Journal of Geosciences, Osaka City University
Vol. 42, Art. 14, p.227-235, March, 1999

Structural Features of the Archean Nellore-Khammam Schist Belt, Southeast India

B. HARI PRASAD [1], OKUDAIRA Takamoto [1], R. S. DIVI [2] and YOSHIDA Masaru [1]

1 Department of Geosciences, Faculty fo Science, Osaka City University, Osaka 558-8585, Japan
2 CNS Geomatics, Ottawa, Canada

Abstract

The Nellore-Khammam Schist Belt (NKSB) lying to the east of the Proterozoic Cuddapah basin is believed to be a prominent Archean granite-greenstone belt in the Dharwar Craton. In the northern part of the belt in the vicinity of Khammam, Andhra Pradesh, it consists of high pressure amphibolites. Based on field relations and mineral assemblages, the rocks are classified into banded amphibolites, garnetiferous amphibolite, foliated amphibolite and massive amphibolite. Except for the intrusive massive amphibolite, the other three rock types are affected by polyphase (D_1, D_2 and D_3) deformation. Folds of the first deformation D_1 are intrafolial isoclinal to tight type with NW-SE fold axes and axial planar cleavage S_1. The D_1 folds are later deformed by NE-SW trending open to close upright folds of the second deformation stage D_2. The third phase of deformation D_3 is characterized by gentle folds, accompanied by minor shear zones parallel to the NW-SE trending axial planes. The structures in the study area are correlated with those in the adjacent and distant areas in the NKSB, and the possibility of some structures to have developed during the Proterozoic is considered.

Key words: Basement structure, India, Nellore-Khammam Schist Belt, Proterozoic.

Introduction

The Nellore-Khammam Schist Belt (NKSB), a narrow curvilinear Archean granite greenstone belt, lies in the eastern fringe of the Dharwar Craton with approximately 600 Km long and 8 to 50 Km wide N-S trend direction extending from the Nellore to Khammam (Fig. 1). The NKSB is considered to be equivalent to the Sargur schist belt (3.3 Ga, Peucat et al., 1995), which is the oldest known supracrustal belt in India. The strike of the NKSB varies from NW-SE in the southwest, through NNW-SSE in the central part, to NNE-SSW in the northeast. The rocks of the NKSB are divisible into lower sequence of predominantly metasedimentary rocks in the northeast and upper part consisting mainly of metabasalts in the southwest (e. g. Narayana Rao, 1983). Metamorphic grade varies from greenschist facies and upper amphibolite to lower granulite facies from southwest to northeast (Vasudevan and Rao, 1975; Babu, 1998). The amphibolites of the NKSB have geochemical characteristics of a back-arc or marginal basin paleotectonic setting (Satyanarayana et al., 1994). Reddy et al., (1994) reported that the suture zone melange metamorphosed under greenschist facies is found in the southern part of the NKSB.

The present study area is within the northeastern fringe of the NKSB and is locally known as the Khammam-greenstone belt consisting dominently of mafic rocks (Fig. 2). There are many anorthosite suites in the study area (Ramaswamy, 1962; Appavadanulu et al., 1976). Appavadanulu et al., (1976) have cited that the Chimalpahad anorthosite complex forms the axial zone of a large scale anticline and all the other minor bodies are concentrated along the shear zones parallel or subparallel to the fold axis (Fig. 2). Most of the studies have been focused on the chemistry and petrology in the NKSB (e. g., Satyanarayana et al., 1994; Rao and Rao, 1986), whereas structural study is lacking. Chetty (1986) has reported out some shear deformational features and suggested a tectonic model for the metamorphic rocks of the Nellore district. Recently Divi et al., (1995) suggested that the area east of Khammam has been affected by the Proterozoic Eastern Ghat orogeny, although the detailed structural analysis has not been enough for understanding the tectonic evolution of the NKSB. Therefore, detailed structural analysis for the Nellore-Khammam Schist Belt is necessary to clarify the Archean tectonics in this part of the Dharwar Craton.

Geological setting

The present study area being formed by latitudes 17°17' and 17°24' and longitudes 80°25' and 80°29' (in the Khammam district). Mafic and felsic rocks are well exposed in the study area. Although small granitic bodies can be recognized, the dominant lithology is amphibolite and can be divided based on their field appearence into garnetiferous, banded, foliated and massive types as described below. Mineral assemblages in the types are also different (Hari Prasad et al., 1998). Garnetiferous amphibolite is mainly composed of garnet, amphibole, plagioclase, and clinopyroxene. It is well exposed in the hills of Kanigiri reserve forest and at the area near Himamnagar. Garnet porphyroblasts aggregates of grains (3-15 cm in diameter) is dominant with many amount of inclusions of clinopyroxene, hornblende and quartz. Garnet phorphyroblasts are rimmed by quartz and Plagioclase grains (Fig. 3A). Hornblende grains are typical dark green in color. Banded amphibolites are also prevalent rock types and show various shear deformational features in the study area. The rocks are medium- to coarse- grained and composed mainly of amphibole, plagioclase, garnet and quartz. Compositional banding is identified by the alternation of amphibole-rich melanocratic and plagioclase-rich leucocratic bands. Foliated amphibolite is composed of fine-grained amphibole, plagioclase, clinopyroxene and sphene. Foliation is formed by the alignment of amphibole. Many asymmetrical crenulation folds and open folds are seen in this lithology (Fig. 3B). Massive amphibolite truncates the first three types of amphibolites, and it is the youngest intrusive in the study area.

Deformation structures

Based on field observations, three phases of deformational structures have been identified and are termed as D_1, D_2 and D_3 from the earliest to the latest. The characteristics of these structures are summerized in Table.1. The mineral assemblages in the absence of epidote and chlorite

Table 1: Structural characteristics of D_1, D_2 and D_3 phases of deformation.

Deformational Phase	Structural Characteristics
D_1	Tight to isoclinal intrafolial mesoscopic folds (F_1) in compositional banding (S_0); axial surface foliation (S_1) is parallel to regional foliation; variable axial trends along NW-SE; intersection (S_0/S_1) lineation plunges moderately to SW.
D_2	Macroscopic and mesoscopic open to tight folds (F_2) in S_0/S_1 foliation; axial planes are upright and steep; axes plunge moderately to SW.
D_3	Gentle to open mesoscopic folds (F_3) in S_0/S_1 foliation, with subhorizontal axial surfaces; some shearing event.

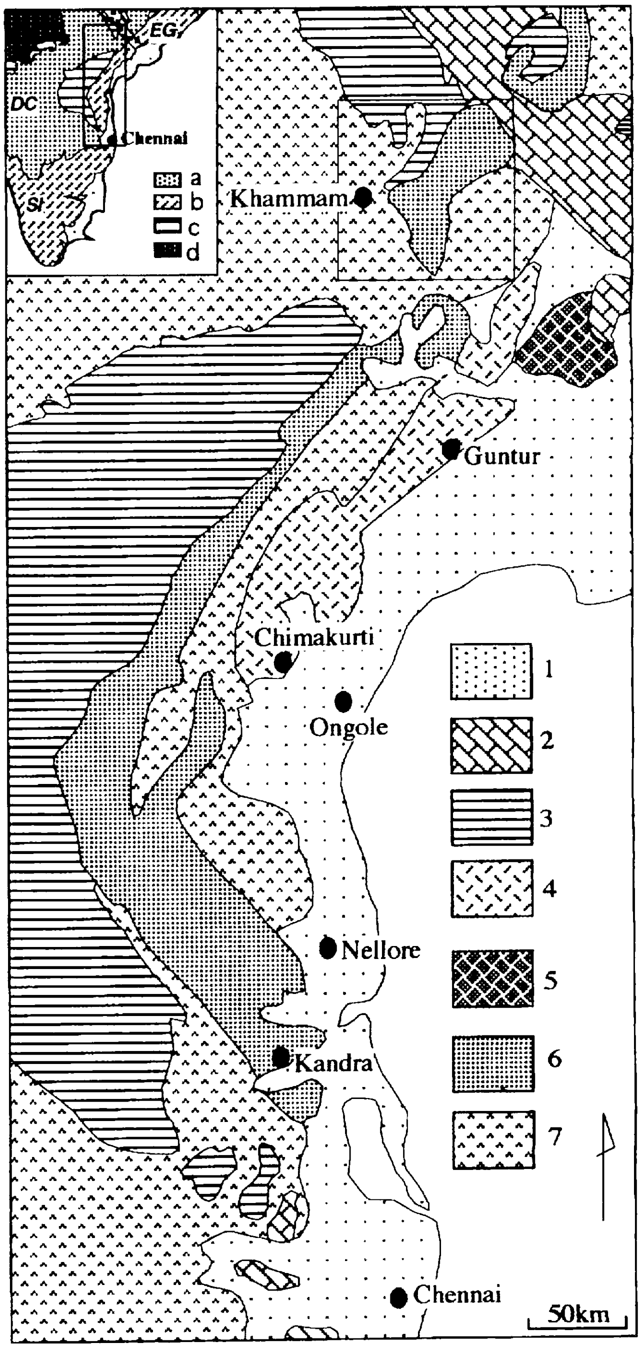

Fig. 1. The Nellore-Khammam Schist Belt and adjacent areas (refered after Geological Survey of India, 1973 and Yoshida et al., 1998 after modifications); frame refers to figure.2. 1: Cenozoic cover, 2: Gondwana sediments, 3: Proterozoic cover, 4: Granulites, 5: Khondalites, 6: Nellore-Khammam Schist Belt, 7: Archean granite-greenstone terrain.
Inset showing the geology of southern India. a: Archean granite-greenstone, b: Proterozoic granulites, c: Proterozoic sediments, d: Deccan flood basalts, DC: Dharwar Craton, EG: Eastern Ghats Mobile Belt, SI: South Indian Granulite Belt. Map of India is modified after Geological Survey of India, 1993, Tani et al., (1998), and Yamamoto (1996).

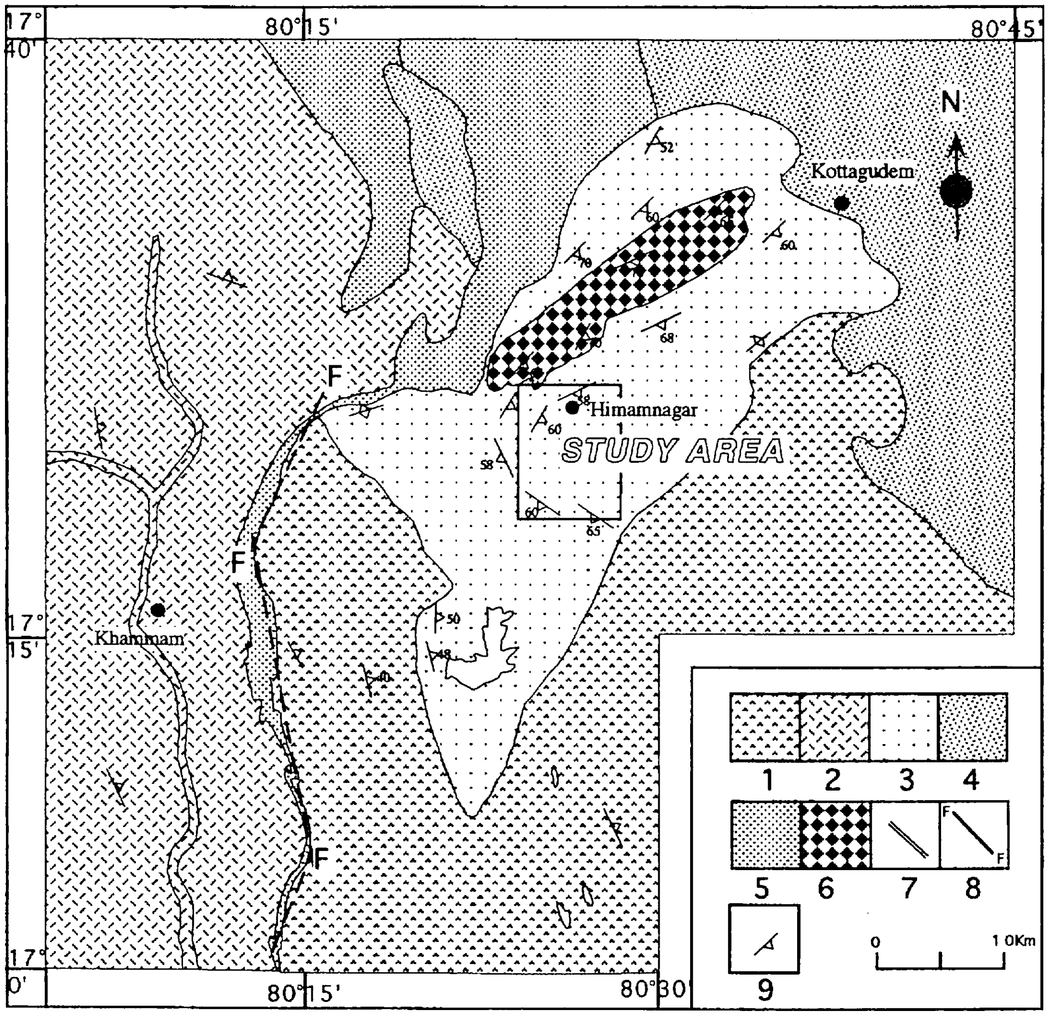

Fig. 2. Geology around Khammam town (NKSB) modified after Sarvothaman, (1994).
1). Garnetiferous Gneiss and Granite. 2). Granodiorite-Adamallite-Granite Suite. 3). Khammam Greenstone Belt. 4). Gondwana sediments of Godavari Graben. 5). Pakhal Group. 6). Chimalpahad Anorthosite-Gabbro (layered) complex. 7). Canal/reservoir. 8) Fault. 9). Trend of major foliations.

described earlier in the text suggests deformation occured under amphibolite facies metamorphic conditions. This is in concordence with estimated P-T conditions of 700 ± 50°C at 1.1 Gpa (Hari Prasad et al., 1998).

Structures of the first deformation (D_1)

The major foliation is formed by the prefered orientation of amphiboles and plagioclase grains. This planar structure is deformed by the later deformational events, and therefore, it is considered to be the earliest structural element in the area and termed as S_1. Intrafolial isoclinal to tight folds (F_1) are often observed within the major compositional banding (Fig. 4A). The axial surfaces of these intrafolial folds are parallel to this dominant foliation, and hence the major foliation and the intrafolial folds are cosidered as cogenetic. The intrafolial folds are mostly of rootles type. Although the rocks in the area have undergone intense deformation, the relationship between the S_1 foliation and S_0 compositional banding can also be observed (Fig. 4 B). The intersection lineations between compositional banding (S_0) and the axial planar foliation (S_1) is conspicious where the F_1 folds are comparatively round hinged. The equal area lower hemisphere stereographic projections, of axes of the intrafolial isoclinal to tight folds are given in the Fig.5. The distribution pattern of the intrafolial fold axes displays NW-SE trend with variable plunges from shallow to steep, which is possibly due to perturbation of later deformation.

Structures of second deformation (D_2)

The structures of the second phase deformation are characterized by macroscopic and mesoscopic folds. Orientation of strike and dip of the S_0 and S_1 clearly displays a distinct

Fig. 3. (A) Garnet phorphyroblast rimmed by quartz and plagioclase in garnetiferous amphibolite

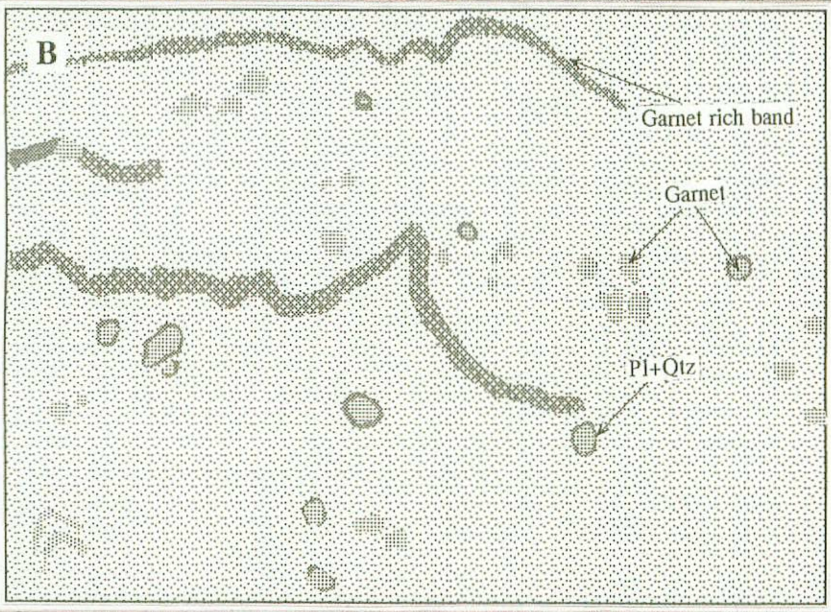

Fig. 3. (B) Sketch of the photograph (A)

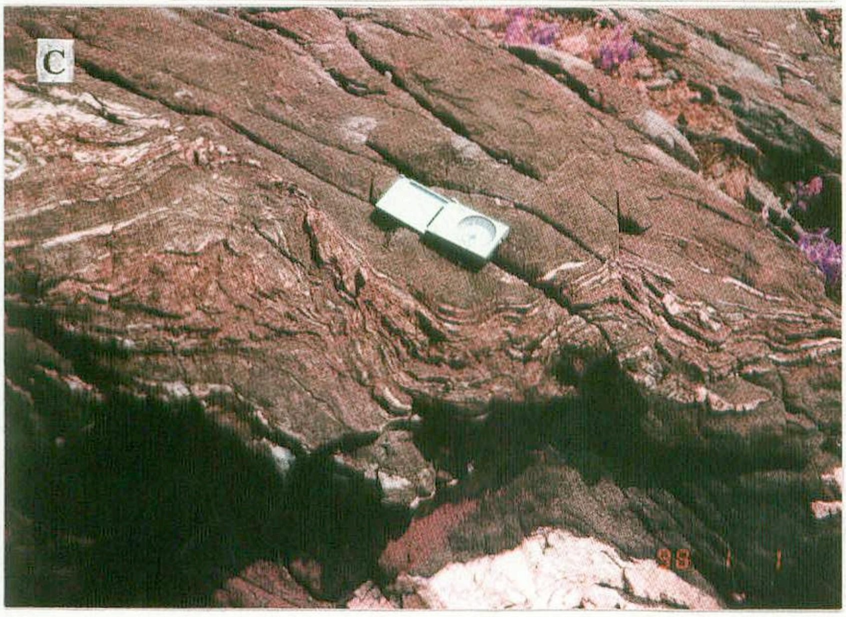

Fig. 3. (C) Folds in foliated amphibolite.

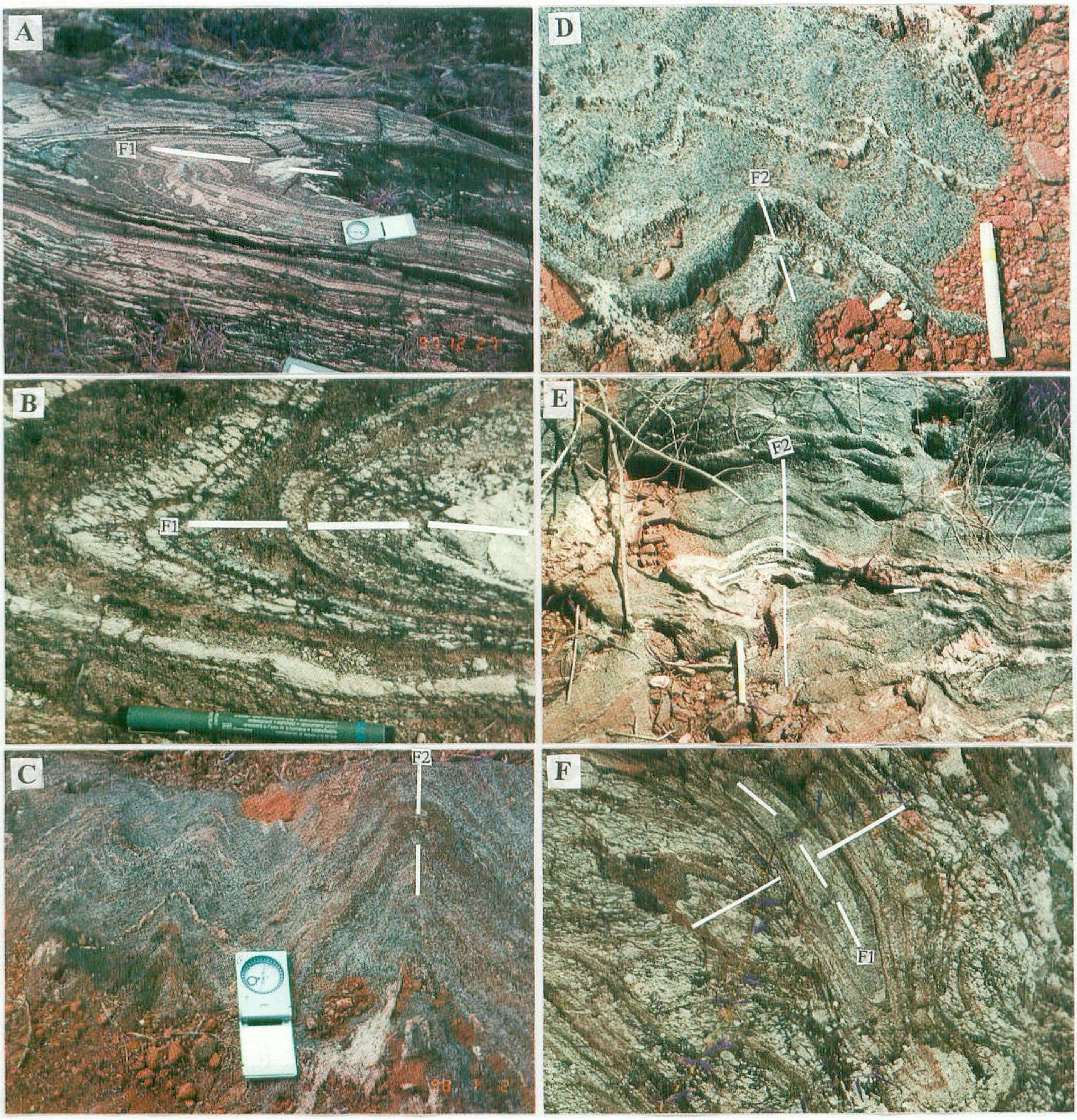

Fig. 4 Field photographs showing the D_1 deformational structures. (A) Intrafolial tight fold in the banded amphibolite rock. (B) Asymmetric intrafolial (F_1) fold with axial plane schistosity in banded amphibolite rock at location near Garlavoddu. (C) and (D) Open (F_2) folds with upright axial planes in amphibolites in the central part of the study area and near Aqueduct at Nasarapu vagu. (E) Isoclinal F_1 fold refolded by gentle F_2 folds; axial planes of the two phases are nearly orthogonal to each other. (F) Refolded F_2 fold by F_3 in banded amphibolite at Yenkur.

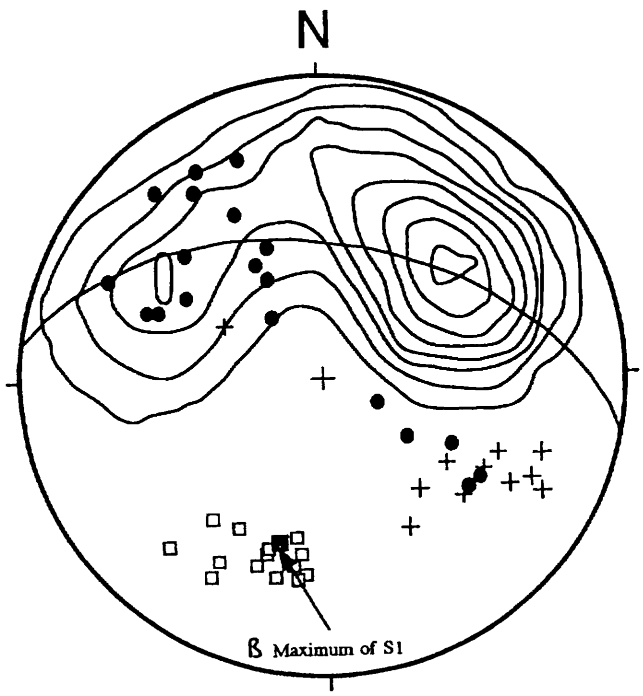

Fig. 5 Schimdt equal area net projections of the structural elements in the study area.

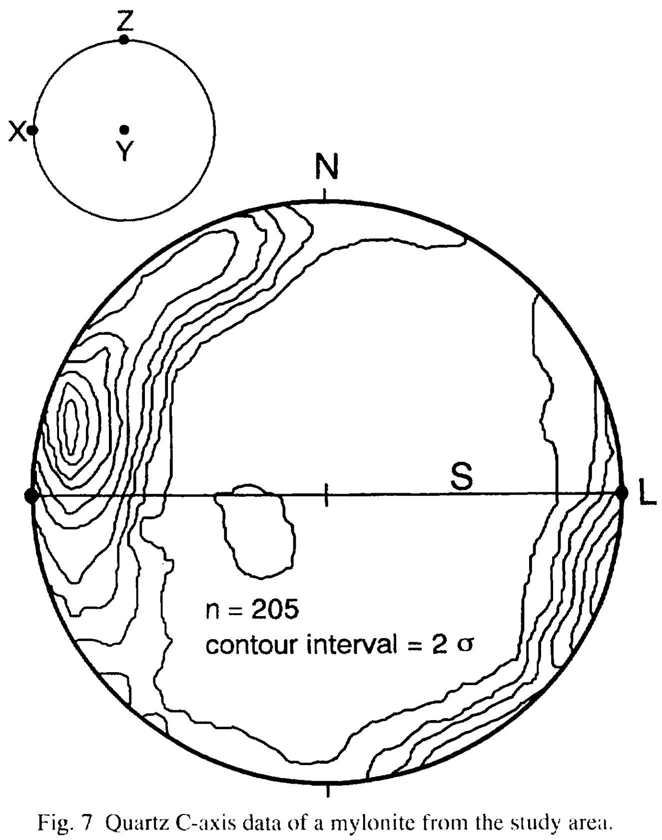

Fig. 7 Quartz C-axis data of a mylonite from the study area.

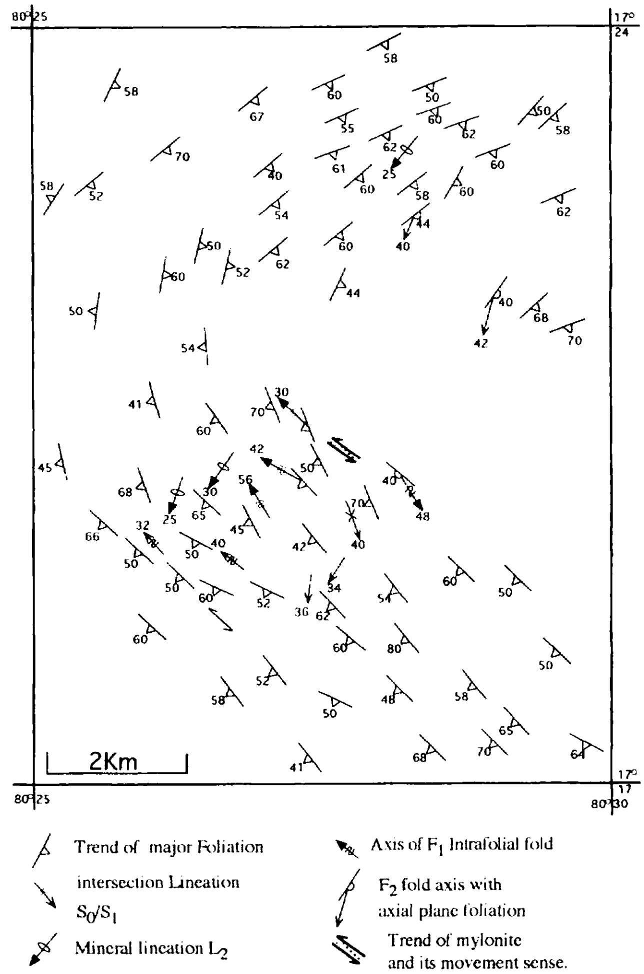

Fig. 6 Structural outline of the study area from Khammam Greenstone belt (NKSB).

swing from NW to NE direction resulting in the formation of a large scale reclined fold (F_2) (Fig. 6). Therefore this large-scale fold is formed after D_1, and is interpreted as F_2 fold. The second generation folds show very gentle plunges with vertical axial planes (Fig. 4 C, D). Some aggragates of garnet grains are folded in the hinge portions of the NE-SW trending mesoscopic F_2 folds. The F_1 isoclinal folds are refolded into very gentle to open folds of D_2 in the amphibolites at some localitions, (Fig. 4 E, F). The axial planes of the refolded folds and F_1 isoclinal folds are at an right angle approximately (Fig. 4 E, F). The fold axes of the F_2 folds are clustered around the ß-maximum of the S_1 (Fig. 5).

Structures of the third deformation (D_3)

Subsequent to the first and second deformations, the amphibolites have witnessed a deformation resulting in gentle to open type of folds with subhorizontal axial planes. Many local shear zones trending NW and SE directions are traced out in the area. Alternating layers of recrystalised feldspar grains and quartz ribbons are ranging from less than 1mm to 3mm thick. These ribbons constitute about 30 to 35 percent within a single thin section. Extensional cracks, filled by quartz, in earlier formed megacrysts are related to this event. Other mylonitic asymmetric features, like rotated phorphyroclasts and pressure shadows have been observed in many sections. The feldspar phorphyroclasts present in between the quartz ribbons are showing highly deformation lamellae. Quartz c-axis fabrics were measured for ribbbons and are distributed around maximum finite strain axis (X), which is parallel to stretching lineations (Fig.7). Such X-point maximum fabric pattern is an indicative of high temperature (> ca.550-600°C) and plastic deformation (e. g. Okudaira et al., 1995).

Superimposed structures

The study area displays polyphase deformational folding resulting in the development of superimposed structures. The F_1 folds axes show variation in trend and plunge due to F_2 folding, superimposition of F_2 on F_1 resulted in type-2 interference pattern (Ramsay, 1967). Hinge - thickening and limb - thining has been observed in the F1 folds, the thinned limb portions are folded by F_2 folds. A type-2 interference pattern suggests superimposition of nearly upright F_2 fold on appressed F_1.

Discussion and conclussions

The three phases of deformation (D_1, D_2, D_3) identified in the study area need to be correlated with those in the adjacent areas and with the regional structures in the Nellore-Khammam Schist Belt in general, for defining structural evolution of the area. Radhakrishnamurthy et al. (1990) have identified three phases of folding, F_1, F_2 and F_3, with axial trends along NNE-SSW, NW-SE and NNE-SSW directions, respectively, in an area adjacent to and lying to the southwest of the study area. The D_1 and D_2 phases in the study area are correlatable with the F_2 and F_3 phases, respectively, of Radhakrishnamurthy et al., (1990), based on fold styles and orientations. Similarly, the D_1 and D_2 phases in the study area can be broadly correlated with D_{A2} and D_{A4} structures, respectively, in the Archean rocks of Kinnerasani area lying at 40 kilometers northeast of the study area (Rajneesh Kumar et al., personal communication).

Further work is needed to check whether F_1 of Radhakrishnamurthy et al.(1990) and D_{A1} and D_{A3} of Rajneesh Kumar et al. (personal communication) are present in the study area or not.

Correlation of D_1, D_2 and D_3 with regional structures observed elsewhere is problematic. For example, Srinivasan et al. (1994) have identified five generations of folding (F_1, F_2, F_3, F_4 and F_5) in Sitarampuram-Kandukur area in the southern part of the NKSB. Although the D_1 in the study area is correlatable with the coaxial F_1/F_2 folds, the D_2 and D_3 phases pose problems, as they have different orientations from those of F_3, F_4 and F_5. In an area nearby to Sitarampuram-Kandukur, Chetty and Kanungo (1986) have also identified early structures (D_1) that are correlatable with the similarly oriented D_1 in the study area.

However, deciphering the age of D_1, D_2 and D_3 phases of deformation in the study area is a bigger problem, as geochronologic data for the rocks in the study area is not available and due to continuing debate as to whether the NKSB belongs to Dharwar craton or to EGMB. For example, Radhakrishnamurthy et al. (1990) considered the structures in the NKSB to have been developed during the Eastern Ghats Orogeny, i.e. during late Proterozoic (Grew and Manton, 1986; Aftalion et al., 1988; Paul etal., 1990; Shaw et al., 1997). Similarly, Rao and Raju (1997) reported that the Chimalpahad layered complex and amphibolite adjacent to the study area, yielded Rb/Sr whole-rock isochron age of 950 Ma. The layered complex has been considered to have been emplaced during the same tectonic event as the amphibolites, because magmatic structures in the complex are parallel to the tectonic fabric in the amphibolite. On the other hand, Sarvothaman (1996) suggested that the amphibolites (metagabbros ?) of NKSB have been structurally emplaced around 2.5-2.6 Ga. The two gechronologic data, i.e. 2.5 Ga and 950 Ma for the amphibolites could be reconciled by considering two tectonothermal events affected the amphibolites in the study area. This interpretation for the study area is compatible with the gechronologic evidence of multiple tectonothermal events that have affected the EGMB in particular, and the older rocks adjacent to EGMB. Metamorphic and geochronologic work is in progress to evaluate such interpretation for the evolution of rocks in the study area.

Acknowledgements

We would like to thank A.T. Rao of Andhra University for his field guidance. We also thank Y. Tani, S. Baba, H. M. Rajesh, T. Yamamoto and Rajneesh Kumar of Osaka City University for their helpful discussion. We thank Prof.T.K.Biswal and Prof.T.Kano for thier constructive reviews which had helped in improving the manuscript. The first author thanks the Ministry of Education, Science and Culture Japan (Monbusho), for a fellowship support. This paper is a contribution to the IGCP 368 and the Gondwana Research Group (Osaka). A part of the expenses for the present study was defrayed by Asia-Japan Collaborative Research Fellowship (Osaka City University) and the Grant-inaid. International Scientific Research of Monbusho. No. 08041109.

References

Aftalion, M., Bowes, D. R., Dash, B. and Dempster,T. J. (1988) Late Proterozoic charnockites in Orissa, India: A U-Pb and Rb-Sr isotopic study. *Jour. Geol.*, **96** 663-676.

Appavadanulu, K., Setti, D. N., Badrinarayan, S., and Subbaraju, M. (1976) The Chimalpahad Anorthosite complex. Khammam district, A.P. *Geol. Surv. India. Misc. Pub.*, No. **23**, Pt. 2, 267-278.

Babu, V. R. M. (1998) Nellore schist belt an Archean greenstone belt, Andhra Pradesh India. In *Gondwana Research Group Memoir* No 4. Precambrian Crustal Processes in East Coast Granulite regions of India and Antarctica within East Gondwana. 97-136.

Chetty, T. R. K. and Kanungo, D. N. (1986), structural analysis of Archean quartzites from a part of Nellore Schist belt, South India. *Geophysical Res. Bull.*, V24, No 3. 99-115.

Divi, R. S., Rajneesh, K., Yoshida, M., and Hariprasad, B., (1995) Structural disposition of Archean-Proterozoic boundary at Kinnerasani, Andhra Pradesh : Imprint of Eastern Ghats Orogeny?. In Roa, A.T et al., (eds). *Proceedings of Sympossium on India and Antarctica during the Precambrian and Granulite and Crustal processes in East Gondwana. Abstr.* Visakhapatnam, India. Gond. Res. Group, Misc. Pub. 2, pp17.

Geological Survey of India (1973) Geological and Mineral Map of Andhra Pradesh, scale 1:2,250,000. Geol. Surv. India, Calcutta.

Geological Survey of India (1993) Geological Map of India, 1:5,000,000. Geol. Surv. India, Hyderabad.

Grew, E. S. and Manton, W. J. (1986) A new correlation of sapphirine granulites in the Indo-Antarctic metamorphic terrain: Late Proterozoic dates from the Eastern Ghats Province of India. *Precamb. Res.*, **33** 123-137.

Hari Prasad, B., Okudaira, T., Yoshida. M and Divi, R, S. (1998) High pressure amphibolites from the Archean Nellore schist belt south-east India. In *The 18th Symposium on Antarctic Geosciences Abstr.* NIPR. Tokyo, 77-78.

Narayana Rao, M., (1983). Lithostatigraphy of the Precambrian rocks of the Nellore schist belt. *Quat. Jour. Geol. Min. Metall. Soc. Ind.*, **55** 83-39.

Okudaira, T., Takeshita, T., Hara, I., and Ando, J. (1995) A new estimate of the conditions for transition from basal <a> to prism c slip in naturally deformed quartz. *Tectonophysics.*, **250** 31-46.

Paul, D. K., Barman, T. R., Mcnaughton, N. J., Fletcher, I. R., Potts, P. J., Ramaakrishnan, M., and Augustine, A. F. (1990) Archean Proterozoic evolution of Indian charnockites: Isotopic and geochemical evidence from granulites of the Eastern Ghats Belt. *Jour. Geol*, **98**, 253-263.

Peucat, J. J., Bouhallier, H., Fanning, C. M., and Jayananda, M., (1995). Age of the Holenarsapur Greenstone belt, relationships with the surrounding gneisses (Karnataka, South India). *Jour. Geol..*, **103** 290-296.

Radhakrishnamurthy, I. V., Gopala Rao, V. V. and Rao, A. T. (1990) Results of a magnetic survey near Sriramgiri, Khammam District, A. P. for possible chromite occurences *Indian Minerals*, Sept.Issue., 11-16.

Rajneesh Kumar., Okudaira,T., Tani, Y., Hari Prasad,B., Divi, R. S. and Yoshida, M. (1999) Structural features around the Archean and Proterozoic terrain boundary in Khammam district, South India. *Jour. Geosci., Osaka City Univ.* 42, 237-245.

Ramaswamy, C. (1962) Meta anorthosites in Khammam district, A. P. *Rec. Geol.Surv. India.*, **89** pt2 483.

Ramsay, J. G. (1967) Folding and Fracturing of the rocks. McGraw Hill, New York, 567p.

Rao and Raju (1997). Geologic setting mineralogy and metamorphism of Chimalpahad Anorthosite complex of Khammam district, Andhra Pradesh, India. In *Precambrian 97*, National seminar on Tectonomagmatism Geochemistry and Metamorphism of Precambrian terrains, Abst Univ. Udaipur. pp 45.

Rao, A. T., and Rao, V. R. (1986) Basic-Ultrabasic magmatism and mineralisation around Enkur in Wira region, Khammam district, Andhra Pradesh. In Proceedings of the seminar on "*Crustal dynamics*", January 22-23, 1986 Indian Geophysical Union, Hyderabad. 78-90.

Reddy, U. V. B., Narayana, B. L and Shanti Kumar, C. (1994) Ophiolitic Melange from Nellore schist belt, an evidence for Precambrian plate tectonics. *Workshop on EGMB*, Geol.Sur.Ind. Vizag. India. Extended Abst, 21-23.

Sarvothaman, H. (1996) Spatial association of Peraluminous and Fe-tholeiites: Evidences from anorthosite-amphibolite association in Khammam Schist belt, Andhra Pradesh. *Geol. Surv. India*, Spl, Publ., **40** 43-58.

Sarvothaman, H. (1994) Studies on granites of Khammam and Krishna districts, Andhra Pradesh. *Rec. Geol. Surv. India.*, **127**, pt.5, 62-64.

Satyanarayana, K., DhanaRaju, R. and Kanungo, D. N. (1994) Geochemistry of Amphibolites from Nellore schist belt, Andhra Pradesh, India : An Example of Back-arc basin low-K Tholeitic Magmatism. *Jour. Geol. Soc. India.*, **44** 253-265.

Shaw, R. K., Arima, M., Kagami, H., Fanning, C. M., Shiraishi, K. and Motoyoshi, Y. (1997) Proterozoic events in the Eastern Ghats Granulite Belt, India: Evidence from Rb-Sr, Sm-Nd systematics, and SHRIMP dating. *Jour. Geol.*, **105** 645-656.

Srinivasan, K. N., Krishnappa, P. M. and Roopkumar, D. (1994) Geology of parts of Nellore schist belt, Andhra Pradesh., *Rec. Geol. Surv. India.*., **127** pt 5 158-159.

Tani, Y., Divi, R. S., Miyashita, Y., Yoshida, M., Yoshikura, S., and Rao, A. T. (1998) Some structural observations in the Eastern Ghats Mobile Belt surrounding Visakhapatnam, South India. *Jour. Geosci. Osaka City Univ*, **41**, 109-122.

Vasudevan, D., and Rao, T. M. (1975) The high grade schistose rocks of the Nellore schist belt, Andhra Pradesh and their Geologic Evolution. *Indian Mineralogist*, **16** 43-47.

Yamamoto, T. (1996) Migmatitic rocks in Tekkali area, Eastern Ghats, India - example of disequilibrium melting. Unpubl. M.Sc thesis, Osaka City Univ, Japan, pp 109.

Yoshida, M. et al., (1998) Geological survey in southern to eastern peninsular India, 1996. *Jour. Geosci. Osaka City University*, **41**, 47-75.

Manuscript received December 3, 1998.
Revised manuscript accepted March 4, 1999.