MINERALOGICAL MAGAZINE, DECEMBER 1969, VOL. 37, NO. 288

# Porphyritic plagioclase–hornblende–pyroxene granulite from charnockitic rocks of Chipurupalli, Visakhapatnam district, Andhra Pradesh, South India

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SUMMARY. An unusual occurrence of porphyritic plagioclase–hornblende–pyroxene granulite (porphyritic basic charnockite) has been observed within the 'Charnockite region' of the Eastern Ghats of the Precambrian formations of India. From the X-ray and chemical data the phenocrysts are considered to be augite phenocrysts. Based on petrographic and chemical evidence it is inferred that the basic charnockites of Chipurupalli area in Visakhapatnam district are formed from tholeiitic magma as a gabbroic mass under deep seated plutonic conditions. The gabbroic mass has been recrystallized as plagioclase–hornblende–pyroxene granulite due to later metamorphism, leaving most of the phenocrysts unaffected.

AN unusual occurrence of porphyritic plagioclase–hornblende–pyroxene granulites—referred to in this text as porphyritic basic charnockites—has been observed for the first time by one of the authors (K. S. R. Rao) near Chipurupalli in Visakhapatnam district, Andhra Pradesh. This falls within the 'Charnockite region' of Eastern Ghats of the Precambrian formations of India (Fermor, 1936). The porphyritic basic charnockites occur as concordant layers in quartz–feldspar–garnet–sillimanite gneisses of the area (fig. 1). The only reported occurrence of porphyritic basic charnockite is the one by Sampat Iyengar from Mysore State (as quoted by Pichamuthu, 1953). These basic rocks are considered to be hypersthene porphyries. The porphyritic basic charnockites located at three places around Chipurupalli are characterized by augite phenocrysts with exsolution lamellae of pigeonite and irregular masses of orthopyroxene, which feature has not been reported earlier from any of the charnockite terrains.

The purpose of the present paper is to discuss the chemistry and origin of the porphyritic basic charnockites with special reference to their augite phenocrysts.

*Field relations.* The porphyritic basic charnockites are most prominently noticed as variation of basic charnockites on a small hillock two miles north-north-east of Chipurupalli. Small exposures of similar rock types are also recognized four furlongs east of Chipurupalli in a stream cutting, and one mile south-east of the same village. The basic charnockites are interbedded with quartz–feldspar–garnet–sillimanite gneisses (paragneisses). They occur as lens-shaped or irregular bodies, which range in size from 8 to 100 ft in width. Although these occur as detached outcrops within the paragneisses, it can be concluded from the well cuttings that they form continuous sill-like bodies in the paragneisses.

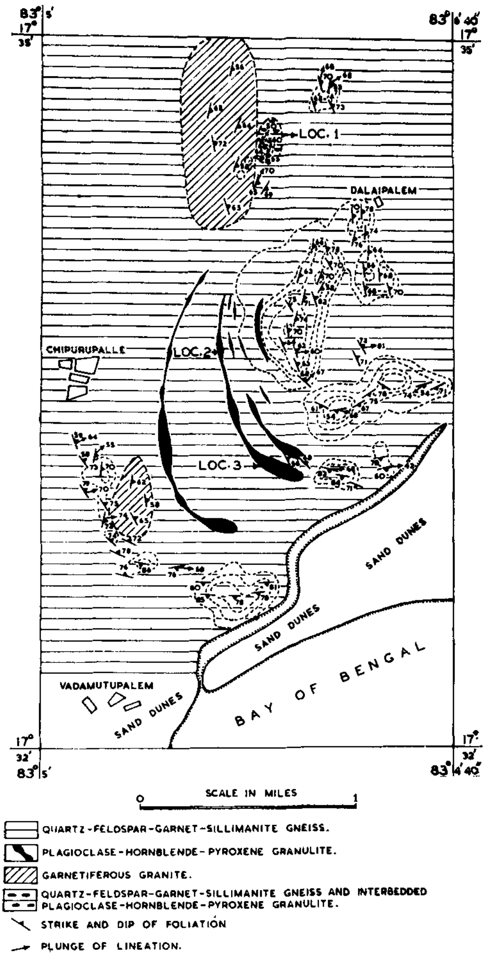


FIG. 1. Geological map of the Chipurupalli area.

The strike of foliation of the associated paragneisses changes from N. 85° E. through E.–W. to N. 70° W. and again swings to N. 10° E. at the furthest exposure in the north. From the relation of the trend of the outcrops to the foliation of the paragneisses, it is evident that the basic charnockites have been involved in the same deformations as the paragneisses. Foliation is generally absent in the former, but is discernible in a few outcrops. Direct contact between the paragneisses and the basic charnockites is rare; there are only two localities where direct contact is exposed in the stream cuttings, this being very sharp.

*Petrography and mineralogy.* In hand specimen the porphyritic basic charnockite consists of augite phenocrysts with bronze lustre in a groundmass of dark green augite, black hornblende, orthopyroxene, and plagioclase. The groundmass is granulitic in texture. The phenocrysts vary in length from 1 to 4 cm and in breadth from 0·5 to 2·5 cm (fig. 2, A and B). Some of the phenocrysts show fractures across the prismatic cleavage planes that are filled up by the groundmass mineral assemblage.

Microscopically, the orthopyroxene is prismatic to anhedral and augite is subhedral to anhedral in the groundmass. The two pyroxenes show wavy extinction and bent cleavages as evidence of strain. The plagioclase is clear and fresh, showing bending of cleavages and twin lamellae. The hornblende occurs as embayed grains, often intimately associated with the pyroxenes. Iron ore inclusions are present along the cleavages of hornblende.

Table I shows the porphyritic basic charnockite analysis, norm and mode (groundmass, vol %) along with two basic charnockite analyses from other areas, to which the present rock is similar chemically.

A specimen was taken from locality 1 (fig. 1) for the detailed optical and chemical studies; the augite phenocryst was collected in the field from the same outcrop and care was exercised that the phenocryst was not contaminated with groundmass pyroxenes. The phenocryst was crushed to −80 to +100 mesh size (ASTM) and the enclosed plagioclase and magnetite grains removed by using a Frantz Isodynamic Separator. The phenocryst with exsolved lamellae and minor acicular needles of

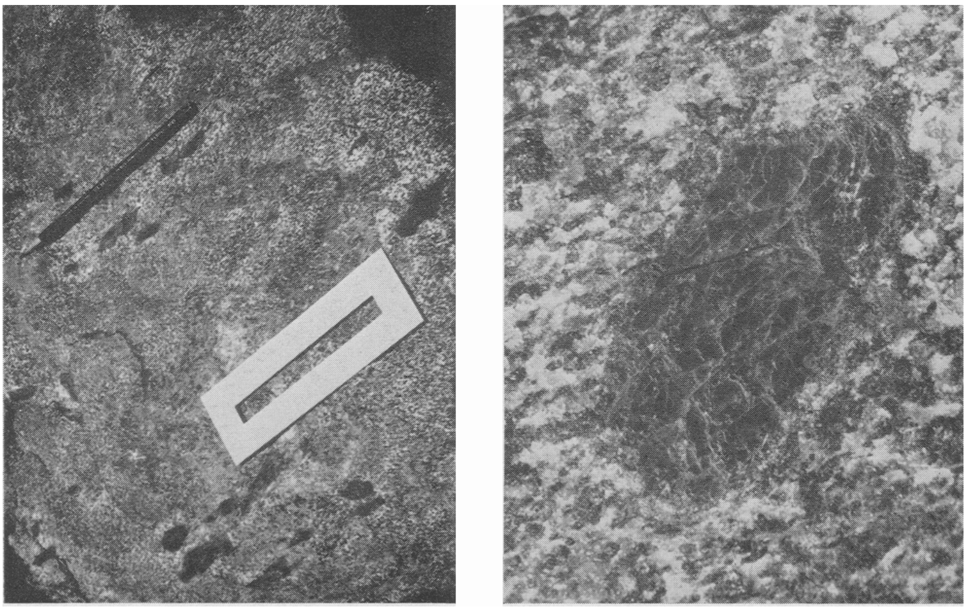

FIG. 2. A (left), porphyritic basic charnockite with augite phenocrysts. B (right), close-up view of an augite phenocryst.

hornblende was analysed chemically, and an X-ray diffraction pattern was taken with Cu-$K\alpha$ radiation at a scanning speed of $1^{\circ}$/minute. The groundmass pyroxenes, hornblende, and plagioclase were also separated with the aid of the isodynamic separator followed by hand-picking and heavy-liquid separation using bromoform and methylene iodide. The final purity of the minerals was 99·5 %. The refractive indices were determined by immersion methods; maximum possible error of the index determination is expected to be $\pm 0{\cdot}002$.

The augite *phenocrysts* display complex exsolution texture. They contain exsolution lamellae of pigeonite and also irregular masses of orthopyroxene. It is not possible to measure the proportion of exsolution lamellae of either pigeonite or orthopyroxene, as the phenocrysts are strained. The determination of the orientation of the exsolution lamellae and their optical properties was impracticable. Small irregular flakes of non-pleochroic biotite are present in the phenocrysts. Fine acicular needles of hornblende are also developed along the cleavages, indicating its secondary origin. The phenocrysts are characterized by corroded outer margins. The cell dimensions of the augite phenocryst are *a* 9·747, *b* 8·930, *c* 5·243 Å, $\beta$ 74° 11′.

In *the groundmass*, augite is non-pleochroic, with $\alpha$ 1·696, $\beta$ 1·702, $\gamma$ 1·725; 2V varies from 53° to 54° and $\gamma \wedge [001]$ from 40° to 42°. Ferrohypersthene is pleochroic with $\alpha$ 1·718, pale pink, $\beta$ 1·730, colourless, and $\gamma$ 1·734, pale green; $2V_\alpha$ varies from 53° to 54°, and $\gamma \wedge [001]$ from 0° to 5°. Ferrohypersthene forms rims at the outer margin

TABLE I. *Analysis of a porphyritic basic charnockite from Chipurupalli, compared with some other basic charnockites*

| | 1 | 2 | 3 | Norm of 1 | | Mode of 1 | |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47·65 | 48·50 | 47·88 | or | 1·11 | Plagioclase | 46·18 |
| $Al_2O_3$ | 14·16 | 14·88 | 14·22 | ab | 13·62 | Hornblende | 23·36 |
| $Fe_2O_3$ | 1·69 | 2·38 | 1·73 | an | 30·58 | Augite | 18·65 |
| FeO | 13·92 | 11·48 | 12·36 | di | 22·22 | Ferrohypersthene | 10·22 |
| MnO | 0·21 | 0·23 | — | hy | 20·92 | Magnetite | 1·50 |
| MgO | 7·08 | 8·66 | 6·35 | ol | 5·64 | Apatite | 0·10 |
| CaO | 11·85 | 9·44 | 10·23 | mt | 2·55 | | |
| $Na_2O$ | 1·56 | 2·01 | 2·47 | il | 2·89 | | |
| $K_2O$ | 0·23 | 0·34 | 0·51 | ap | 0·67 | | |
| $TiO_2$ | 1·49 | 1·18 | 2·95 | | | | |
| $P_2O_5$ | 0·32 | 0·21 | 0·40 | | | | |
| $H_2O^+$ | 0·31 | 0·38 | 0·23 | | | | |
| $H_2O^-$ | 0·05 | 0·15 | 0·07 | | | | |
| Total | 100·52 | 99·84 | 99·40 | | | | |

1. Porphyritic basic charnockite, Chipurupalli. Analyst: K. S. R. Rao.
2. Norite (basic charnockite), Nagarmalai, Salem, Madras (Howie, 1955).
3. Plagioclase–hornblende–pyroxene granulite, Bunker Bay, Western Australia (Prider, 1945).

of the augite and the reverse phenomenon is not uncommon; the composition inferred from the analysis is Fs 54·9. Hornblende is the prominent mafic constituent of the porphyritic basic charnockite; it is pleochroic with $\alpha$ light yellow, $\beta$ dark brown, and $\gamma$ dark yellowish-brown, $2V_\alpha$ 78–82° and $\gamma \wedge [001]$ 12–18°. The refractive indices are $\alpha$ 1·688, $\beta$ 1·702, $\gamma$ 1·712. The hornblende is hastingsite in composition as inferred from the chemical analysis (unpublished data). Plagioclases are medium grained and mostly devoid of twinning and show variation in optic axial angles from $2V_\alpha$ 82° to 88° or $2V_\alpha$ 86° to 88°; $\beta$ is around 1·570. The range of composition determined in thin section by means of twin laws, albite, albite ala-B is 68–76 % anorthite. The composition indicated from partial chemical analysis of the plagioclase is bytownite with 72·1 % anorthite content.

The chemical analyses and structural formulae of the augite phenocryst, groundmass augite, ferrohypersthene, and plagioclase are given in table II.

Comparison of the augite phenocryst and the groundmass pyroxenes shows slight variations in the principal cations Ca, Mg, Fe, and Al. Al decreases from augite phenocryst to groundmass augite and ferrohypersthene both in tetrahedral and octahedral positions. Generally the major variation in the composition of the pyroxenes during fractionation is the enrichment of Fe at the expense of Mg and this may be accompanied by small variation in Ca also. It may be clearly seen from the above table that FeO is more and CaO and MgO less in the augite phenocryst than in the groundmass augite. This apparent inverse relation may be either due to the presence of exsolution lamellae in the augite phenocryst or recrystallization of groundmass

TABLE II. *Chemical data for pyroxenes and feldspar from porphyritic basic charnockite, Chipurupalli. Anal. K. S. R. Rao*

| | 1 | 2 | 3 | 4 | | 1a | 2a | 3a | 4a |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49·08 | 50·38 | 50·12 | 49·26 | Si | 1·893 | 1·921 | 1·960 | 9·048 |
| $Al_2O_3$ | 4·38 | 2·96 | 1·28 | 32·16 | $Al^{iv}$ | 0·107 | 0·079 | 0·040 | 6·963 |
| $Fe_2O_3$ | 0·96 | 1·52 | 1·23 | 0·06 | $Al^{vi}$ | 0·092 | 0·054 | 0·019 | — |
| FeO | 14·41 | 12·68 | 31·45 | — | $Fe'''$ | 0·028 | 0·043 | 0·035 | 0·011 |
| MnO | 0·27 | 0·31 | 0·38 | — | $Fe''$ | 0·457 | 0·404 | 1·028 | — |
| MgO | 10·44 | 11·04 | 15·03 | — | Mn | 0·009 | 0·010 | 0·013 | — |
| CaO | 18·62 | 20·19 | 0·27 | 14·64 | Mg | 0·598 | 0·627 | 0·875 | — |
| $Na_2O$ | 0·36 | 0·24 | 0·09 | 2·96 | Ca | 0·769 | 0·824 | 0·012 | 2·880 |
| $K_2O$ | 0·12 | 0·18 | 0·05 | 0·25 | Na | 0·028 | 0·018 | 0·007 | 1·059 |
| $Cr_2O_3$ | 0·05 | 0·04 | — | — | K | 0·005 | 0·009 | 0·002 | 0·055 |
| $TiO_2$ | 0·30 | 0·22 | 0·14 | — | Cr | 0·002 | 0·002 | — | — |
| $H_2O^+$ | 0·36 | 0·28 | 0·08 | — | Ti | 0·009 | 0·007 | 0·005 | — |
| $H_2O^-$ | 0·12 | 0·10 | 0·04 | — | *Z* | 2·00 | 2·00 | 2·00 | 16·02 |
| Total | 99·47 | 100·14 | 100·16 | 99·33 | *XY* | 1·997 | 1·998 | 1·996 | 3·994 |
| | | | | | Ca | 41·3 | 43·1 | 0·5 | An 72·1 |
| | | | | | Mg | 32·2 | 32·9 | 44·6 | Ab 26·5 |
| | | | | | Fe | 26·5 | 24·0 | 54·9 | Or 1·4 |

1. Augite phenocryst. 2. Groundmass augite. 3. Ferrohypersthene. 4. Bytownite.
1a, 2a, 3a. Ionic ratios on a basis of 6 oxygen. 4a. Ionic ratios on a basis of 32 oxygen.

augite during metamorphism. The clinopyroxene with exsolution lamellae of orthopyroxene (23 %) from Skaergaard intrusion (Muir, 1951) has almost the same composition as that of the augite phenocryst described here, except for the higher content of MgO.

Based on the chemical analysis the phenocryst is considered to be augite and this has been confirmed by X-ray study of the phenocryst. Poldervaart and Hess (1951) showed that particular exsolution textures in the pyroxenes are connected with various stages of fractionation of a basaltic magma. Although the order of crystallization is difficult to determine as the groundmass pyroxenes were recrystallized during metamorphism, the exsolution texture present in the augite phenocrysts might be closely related to the cooling history of the magma that has given rise to the basic charnockites. The exsolution lamellae present in the augite phenocrysts must be either orthopyroxene lamellae parallel to (100) or pigeonite parallel to (001) (Poldervaart and Hess, 1951); but, owing to the strain effects observed here the orientation of the lamellae could not be determined. Poldervaart and Hess (1951) have stated that the Mg-rich augite crystallizes first with exsolution lamellae of orthopyroxene parallel to (100) in the crystallization of pyroxene during fractionation; on further fractionation Fe-rich augite, approximately $Ca_{41}Mg_{44}Fe_{15}$, crystallizes above the pigeonite–orthopyroxene inversion temperature, with exsolved lamellae of pigeonite parallel to (001). In the light of the above, it is presumed that the exsolution lamellae present in the augite phenocryst might be pigeonite, as the phenocryst is iron-rich augite. The irregular mass of orthopyroxene is considered to have been formed during further fractionation of the magma.

*Petrogenesis.* From the structural concordance and the parallelism of the basic charnockites within the paragneisses, one may be tempted to consider the porphyritic basic charnockites as of sedimentary origin or as syntectonic basic intrusives. However, the crystallization of augite phenocrysts with exsolution lamellae of pigeonite strongly suggests an igneous origin for the basic charnockites. The petrographic and chemical evidence does not indicate their derivation either by differentiation of a charnockite magma (Holland, 1900) or from noritic parental magma (Naidu, 1963). The association of two pyroxene phases is considered to be characteristic of tholeiitic magma affinity (Deer *et al.*, 1963), and hence in this area the porphyritic basic charnockites are inferred to have been derived from tholeiitic magma. According to Kuno (1955) the presence of a considerable amount of aluminium in the augite phenocryst indicates affinity to tholeiitic magma.

Subramaniam (1959) considered the basic division of the charnockites as norites and basic granulites (derived mostly from norites and gabbros), which are syntectonic intrusives and basement rocks respectively. Sen (1967) presented strong evidence that the basic charnockites (pyroxene granulites) are derived by metamorphic convergence at granulite facies from cafemic sediments and norites. Narayanaswamy and Lakshmi (1967) described the basic charnockites from Tinnevelly and considered them to have been formed from metamorphism of basaltic lava flows or sheets associated with geosynclinal sedimentation. Murty (1961) ascribed the basic charnockites from Visakhapatnam as metamorphic derivatives from volcanics or dolomitic sediments. In the present area the augite phenocrysts with exsolution lamellae of pigeonite and orthopyroxene, characteristic of plutonic crystallization (Poldervaart and Hess, 1951), indicate that the basic charnockites might have crystallized as a gabbroic mass from tholeiitic magma under deep-seated plutonic conditions. Tyrrell (1916) and Groves (1935) have already envisaged the transformation of certain plutonic igneous masses into granulites by later metamorphism. Howie (1955) described the charnockite series from Madras type area as plutonic igneous rocks that have been subsequently metamorphosed in the solid state under plutonic conditions. In this area also the gabbroic mass is considered to have been subsequently recrystallized due to later metamorphism as plagioclase–hornblende–pyroxene granulite under plutonic conditions. But most of the phenocrysts, if not all, do not seem to have been affected during metamorphism except for the minor development of biotite and acicular needles of hornblende along cleavages. Geijer (1963) has also reported phenocrysts from leptite formations of Sweden which remained intact during metamorphism.

*Acknowledgements.* The authors wish to thank Dr. R. A. Howie, King's College, London, for critically reading the manuscript and for suggestions. Thanks are also due to Dr. G. S.

Siddhu, Director, Regional Research Laboratories, Hyderabad, India, for providing X-ray data of the augite phenocryst. The first and second authors acknowledge financial assistance from University Grants Commission, New Delhi, India.

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[*Manuscript received 20 March 1969*]