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# Petrological and Geochemical Studies of Anorthositic Rocks and their Tectonic Setting in the Khammam Schist Belt, Telangana

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***Abstract*— The Khammam Schist Belt (KSB) falls in Khammam and Bhadradri Kothagudem Districts of Telangana State bounded by the latitudes by the latitudes 17°15' and 17°35' N, and longitudes 80°20' and 80°35' E and covers an area of about 300 sq. km. The Khammam Schist Belt (KSB), unlike other schist belts of the Eastern Dharwar Craton (Gadwal and Peddavura etc.) there is no linear belt like configuration and does not contain entire litho package of schist belt. Chimalpad Layered Anorthositic Complex (CLAC) was syntectonically emplaced as "sill-like" intrusive body within the KSB along NE-SW direction. The main lithounits of the study area is mainly divided into (1) Anorthositic rocks, (2) Amphibolites. The geochemical data suggests that the Anorthosites and Amphibolites of the KSB are of the calc-alkaline and tholeiitic affinity respectively. The tectonic discrimination diagrams of the anorthosites and amphibolites infers that the rocks are formed by calc-alkaline and tholeiitic magmas respectively. The Khammam Schist Belt and Chimalpad Layered Anorthositic Complex is a Late Archean to Proterozoic subduction zone segment of the oceanic island arc setting.**

***Index Terms:*** **Khammam Schist Belt, calc-alkaline, tholeiitic, island arc setting.**

## INTRODUCTION

The Khammam Schist Belt (KSB) falls in Khammam and Bhadradri Kothagudem Districts of Telangana State falling in parts of the Survey of India Toposheet Nos. 65 C/06, C/07, C/08, C/10 & C/11 and bounded by the latitudes by the latitudes 17°15' and 17°35' N, and longitudes 80°20' and 80°35' E and covers an area of about 300 sq.km (Fig. 1.1). The present study is mainly focus on the anorthositic and associated amphibolite rocks exposed throughout the schist belt and their interrelationship and setting in the KSB. The Khammam Schist Belt (KSB), unlike other schist belts (Gadwal and Peddavura etc.) of the Eastern Dharwar Craton, there is no linear belt NW-SE configuration as well as it does not contain entire litho package of schist belt it contains mainly Amphibolites.

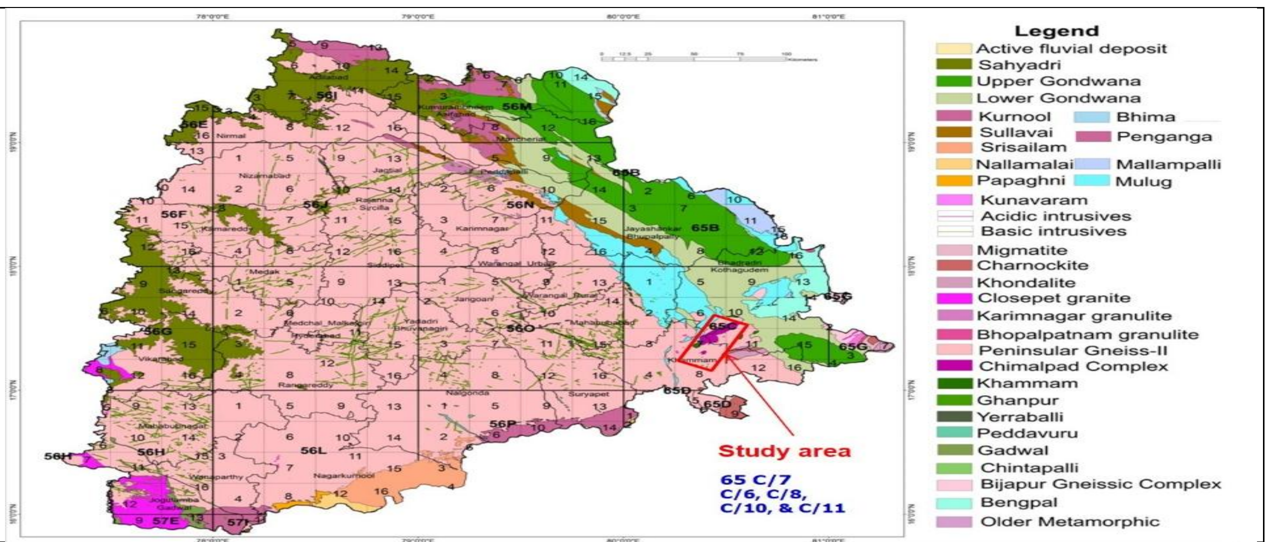
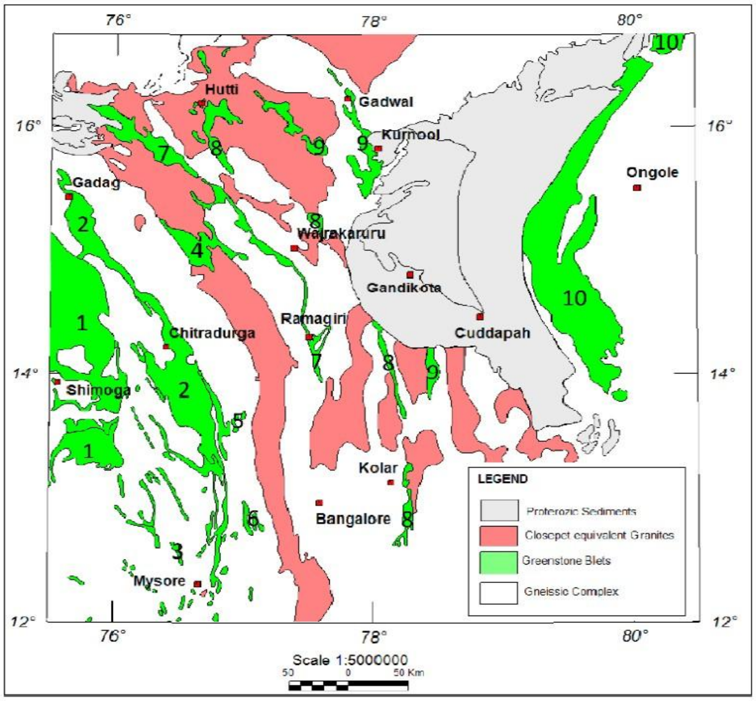



Fig. 1.1 Geological Map of Telangana Showing the study area i.e. Khammam Schist Belt




**WESTERN DHARWAR CRATON:**

1. Bababudan – Shimoga Super belt
2. Gadag – Chitradurga Super belt
3. Sargur Group belts

**CENTRAL DHARWAR CRATON:**

4. Sandur schist belt
5. Javana Halli belt
6. Kunigal belt

**EASTERN DHARWAR CRATON:**

7. Ramgiri-Penakacherla-Srigire-Hungund Super belt
8. Kolar-Kadiri-Jonnagiri-Hutti Super belt
9. Veligallu-Raichur-Gadwal Super belt

**TRANSITION ZONE (EDC to EGMB)**

10. Nellore-Khammam Schist Belt

Fig. 1.2 Geological Map of Schist Belts of the Dharwar Craton

Anorthosites are coarse grained, plagioclase-rich (>70 vol. % of rock-modal composition) cumulates of plutonic igneous rocks that have crystallized from tholeiitic basaltic magmas of mantle origin. (Ashwal, 1988; 1993). They have any composition between about $An_{20}$ to $An_{100}$. Anorthosites refers strictly to igneous rocks consisting of 90% or more plagioclase. The occurrences of anorthosites are volumetrically minor and spread the entire geological column, but more restricted to Precambrian terrains. Majority of anorthosites were mainly confined to high grade granulate-gneiss belts and low grade granite-greenstone belts of the Precambrian terrains (Windley et al., 1981; Phinney et al., 1988). Minor anorthosite components in the younger mafic layered intrusions and in basaltic volcanic provinces of the Phanerozoic to recent periods are uncommon.

The world-known anorthositic occurrences are broadly classified into six major and distinct groups on the basis of their form, internal structure, texture, nature and composition of plagioclase feldspar (Ashwal, 1993):

(1) Archaean deformed & metamorphosed layered anorthosite complexes (Fiskenaesset type);

(a) Megacrystic anorthosites.

(b) Layered (deformed) anorthosites.

Examples: - Sitampundi and Chimalpahad Anorthosite complexes in India.

(2) Proterozoic massif anorthosites (Adirondack-type);

(3) Layered mafic intrusions (Bushveld-type);

(4) Anorthosites in oceanic setting (in ophiolites);

(5) Anorthosite inclusions in other igneous rocks; and

(6) Extra-terrestrial anorthosites (Lunar-type).

## 2. GEOLOGICAL SETTING

Anorthositic rocks occur as sills, bands and sheets in entire Khammam Schist Belt (KSB) which run about 120 km from south of Nandigama in Krishna District, Andhra Pradesh to north of Bhadrachalam, Telangana (Narsimha Reddy, M. et. Al, 1985). The Anorthositic rocks are mainly exposed at Chimalpahad, Jannavaram, and Wira and Siripuram places in KSB (Fig. 1.3). They have variable thickness of layers from <2m to >200m within schistose and gneissose rocks of KSB. The centrally placed Chimalpahad Layered Anorthositic Complex is approximately 30 km long and in average 6 km wide body, situated 8 km SW of Kothagudem. It is spreading over around 200 sq km area within the schist belt. It is considered as largest mafic-ultramafic complex in India. It trends in NE-SW between Gadigutta in NE and Rangapuram in SW, and swerves towards almost east near Rangapuram.

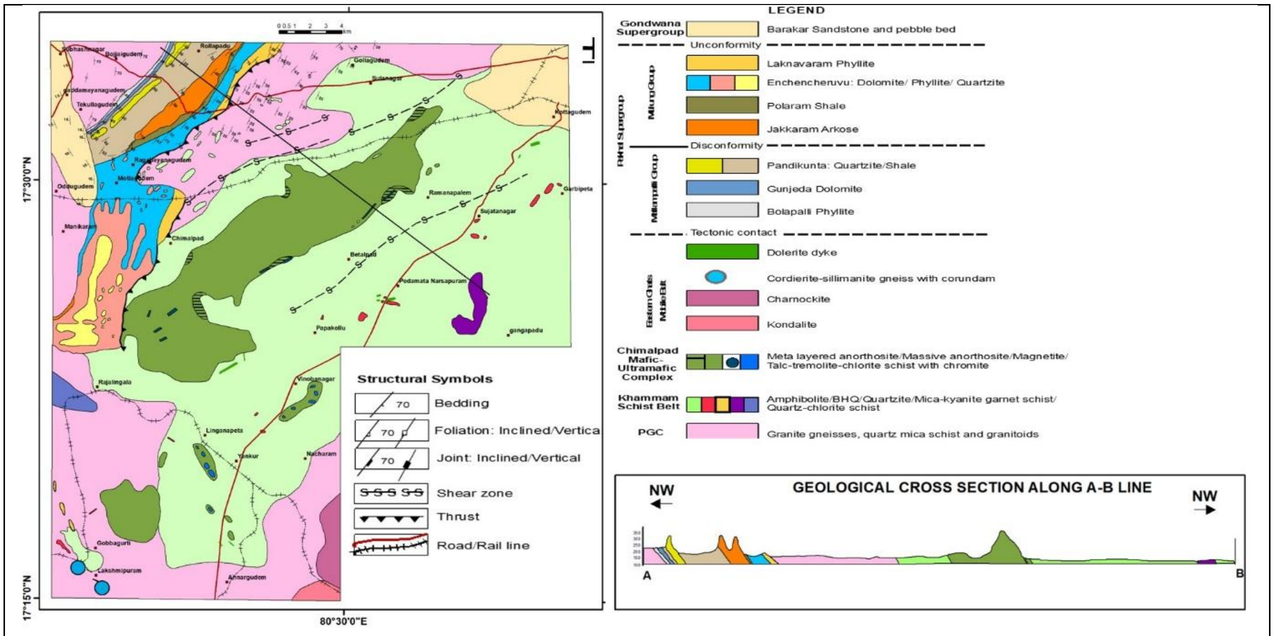



Fig. 1.3 Geological Map of the study area of the Dharwar Craton i.e. Khammam Schist Belt includes Chimalpad Layered Anorthositic Complex (CLAC)

The lithounits of the study area is mainly divided into (1) Anorthositic rocks, (2) Amphibolites.

2.1 Anorthosites: Anorthosites are major litho-unit of the Chimalpad Layered Anorthositic Complex (CLAC) but restricted in the areal extent in the remaining parts of the Khammam Schist Belt. So, Anorthosites of the area have been described as (i) CLAC Anorthosites and (ii) Satellite Anorthosites. Anorthositic rocks include anorthosites (> 90% felsic minerals with 0-10% of mafic minerals), Gabbroic Anorthosites (80-90% felsic minerals with 10-20% of mafics) and Anorthositic Gabbros (65-80% felsic minerals with 20-35% of mafics).

Chimalpad Layered Anorthositic Complex (CLAC) was syntectonically emplaced as "sill-like" intrusive body within the Khammam Schist Belt (KSB) along NE-SW direction. The Anorthositic rocks showed several cumulus layering (Fig. 1.4 B) features include magmatic cross bedding, graded bedding, rhythmic layering and zebra banding (Fig. 1.4 A). Anorthosites of the KSB can be divided into two types based on the presence of garnet (1) Garnet bearing (Fig. 1.4 D) Anorthosites (2) Garnet-free Anorthosites. The field relationships among Anorthositic rocks and cumulus / layering features indicates of undoubtful igneous origin of the CLAC.

2.2 Amphibolites: It is the dominant rock type of the Khammam Schist Belt and exposed throughout the study area. Amphibolite is mesocratic to melanocratic, medium to coarse grained rock and is composed of amphibole, pyroxene, plagioclase, with or without garnet and some minor amounts of quartz, biotite and opaque minerals. Amphibolite in this area occurs as different variants like garnetiferous amphibolite (Fig. 1.5 A), non-garnetiferous amphibolite, amphibolite with salt and pepper texture and sheared amphibolite. Garnetiferous amphibolite is predominant except central part of KSB where non-garnetiferous amphibolite, amphibolite with salt and pepper texture and sheared amphibolite (Fig. 1.5 C) are present. In the central part, the rock is highly sheared (Fig. 1.5 C). In garnetiferous amphibolite (Fig. 1.5 B) garnet occurs as porphyroblasts (upto 5 cm diametre) and is often fractured. At places garnet shows box work pattern or parallel bands. The size and amount of garnet decrease from east to west. Amphibolite, at places, is traversed by veins of quartz and quartzo-felspathic injections which are present along as well as across the foliations. The shear zone trends in NE-SW direction. Felsic and mafic layers are developed along this shear zone in amphibolite. The felsic layers are of mainly plagioclase and mafic minerals are hornblende, pyroxene and biotite. Asymmetric folding (Fig. 1.5 C), elongated grains of feldspar and hornblende have also been noticed in the sheared amphibolite.

Enclavial patches of amphibolite of KSB are present within PGC. From query section and river section amphibolite shows intrusive relationship into PGC. The field evidences in support of this view are cross cutting relationship of amphibolite into granite gneiss, the grain size of the amphibolite is finer towards the contact.

2.3 Pyroxenite:

Pyroxenite and sometimes hornblendite is recorded at the foot hill of CLC at lower level. In hand specimen pyroxenite is coarse grained, melanocratic (dark greenish), monomineralic and composed mainly of pyroxene. These are sporadic lensoidal bodies with dimension upto 100 m long and 0.5 m thick. This unit is not shown in the geological map because of its unmappable size. These are aligned along the strike direction of Chimalpahad hill. Three metapyroxenite layers have been noticed forming alternating layers with layered anorthosite. Lenses of titanifeous magnetite occur at the interface of meta-pyroxenite and meta-layered anorthosite. It indicates that these are cumulates formed from fractional crystallization.

2.4 Khondalite: Khondalite is exposed in Kannegiri hill, NE of Kotta-Venkatagiri. It is grayish white to pink, hard and massive. It is composed essentially of quartz, plagioclase, garnet and acicular sillimanite with minor hornblende and opaques.

2.5 Charnockite: Charnockite occurs along with Khondalite as irregular bands in Kannegiri hill. The rock is grayish coloured, coarse grained, massive and schistose at places. The foliation planes trend in NE-SW direction dipping in high angle towards SE. It is quartzo-feldspathic, hypersthene bearing gneiss and is composed of quartz, potash feldspar, minor plagioclase, garnets, hypersthene and biotite. Unmappable patches and enclaves of charnockite are observed west of Himmamnagaram, west of Gobbagurti and NE of Kotta Venkatagiri within the gneisses and granites.

2.6 Banded Magnetite Quartzite

Detached enclavial outcrops of banded magnetite/hematite quartzite is exposed SE of Lakshyagudem, East and NE of Akkinipuram tanda and NNW of Gobbagurti, SE of Laxmidevipalli, near Yerra Tanda, Vinoba Nagar, Papakollu, Julurpad, Pedamata Narsapuram, Sujatanagar, Sarvaram, Sitampeta, west of Chimalpad village and west of Garibpeta. The bands have variable dimensions. The rock is brownish grey to reddish grey, medium to fine grained showing weak development of bedding (So) plane. It is composed of alternate magnetite/hematite and siliceous/quartz rich bands. The magnetite rich bands are greyish black. Thickness of each band varies from few milimeter to one centimeter showing sharp and wavy contact between the two. Locally hematite is observed in place of magnetite bands. Amphibole is invariably associated with the BMQ. At places, megascopically bedding is not clear but it is visible under microscope.

2.7 Granite Gneiss:

Granite Gneiss is grey to greyish white, fine to medium grained and leucocratic granitic rock. The major minerals are quartz, felspar, hornblende and mica. Except at some places, the gneissosity is not discernible. Dark bands are mostly hornblende and biotite rich whereas the light bands is quartz and feldspar rich. In the southern part gneisses are often garnetiferous. They are traversed by pegmatite and quartz veins which stand out prominently at places due to differential weathering. In western part of the area granite gneiss is medium to coarse grained with porphyroblast of feldspars. At places it becomes streaky gneiss. Mesoscopic folds have been observed in the granite gneiss which folded the foliation plane. It has been sheared leading to mylonite with stretched quartz and feldspar grains and shows S-C fabric. Shear planes are also folded in granite gneiss as observed near Thadikalpadi. At places L tectonites are also observed.

2.8 Granite:

The younger granites or granitoids has been exposed in the southern part of the area within the PGC. The granites are generally occupy plain areas and rarely form hillocks and mounds and are exposed Jangu Banjar, Gaddalagudem and Annargudem. They are light to dark grey, medium to coarse grained, and equigranular to porphyritic. Essential minerals are quartz, plagioclase and K-feldspar and with some mafic minerals (hornblende & biotite). The compositional variation within the group is manifested by the variation in K-feldspar plagioclase ratio and mafic content. The rock locally grades to granodiorite and further to tonalite with the decrease in the proportion of K-feldspars.

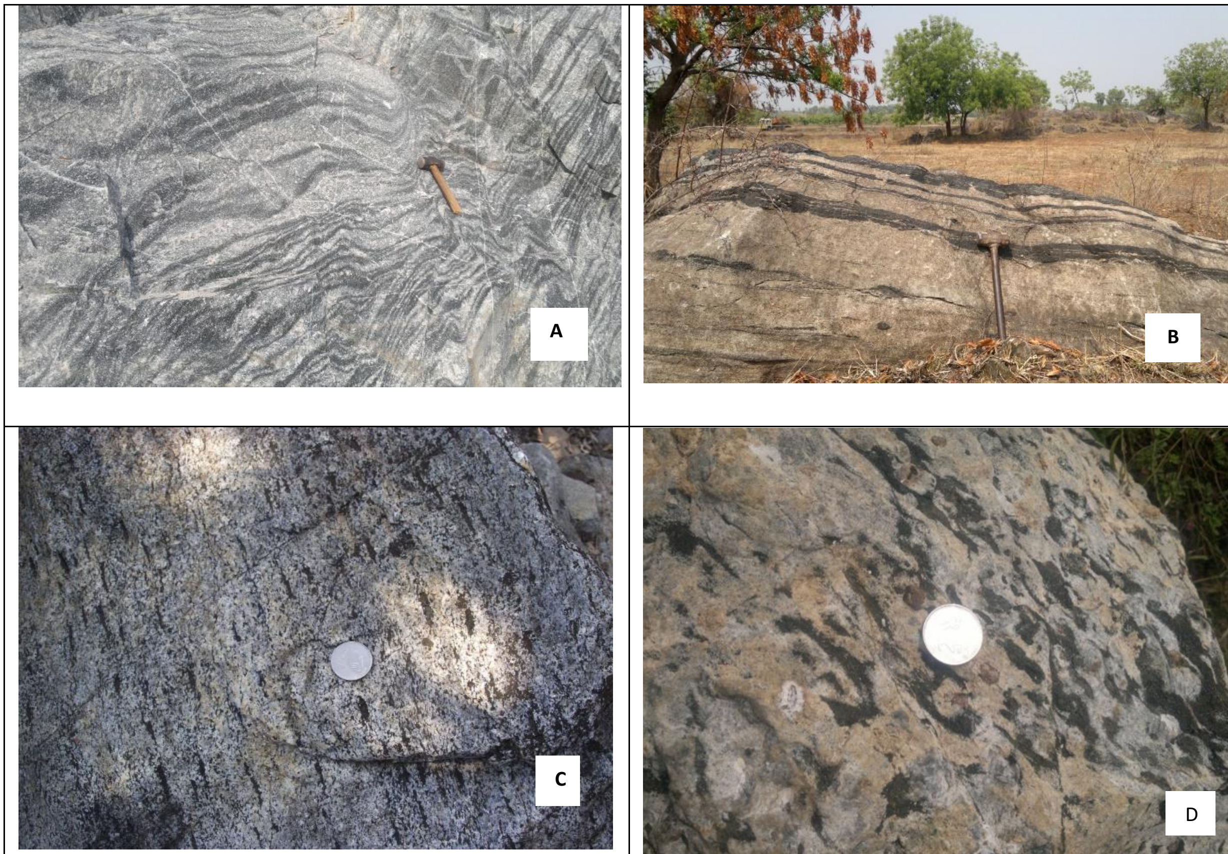



Fig. 1.4 (A) Anorthosite showing layered Zebra banding (B) Anorthosite exhibiting alternate felsic and mafic bands (C) Mineral lineation in Anorthosite (D) Garnets in Anorthosite

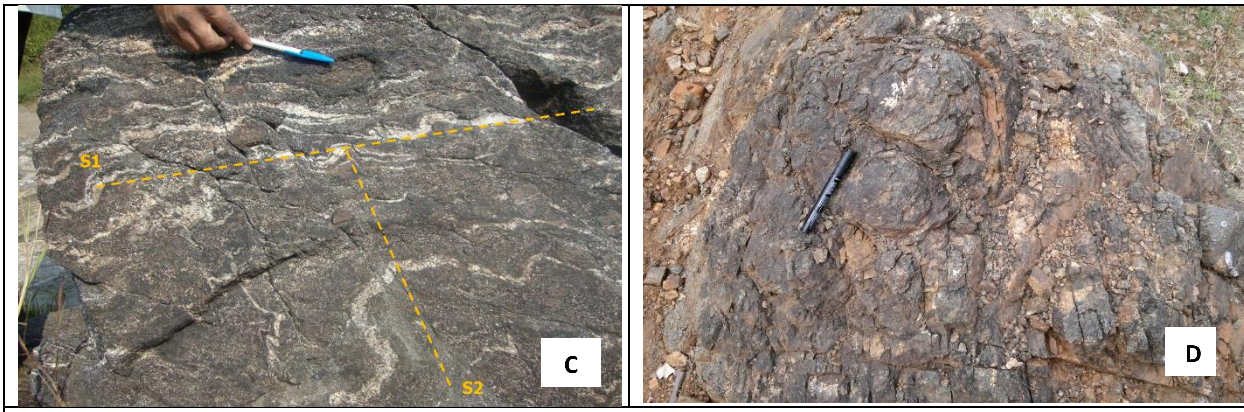



Fig. 1.5 (A) Garnet porphyroblasts in amphibolite near Vinobanagar (B) Close up of the Garnets *Inlcusions* in amphibolite (C) Sheared Amphibolite showing light and dark (felsic and mafic) bands with asymmetrical folding and two sets of foliation. (D) Amphibolite (meta basalt) showing pillow breccia.

## 3. PETROGRAPHY

### 3.1 Anorthosites

The mineralogical composition of anorthosite is Plag + hbl + cpx + scapo ± gar. Garnet is occasionally present as porphyroblasts and as coronas around plagioclase and hornblende in meta-layered anorthosite. The alignment of hornblende and other mafic minerals form mineral lineation in NE-SW direction. One foliation plane defined by parallel alignment of hornblende is noticed trending in NE-SW direction and dipping 600 towards SE. The rock has undergone metamorphism as alteration of pyroxenes to hornblende (Hbl) is seen. The twin lamellae in plagioclase are often tapering or bent indicating deformation. The modal analysis of the rock is as follows: Plagioclase (92 %), Clino-pyroxenes (6.6 %), hornblende (1.2 %) and Opaques (0.2%).

Petrographic study revealed that is a medium to coarse grained rock showing hypidiomorphic texture with sub-hedral grains. The mineralogical composition is Plag + hbl + cpx ± opx ± gar ± Zo ± epidote. Both clinopyroxene and orthopyroxene present in the rock as relict. Garnet is occasionally present as porphyroblasts and as coronas around plagioclase and hornblende. The modal analysis of the rock is as follows: Plagioclase (82.8%), hornblende (14.2 %), clino-pyroxenes (1.6%) and opaques (1.4%).

Anorthosite is medium to coarse grained, and contain predominant plagioclase (˜An85) and minor hornblende. Plagioclase occasionally shows megacrystic texture. Pyroxenes are totally absent. Scapolite, zoisite and calcite are important accessories. Common planer boundaries, triple junctions, polygonal textures and equant grains are typical product of equilibrium condition of crystallization. It is showing granoblastic texture and clino pyroxene occurring as intercumulus grain within plagioclase cumulus. Untwined plagioclases are frequent.

*Gabbroic Anorthosite*: Petrographic study revealed that is a medium to coarse grained rock showing hypidiomorphic texture with sub-hedral grains. The mineralogical composition is plag + hbl + cpx ± opx ± gar ± Zo ± epidote. Both clinopyroxene and orthopyroxene present in the rock as relict. Garnet is occasionally present as porphyroblasts and as coronas around plagioclase and hornblende. The modal analysis of the rock is as follows: Plagioclase (82.8%), hornblende (14.2 %), clino-pyroxenes (1.6%) and opaque's (1.4%).

Gabbroic anorthosite is medium to coarse grained and consist of 80-90% plagioclase and 20% mafic minerals, the most important of which is hornblende. Pale bluish clinopyroxene is usually present, its textural relation suggests it is a relict primary igneous phase. Common planar boundaries and triple point contact showing metamorphism and are typical product of equilibrium condition of crystallization. Plagioclase mainly occurs as cumulates indicating original magmatic texture and tapering lamellae of plagioclase indicating deformation. Garnet is occasionally present as porphyroblasts and as coronas around plagioclase and pyroxene.

*Anorthositic gabbro*: Microscopic study shows it is a medium to coarse grained rock showing hypidiomorphic texture with sub-hedral grains. The mineralogical composition is Plag + hbl + cpx ± opx ± gar ± Zo ± epidote. Modal analysis result gives Plagioclase (67.8%), hornblende (28 %), clino-pyroxenes (3.8%) and opaque's (1%).

The rocks contain 65-80 % plagioclase and 20-35 % mafic minerals. It consists of hornblende, epidote, zoisite, garnet and clinopyroxene. Garnet is present in minor amount. Granoblstic texture indicating metamorphic fabric, hornblende occurs as interserial within the dominant plagioclase cumulus.

3.2 Amphibolites

Thin section study of garnetiferous amphibolite showed that it consists essentially of hornblende, plagioclase, garnet, orthopyroxene, clinopyroxene, minor amount of zoisite. The texture is hypidiomorphic with subhedral grains. At places it shows subidioblastic texture. It is weakly foliated. Foliation is defined by preferred alignment of hornblende prisms. Clinopyroxenes are completely rimmed by aggregate of hornblende. Garnets form rim around hornblendes separating them from adjoining plagioclase. Development of banded character is seen which is defined by alternate plagioclase rich microlithons with hornblende rich cleavage domains. Plagioclase is marginally recrystallised into fine granular aggregates in the amphibolite occurring close to Chimalpahad Complex. Corona of garnet (Fig. 1.6 A) has grown at the contact of plagioclase and hornblende suggesting prograde metamorphism. Sometimes hornblende contains inclusions of plagioclase and garnet (Fig. 10B) which indicates retrograde metamorphism. So both pro and retrograde metamorphism has been noticed in the amphibolite of KSB. Coarse garnet porphyroblasts have overprinted the foliation. The schistocity swerves round coarse grained sub-idioblastic to xenoblastic garnet porphyroblasts with inclusion trails defined by preferred alignment of hornblende and plagioclase. Twinned plagioclase are also present (Fig. 1.6 D). Occurrence of zoisite alongside garnet is an indication of retrograde metamorphism.

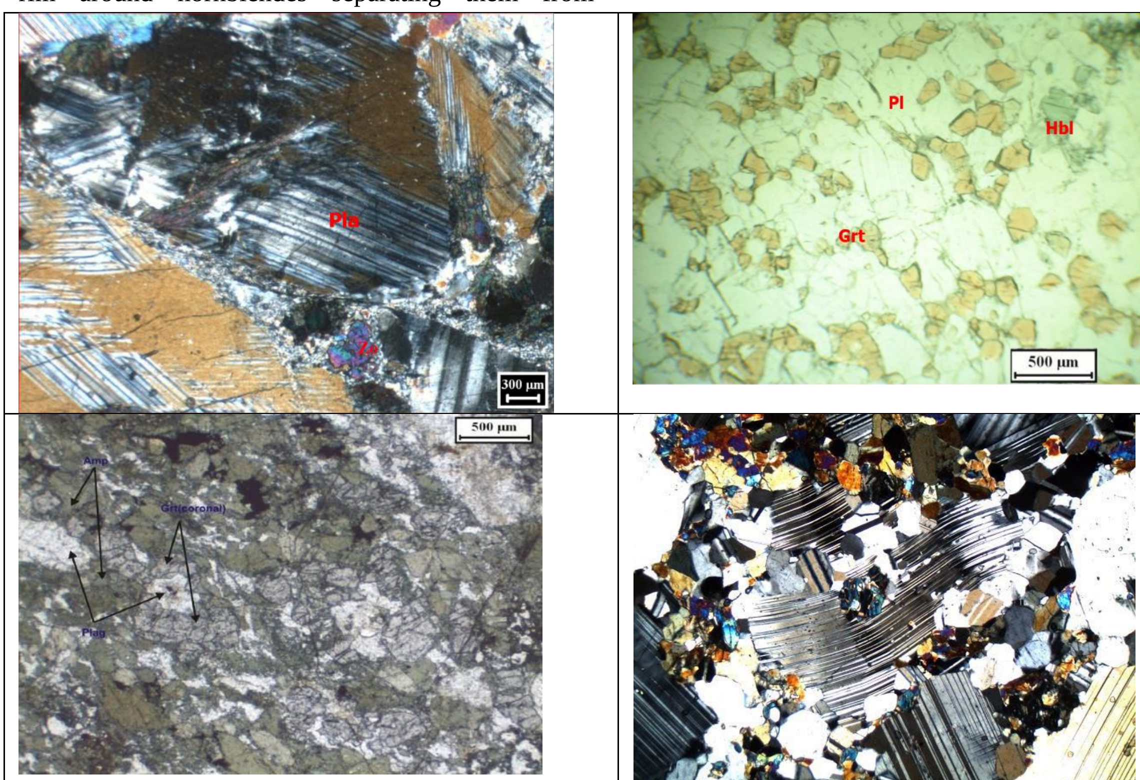



Fig. 1.6 (A) Plagioclase showing bent lamellar twinning and recrystalisation on margin of plagioclase & presence of zoisite, XPL (B) Garnetiferous anorthosite showing garnet porphyroblasts, PPL (C) Photomicrograph showing garnet corona around plagioclase (D) Photomicrograph showing bent twin/saw tooth

lamellae twinning in plagioclase in Deformed Anorthosite.

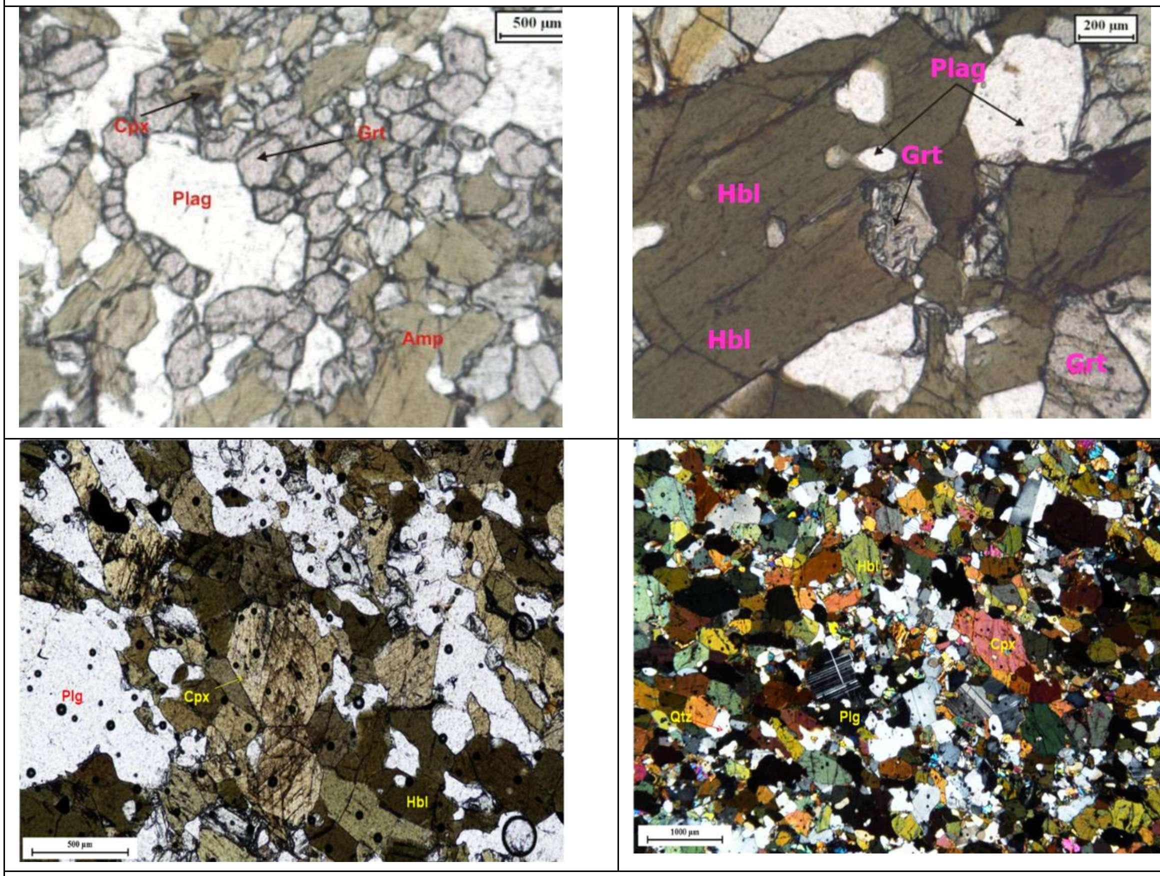



Fig. 1.6 (A) Photomicrograph of amphibolite showing formation of Garnet corona around plagioclase indicating prograde metamorphism, PPL (B) Photomicrograph of amphibolite, hornblende contains inclusions of plagioclase and garnet, PPL (C) Photomicrograph showing triple junction contact of minerals in amphibolite. (D) Photomicrograph showing hypidiomorphic texture in amphibolites.

## 4. GEOCHEMISTRY

The bulk geochemistry of the Anorthositic rocks from the CLAC is mainly controlled by the proportion of cumulus high-Ca rich plagioclase and inter-cumulus mafic silicates such as hornblende and clino-pyroxenes. The high Anorthoite content and high plagioclase (>65%) will be naturally leads to very high content of CaO (10.54-17.30 wt. %) and Al2O3 (23.57-35.97%) contents in the whole-rock analyses.

Three types of Anorthosites have been identified based on the REE patterns. The Type-I anorthosite showing strong positive Eu anomaly (Fig. 1.12 ), Type-II Anorthosites REE patterns reflecting enrichment in LREE with flat HREE (Fig. 1.13 ) and Type-III Anorthosites have strong enrichment in LREE with gentle dipping HREE (Fig. 1.14).

The geochemical data suggests that the Anorthosites and Amphibolites of the KSB are of the calc-alkaline and tholeiitic (Fig. 1.8) affinity respectively (Fig 1.7). The amphibolites of the study area are falls mostly in Boninitic Island arc calc-alkaline basalt (Fig. 1.9), Island arc tholeiite and MORB setting in TiO2–MnO–P2O5 ternary Diagram of Mullen (1983). The rocks also falls in Oceanic island arc setting (Pearce et al. 1977).

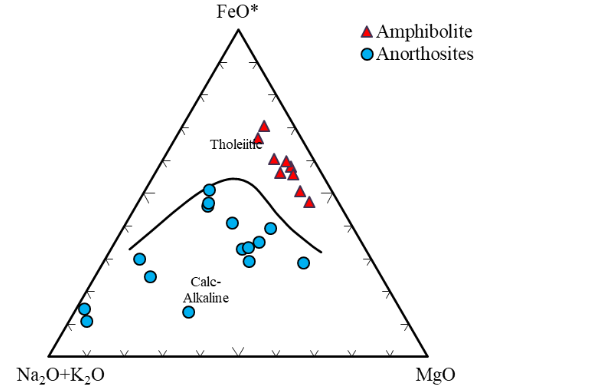



Fig. 1.7 AFM triangular diagram for amphibolites and associated anorthosites, gneisses and schists after Irvine and Baragar (1971).

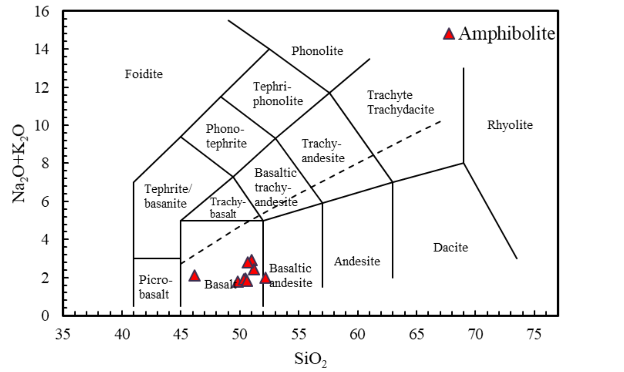



Fig. 1.8 SiO2 versus total alkalies (Na2O) + K2O) classification diagram for amphibolites after Le Bas et al (1986).

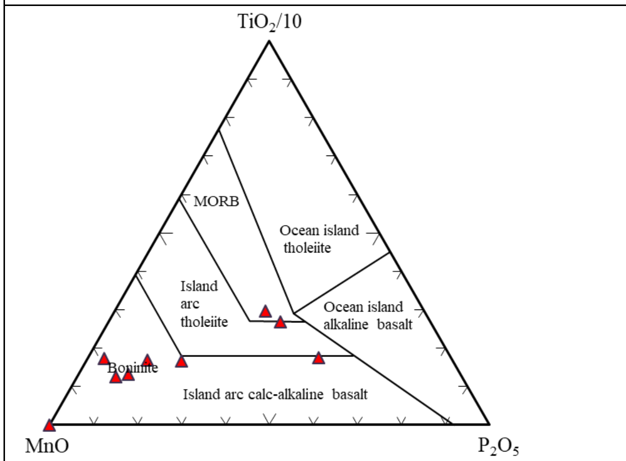



Fig. 1.9 TiO2– MnO–P2O5 ternary Diagram of Mullen (1983) of Amphibolites of the study area. Samples falls in Island arc calc-alkaline basalt, Island arc tholeiite and MORB setting.

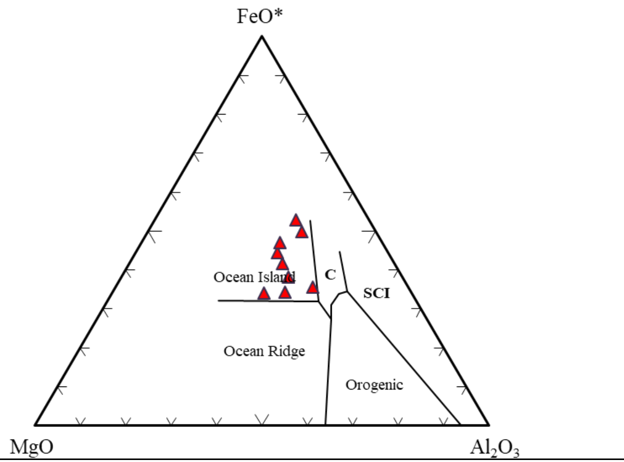



Fig.1.10 FeOt-MgO-Al2O3 ternary diagram (Pearce et al. 1977) from different tectonic settings.
C: Continental SCI: Spreading Centre Island

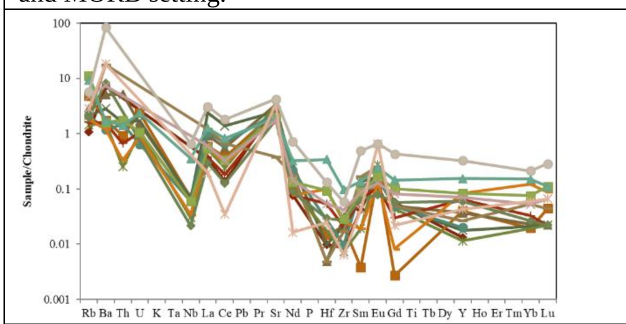



Fig. 1.11 Chondrite-normalized multi-element diagram for Anorthosites from the study area Sun and McDonough (1989).

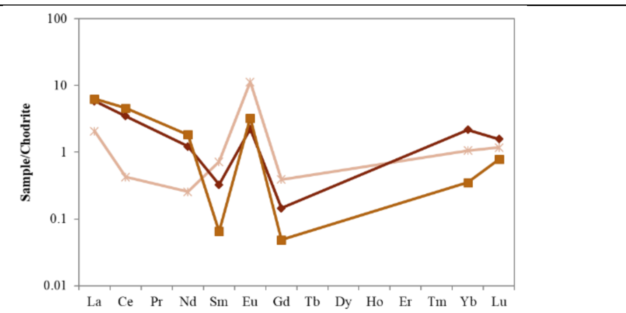



Fig. 1.12 Chondrite-normalized diagram for anorthosites showing strong positive Eu anomaly Sun and McDonough (1989).

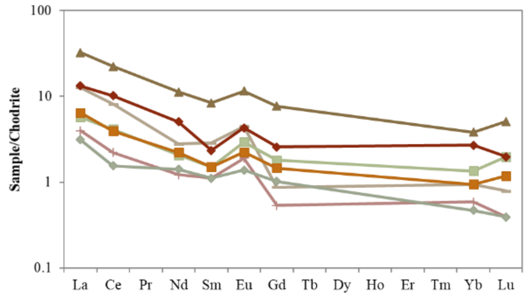



Fig. 1.13 Chondrite-normalized diagram for anorthosites showing enrichment in LREE with flat HREE Sun and McDonough (1989).

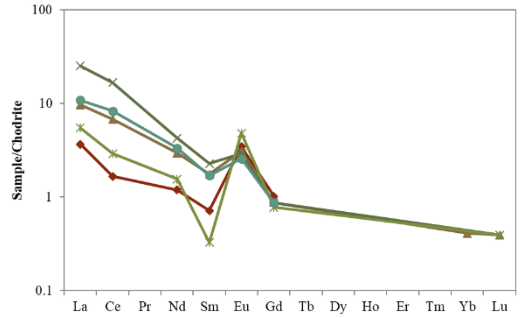



Fig. 1.14 Chondrite-normalized diagram for anorthosites showing strong enrichment in LREE with gentle dipping HREE Sun and McDonough (1989).

## 5. CONCLUSIONS

The lithounits of the Khammam Schist Belt, both the Anorthosites and Amphibolites are formed by the igneous origin. The evidences for the igneous origin is showed in the form of magmatic cross bedding, graded bedding, rhythmic layering and zebra banding in the field. The petrographical studies of the Anorthositic rocks shows twin lamellae / saw tooth lamellae.

It is traditionally accepted that the layered complexes are generally formed by the magmas gravitative settling of alternate felsic minerals and mafic minerals (Fig. 1.4 C) with layers of rhythmic layering. The presence of cumulus and inter-cumulus crystals / minerals with banding / layering infers that they are crystallized by continuous moving of liquid from the magma reservoir. Convection currents mechanism (Wager, 1968) could be postulated for formation of these banding / layering of alternate lighter and heavier minerals. The beautiful layering in some parts of the complex could be explained by imbalance in velocity of the convection currents in time and space for variation in percentage of these alternate lighter and heavy minerals settlement in magma chamber (Mose, 1980; Ramamohan Rao and Satyanarayana Raju, 1986). This might be best suitable archetype to explain about the rhythmic banding / layering in the CLAC. Chimalpad Layered Anorthositic Complex (CLAC) is pure igneous origin and syntectonically emplaced as “sill-like” intrusive body within the Khammam Schist Belt (KSB).

The CLAC is definitely Archean metamorphosed Layered Complex, because it consists of many characteristics of the same. The plagioclase percentage is obviously high ranges from An60 to An90 which is a basic character of most of the Archaean Anorthosites. Many textural similarities in the form of large Megacrystic plagioclase, schlieren of hornblendes, cumulus and inter-cumulus minerals are comparable with most of the Archean Complexes especially Fiskenesset Complex, Greenland.

The whole-rock major element geochemistry of the CLAC shows that the Anorthositic rocks are strikingly rich in Cao and $Al_2O_3$ as well as poor in alkalies which is in similarity with the Archaean layered Anorthositic rocks. The whole-rock trace element geochemistry of the CLAC showed that the higher values of Ba and Ni is also in conformity with Archaean layered Anorthositic complexes. The AFM diagram shows that the Anorthosites are of pure calc-alkaline magma product and compares worlds Archean anorthosite complexes.

The tectonic discrimination diagrams of the anorthosites and amphibolites infers that the rocks are formed by calc-alkaline and tholeiitic magmas respectively in subduction zone oceanic island arc setting.

Based on the above field relationships, petrological, petrographic features and geochemical signatures the rocks of the Khammam Schist Belt are formed during Late Archean to Proterozoic period.

The rocks of the Archean metamorphosed Chimalpad Layered Anorthositic Complex (CLAC) was injected as sill-like emplacement. The rocks of the complex were mostly at deeper parts by magmatic differentiation and subsequently emplaced to the surface.

The study area i.e. Khammam Schist Belt (KSB) and Chimalpad Layered Anorthositic Complex (CLAC) is a Late Archean to Proterozoic subduction zone segment of the oceanic island setting.

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