

## The Purimetla gabbros, Prakasam District, Andhra Pradesh, India

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**Abstract.** Gabbros at Purimetla occur in close association with the alkaline pluton. Petrography and petrochemistry of these gabbros indicate their tholeiitic nature. Chemical variation of these tholeiites suggests that an initial undersaturated tholeiitic magma yielded oversaturated fractions in the final stages of differentiation. Their regional distribution suggests that basic magmatism preceded the emplacement of the alkaline rocks in the Prakasam alkaline province.

**Keywords.** Gabbro; tholeiite; corona; diffusion; differentiation index; Andhra Pradesh (Purimetla/Prakasam District).

### 1. Introduction

The area around Purimetla in the Prakasam District of Andhra Pradesh experienced three Proterozoic magmatic emplacements. The first one produced gabbros, the second gave rise to a series of syenites constituting the Purimetla alkaline pluton and the third one produced ocellar lamprophyre dykes which traverse solely the alkaline pluton. Detailed petrographic accounts of the rocks of second and third magmatic emplacements have already been published (Leelanandam and Ratnakar 1980, 1983), and the present contribution incorporates only certain petrological aspects of the gabbros.

### 2. Field relationships

The gabbros occur at the northwestern and the southwestern boundaries of the alkaline pluton as triangular and roughly square-shaped masses respectively. The country rocks are granite gneisses and amphibolites; the contacts between these and the gabbros are fairly sharp (figure 1), without any chilled margins in the gabbros, suggesting that the country rocks were preheated at the time of intrusion. The gabbros are massive without perceptible layering which suggests that crystallization was not *in situ* and emplacement occurred as crystal mushes into the country rocks. The absence of xenoliths of country rocks (amphibolites and granite gneisses) in these rocks reflects their permissive emplacement and lower structural level (see Upton 1974, p. 230). The attitude of foliations of country rocks around the gabbro masses suggests their probable lopolithic form. However, gabbroic xenoliths are not uncommon in the alkaline pluton (figure 1). The xenolithic gabbros show occasional intermixing with the alkaline rocks with the resulting transitional contacts. Such a field relationship between the gabbros and alkaline rocks obviously indicates that the intrusion of the former preceded the latter.

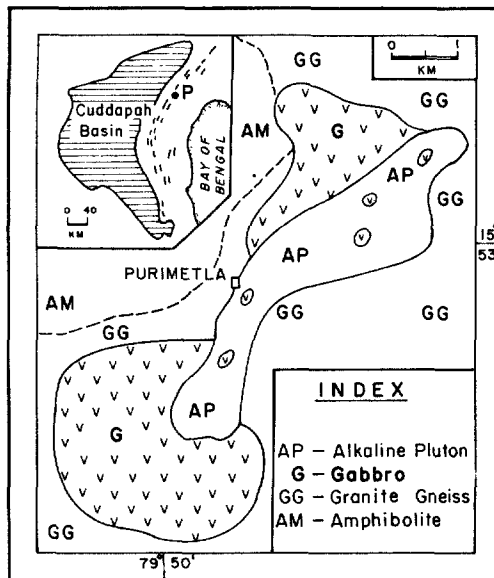


Figure 1. Lithological map of the Purimetla area. Inset map shows the location of Purimetla (P) in the Archaean terrain (with trend lines) east of the Cuddapah Basin.

### 3. Methods of study

Modal analyses of the gabbros were done by the Swift automatic point counter. The anorthite content of plagioclase feldspars was determined by measuring the extinction angles in sections perpendicular to  $X$ , showing two sets of cleavages parallel to (001) and (010) planes (see Deer *et al* 1963). The unaltered and representative gabbros of the area were analysed for  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  by spectrophotometry;  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{MnO}$  by atomic absorption spectrophotometry (AAS-model-Varion Techtron AA6);  $\text{FeO}$  by titrimetry; and  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$  by flame photometry, in the Chemical Laboratories of the Atomic Minerals Division, Hyderabad. Precision and accuracy were checked by analysing the samples in duplicate along with standard samples.

### 4. Petrography

The gabbros are medium to coarse grained, heavy and dark coloured rocks. In thin section they generally exhibit sub-ophitic texture; a few rocks exhibit meagre cataclastic deformational effects without erasing the original igneous textures.

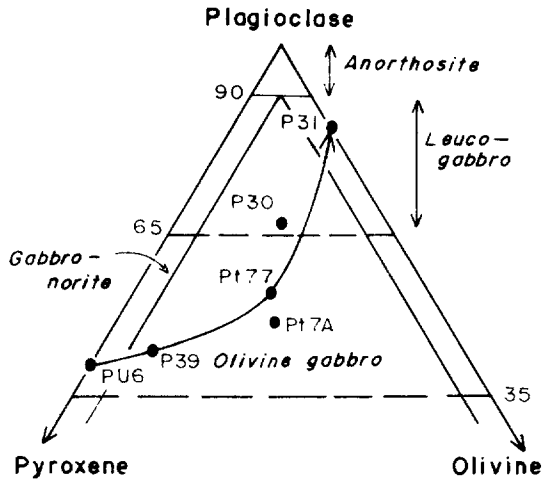
The essential minerals are clinopyroxene, plagioclase, olivine, and orthopyroxene while the accessories include biotite, opaques, sphene, apatite and calcite. The alteration of plagioclase results in scapolite which occurs in minor amounts (table 1). Appearance of orthopyroxene in some rocks and considerable depletion of clinopyroxene and olivine with a consequent rise of plagioclase in these rocks bring linear lithological variation from gabbro-norite through olivine gabbro to leuco-gabbro (figure 2; table 1).

**Table 1.** Modal compositions (vol%) of the Purimetla gabbros.

| Sample        | PU6  | P39  | Pt7A | Pt77 | P30  | P31  |
|---------------|------|------|------|------|------|------|
| Plagioclase   | 38.9 | 37.4 | 45.5 | 49.0 | 59.4 | 76.6 |
| Orthopyroxene | 5.2  | —    | —    | —    | —    | —    |
| Clinopyroxene | 30.0 | 40.5 | 24.3 | 25.2 | 14.3 | —    |
| Olivine       | —    | 7.0  | 22.2 | 20.0 | 16.2 | 18.3 |
| Biotite       | 1.0  | —    | —    | 0.4  | 1.0  | 0.4  |
| Opagues       | 0.1  | 4.5  | —    | —    | 9.0  | —    |
| Sphene        | 0.1  | —    | —    | 0.4  | 0.1  | —    |
| Apatite       | —    | 3.0  | 3.0  | —    | —    | —    |
| Calcite       | 0.1  | 3.6  | —    | 2.0  | —    | 0.1  |
| Scapolite     | 0.1  | 4.0  | 5.0  | 3.0  | —    | 4.6  |

| IUGS nomenclature | Gabbro-norite | Olivine gabbros | Leuco-gabbros |
|-------------------|---------------|-----------------|---------------|
|                   |               |                 |               |



**Figure 2.** Triangular diagram (after IUGS 1973) showing linear modal variations of major minerals in the gabbros.

Occasionally absence of clinopyroxene leaves an anorthositic stamp on certain rocks (see for example P31 in figure 2). The crystallization sequence is chiefly controlled by fractionation of olivine, plagioclase and clinopyroxene and to some extent by orthopyroxene. Less commonly all these four mineral phases coexist in the same rock. Presence of biotite in traces may be interpreted to signify a tendency towards undersaturation in silica and involvement of little amounts of water in the closed petrogenetic system (see MacKenzie 1957; Morse 1969).

Subhedral *clinopyroxene* exhibits diallage (100) parting, zoning, exsolution lamellae of ilmeno-magnetite along *c* direction of the mineral, simple twinning, weak pleochroism in purple or pinkish colours (titan-augite), and contains partially included laths of plagioclase. Euhedral crystals of *plagioclase* ( $An_{46-68}$ ) are characterised by the absence of zoning in rocks rich in this mineral and by normal zoning in those with less

plagioclase; they further show interpenetration and polysynthetic twins in addition to Carlsbad twins. Euhedral to subhedral *orthopyroxene* rarely shows one set of cleavage but invariably exhibits strong pleochroism from brownish pink to violet colours.

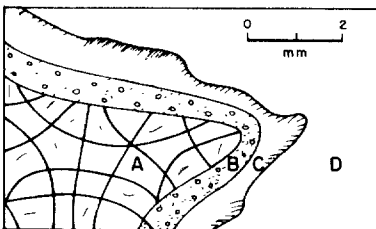
Resorbed and sufficiently serpentinized grains of *olivine* are typified by coronation (Ratnakar 1981). The core of anhedral, corroded and fractured olivine is enveloped by a narrow shell of colourless clinopyroxene followed by a zone of pale-green amphibole with sharp contacts (figure 3). The other portion of the amphibole zone (i.e. portion very close to the adjacent plagioclase) is heavily intergrown with brownish vermicules of spinel to give a symplectitic appearance. Plagioclase, close to the coronas, characteristically exhibits clouding due to the disseminated spinel. This coronal sequence olivine-clinopyroxene-amphibole-plagioclase resembles the one reported from the Thessaloniki gabbros of North Greece (Sapountzis 1975). The shapes of the coronal minerals (clinopyroxene and amphibole) in the Purimetla gabbros are strictly controlled by the crystal outlines of olivine and plagioclase. Furthermore, the spinel-clouded plagioclase indirectly explains that these coronal minerals are formed by a simple process of two-way diffusion across the original olivine-plagioclase boundary in which iron and magnesium migrated into plagioclase, and aluminium and calcium into olivine (figure 4). Such reaction relations seem to be facilitated by hydrous environments which experienced a gradual fall of temperature (Griffin and Heier 1973).

Presence of resorbed olivine with coronas and orientation of opaque exsolution lamellae along the *c*-axis of clinopyroxene in gabbros indicate their tholeiitic nature (Sapountzis 1979).

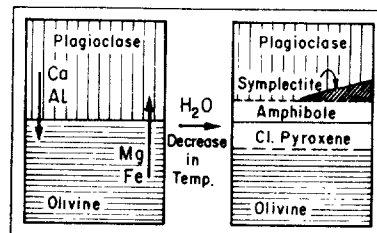
## 5. Petrochemistry

The chemical analyses and CIPW norms of the Purimetla gabbros, along with the Nockolds' (1954) averages, are presented in table 2. The analyses are arranged in the increasing order of differentiation.

Table 2 reveals a close chemical proximity between gabbros of Purimetla (PU6 and Pt77) and the average olivine gabbro, 1, but not the average alkali gabbro, 2, of Nockolds. The chemical composition of the sample P31 is very close to that of the average anorthosite, 3, of Nockolds justifying its position near "anorthosite" field in figure 2.



**Figure 3.** Corona structure with successive shells of clinopyroxene (B) and amphibole with vermicules of spinel (C) between olivine (A) and plagioclase (D)



**Figure 4.** Visualised mode of origin of corona structure (for explanation see text)

**Table 2a.** Chemical analyses of the Purimetla gabbros with Nockolds' (1954) averages.

| Oxide wt %                     | PU6               | Pt77              | P31               | 1                 | 2                 | 3                 |
|--------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| SiO <sub>2</sub>               | 46.39             | 46.79             | 52.03             | 46.83             | 43.94             | 54.54             |
| TiO <sub>2</sub>               | 1.16              | 1.56              | 0.67              | 0.97              | 2.86              | 0.52              |
| Al <sub>2</sub> O <sub>3</sub> | 14.48             | 17.19             | 23.39             | 12.38             | 14.87             | 25.72             |
| Fe <sub>2</sub> O <sub>3</sub> | 3.19              | 3.38              | 1.83              | 1.91              | 4.85              | 0.83              |
| FeO                            | 8.40              | 7.10              | 2.70              | 8.20              | 7.80              | 1.46              |
| MnO                            | 0.17              | 0.13              | 0.07              | 0.14              | 0.16              | 0.02              |
| MgO                            | 12.97             | 9.12              | 3.32              | 10.03             | 9.31              | 0.83              |
| CaO                            | 10.49             | 10.49             | 11.89             | 11.36             | 12.37             | 9.62              |
| Na <sub>2</sub> O              | 2.00              | 2.56              | 2.63              | 2.03              | 2.32              | 4.66              |
| K <sub>2</sub> O               | 0.43              | 0.33              | 0.29              | 0.40              | 0.92              | 1.06              |
| P <sub>2</sub> O <sub>5</sub>  | 0.11              | 0.07              | 0.07              | 0.12              | 0.44              | 0.11              |
| H <sub>2</sub> O + / -         | 0.06 <sup>-</sup> | 0.06 <sup>-</sup> | 0.06 <sup>-</sup> | 0.63 <sup>+</sup> | 0.66 <sup>+</sup> | 0.63 <sup>+</sup> |
| LOI                            | 0.22              | 0.18              | 0.61              | —                 | —                 | —                 |
| Total                          | 100.07            | 98.96             | 99.56             |                   |                   |                   |

**Table 2b.** CIPW norms.

|                    | PU6   | Pt77  | P31   |
|--------------------|-------|-------|-------|
| Q                  | —     | —     | 4.63  |
| or                 | 2.56  | 1.95  | 1.71  |
| ab                 | 16.77 | 21.48 | 22.22 |
| an                 | 29.30 | 34.32 | 51.02 |
| wo                 | 9.16  | 7.19  | 3.31  |
| en                 | 6.30  | 4.90  | 2.35  |
| fs                 | 2.11  | 1.72  | 0.66  |
| en                 | 3.23  | 4.63  | 6.06  |
| fs                 | 1.11  | 1.59  | 1.65  |
| fo                 | 16.00 | 9.28  | —     |
| fa                 | 6.02  | 3.53  | —     |
| mt                 | 4.64  | 4.87  | 2.64  |
| il                 | 2.20  | 2.98  | 1.27  |
| ap                 | 0.26  | 0.17  | 0.01  |
| Total              | 99.66 | 98.61 | 97.53 |
| An/(An + Ab) × 100 | 63.3  | 61.2  | 69.6  |
| DI                 | 19.33 | 23.43 | 28.56 |

Samples PU6, Pt77 and P31 from Purimetla; 1, 2 and 3 are Nockolds' averages of olivine gabbro, alkali gabbro and anorthosite respectively; DI-differentiation index (normative Q + or + ab) of Thornton and Tuttle (1960).

The chemical variation of these rocks is demonstrated against MgO and differentiation index (DI) (Thornton and Tuttle 1960) (figure 5). SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Na<sub>2</sub>O show a regular increase, while CaO shows moderate to steep increase towards the culmination of differentiation. The anomalous increase of calcium is due to the highest amount of modal plagioclase in the sample (see P31 in table 1). The normative anorthite (An/

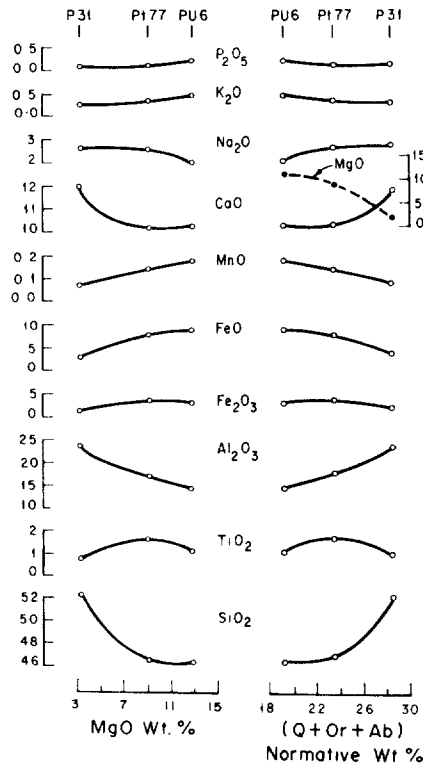


Figure 5. Major element oxide (wt %) variation against MgO and differentiation index (after Thornton and Tuttle 1960) in the Purimetla gabbros.

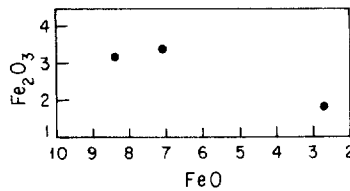


Figure 6. Variation of  $\text{Fe}_2\text{O}_3$  and FeO in the Purimetla gabbros.

An + Ab) content also shows a perceptible increase towards the late stage of differentiation (table 2). Although a little range of variation is observed for sodium and potassium, the former shows positive correlation with DI because of increase in plagioclase while the latter shows a reciprocal relation owing to the depletion of modal biotite in these rocks. The progressive decrease of MgO against DI is mainly due to the diminution of the enstatite molecule of diopside and forsterite. Likewise the systematic and gentle fall of FeO can be correlated to the similar behaviour of "ferrosilite" of diopside and fayalite (table 2). Very minor enrichment of  $\text{Fe}_2\text{O}_3$  in the middle stage member (compared to the early and late stage ones) is most likely due to the non-removal of sufficient iron from the magma in the form of magnetite under slightly reducing conditions. This is also revealed in the FeO- $\text{Fe}_2\text{O}_3$  plot (figure 6) in which a wide spread of the plots along the abscissa relative to the ordinate testifies the prevalence of reducing conditions at the time of intrusion of the magma (see Upton *et al* 1971).

The Purimetla gabbros are tholeiitic in character (figure 7a); they lack normative nepheline and have quartz and/or hypersthene. A very low content of alkalis ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ ), less than 3% by weight (table 2), also suggests their non-alkaline nature (Yoder and Tilley 1962). Some gabbros of Purimetla appear to have high alumina basaltic affinity (for example Pt77 in figure 7b); such rocks contain considerable amounts of modal olivine typified by coronas, little normative quartz and/or hypersthene and higher amounts of  $\text{Al}_2\text{O}_3$  (Kuno 1960; Morse 1969).

The presence of hypersthene and olivine in the norm of PU6 and Pt77 indicates their undersaturated tholeiitic character while that of quartz and hypersthene in P31 suggests its oversaturated tholeiitic nature (Yoder and Tilley 1962); the differentiation index increases from undersaturated to oversaturated tholeiites (see table 2).

In the AFM diagram these rocks define a clear but restricted compositional variation (figure 8). The closeness of the curve to the FM side of the triangle alludes that the parental magma was much more basic than the composition represented by the basic

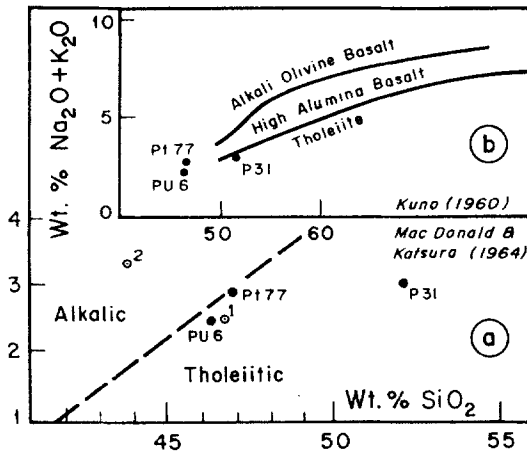


Figure 7. Alkali-silica diagrams (a and b) for the Purimetla gabbros (PU6, Pt77 & P31). For comparison Nockolds (1954) average olivine gabbro (1) and alkalic gabbro (2) are also plotted.

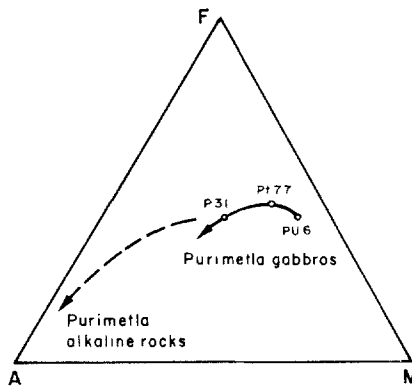


Figure 8. AFM diagram for the gabbros (solid curve) and alkaline rocks (discontinuous curve) of Purimetla, showing the curves of compositional variation.

end of the curve. Further it is seen in the AFM diagram that the early formed alkaline rocks of the pluton lie close to the late formed gabbroic rocks.

A very limited range of differentiation index from 19.33 to 28.56 is suggestive of curtailed temporal range of magmatic differentiation. It is during this period of reducing conditions, that the fractionation of iron took place which is reflected as perceptible convexity of the curve in the AFM diagram (figure 8).

## 6. Petrogenesis

The gabbros of Purimetla are formed from a tholeiitic basalt magma of possible mantle derivation. The crystallization sequence was dominated by olivine, plagioclase and clinopyroxene under low  $P_{H_2O}$  and reducing conditions. The magma underwent limited differentiation with a marked rise in the silica saturation from early undersaturated to late oversaturated member.

The rocks were emplaced as crystalline mushes and by preheating the country rocks during post-tectonic regime. The westward thrusting of the Eastern Ghat mobile belt resulted in crustal-thickening and -shortening, and mantle upwarp (Kaila and Bhatia 1981; Drury *et al* 1984) with subsequent emplacement of gabbros and alkaline rocks during different successive magmatic episodes in compressional margin setting.

## 7. Gabbro-alkaline rock association in the Prakasam alkaline province

### 7.1 Sequence of emplacement

Tholeiitic gabbros and alkaline rocks are the two important plutonic igneous rocks in the Prakasam alkaline province (Leelanandam 1981). There is a persistent tendency throughout this province for less differentiated magma to precede the more differentiated (cf., Upton 1974). Early tholeiitic magmas, intruded at different centres as at Chimakurti, Pasupugallu and Boggulakonda in this province, were chiefly committed to gabbro(norite)-anorthosite-troctolite range of differentiation at the time of intrusion. Alkaline rocks (with early intruded gabbros) at Settupalle (Srinivasan 1981), Purimetla (Leelanandam and Ratnakar 1980, 1983) and Uppalapadu (Leelanandam and Krishna Reddy 1981), in this province, post-date the tholeiitic magmatism. All these gabbroic and alkaline rock occurrences lie outside the eastern edge of the Cuddapah basin in an arbitrary zone 60 kms long and 20 km wide (see figure 1 in Leelanandam 1981). The early intrusion of the gabbroic rocks created focii of structural weakness which facilitated the intrusion of younger alkaline magma in this province, as in the case of the well known alkaline provinces of Greenland (Upton 1974) and the Kola Peninsula (Gerasimovskii *et al* 1974).

### 7.2 Genetic relation

The prevalence of alkaline ultramafic (melanocratic) cognate xenoliths in the alkaline plutons signifies that undersaturated basic magmas were precursors to the alkaline residues in evolution (Leelanandam and Ratnakar 1983). These parental magmas may



be expected to have originated directly from the upper mantle (Gittins 1979) enriched in alkalis, or they may be derived from an early tholeiitic magma under variable degrees of clinopyroxene fractionation at depths 60-15 kms or by extended fractionation of basaltic magma under eclogite facies conditions (see Upton 1974). Periodic intrusion of this alkaline magma at different locales, subsequent to the early tholeiitic magmatism, in the Prakasam Province resulted in gabbro-alkaline rock association. The genetic meaning of this association, for instance at Purimetla, can be best understood from the field set-up (figure 1) and differentiation trends (figure 8) of these plutonic igneous rocks.

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### **References**

- Deer W A, Howie R A and Zussman J 1963 *Rock forming minerals 4 Framework silicates* (London: Longmans)
- Drury S A, Harris N B W, Holt R W, Reeves-Smith G J and Wightman R T 1984 *J. Geol.* **92** 3
- Gerasimovskii V I, Volkov V P, Kogarko L N and Polyakov A I 1974 in *The alkaline rocks* (ed.) H Sorensen (London: Wiley Interscience) p. 206
- Gittins J 1979 in *The evolution of the igneous rocks* (ed.) H S Yoder (Princeton: Univ. Press) p. 351
- Griffin W L and Heier K S 1973 *Lithos* **6** 315
- IUGS 1973 *Geotimes* **18** 26
- Kaila K L and Bhatia S C 1981 *Tectonophysics* **79** 129
- Kuno H 1960 *J. Petrol.* **1** 121
- Leelanandam C 1981 *Curr. Sci.* **50** 799
- Leelanandam C and Krishna Reddy K 1981 *J. Geol. Soc. India* **22** 39
- Leelanandam C and Ratnakar J 1980 *Q.J. Geol., Min. Metall. Soc. India* **52** 77
- Leelanandam C and Ratnakar J 1983 *Q.J. Geol., Min. Metall. Soc. India* **55** 14
- MacDonald D A and Katsura T 1964 *J. Petrol.* **5** 82
- MacKenzie W S 1957 *Am. J. Sci.* **255** 481
- Morse S A 1969 *Geol. Soc. Am., Mem.* **112** 140
- Nockolds S R 1954 *Geol. Soc. Am. Bull.* **65** 1007
- Ratnakar J 1981 *Geoviews* **9** 35
- Sapountzis E S 1975 *Contrib. Mineral Petrol.* **51** 197
- Sapountzis E S 1979 *J. Petrol.* **20** 37
- Srinivasan T P 1981 *Geoviews* **9** 379
- Thornton C P and Tuttle O F 1960 *Am. J. Sci.* **258** 342
- Upton B G J 1974 in *The alkaline rocks* (ed.) H Sorensen (London: Wiley Interscience) 221
- Upton B G J, Thomas J E and MacDonald R 1971 *Lithos* **4** 163
- Yoder H S and Tilley C E 1962 *J. Petrol.* **3** 242