-forming plagioclase is more acidic; on the other hand the formation of hypersthene from sahlite and hornblende makes the plagioclase more calcic. This is seen clearly from the average plagioclase composition  $An_{45}$  in the amphibolite and  $An_{55}$  in the other basic members. The confinement of the iron ore inclusions to the sahlite leaving a clear halo indicates that they are exsolved from the sahlite during its formation.

It was recorded earlier that the charnockite series of rocks are associated with the leptynite and garnet-biotite-sillimanite gneiss. The leptynite is a recrystallized form of the gneiss, the biotite in the gneiss giving rise to the garnet. With the further rise in the metamorphic intensity the more stable hypersthene is found at the expense of the garnet. This is seen from the close association of hypersthene with garnet in the charnockite. Thus, the charnockite, leptynite, and gneiss are closely genetically related.

The aluminous nature of the hypersthene may be due to its formation from aluminium-bearing minerals like hornblende, biotite, and garnet.

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