MINERALOGICAL MAGAZINE, SEPTEMBER 1974, VOL. 39, PP. 807–10

Minerals from the charnockite series of Amaravathi, Andhra Pradesh, South India

A. RAMASWAMY, Ph.D., AND M. S. MURTY, D.Sc.

Department of Geology, S.V. University, Tirupati, South India

SUMMARY. The potash feldspar in the charnockites is orthoclase and they are inferred to have been formed around 700 °C. A twin-law study of the plagioclase indicates an igneous origin of the charnockites and pyroxene granulites. The K_D values of the coexisting pyroxenes in the granulites are appropriate to equilibrium at 670 °C. A substantial substitution of Al for Si in the Z group in all mafic minerals studied also indicates relatively high temperatures of formation. Almandine is pyrope-rich, a result of high pressure. The charnockites and pyroxene granulites are inferred to be formed under conditions of high pressure and temperature.

THE Amaravathi area (16° 20′–16° 35′ N., 80° 21′–80° 28′ E.) is a part of the high-grade metamorphic terrain of the Eastern Ghats in Andhra Pradesh. In this area there are rocks of the khondalite and charnockite series, granites, and dolerites. The charnockite series is represented by gabbro, hornblende gabbro, biotite gabbro, norite, hornblende norite, garnetiferous hornblende norite, biotite norite, and garnetiferous biotite norite in the basic division (pyroxene granulites) and by granitic, syenitic, granodioritic, and dioritic types in the acid division (charnockites). The field relations indicate that the khondalite series of rocks and the pyroxene granulite are the basement rocks into which charnockites, granites, and dolerites were successively emplaced. The present paper deals with the mineralogy of the charnockite series.

The bluish-grey colour of the *quartz* together with the greenish-blue colour of feldspars makes the charnockite look more basic than it actually is. A satisfactory explanation to the colour of the quartz is yet to be found, although some attribute it to the randomly oriented inclusions and some to some chemical element such as titanium.

Potash feldspar is untwinned and invariably perthitic. Of 100 extinction-angle measurements, over 80 % of the grains exhibit straight extinction and the rest oblique extinction up to a maximum of 3° with the (010) cleavage trace on (001). 125 out of 150 grains have 2Vα 50 to 65° indicating orthoclase (Harker, 1954) and only 25 have 2Vα 66 to 78° indicating transitional microcline.

Five representative samples of potash feldspar from Amaravathi, two each from Kondapalli and Chimakurti (all areas in the Eastern Ghats) were X-rayed; none showed any separation of the 131 and 130 reflections, indicating zero obliquity. Murty (1965) has also shown the potash feldspar of Visakhapatnam (in the Eastern Ghats) to be orthoclase. These studies prove that the potash feldspar from the charnockites not only of Amaravathi, but of part if not the entire region of the Eastern Ghats is orthoclase. Nevertheless in the type Madras area it is microcline. In the light of these observations, Naidu's (1954) contention that the potash feldspar of the Indian charnockites is exclusively microcline is incorrect. Ordering of Si and Al atoms in potash feldspar begins (Laves, 1952) below 700 °C indicating that the orthoclase-bearing charnockite is formed around that temperature.

The plagioclase blebs in perthite are very fine and have regular orientation; the blebs are mostly strings, stringlets, and rods and scarcely vein and patch-types; they are confined to the core of the host and are more acidic (An_{10-20}) than the normal plagioclase (An_{25-40}) that occurs as individual grains. These features indicate the exsolution origin of the perthites.

The composition of the perthite, from the chemical analysis (Table I), is $Or_{69\cdot7}Ab_{27\cdot8}An_{2\cdot5}$; this gives a host to bleb ratio 70:30 (if Or has little Ab phase), which is close to the value 75:25 of exsolution perthites.

The anorthite content and twin laws of the *plagioclase* were determined with a 4-axis universal stage. The anorthite content of the plagioclase varies from 25 to 40 % in the charnockite and from 40 to 68 % in the pyroxene granulite; chemical analysis give $Or_{1\cdot7}Ab_{45\cdot2}An_{53\cdot1}$ for plagioclase in the norite and $Or_{3\cdot9}Ab_{31\cdot7}An_{64\cdot4}$ for that in the gabbro.

Untwinned plagioclase grains are scarce in the charnockite series; of 29 twins in charnockites 13 are Albite-Ala, 8 Albite, 5 Manebach, 2 Carlsbad, and 1 Pericline. Of 81 twins in pyroxene granulites 40 are Albite, 28 Manebach, 6 Albite-Ala, 4 Albite-Carlsbad, and 3 Carlbad. The paucity of untwinned plagioclase grains together with the dominance of *C* twins over *A* twins is, according to Gorai (1951), indicative of igneous origin for both charnockites and pyroxene granulites.

A detailed account of the *pyroxene* of the charnockite series in the Amaravathi area is given by Ramaswamy and Murty (1973*a*). The orthopyroxenes in the charnockites are in the Fs_{30-50} and those in the pyroxene granulites are in the range Fs_{35-60}. The clinopyroxenes are in the sahlite range and have the granulitic trend on a Wo–En–Fs plot. The tie-line projections and the distribution coefficient of magnesium and iron (K_D) values for the pyroxene pairs indicate conditions of chemical equilibrium around 670 °C.

Hornblende is confined to the pyroxene granulites. Two types are noted: a dominant primary brown variety and a green variety, secondary after pyroxene. The chemical analyses and optical properties for two brown hornblendes are given in Table I. The ratio of Na+K to tetrahedral Al is about $\frac{1}{2}$ as would be consistent with a pargasite-like substitution. The substitution of Al for Si in the *Z* group indicates relatively high temperatures; and the high temperature, with a parent material low in water may be the cause for the formation of this mineral.

Unlike hornblende, *biotite* is noted in variable quantities in the entire charnockite series; the maximum is present in the garnetiferous varieties (garnetiferous charnockite contains 12 % and garnetiferous biotite norite 21·7 % modal biotite). It is pleochroic in light to dark shades of brown and has $\gamma = 1{\cdot}643$ and $\gamma - \alpha = 0{\cdot}048$, indicating a composition with about equal amounts of iron and magnesium (Winchell, 1956).

The presence of *garnet* in the proximity of pelitic gneiss (khondalite) inclusions in the charnockite and its absence away from them is a clear indication that the garnet

TABLE I. *Chemical analyses and optical properties of minerals of the charnockite series*

	1	2	3	4	5	6
SiO_2	64·65	54·62	52·10	41·50	41·70	37·37
Al_2O_3	19·70	29·12	30·43	12·08	11·49	21·34
TiO_2	—	—	—	0·94	1·94	0·03
Fe_2O_3	0·10	0·22	0·26	2·77	3·15	0·88
FeO	0·07	0·11	0·09	16·40	14·92	32·40
MnO	—	—	—	0·14	0·12	0·93
MgO	0·16	0·04	0·03	11·32	10·67	5·08
CaO	0·48	10·50	12·82	10·76	11·75	1·86
Na_2O	3·23	5·28	3·68	1·54	1·75	0·06
K_2O	11·64	0·34	0·67	1·62	1·43	0·11
H_2O	—	—	—	1·20	1·04	0·05
Total	100·03	100·23	100·08	100·27	99·96	100·11
Number of metal atoms on the basis of 24 oxygens:						
Si	8·839	7·391	7·103	6·314	6·359	5·938
Al^{iv}	3·167	4·630	4·876	1·686	1·641	0·062
Al^{vi}	—	—	—	0·486	0·426	3·922
Ti	—	—	—	0·100	0·220	—
Fe^{3+}	0·016	0·016	0·033	0·329	0·366	0·114
Fe^{2+}	0·008	0·008	0·008	2·080	1·894	4·288
Mn	—	—	—	0·009	0·009	0·124
Mg	0·033	—	—	2·582	2·443	1·210
Ca	0·074	1·527	1·874	1·761	1·931	0·324
Na	0·853	1·380	0·982	0·438	0·531	0·038
K	2·018	0·049	0·115	0·310	0·275	0·020
OH	—	—	—	1·223	1·024	—
Z	12·006	12·021	11·979	8·000	8·000	6·000
Optical data:						
$2V\alpha$	56–66°	93–98°	97–100°	69°	64–66°	—
β	—	—	—	1·679	1·676	—
γ	1·532	1·562	1·564	—	—	—
$\gamma-\alpha$	0·006	0·007	0·008	0·020	0·019	—
γ:[001]	—	—	—	19–21°	17–19°	—

1. Perthite from granitic charnockite.
2 and 3. Plagioclase from norite and biotite gabbro respectively.
4 and 5. Hornblende from hornblende gabbro and garnetiferous hornblende norite respectively.
6. Garnet from garnetiferous granitic charnockite.
All the samples are from the quarries of Tadikonda–Amaravathi area. Analyst: A. Ramaswamy.

formation is linked with the inclusions. The charnockite during its crystallization from melt may have assimilated the gneiss material, thus providing suitable bulk composition for the formation of garnet among others.

The analysed garnet from charnockite has a composition $Alm_{72\cdot2}Py_{20\cdot3}Gr_{2\cdot5}And_{2\cdot9}Sp_{2\cdot1}$. Oliver (1964) has shown that granulite-facies garnets are richer in pyrope than amphibolite-facies ones and Chinner (1962) is of the view that high pressure may be responsible for the increase of pyrope in garnet.

Conclusions. The field relations, petrography, and chemistry of the charnockite series, presented elsewhere (Ramaswamy and Murty, 1973*b*), and the mineralogical evidence presented here show that the charnockites and pyroxene granulites are formed under conditions of high pressure and temperature.

Acknowledgements. The authors thank Professor M. G. Chakrapani Naidu for providing the facilities to carry out this work. Ramaswamy greatly acknowledges the financial assistance of the C.S.I.R.

REFERENCES

CHINNER (G. A.), 1962. *Journ. Petrology*, **3**, 316–40.
GORAI (M.), 1951. *Amer. Min.* **36**, 884–902.
HARKER (R. I.), 1954. *Geol. Mag.* **91**, 129.
LAVES (F.), 1952. *Journ. Geol.* **60**, 549–74.
MURTY (M. S.), 1965. *Min. Mag.* **35**, 393–400.
NAIDU (P. R. J.), 1954. *Schweiz. Min. Petr. Mitt.* **34**, Heft. 2.
OLIVER (R. L.), 1964. *22nd Int. Geol. Congr. Sect.* **13**, 59–78.
RAMASWAMY (A.) and MURTY (M. S.), 1973*a*. *Min. Mag.* **39**, 74–7.
—— —— 1973*b*. *Geol. Mag.* **110**, 171–84.
WINCHELL (A. N.), 1956. *Elements of Optical Mineralogy*, Pt. 2, 551.

[*Manuscript received 12 November 1973; revised 28 January 1974.*]