This book deals with the detailed studies on the geological, structural, petrographical, geochemical, controls of mineralisation and remote sensing & GIS studies related to the mineralisation of Corundum in parts of Khammam Schist Belt in Andhra Pradesh, India. The book also provides the locations for occurrance of semi precious corundum within the area of research which has been revealed in the field photographs.

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CHAPTER - 1

INTRODUCTION

Corundum is pure alumina, the oxide of the metal aluminum, composed of 53.2 % of the metal and 46.8 % of oxygen. Natural corundum is probably never chemically pure and the inclusions of foreign elements, even the mere traces, impart colour that makes the gem.

The term “ruby” is used for Cr-bearing corundum including pink and purple coloured crystals. Geological investigations resulted in the first discovery of rubies in marbles and in the development of prospecting programmes leading to the discovery of corundum bearing placer deposits. (Sutherland, et al., 1988)

In Southern Vietnam, the corundum commonly includes blue-green-yellow sapphires called BGY-Sapphires. East Australia and South East Asia exploit rich corundum deposits from their basalt fields, which include, processing and cutting industries. (Mumme, et al., 1988)

There are at least nine coloured varieties, other than the red ruby and blue sapphire, and are named for the gems of other mineral species that they resemble in colour only with the distinguishing prefix of "Oriental." The arbitrary names and colours are: Ruby (Oriental ruby), red; Sapphire (Oriental sapphire), blue; Leuco-sapphire (White sapphire), colourless; (Oriental aquamarine), light bluish-green; (Oriental emerald) green; (Oriental chrysolite), yellowish-green; (Oriental topaz), yellow; (Oriental hyacinth), aurora red and (Oriental amethyst), violet.

Inclusions of tiny, slender, parallel rutile needles in ruby cause a polished gem to exhibit asterism. Rubies displaying asterism are known as "Star Rubies", and if transparent are highly prized. Star rubies exist in six ray stars. Very rarely, twelve ray stars also occur. Occasionally, ruby also exhibits cat's eye effect. Colour zoning, which forms from growth layers that build up during the formation of the stone, is present in certain rubies.
Corundum, in the form of ruby and abrasive variety is occurring in and around Lakshmipuram and Gobbagurti areas of Khammam District within the Khammam Schist Belt., which is a part of the Indian Peninsular Shield (Ramam and Murthy, 1997). The exploitation activity of corundum by the local entrepreneurs along certain faiths and beliefs, is taking place in these areas over few decades. The State Department of Mines and Geology and Andhra Pradesh Mineral Development Corporation (APMDC) have investigated these areas where exploitation is carried out. (Dayashankar, et al 2001). The nature of occurrence of corundum in these areas represents float, in-situ and placer accumulations.

A detailed and comprehensive geological studies on the sporadic occurrences of precious and semi-precious corundum over wide areas associated within zones of metamorphosed supracrustals has not so far been done in the Khammam district of Andhra Pradesh, India. Further, the area is a part of Nagarjuna Sagar Right Canal command area and contains scanty outcrops except in the higher hilly tracts. It possesses corundiferous outcrops in the plains mostly covered by soil cover. In view of the complexities involved on the nature and controls of mineralisation of corundum, not only in the mined out areas, but also in the inaccessible virgin areas, particularly the Gobbagurti Reserve Forest, systematic investigations comprising remote sensing, petro-mineralogical and geochemical investigations were attempted to explore the genetic significance for the occurrence of corundum so as to identify newer occurrences in a similar geological set-up. Keeping these aspects into consideration, research work leading to the award of Ph.D degree has been chosen on the topic: "Geoscientific Evaluation of Corundum in and around Konijerla Mandal, Khammam District, Andhra Pradesh, India".

1.1 LOCATION AND ACCESSIBILITY:

The study area is bounded by 17° 10': 17° 20':: 80° 15': 80° 25' covering parts of the Survey of India Toposheet Nos. 65C/7 (SW & SE), and 65C/8 (NW & NE) respectively. It covers an area of 316 Sq. Kms. The area is located 20 Kms, East of Khammam town and is quite accessible (Fig.1.2). (Location Map). In this area, corundum occurs at Wyra (17° 10' : 80° 23'), Pallipadu (17° 12' : 80° 20'), Konijerla (17° 13' : 80° 18'), Tanikella (17° 14' : 80° 16') and Singaraipalem (17° 14' : 80° 22') areas of 65C/8 and Donabanda (17° 18' : 80° 17'), Mekalkunta (17° 16' : 80° 20'), Lakshmipuram (17° 16' : 80° 22'), Gobbagurti (17° 17' : 80° 22'), Anjanapuram (17° 12' : 80° 27') and Jannaram (17° 18' : 80° 24') areas of 65C/7 respectively.

1.2 PHYSIOGRAPHY, GEOMORPHOLOGY AND DRAINAGE:

Physiographically, the study area exhibits undulating, topography with tors, domes, inselbergs, undulating uplands, plains and valleys. The relief of the area is irregular and the land surface in the area is mostly uneven.

GEOMORPHOLOGY:

The common landforms of the study area include hills, hill tops, hill weathered, hill slope, residual hills, linear ridges, inselbergs, piedmont slope, piedmont slope with vegetation, pediment, pediment with canal command area, pediment with vegetation, rocky area/stony waste, pediplain, pediplain with canal command, pediplain shallow weathered, pediplain shallow weathered with vegetation, pediplain moderate, valley fill shallow, valley fill moderate and gullied land. The area displays a distinct varied topography wherein high steep hillocks are covered by sharp gullies as erosional features. At Gobbagurti, the highest topography altitude i.e. 399 m is observed and the hill range extends in NE-SW direction, located due NW of Tallada (Fig. 7.3).

DRAINAGE:

The important and significant water body in the area is the Wyra Lake. Drainage pattern in the area is mostly dendritic to sub dendritic and at places parallel to sub parallel. The drainage pattern and texture are indicators of landforms and bed-rock type and also suggest soil characteristics and site drainage conditions. The dendritic to sub-dendritic drainage pattern in the district is a well-integrated pattern, which is observed on relatively homogenous material such as granite. The drainage pattern of the area is mainly controlled by structure of the lithology and Nagarjunasagar Right Canal passing through the area. The area is a part of Nagarjunsagar Right Canal command area. Steep gorges are made through the rocks to make passage of the water through the area. Coupled with drainage pattern is drainage texture. The study area is mostly comprised of fine textured patterns, developed where the soils and rocks have poor internal drainage and high surface runoff. At places, the area is covered by hard massive rocks such as granites and gneisses, and coarse textured patterns were developed where the soils and rocks have good internal drainage and little surface runoff. In addition to the major water body, are the ephemeral nallas and vagu which comprise various sub basins within the main basin.

1.3 CLIMATE AND RAINFALL:

The area experiences hot, semi-arid to arid climate. The climate of the area is generally hot in summer (40-45^{0}C) but the winters are relatively pleasant especially on the plateaus of the interior. The area shows four distinct climatic seasons, namely; Summer season (March – May), Southwest monsoon season (June – September), Northeast monsoon (October – November) and Winter season (December – February). The average annual temperature is 27^{0}C.

The rainfall is received from southwest monsoon. Most of the rainfall is received during June – October. The intensity of the southwest monsoon depends upon the movement of low-pressure systems from Bay of Bengal. Generally, 2-3 depressions are observed during southwest monsoon period, bringing in fairly widespread rainfall and scattered heavy rains in northern parts. There are regular breaks in the southwest monsoon during July-August, which extend from 1 to 3 weeks. The average annual rainfall is approximately 80 cms.

1.4 NATURAL VEGETATION, AGRICULTURE AND SOILS:

Natural vegetation in the area is controlled by physiography, climate, edaphic conditions and biotic influence. The study area has a negligible area under forests compared to the entire district, except for the Gobbagurti Reserved Forest and Irlapudi Reserved Forest.

AGRICULTURE AND SOILS:

The main crops of the district are Rice, Jowar, Bajra, Maize and small millets. Other crops include Cotton, Chillies, Tobacco, and Redgram. The main source of irrigation is

Nagarjunasagar Left Canal. In addition to these, there are few minor irrigation sources like Wells, Tubewells and Tanks.

SOILS:

The area forms a part of the South Deccan Plateau where soil formation is dominantly influenced by parent material, climate and topography. The major soil orders of the district include Alfisols, Vertisols and Entisols. The soils are shallow to deep, loam to clay, mixed gravelly red and black soils. The soils are excessively drained and severely eroded. The study area is represented by different soil classes namely, Rhodic Paleustalfs, Lithic Ustorthents, Lithic Ustropepts, Vertic Ustropepts, Aquic Ustropepts, Typic Ustropepts, Typic Paleustalfs, and Typic Haplustalfs (65 C/7) and Vertic Ustropepts, Rhodic Paleustalfs, Aquic Ustropepts, Typic Paleustalfs, Typic Rhodustalfs, and Typic Haplustalfs (65C/8). (Soil Map of India on 1:7 million scale and Soil Resource Map of A.P).

1.5 AIM AND SCOPE OF PRESENT WORK:

The main aim of present work is to evaluate the occurrences of corundum with respect to its host rock and identify the controls of mineralisation in and around Konijerla Mandal of Khammam District, Andhra Pradesh, India. Although corundum has been reported and excavated at different places in Konijerla Mandal, no comprehensive model for its genesis has been evolved in order to identify newer areas. The study was aimed at evaluating different aspects of geological, geochemical, and remote sensing investigations. A thematic geological map has been digitized to evaluate the structural continuities of the mineralized areas, barren areas and the associated petro-mineralogical set-up. The study warrants a multi dimensional approach and may provide an ample scope for the identification of favourable lithologies which help in crystallizing genetic ideas on corundum mineralisation.

1.6 OBJECTIVES OF PRESENT WORK:

The main aim of research work is to appraise the occurrences of corundum with respect to lithology and controls of mineralisation in and around Konijerla Mandal of Khammam District, Andhra Pradesh, India.

The objectives of the present work are as follows: -

(i) To study the geological and structural aspects of the area in order to understand the nature of occurrence of corundum and its mineralization.

(ii) Application of remote sensing studies on a GIS platform in the study area.

(iii) To study the petrography and geochemistry of the associated rocks related to corundum mineralization.

(iv) To identify the possible genesis of corundum in the study area.

(v) Interpretation of all the above data for geoscientific evaluation of corundum in Konijerla Mandal, Khammam District, Andhra Pradesh, India.

1.7 METHODS OF STUDY AND DATA USED:

The mineralization of corundum has been studied formulating an appropriate methodology. The method of studies involved detailed field investigations of the study area with respect to its geology, geomorphology and structural controls, supported by laboratory studies.

These include:

(i) Field work in the area to understand the nature of occurrence of corundum.

(ii) Studies on the geology, geomorphology and structure along with the nature of intrusives and associated rock types in the area.

(iii) Preparation of thematic layers on the geology, geomorphology and structures using the Survey of India toposheets , satellite data of the study area and the ground truths.

(iv) Petrographic studies on corundum bearing formations.

(v) SEM studies and EDX analysis of corundum samples.

(vi) EPMA of rock samples associated with corundum occurrences.

(vii) Geochemical studies viz., Major element studies and Trace element studies.

(viii) Tectonic classification of rocks.

(ix) Studies related to the origin and nature of corundum occurrences in the area.

DATA USED:

The following data were used for research work.

(a) Survey of India Toposheets Nos. 65C/7 & 65C/8 on 1:50,000 scale pertaining to the study area.

(b) IRS IC/ID LISS-III FCC (Feb.1999) of 65C/7 & 65C/8 on 1:50,000 scale pertaining to the study area.(Fg 1.1)

(c) Existing geological information.

(d) Softwares such as Arc GIS (9.0) and MS Office-98.

1.8 PREVIOUS LITERATURE:

Rubies were first synthesized in 1902 by French Chemist Auguste Verneuil. The process of creating synthetic rubies is known as the Verneuil process. Many rubies on the market are synthetic. Only experts can distinguish between natural and synthetic rubies (Levin, 1913).

Ruby is faceted into many styles of cuts, although the brilliant and step cuts are the most preferred. Stones displaying asterism are polished as cabochons. Synthetic rubies are inexpensive and often used as a substitute for natural rubies.

The colour-varieties of corundum are found in irregular grains and as crystals embedded in crystalline rocks and metapelitic schists. The gem-varieties frequently occur as secondary contact minerals, developed in limestone. These embedded crystals are frequently liberated by the weathering and are found in the debris along the streams.

Corundum not only forms a minor component of a number of metamorphic rocks, such as, marbles, gneisses and schists, but also of pegmatites and syenites. It is often unevenly distributed in the rock, and one can observe rich pods with high volume corundum in an otherwise nearly barren rock. (Simandl and Paradis, 1999)

Corundum can be found in several different types of 'silica deficient' rocks. These include syenites with much feldspar and limestones. Corundum is very hard, and it is often mined from so-called secondary deposits like river gravels, where the corundum is localised even if the rest of the rock has decomposed. In fact, only very little corundum is mined from primary rocks.

Boulders of the assemblage- ruby-sapphire corundum, chromian muscovite, margarite and tourmaline (chromian chlorite, Zn-Mn chromite and Mn-Ti magnetite) occur in glacial moraines and also in the rivers of North Westland, South island of New Zealand. The Cr-rich corundum of the boulders and the presence of rare serpentinite finds indicate that they are derived from ultramafic rocks (Pounamu ultramafics) that occur within the Alpine Schist of the Southern Alps. In the corundum, Cr_2O_3 content ranges from 0.5 to 13%, with red colouration becoming more intense with increasing chromium. Corundum has grown by the replacement of the micaceous matrix that consists of chromian muscovite (0.1-4.1% Cr_2O_3) and chromian margarite (0.4-1.2% Cr_2O_3). Corundum – Cr silicate rocks are the products of extreme metasomatic alteration of quartzo felspathic schist enclaves in serpentinites.

It is observed that there is a concentric mineral zonation in single rock samples along with zoning and replacement in minerals. For e.g., Cr in corundum and chromite, Ti and Fe in corundum, Ba in muscovite, Sr in margarite and Mn and Zn in chromite and magnetite imply element redistribution during metasomatism.The temperature of metamorphism of garnet zone rocks (450^{o}C) that contain the corundum-Cr-silicate rocks is well below that of the breakdown of muscovite and margarite to form corundum and indicates the importance of fluid composition, particularly the cation-hydrogen variables Ca^2+/H+, K+//H+ and SiO_2. (Rodney Grapes and Ken Palmer, 1995)

Corundum+quartz-bearing assemblages occur in small lenses in granulite facies metapelites in Rayagada, North-central part of the Eastern Ghats Granulite Belt, India. Corundum porphyroblasts and quartz co-exist with porphyroblastic almandine-rich garnet, hercynite spinel, ilmenite and magnetite. Corundum and quartz are separated by sillimanite or a composite corona consisting of sillimanite and garnet, where corundum shows sharp grain boundaries with spinel, ilmenite and magnetite. Porphyroblastic corundum contains prismatic sillimanite inclusions in which irregularly shaped quartz is enclosed. Two distinct reactions are inferred from the textural features: corundum+quartz=sillimanite and spinel+quartz=garnet+sillimanite (Shaw and Arima, 1998).

Corundum-bearing silica-undersaturated granulites are reported from the In Ouzzal granulitic unit at North West of Hoggar. They have also been reported in the Limpopo belt (Ackermand et al., 1982) and Namaqualand in South Africa (Waters, 1986). Central Sri Lanka. (Kriegsman and Schumacher,1999) Central Australia, the Gruf complex, Italian Central Alps and the Wilmington complex, USA, (Ouzegane and Guirand, 2003)

Corundum formation is observed in a metasomatic reaction zonation around an ultramafic body within a metapelitic sequence. Corundum-bearing schist is usually found near calc-silicate reaction bands. Tourmaline is a major component in some of the corundum-bearing high-grade schists. The most complete assemblages in the high-grade schists and gneisses are: Bt ± Grt + Fib + And + corundum (Crn) + Kfs + Pl + Ilm; in corundum-bearing schists and Bt ± Grt + cordierite (Crd) + Fib + And + Kfs + Pl + Ilm + magnetite (Mag) + Qtz in banded pelitic gneisses (Stuwe. et al, 2005).

1.9 CLASSIFICATION OF GEM CORUNDUM DEPOSITS, NOTEWORTHY LOCALITIES AND OTHER IMPORTANT OCCURANCES AND OF CORUNDUM:

Genetic classification of sapphire and ruby deposits takes into consideration the geological origin of the deposits, i.e. the geological processes which generate them, and thus follows the classification of rocks. (Simonet, 2008)

Simonet observed that in primary deposits, corundum is hosted by the rock in which it is formed. Primary deposits are divided into igneous and metamorphic categories. Igneous deposits are rare and include syenitic rocks in which corundum is the result of an early stage of magmatic crystallisation.

In secondary deposits, corundum is an inherited mineral. Secondary deposits include sedimentary deposits (alluvial, colluvial and eluvial), as well as volcanic deposits where corundum occurs as a xenocryst in lava.

Metamorphic deposits are highly variegated due to the fact that corundum can appear in different thermo-barometric conditions, particularly in hornfels, amphibolite and granulite facies, and in different geological environments. Two types of metamorphism are to be considered. The first one is isochemical metamorphism of alumina rich and/or silica poor protoliths. Corundum-bearing hornfels are the result of dehydration or incongruent melting of mica at high temperature. In this type of deposit, corundum is usually of small size and thus cannot be used as a gemstone. Ruby-bearing marbles (Burmese, Pakistani, Nepalese deposits) (Giuliani, 2007)_are owed to the regional metamorphism of marbles containing mineral impurities. Ruby - or sapphire-bearing gneiss and granulites are linked to the metamorphism of aluminous metasediments in amphibolite to granulite facies conditions. These rocks form large provinces (Sri Lanka, East Africa) where they are associated to other types of corundum deposits Ruby-bearing amphibolites, among which the best-known example is the Longido deposit in Tanzania, are the result of the hydration of metagabbros or meta -anorthosites in granulite facies, in addition to the corundum -bearing anatexites.The second type of metamorphism is exochemical metamorphism, in which small scale metasomatic phenomena is involved which imply chemical exchanges between silica poor rocks (peridotites, serpentinites, marbles) and silica and alumina rich rocks (gneisses, pegmatites). The later are desilicified by the former and alumina recrystallises as corundum. Sapphire -bearing skarns, common in Sri Lanka, are the result of interactions between granitic or syenitic pegmatoids and marbles.

Metasomatic alterations of corundum deposits are important. Sapphires, and sometimes rubies, are found as xenocrysts in alkali basalts of continental rift structures. Two suites of corundum have been distinguished, with different characteristics based on inclusions, chemistry, habitus and colour.

Amphibolite to granulite facies metamorphism of alumina -rich rocks such as aluminous metasediments (pelites) and/or silica –poor rocks such as metagabbros or meta - anorthosites host the gemstones.

For metasomatic deposits, the juxtaposition of silica-poor rocks and silica-alumina-rich rocks, in metamorphic conditions of amphibolite to granulite facies, is considered promising. The existence of corundum provinces has been noticed, such as the Highlands

Group in Srilanka, and the Mozambique Belt in East Africa and Madagascar. (Simonet, 2008)
Prospecting of basaltic sapphire deposits is led by the presence of a continental rifting environment, with alkali basalt emission (plateau or scattered volcanism), the presence of peridotite xenoliths in the basalt, and basal layers of phreatomagmatic tuffs. The possibility of using modern prospecting methods (geophysics, geochemistry, remote sensing) is also of great importance.

The direct host of the Mangare mineralisations of Southern Kenya, as described by Simonet, is a series of marbles, graphite gneisses, amphibolites and various gneisses .It underwent amphibolite to granulite facies of metamorphism. The Mangare ruby mineralisations are the result of metasomatic phenomena involving boron-rich fluids originating from metapelites, which have been subsequently reequilibrated with meta - ultrabasites. Mineralisations are spatially linked to ultrabasic bodies (metadunites) that underwent multiphase metamorphic and metasomatic alteration. These alteration phases include early serpentinization (hydration) and later silicification and carbonation. The resulting assemblage is enstatite + talc + magnesite +/ - anthophyllite +/- chalcedony +/- serpentine. In some cases, metasomatic alteration is characterised by a gain of Si and overall Al, and a loss of Mg and Cr. This leads to the syntectonic crystallisation of phlogopite + Mg-Al-amphibole + spinel + corundum assemblages.

In the case of the ruby-bearing plagioclasite vein at Kimbo Pit (John Saul Mine) of Southern Kenya, mineralisation appears as a sub vertical vein following the contact between an ultrabasic body and its host graphite gneisses. It is characterised by a plagioclase -corundum assemblage, with varying amounts of kyanite, muscovite, tourmaline and graphite. It shows several generations of corundum crystals having different characteristics and quality. Corundum crystallised together with tourmaline in a pegmatitic phase with indirect desilication, involving a fluid of metapelitic origin subsequently equilibrated with ultrabasic rocks (Cr and Ni enriched). It is proposed that the mineralising fluid was ascending. Desilication leads to the disappearance of quartz and the crystallisation of corundum in the pegmatite.

Summarising the corundum gem variety deposits in his unpublished thesis, Simonet observed that a plumasite, sensu stricto consists of grey or bluish corundum, oligoclase and biotite. Gem corundum deposits are closely related to plumasites that include Southern Madagascar sapphire deposits, Kashmir sapphire deposits and Umba fancy sapphire deposits in Tanzania. Ruby deposits of the Mangare area appears to have originated from more complex desilication phenomena involving pegmatites and ultrabasites.

Rubies from Mangare area are dipyramids and contain up to 0.4 wt % Cr_2O_3 and less than 0.05 wt % FeO (Desilicated gneisses). Metasomatic alteration, including desilication, can also affect felsic rocks such as gneisses or other quartzo-feldspathic rocks that have been tectonically put in contact with ultramafites. Examples of such rocks include some ruby and sapphire deposits of Southern Kenya (Corundum-bearing Skarns). These rocks are the result of reactions between pegmatites, or metapelite-equilibrated fluids, with meta-limestones. The desilication reaction is initiated by the silica deficient host rock.

Anatectic deposits are link and the frontier between metamorphism and magmatism, and metamorphic reactions occur during anatexis. This justifies the choice of including corundum-bearing anatexites in metamorphic corundum deposits. Anatexis is essentially a differentiation process, and as such can be a desilication process. When a metapelitic rock melts, silica enters the melt first and the melting residue is usually richer in alumina and poorer in silica than the produced liquid. In originally alumina-rich rocks, corundum may thus appear in anatexis residues. Examples of corundum-bearing anatexis are from rocks of the Mozambique Belt near Morogoro in Tanzania (Schwarz, 2008) and also from Archaean rocks of Northern Scotland. (Upton, 1999)

Gem-corundum sedimentary deposits are eluvial or colluvial accumulations, alluvial and marine placers. They may or may not be consolidated depending on their age. Corundum crystals are present as clasts inherited from other types of deposit. These deposits are a major source of gem-corundum, especially in Sri Lanka (Dahanayake and Ranasinghe, A 1980), and in Eastern Australia and in Southern Tanzania. The formation of gem-corundum alluvial deposits obeys the same rules as that of other heavy minerals deposits. Concentration of gem-quality corundum in such deposit is higher than in primary deposits, due to a cleaning process during rocks erosion and transport, the most intruded and fractured stones being more rapidly destroyed.

Corundum also occurs in alkaline basaltic lava and pyroclastites of some continental rifts and are most of the time accompanied by zircon and black iron spinel. These minerals have not crystallised from the basaltic liquid but are xenocrysts (Coenraads, 1992).

Two main suites of corundum xenocrysts have been recognised by Sutherland_on the basis of their crystallographic and chemical features. The "basaltic" (or "BGY", for blue-green-yellow) suite includes dark green, blue-green, green and yellow barrel-shaped sapphires with sharp colour zonation. It is the most common and usual suite, that is present in every basaltic deposit. Inclusions are mostly zircon, K-feldspar, acidic plagioclase, Ti-Nb-Ta oxides, U and Th minerals. It is rich in Ga_2O_3 (up to 0.4 wt %) and in FeO (up to 1.5 wt %). Because of the high iron content, Fe pairs are more likely to form and therefore the blue colour is mostly due to Fe^{2+}-Fe^{3+} intervalence charge transfers. The "metamorphic" suite includes pastel coloured sapphires with no colour zonation. It is poorer in FeO, Ga_2O_3, and richer in Cr_2O_3. Inclusions are mostly spinel, chromian spinel and sapphirine. Corundum of the "metamorphic" suite is considered to be of crustal or upper mantle of metamorphic origin but the origin of the "basaltic" suite corundum is less clear and is still a matter of debate. A model was proposed according to which corundum crystallised from interactions between carbonatitic and pegmatitic liquids, and was then uplifted to the surface during a later rifting and igneous activity event.

It is observed that the low-degree melting of amphibole-bearing pyroxenites or peridotites, during the passage of the lithosphere above a mantle plume, may produce small volumes of liquids that may crystallise corundum. More recently, a model was proposed where corundum crystallises from trachytic melts resulting from the fractionation of basaltic melts.

The proposed classification identified by Simonet in 2008 has several points of interest. It allows to see clearly the relation between different gem-corundum deposits, and to link them to some particular geological environments. In addition to the scientific interest, this classification is turned towards prospecting and mining. On a regional scale, two major geological environments exist that are favourable to the formation of gem-corundum deposits. These are: (1) amphibolite to medium pressure granulite facies metamorphic belts: The existing P-T data on some metamorphic and metasomatic gem-corundum deposits, shows the existence of a "gem-corundum domain" corresponding to pressures above 3 kbar and to temperatures above 450°C for 3 kbar and 550°C for 7 kbar. The favourable lithologies are alumina-rich and/or silica-poor rocks: marbles, aluminous gneisses, calcic plagioclase-rich metabasites, and the juxtaposition of felsic and silica-poor rocks. The role of metasomatism was also underlined and the proximity of tectonic structure leading fluids and heat transfers is also considered as a favourable factor for the presence of gem-corundum mineralisation. Such conditions are commonly noticed in Pan African metamorphic belts such as the Mozambique Belt (Mercier, 1999). This explains the existence of a wide gem corundum province covering East Africa, Madagascar, and Sri Lanka. (Rakotondrazafy, 2008) (2) Alkaline basaltic volcanism in continental rifting environment: Gem-corundum mineralisation is strongly linked to the first eruptive phases, and to accompanying phreatomagmatic dynamism. The absence of differentiation and the presence of peridotite xenoliths are factors that warrant the possibility that lava also carried corundum xenocrysts up. These factors are linked to the existence of a dispersed or unidirectional fracturation that will allow a rapid transfer of the lava from the mantle to the surface. This identification, which takes into account the internal features of the gemstone (inclusions, chemistry, zonations, growth features, etc) partly goes through the identification of the geological origin of the stone and most of the minerals of corundum-bearing rocks can be considered as potential inclusions. Geologically different types of deposit may co-exist in close geographical proximity.

Noteworthy localities:

The area near Mogok, Myanmar (Burma), is the source of many gem quality rubies and some sapphires. India, Madagascar, Brazil, and Afghanistan have also produced fine gem material. Rubies with a brownish tint come from Thailand, in the Chantaburi District (Richard and Hughes, 2008). In the U.S., the Yogo Gulch in Judith Basin Company has produced choice, deep blue sapphire crystals. Montana is also the claim to a few other localities: Salesville, Gallatin Company., Rock Creek, Granite Company., and Cottonwood Creek, Deer Lodge Company. The region along the Umba River in Tanzania has produced fine ruby crystals embedded in green zoisite. In Sri Lanka, especially the area around Ratnapura is an excellent source of gem quality corundum of all colours.

Other important occurances of Corundum:

Metasedimentary migmatites from the Archaean charnockitic terrain of South India contain the five-phase equilibrium assemblage spinel-cordierite-garnet-corundum-sillimanite. The assemblage is a result of anatexis, which has generated a silica-deficient anhydrous restite. Peak metamorphic conditions are defined by the intersection of two divariant reactions in the $A1_2O_3$-SiO_2-FeO-MgO system at which the five phases coexist. These reactions are univariant and their intersection invariant if the Fe/Mg ratio of at least one femic phase is fixed (Harris, 1962).

The cordierite-bearing gneisses occurring as elongate patches along the Achankovil fault-lineament at the northern margin of the Southern Kerala crustal segment represent an important lithological unit in the archaean granulite terrain of South India. The textural relationships in these rocks are consistent with the following main reactions: (Santosh, 1987)

1) Garnet+quartz=cordierite+hypersthene;

2) Garnet+sillimanite+quartz=cordierite;

3) Hypersthene+sillimanite+quartz=cordierite;

4) Sillimanite+spinel=cordierite+corundum; and

5) Biotite+quartz+sillimanite=cordierite+K-feldspar.

Occurrences of garnet and corundum are reported in Mg–Al-rich rocks at Sevitturangampatti (Namakkal district) in the Palghat-Cauvery Shear Zone System (PCSS), Southern India. These rocks contain several rare mineral assemblages such as garnet–corundum–sillimanite–cordierite–sapphirine–spinel–Mg-rich staurolite, garnet–corundum–sodic gedrite–cordierite–sillimanite/kyanite, garnet–Mg-rich staurolite–sillimanite/kyanite and sodic gedrite–Mg-rich staurolite–corundum–sapphirine. Biotite–corundum in these rocks occur as coarse-grained (1 mm to 10 cm) porphyroblasts in the matrix of sillimanite, cordierite and gedrite.

Porphyroblastic occurrence of garnet + corundum as well as staurolite and kyanite inclusions suggests that the area underwent prograde high-pressure metamorphism, probably in the eclogite facies conditions (Santosh. et al, 2004).

The Precambrian terrain of the Meghalaya Plateau is characterised by the presence of a thin, long, discontinuous band of quartz-sillimanite schist which hosts the massive sillimanite-corundum deposits in the Sonapahar area. The massive sillimanite-corundum occurs as randomly distributed bodies of variable size and shape within the quartz-sillimanite schist. The major-element chemistry of the massive sillimanite- corundum and quartz-sillimanite schist does not correspond to that of any common sedimentary or igneous rock. The present study reveals that their origin can be attributed to a peculiar protolith of an unusual bulk composition prior to metamorphism. The massive sillimanite-corundum and quartz-sillimanite schist are interpreted to represent an erosional unconformity in the Precambrian rocks of the Meghalaya Plateau, India. (Golani, 1989)

Sillimanite and corundum are the economic minerals present in the area near Sonapahar and Wamsophi villages. The area mainly comprises granite gneiss and migmatites of the Pre Cambrian Gneissic Complex with enclaves of basic granulite, charnockite and amphibolites which were, intruded by gabbroic anorthosite-norite suite of rocks (Achaean to Proterozoic age).

Small occurrences of chromite and corundum within anorthosite are reported southwest around Karungalpatti. A number of occurrences of precious and semi-precious stones are reported from the Gemstone Belt of Eastern Ghats Belt in parts of East Godavari, Vishakhapatnam and Vizianagaram districts.

The present work is based on the studies and is presented in the following chapters which include:

1. Corundum occurrences in the entire area of Konijerla Mandal with respect to the chemically receptive felsic rocks is observed as the product of desilicification, occurring in the tonalitic basement of Archaean gneisses.
2. The importance of the study of geology with special reference to the controls of mineralisation in understanding the nature of occurrence with genetic fervor has been envisaged.

3. The lithological components with their structural trends and their associated tectonic set-up are carefully studied to understand the relationship between the ore occurrences and the host rock. There by, the record of major and minor structures of the area has resulted into a structural map and also deciphered with the help of remote sensing technique.
4. By applying distinct attributes of lithology, structure, and drainage, respective maps were prepared on a GIS platform utilizing the IRS IC/ I D LISS III FCC satellite imagery.(Fig:1.1)
5. A number of representative samples of the mineralized area associated with the lithological units were studied and analysed. Petrographic characteristics with the help of structure and texture of the component mineralogy have been manifested in the studies of the rock units.
6. The study of mineralogy, particularly with respect to the occurrences of corundum has been systematically recorded and the various salient features associated with host mineralogy have been brought out. The mineralogical studies exhibited the interrelationship of the minerals and the alterations associated with the host rock after the event of mineralization.
7. Major and trace element analyses have been carried out not only to understand the significance of the elemental behaviour but also to evaluate the tectonic history of the rock type. Its importance has been accordingly utilized in understanding the nature of mineralisation. The studies were also supported by EPMA and SEM studies.
8. The data presented in the following chapters have been carefully and systematically interpreted with the help of appropriate softwares.

9. Based on these criteria, an attempt has been made to discuss these occurrences with the occurrences available both in India and outside the country.
10. Useful conclusions, pertaining to the genesis, nature of occurrence, and controls of mineralisation of corundum in and around Konijerla mandal, Khammam district, Andhra Pradesh, India, a part of the Khammam Schist Belt, have been drawn and accordingly presented.

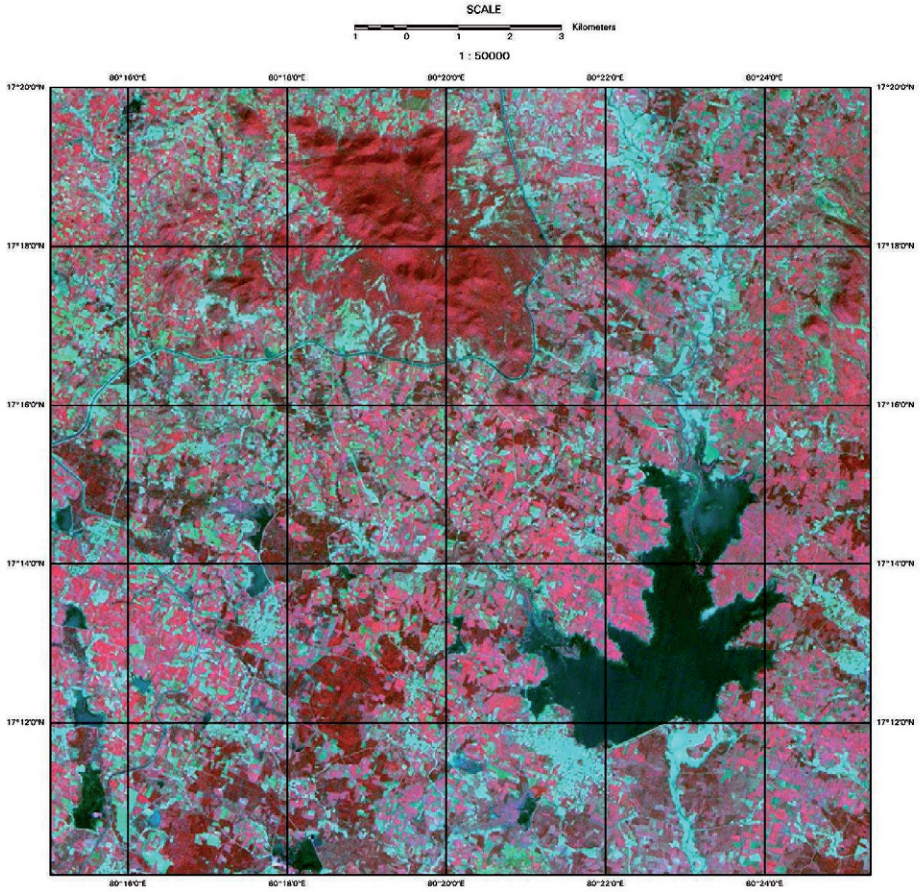


Fig No: 1.1 IRS ID LISS III – BAND (321) SATILITE IMAGERY SHOWING PARTS OF TOPOSHEET No.65 C/7,C/8

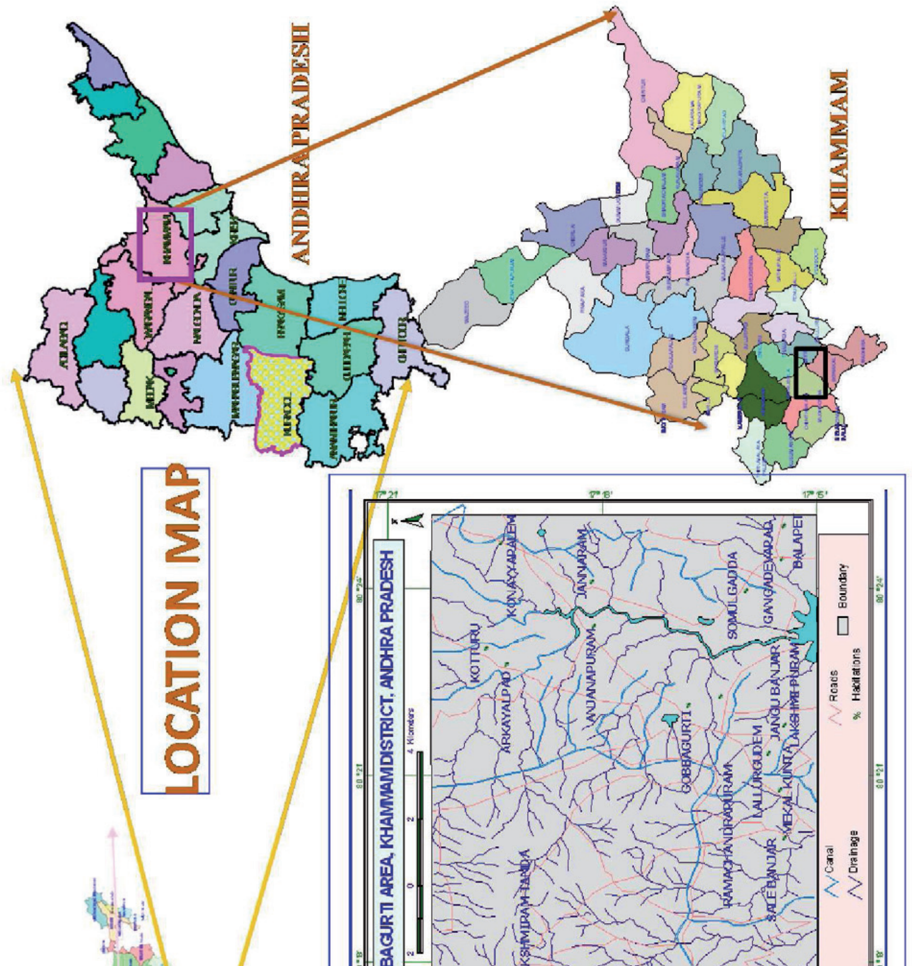


Fig. No: 1.2 Location Map of Study Area

CHAPTER - 2

GEOLOGICAL SETTING

2.1 REGIONAL GEOLOGY

Khammam Schist Belt (KSB):

The study area forms a part of the Khammam Schist Belt in Andhra Pradesh and is considered as a northern extension of the Nellore Schist Belt (NSB). Both KSB and NSB are referred to a single unit of 600 km long west-vergent Nellore-Khammam Schist Belt (NKSB) occurring as a paleo - proterozoic/late archaean greenstone belt on the basis of similar geological and structural setup in the Precambrian terrain of South India. The Nellore Khammam Schist Belt (NKSB) is considered to be the equivalent of Sargur Schist Belt (Peucat, et al; 1995).

The Khammam Schist Belt (KSB) forms a curvilinear belt in parts of Khammam and Krishna districts of Andhra Pradesh. The KSB is inferred to be a tectonised belt sandwiched between the Dharwar Craton in the West and the Eastern Ghat Mobile Belt (EGMB) in the East. The KSB mainly consists of metamorphosed felsic and mafic volcanic, now preserved as quartzo-felspathic gneisses, hornblende schists and schistose amphibolites, with or without garnet. The pelitic meta-sediments such as sillimanite-kyanite schists, sillimanite- cordierite-orthopyroxene-corundum bearing rocks (Fig. 2.1), pegmatites and banded iron formations (quart-magnetites). Garnet bearing quartzites are rare and insignificant in volume in the KSB. The present study area is bounded by 17^o 10’: 17^o 20’: 80^o 15’: 80^o 25’. Mafic and Felsic rocks are exposed in the area. The dominant lithology comprises amphibolites, which may be described as banded, foliated, garnetiferous or massive based on its field appearance. The lithological formations of

KSB form a basement for the proterozoic pakhals and phanerozoic gondwana sediments. The KSB is endowed with economically viable corundum (ruby variety) and podiform chromite occurrences; however, they are significantly controlled by both lithology and structure.

According to Subbaraju (1975), a metabasic volcanic suite comprising hornblende-plagioclase assemblage constitutes a large part of the KSB. It is referred to as supracrustal amphibolite. Thin bands of kyanite-garnet schist, quartzite, banded iron formations and anorthosites are at places associated with the supracrustal amphibolites. Metamorphosed basic dykes (amphibolitic in composition) have intruded the supracrustals as well as the gneiss-granite assemblage hosting the KSB. The supracrustal amphibolites grade from hornblende - bearing tonalite gneiss, through hornblende - gabbro to amphibolite or hornblende -schist, which may or may not be garnetiferous. The contact of supracrustal amphibolites with the host gneisses is inferred to be of tectonised nature based on the presence of xenoliths of amphibolites within the gneisses.

The study area is occupied by different rock groups of biotite-granite-gneisses, schists of various types, amphibolites, tonalites, quartzo-felspathic intrusives (quartz veins and pegmatites) (Fig. 2.2), and gabbroic anorthosites.

Pakhals:

The Pakhal formations occur towards the West and North West of the study area. It is part of “Shernawala outlier”, narrow strip of meta sedimentary rocks, described by Robert Bruce Foote in 1888. They are represented by phyllites, slates, dolomitic limestones, marbles and quartzites. The pakhal group belongs to Proterozoic eon.

Gondwanas:

The Phanerozoic gondwanas are situated in the East and North East of the study area. Gondwanas are represented by boulder beds, coal bearing sandstones, and quartzites.

2.2 PREVIOUS WORK:

A number of workers have studied this area, which is a part of KSB, on the geology and petrogenetic evolution as it occupies a pivotal position among the various lithounits of the schist belts in the Eastern Dharwar Craton (Balakrishna and Subbaraju, 1976, Leelanandam, and Narsimha Reddy, 1985, Ramam, and Murthy, 1997. Ramakrishnan, et.al 1998, Sarvothaman, 2001, Narayan Sangam and. Pavanaguru,2002). The geology of corundum occurrences have been a subject of considerable interest and economic importance and many workers in recent times have contributed on this subject (Rama Rao, 1962, Vishwanatha, 1972, Appavadhanulu, et al 1976, Devaraju, and Ali Khan, 1981, Gandhi Prasad et.al 1984, Panjikar et.al 1984, Ravindra et.al 1990, Dayashankar et.al 2001). The earliest available reference on the geology of the area was by King (1880) who opined that the gneisses and schists of KSB are the northern extension of the Nellore and Krishna crystallines. Bruce Foote (1888) considered the schistose group as overlying the denuded surfaces of the Archaean crystalline basement gneisses.

It is rather a difficult task to construct and frame a rational stratigraphic sequence and classification of the area under study because; the area forms a part of the main KSB, which comprises of different lithological units of different modes of occurrence and petrology. An attempt was made by Subbaraju to formulate a classification of the various rock types in the KSB and correlated its stratigraphic position which is equivalent to the Dharwar group.

2.3 GEOLOGY OF THE AREA:

As mentioned above, the study area forms a part of the KSB. The main rock formations of the study area include amphibolites, schists, and gneisses of various compositions and also include anorthosites, pegmatites and quartz veins, magnesium-aluminium rich pelitic granulites (corundum bearing) and hornblende pyroxene granulites. Careful observation of the gneissic tract reveals the continuity of the Nellore Schist belt into the KSB, across the districts of Guntur and Krishna, making the Khammam Nellore belt, a single transcratonic, continuous supracrustal belt (Babu, 1972). The lithology of the KSB is almost identical to that of the lower part of the NSB. Metamorphosed pelitic, psammitic and calcareous sediments are represented by garnetiferous biotite muscovite kyanite - chlorite schists, kyanite and sillimanite bearing meta - pelitic schists, calc-silicate rocks, quartzites, fuchsites, and magnetite quartzite. The meta-sedimentary unit is tectonically emplaced below a metavolcanic unit made up of quartz-chlorite schists, hornblende schists and tonalitic gneisses. The KSB rocks are intensely migmatized with the development of streaky biotite gneiss and hornblende gneisses. amphibolites, meta - ultramafics and meta-gabbros, meta-anorthosite gabbro complex as well as pink granite are the intrusive phases into the KSB assemblage. (Fig 7.1)

The area where corundum is found consists of biotite gneisses, amphibolites, pyroxene granulites and tonalitic gneisses within which, sillimanite schists and cordierite-corundum rock (Fig. 2.3) form small lenticular bodies. The host rocks for corundum are pegmatite veins which have cut through the archaean suite of rocks. (Pavanaguru, and Narayan Sangam, 2005)

The Achaeans comprising garnet-ferous quartzo-felspathic gneisses and garnetiferous quartz pyroxene magnetite gneisses occur as sparsely distributed lenses within the dharwarian gneissic terrain. The dharwarian equivalents form the major rock constituents of the area and occupy the vast plains and hills. The rocks of the KSB are sparsely exposed in entire plains but are clearly noticed in stream sections and well cuttings. Out crop mapping of all the lithological units of the KSB has been carried out and a map (Fig-7.1) to that effect was prepared. On account of: a) Thick soil cover, b) thinning and thickening of the different litho-units during different periods of deformational events and c) paucity of exposures, detailed mapping of the area could not be possible. The rocks of KSB are intensively metamorphosed and enclose pyroxene-granulites, biotite-gneisses and garnet-amphibolite and sillimanite schists. They are occasionally intruded along weak planes, by felsic magmatic rocks such as granites, pegmatites and aplites. These rock types are sporadically exposed as most of the area is covered by soil cover.

The trends of amphibolite dykes are along WNW-ESE to NW-SE, suggesting that they intruded into supracrustals and the gneisses along the fractures developed due to the latter deformation. Outcrops of amphibolite studded profusely with plagioclase megacrysts (2cm x 1cm to 6cm x 3cms in dimension) are observed about 2 Km s N 25° E of Lallapuram which rarely display a preferred orientation (Sarvothaman, 2001)

2.4 FIELD DISPOSITION OF LITHO – UNITS AND THEIR INTERRELATIONSHIPS:

The Gobbagurti metagabbro-complex is occupying an area of 50 Sq. Km. This metamorphic complex was localised in a gneissic host rock. The low-lying hillock extends over a length of 7 km. with an average width of 3 km. in a NW-SE direction. The higher-grade metamorphic rocks (basic granulites) in the area are mostly confined to the South, SE and SW part constituting the Gobbagurti hillock. A small enclave of calc-granulite is observed to the south of Gobbagurti and to the west of anjanapuram. Basic granulites occurring in Gobbagurti complex are of garnetiferous and non-garnetiferous nature. In garnetiferous varieties, the associated garnet is much in abundance at the SE part of the range and slowly decreases towards NE with concomitant enrichment in hornblende (Fig. 2.4). Quartzitic bands are associated with basic granulites to the West of Gobbagurti village. The gneissic terrain is rather different near Gobbagurti (17° 21 '00": 80° 22' 00") exhibiting cataclastic nature. Prominent ridges of gneisses can be seen at Pangidi and Irlapudi where scattered grains of garnets are seen. The hornblende gneisses SE of Gobbagurti are found progressively changing to pyroxene bearing gneisses towards NW of the range. The gneisses are leucocratic to mesocratic, fine to medium grained and bear a cataclastic imprint. Contorted gneissic bands are common. The gneissic country is cut across by dolerite dykes (amphibolite) trending mainly due NW. Enclaves of amphibolite were reported along the SW side of Gobbagurti village and Northern and NE side of the Donabanda village. (Roop Kumar and Somayajulu, 1983)

The contacts between gneisses and basic rocks are sharp where outcrops are well exposed, but otherwise, obscured due to soil cover. At Gobbagurti, amphibolites are exposed in the northern and NW flanks of hill range, as caught up enclaves in gneisses and granulites. At Donabanda, amphibolites are restricted to the hill of elevation 190 feet. (Triangulation station)

2.5 STRATIGRAPHIC SUCCESSION OF THE STUDY AREA

Stratigraphic Succession of the Study area

Era	**Lithology**
Recent	Soil cover
Precambrian	Quartzites Amphibolites Anorthosites Mafic granulites Sillimanite-Cordierite-Opx-Corundum rocks Schistose amphibolites Hbl-Plag gneisses Quartzo-felspathic gneisses (Tonalites)

Appavadhanulu, et al.,(1976) opined that the rocks of Khammam schist Belt are Dharwarian in age. The schistose rocks as amphibolites, granulites etc. rest over the eroded gneissic terrain (basement complex). The area is predominantly composed of meta-igneous rocks with subordinate migmatised gneisses.

2.6 GEOLOGY OF CORUNDUM OCCURRENCES:

Occurrence of semi-precious corundum of abrasive variety and rare occurrences of gem variety are observed in the exploration pits at Lakshmipuram where the host rock is sillimanite-corundum schistose rock. At Gobbagurti and Singaraipalem corundum occurs in association with kyanite schists. However, at Lallurgudem corundum is occurring locally in the soil cover accounting for placer concentrations. The contact zones of altered basic rocks and pelitic schists host corundum at Salebanjar. The Donabanda area exhibits similar occurrence along the contact zones of pegmatitic veins and schists. The Tummalapalle occurrence is associated with pyroxene granulites and gneisses. In the Mekalkunta area, sillimanite schists and gneisses host corundum. At Wyra, corundum occurs with cordierite-sillimanite schists and gneisses. Majority of the occurrences are observed in the silica deficient geogenic system and account for its concentration.

Fig. 2.1 Cordierite gneisses

Fig. 2.2 Quartzo - felspathic intrusive in amphibolites.

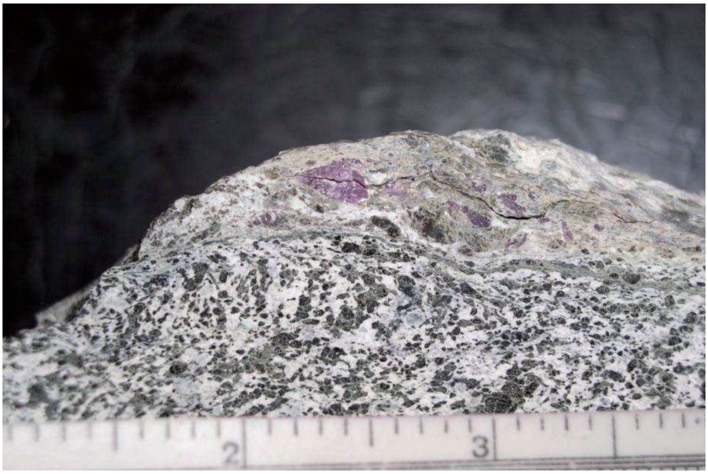


Fig. 2.3 Corundum occurrence along contact zone of cordierite gneiss and tonolite

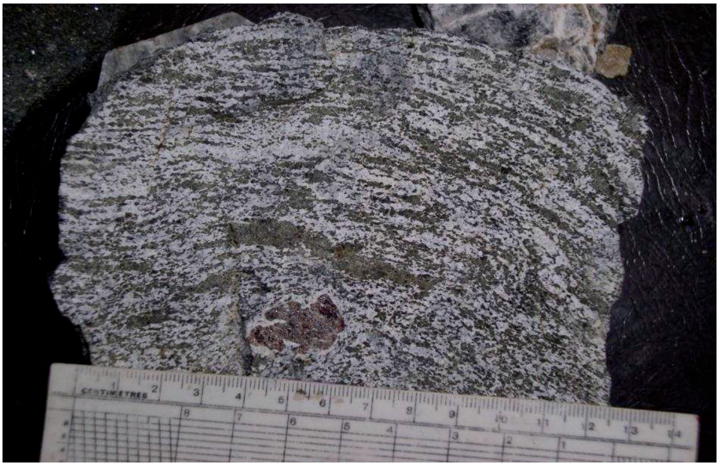


Fig.2.4 Garnetiferous banded Amphibolite

CHAPTER - 3

STRUCTURE

Regionally, Gobbagurti area in Khammam district hosting corundum mineralization is a part of a NW-SE trending cratonic fold belt and occupying the major fracture developed normal to the axis of the Chimalpahad Anothositic Gabbro Complex (CAGC). The general strike of the foliation varies from N 30° W – S 30° E to N 50° W – S 50° E with shallow dips (20 ° – 30 °) towards NE.

Three sets of joints are prominently observed along: N 45 ° E – S 45 ° W / 70 °**,** N 10° W – S 10° E and N 45 ° W – S 45 ° E. Until otherwise stated, all the joint sets exhibit vertical dips. The structural units are observed as surface expressions are fractures, faults; shear zones, schistosity, folds and joints.

In the Khammam Schist Belt (KSB), successive deformations are represented by F_1 (NE-SW), F_2 (NW-SE), F_3 (NE-SW), F_4 (NNE-SSW), and F_5 (E-W) folds. The rocks were subjected to retrograde metamorphism during the successive periods of deformation after the F_2 fold event. It has also been reported as faults, thrust faults; shear zones and enechelon shear zones of different ages within the KSB (Babu, 1998).

The Khammam Schist Belt (KSB) as a whole shows considerable evidence of structural disturbance. Based on regional studies, Subbaraju, observed that the region has suffered five periods of deformation and two periods of metamorphism.

The Dharwar schists and gneisses occupying the plains between Wyra lake and Gobbagurti, exhibit a general foliation along NE-SW (varying between ENE-WSW to

NNE-SSW) with moderate to steep foliation dips varying from 40° – 70° due SE. (Apavadhanulu, et al. 1976)

The deformational history of the rocks of the KSB appears to have commenced with the folding of the sediments (F_1) resulting in the development of the NE-SW foliation, which was later at places modified by subsequent deformations. Following the F_1 folding, emplacement of basic rocks took place and was metamorphosed into the amphibolites manifested in the form of schists and gneisses mostly along the foliation and also at places cutting across the foliation. Subsequent to F_1 folding, the schistose rocks were subjected to a second generation, N.W-S.E, folding (F_2). Local N.W.-S.E. axial plane foliation, shear zones and minor folds plunging to northwest or southeast were developed as a consequence of F_2 folding. The N.W.-S.E. foliation and shear zones are prominently exposed in the Gobbagurti hills. Regional metamorphism of almandine-amphibolite facies appears to have taken place syntectonically with F_2 folding and prior to migmatisation. The granitic fluids caused extensive metamorphism manifested in migmatisation of the schists and amphibolites giving rise to streaky biotite- gneisses, felspathic quartz-chlorite schists and hornblende gneisses. The migmatising fluids generally followed the foliation planes and were at places transgressive. Subsequent to F_2 deformation, a number of pink granite bodies were injected along the N.W-S.E. shear zones. These pink granites intruded into the schists, gneisses and amphibolites that followed F_1 deformation. Subbaraju observed that during the third period of deformation (F_3), the schists and gneisses were thrown into isoclinal folds with N.E-S.W. axes and number of shear zones were developed parallel or sub parallel to these fold axes.

The strike of the Nellore Khammam Schist Belt (N/KSB) varies from NW-SE in the southwest, through NNW-SSE in the central part, to NNE-SSW in the northeast. Divi, et al (1999) suggested that the area East of Khammam has been affected by the Proterozoic Eastern Ghat Orogeny, although it warrants detailed structural analyses for understanding the tectonic evolution of the N/KSB. It further clarifies the Precambrian tectonics in this part of Dharwar Craton, which also includes the present area of investigation.

Only a few detailed studies have been focussed on the deformational and structural observations. The detailed field investigations of the structures with kinematic interpretation are needed to elucidate the structural and deformational history and its bearing on the tectonics of the N/KSB. Considering its importance in the study area, particularly to understand the structural controls of mineralisation, a detailed structural map is also prepared (Fig.7.4). In this context, the following deformational structures have been summed up:

3.1 DEFORMATION STRUCTURES:

Four deformational stages can be identified in the Precambrian terrain and termed as D1, D2, D3, & D4 from earliest to latest and is tenable to the study area. The structural elements reported are given as under:

D 1 STRUCTURES

Structures of the D1 deformation are characterised by NE-SW trend with mylonitic foliation (S1) and intrafolial folds (F1) of tight to isoclinal type. The axial surfaces of these intrafolial folds are parallel to S1. In a stereographic projection (lower hemisphere), the F1 fold axes show scattering with gentle plunge towards east. Distributions of F1 fold axes are not concentrated, but have gently eastward plunging. The scatter may be attributed to interference by later folding.

D2 STRUCTURES:

Structures of the D2 deformation are characterised by NNW-SSE trending macroscopic folds of open to close type with moderate to steep dipping plunge towards southeast (F2).

D3 STRUCTURES:

Structures of the D3 deformation are characterised by E-W trending open to close mesoscopic F3 folds with an inclined axial plane cleavage. Assymetric mesoscopic F3 folds show northward vergence.

D4 STRUCTURES:

D4 structures are characterised by macroscopic to mesoscopic upright folds. Mesoscopic upright tight to isoclinal folds with steeply dipping axial surface with a horizontal to sub horizontal fold axes along NE-SW axis characterise these folds. NE-SW trending faults are also identified. These faults are truncating the structures of D1-D4 folds implying their latest stage of tectonic imprint in the Precambrian terrain.

For the Precambrian N/KSB and other schist belt in the Dharwar craton, (Babu, 1998) around 2500-2000 Ma ages are given for a series of deformational events, F_1 (NNW-SSE), F_2 (NW-SE) and F_3 (E-W) folds. The latest phase (D4), structural elements in the Precambrian terrain are similar to those of the first phase deformation (D1) of the Proterozoic Pakhal group.

Deciphering the age of the different types of deformations in the study area is a bigger problem, as geochronological data for the rocks in the study area is not available due to the controversial opinion as to whether the N/KSB belongs to Dharwar Craton or to Eastern Ghats Mobile Belt (EGMB). The structures in the N/KSB have been developed during the Eastern Ghats Orogeny, i.e. during late Proterozoic. (Grew and Manton, 1986). It is reported that the entire ensemble suffered two other folding movements, probably after the deposition of the Proterozoic Pakhal Supergroup. (Ramam. et al, 1997)

In the investigated area, the Gobbagurti hills trend N.W.-S.E. and are observed to represent a major fracture trending in the same direction. In the northern part of the Gobbagurti hills, South of Pangidi, the formations strike ENE-WSW to E-W, parallel to the cross fold axis of the major N-E plunging anticline (isoclinal). The quartzo-felspathic intrusives in the area significantly trend either NW – SE or ENE – WSW. In the southern and southeastern parts of Gobbagurti hills, on the western side of the Wyra Lake, the metadolerites are observed, particularly the hornblende granulites trending in N.W.-S.E. direction. It may be inferred that the pyroxene granulites and hornblende granulites in the Gobbagurti hills follow a major N.W.-S.E. trending fracture, which resulted from the northeasterly plunging anticline and development of parallel shear zones. (Appavadhanulu et al, 1976)

The anorthosites and other intrusives of the Chimalpahad Anorthosite Gabbro Complex (CAGC), north of the study area, occupy the core of an anticline in the main CAGC hills. At a number of places, enechelon shear zones resulted from folding are seen. The intrusives are seen to follow the fold axis very often. Near Donabanda, two shears, one in N70°E-S70°W and the other in N70°W-S70°E are noticed. Both were marked by sheared quartz veins in a small anticlinal structure plunging ENE. Between Wyra and Venkatayapalem, the foliation trends are dominantly NNW-SSE with ENE dips, though; local swerves to NW-SE and NNE-SSW are seen at places. The general strike of the foliations in the schists of various types varies from N 35°W to NW, with varying dips towards East. Predominant shear joints parallel to major shear zones (interpreted from satellite imagery) are observed along N 10° W and N-S with almost vertical dips. The foliation trends and the shear planes can be correlated with the well-preserved transpressional shears observed in the CAGC.

The structural elements observed in the area are: Joints, Joint sets and Foliation Trends.

Three sets of Joints are observed along: N 45 ° E – S45 ° W / 70 °, N10° W – S10° E and N45 ° W – S45 ° E.

3.2 FOLIATION TRENDS

Table 3.1 Table showing the locations of prominant foliation trends in the study area

Location	**Foliation Trends**
Lakshmipuram	N25^{0}W-75^{0}NE, N30^{0}W-70^{0}NE, N25^{0}W-45^{0}NE, N30^{0}W-70^{0}NE, N20^{0}W-55^{0}NE,N35^{0}W-40^{0}NE, N40^{0}W-70^{0}NE, N45^{0}W-60^{0}NE,N50^{0}W-80^{0}NE,N55^{0}W-85^{0}N,N55^{0}W-65^{0}NE, N60^{0}W-50^{0}NE,N65^{0}W-50^{0}NE,N70^{0}W-45^{0}NE, N75^{0}W-75^{0}N, N40^{0}W-45^{0}NE, N35^{0}W-70^{0}NE,N50^{0}W-65^{0}NE , N70^{0}W-70^{0}NE,N43^{0}W-65^{0}NE, N43^{0}W-60^{0}NE, N40^{0}W-50^{0}NE,N65^{0}W-70^{0}NE, N85^{0}W-70^{0}NE, N25^{0}W-75^{0}NE, N60^{0}W-40^{0}NE, N45^{0}W-70^{0}NE,N55^{0}W-45^{0}NE, ,N35^{0}W-50^{0}NE, N70^{0}W-55^{0}NE,N50^{0}W-65^{0}NE, N20^{0}W-20^{0}NE
Gobbagurti	N30^{0}W-50^{0}SW, N10^{0}W-45^{0}E, N3^{0}W-50^{0}E,N2^{0}W-40^{0}E, N60^{0}W-60^{0}SW, N5^{0}W-55^{0}E, N50^{0}W-75^{0}SW, N30^{0}W-50^{0}SW, N10^{0}W-40^{0}E
Wyra	N30^{0}E-40^{0}SE, N30^{0}E-60^{0}E, N25^{0}E-80^{0}E, N30^{0}E-60^{0}E, N5^{0}E-60^{0}E, N10^{0}E-80^{0}E, ,N20^{0}E-60^{0}NE, N35^{0}E-20^{0}NE,N35^{0}E-45^{0}SE,N40^{0}E-30^{0}SE, N45^{0}E-55^{0}SE, N50^{0}E-40^{0}SE, N60^{0}E-55^{0}SE, N70^{0}E-60^{0}SE, N75^{0}E-45^{0}N,N80^{0}E-45^{0}N,N3^{0}E-50^{0}E,N5^{0}E-65^{0}E, N2^{0}E-55^{0}E, N40^{0}E-50^{0}SE, N60^{0}E-60^{0}SE, N62^{0}E-40^{0}SE,N3^{0}E-65^{0}E, N25^{0}E-70^{0}SE, N35^{0}E-60^{0}SE,N55^{0}E-75^{0}SE,N70^{0}E-50^{0}SE, N80^{0}E-60^{0}SE, N40^{0}E-75^{0}SE, N45^{0}E-45^{0}SE, N75^{0}E-45^{0}NE ,N50^{0}E-65^{0}SE,N65^{0}E-45^{0}SE,N75^{0}E-75^{0}NE, N30^{0}E-40^{0}SE, N60^{0}E-60^{0}SE, N5^{0}E-45^{0}E,N20^{0}E-50^{0}E,N25^{0}E-70^{0}SE

3.3 METHODS OF PLOTTING

Preparation of rose diagram:

A rose diagram was prepared by plotting all the foliation trends (89 No's) recorded from different locations from within the study area by using the appropriate software. (Fig. 3.1)

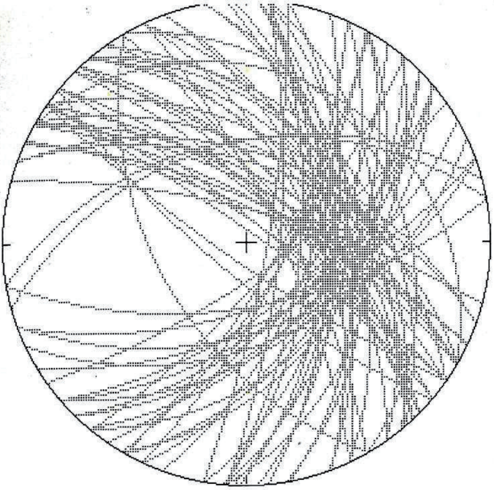
Preparation of point diagram:

About 78 data points of the foliation trends were plotted on an **EQUAL AREA NET** and are represented in figure 3.2. Out of the 78 data points, >10% of data points fall in the Northeast - Southwest (N.E. – S.W.) direction and >5% of data points fall in the North-South (N-S) direction.

The field observations confirm that the occurrence of corundum along N-S and NE-SW trends are more favourable than along the other trends.

Software used:

A software called **Rockpic** was used to plot about 78 such foliation trends and the poles as mentioned above.



Great circles of 78 data points

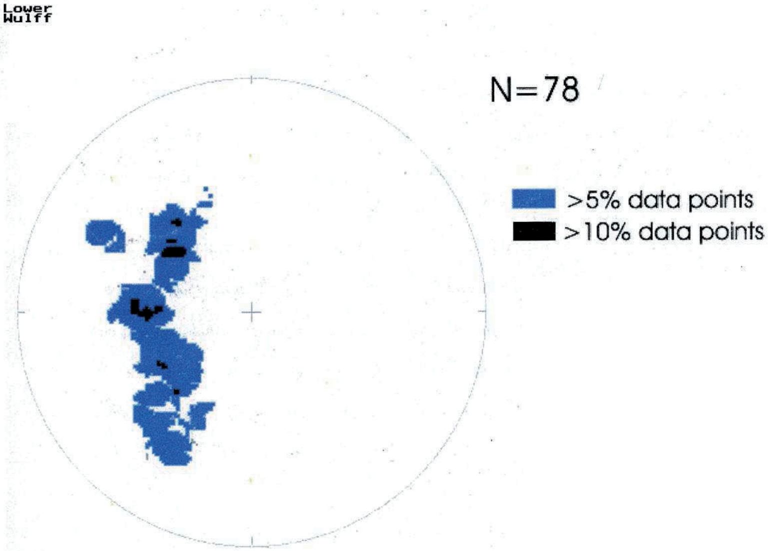


Fig No. 3.1 Point Diagram showing foliation trends in the study area

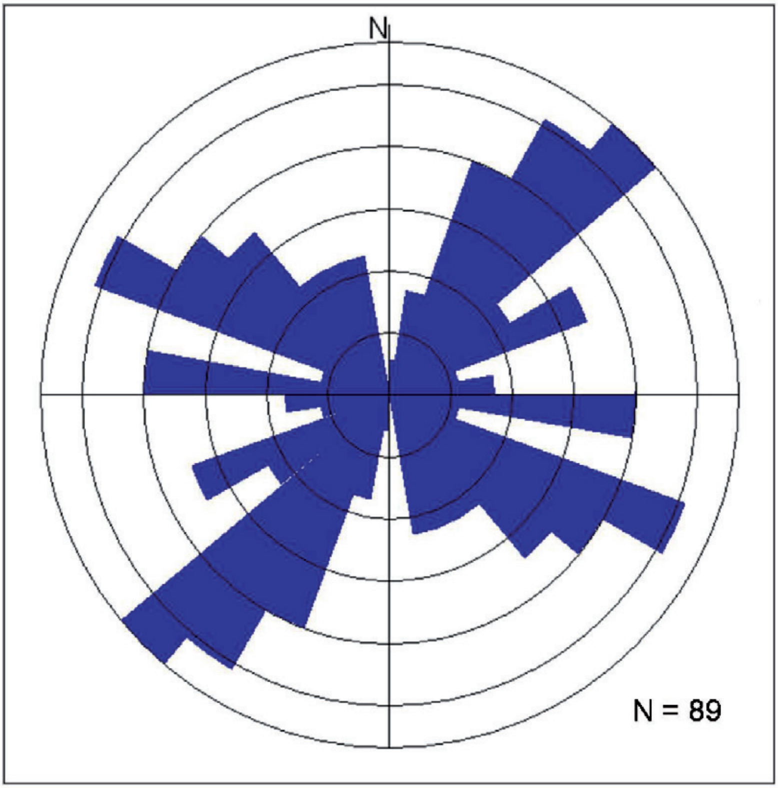


Fig No. 3.2 Rose Diagram showing foliation trends in the study area

CHAPTER - 4

PETROGRAPHY

Khammam Schist Belt (KSB), which encloses the Konijerla area, is a house of economically viable corundum (Ruby Variety), chromite and magnetite occurrences. The KSB is unique from other schist belts in the granite greenstone terrain of the Dharwar Craton by the presence of workable deposits of corundum in this belt. The petrographic studies on the rocks of KSB are vital and of significant value for not only demarcating the mineralized zone but also for understanding the genesis of corundum.

The KSB is predominantly composed of schistose and gneissose rocks of the Precambrian age. These rocks form the entire plain country of the KSB and occur as discontinuous deformed interlayers/bands. Hornblende schists, Schistose amphibolites and Tremolite-actinolite-talc-chlorite schists occur as dark bands, streaks and lenses within the tonalite gneisses and pelitic gneisses in the KSB, forming the basement for younger anorthosites, amphibolite dykes, mafic and felsic granulites, meta-dolerites and granitoids. All these rocks are deformed and metamorphosed under upper amphibolite to lower granulite facies conditions. (Appavadhanuluet al., 1976)

A number of representative samples were collected for the close examination of various rock types in the area. As many as 100 thin sections were prepared to establish the petrographic character of the rocks. The following petrographic characteristics of these rocks have been observed and are described below for evaluating corundum mineralisation in the KSB.

4.1 GENERAL DESCRIPTION OF ROCK TYPES

Tonalite gneisses:

These rocks are the dominant lithounits in the study area. They contain plagioclase, quartz and hornblende as dominant minerals. Garnet, epidote and sphene occur as subordinate minerals. Plagioclase (An_{30}-$_{40}$) and quartz form white band, while hornblende, garnet and epidotes concentrate in dark bands of tonalite gneisses. The typical minerals present in these gneisses are quartz, felspars, pyroxenes, hornblende, biotite, perthite and epidote. Garnet, apatite, zircon, sphene, scapolite and sericite are minor accessories. These rocks show typically granular texture with equant mineral grains, and planar boundaries (Fig. 4.1).

Streaky biotite gneisses and tonalite gneisses are the representative rock types of the Precambrian suite in the study area. They are comprising garnetiferous quartzo-felsic gneisses, garnetiferous quartz-pyroxene-magnetite gneisses and charnockite occurs as sparsely distributed xenoliths or inliers in the form of thin bands and lenses within the Precambrian gneissic terrain. Narrow bands of garnetiferous quartzo-felspathic gneisses occur on the southeastern tipoff Δ 213 hill, 1.5 km. South - west of Pangidi and south of Donabanda village. These rocks are medium to coarse grained and characterized by excess of felsic minerals. Plagioclase is coarse-grained. Fine re-crystallised quartz occurs as micro veins within and surrounding the plagioclase feldspar (Fig. 4.2).

HORNBLENDE – PLAGIOCLASE – GNEISSES:

These rocks occur as intercalated bands with tonalite gneisses. They consist mainly of hornblende, in hornblende rich dark layer and plagioclase (with little quartz) in plagioclase rich white layer. These rocks are slightly coarser than those of adjacent tonalite gneisses. These rocks show gneissosity with equant plagioclase and quartz in white band and tabular hornblende in dark band. Garnet and epidote are frequently found in these rocks. Bent lammellae of plagioclase indicate that these rocks were deformed during or after their emplacement in the KSB (Fig. 4.3).

BIOTITE GNEISSES AND PINK GRANITE GNEISSES:

The outcrops of biotite gneisses and pink granite gneisses are scanty and occupy the vast undulating plains and partly the hills. They also occur as xenoliths within the meta-anorthosites. The terrain is soil covered, and cultivated. The rocks are very often garnetiferous and seldom schistose. Both the rock types along with the amphibole gneisses are intricately folded and traversed by pegmatite and quartz veins. The biotite gneisses are fine to medium grained and are essentially constituted of plagioclase, perthite and quartz with biotite, green hornblende, muscovite, epidote, apatite, zircon, magnetite and occasssionally sphene, myrmekite, scapolite, opaques and sericite occur as minor accessories. Mortar texture is more prominent having formed as a result of marginal granulation of quartz porphyroblasts. Porphyroclasts of plagioclases are surrounded by fine grains of quartz as well as plagioclases (Fig. 4.4). Pink granite gneisses consist of quartz, orthoclase, microcline and plagioclase as essential minerals and biotite, apatite and zircon as accessories. Both the felspars (k-felspar and plagioclase felspar) occur as phenocrysts and quartz occurs as recrystallised grains. The sections of ultramylonite showed the presence of quartz, microcline, biotite flakes, rounded grains of zircon, and opaques. They are highly sheared and referred to as sheared quartzo-felspathic gneisses (Fig. 4.5) (Narayan Sangam & Pavanaguru, 2005).

Amphibole Gneisses:

These occur as thin bands within the biotite gneisses. They are medium to coarse grained, melanocratic, gneissic to schistose, very often garnetiferous. The amphibole gneisses are essentially containing green hornblende and plagioclase felspars. as major constituents while actinolite-tremolite, epidote, quartz and sphene occur as accessory minerals. Plagioclase felspar, the dominant mineral and subordinate k-felspar occurs as porphyroclasts. Gneisses are medium to fine grained. Porphyroclasts of plagioclases are surrounded by fine grains of quartz as well as plagioclases. Presence of hypersthene imparts a charnockitic affinity to the rock. Rocks of gneissic group are leucocratic to mesocratic, medium to coarse grained, and with feeble and contorted gneissic bands which is due to low mafic content. The Gneisses are essentially constituted of the following mineral associations: quartz-plagioclase- hornblende- garnet, quartz-plagioclase- hornblende- biotite, quartz-plagioclase- hornblende- hypersthene-biotite, quartz-plagioclase- hornblende- epidote and zircon, apatite, sphene, myrmekite, sericite, scapolite and opaques are accessories. The gneissic sections showed the presence of quartz, plagioclase, microcline and biotite. Quartz is strained and showed preferred orientation. Opaques show linear alignment. Presence of hornblende and garnet is observed in some sections. The rocks are affected by regional metamorphism and mineral assemblage indicates change from amphibolite facies to granulite facies.

Pelitic Gneisses:

These rocks occur as bands and deformed sheets along those of hornblende-plagioclase gneisses in KSB, which are volumetrically minor and are exposed to the surface at local places all along the hornblende-plagioclase gneisses in the study area. They mainly contain kyanite/sillimanite, cordierite, talc, plagioclase and amphibole with or without garnet. Garnet free pelitic gneisses only contain corundum with spinel, rutile and zircon as accessory minerals (Fig. 4.11, 4.12, 4.13 and 4.14)

Quartz - Chlorite - Biotite Schists:

Quartz-chlorite schists, felspathised quartz-chlorite schists, and quartz-chlorite biotite schists occur in small patches in association with the gneisses described earlier. They are highly puckered, schistose, very often garnetiferous and at places sericite bearing. These Schists are essentially constituted of quartz, felspars, biotite, chlorite and sericite. Undulose extinction in quartz is seen which indicates strain effect.

Quartz - Muscovite Schists:

They also occur as thin bands within the biotite gneisses. These are leucocratic, gneissose and at places garnetiferous. They are seen as xenoliths within the meta-anorthosites. These schists are essentially constituted of quartz and muscovite as essential minerals while biotite, felspar, kyanite and garnet are the accessory minerals. Muscovite occurs as elongated flakes with basal cleavage. The cleavages are bent and show wavy extinction, with incipient alteration.

Garnetiferous Kyanite – Muscovite Schists:

They occur as small pockets within the biotite gneisses and schists. These schists are essentially constituted of quartz, muscovite, biotite and garnet as the major constituents while kyanite and felspar as accessory minerals. Most of the thin sections revealed the presence of sillimanite, with characteristic sugarcane structure and straight extinction, schistose texture wherein; foliation planes are aligned by the linear orientation of sillimanite and micaceous minerals (Fig. 4.6). Plagioclase exhibits polysynthetic twinning. Sections showed admixture of sillimanite and plagioclase.

Meta – Ultramafics:

Actinolite-tremolite schists, talc-actinolite-tremolite-schists with lenses of kyanite-corundum fuschite rock, and meta-pyroxenites constitute the meta-ultramafic rocks in the area. The schists are generally seen as small, patchy, lensoidal outcrops, being rather soft, are easily weathered. The meta-pyroxenites are very coarse grained with rugged surface; occur as narrow and short but bold dykes. These rocks are intrusive into the dharwarian gneisses and meta-anorthosites. Prominent outcrops of talc-amphibole schists occur as en-echelon lenses in quartz-chlorite-schists and biotite gneisses. They are seen to occupy shear zones, which are rendered conspicuous by highly broken, platy quartz. They are noticeable as parallel bodies, following the gneissosity of the biotite gneisses. Many small lenses of actinolite-tremolite rocks fairly rich in quartz occur within the amphibole gneisses. They are traversed by pegmatites and contain lenses of Chromite.

Corundum- kyanite rock (in rubble form) is seen within the actinolite-tremolite rocks traversing the meta-anorthosites. Its invariable association with the ultramafic rocks which traverse rocks rich in silica, and alumina point to its probable origin due to the desilication of the enclosed rocks. Meta-pyroxenites are seen as bold dykes within the meta-anorthosites. These rocks show hypersthene and green diopside, as essential minerals while enstatite and amphibole form the important accessory minerals. Garnet, green spinel and magnetite are present in minor amounts. (Roopkumar, and Somayajulu, 1983)

Granulites:

Granulites are of 3 Categories, namely basic granulites, acid granulites and calc granulites. The basic granulites are mostly confined to the South-SW region of the area. (gobbagurti). At Gobbagurti, basic granulites are emplaced in an environment of granitic gneisses with pockets of amphibolites and calc granulites. Basic granulites are observed as garnetiferous and non-garnetiferous varieties. The Gobbagurti basic granulites contain garnet in abundance at the southeast margin of the hill and slowly decreases towards the northeast border with enrichment of hornblende when a complete traverse is taken from SE-NE. Pockets of quartzite are encountered to the west of Gobbagurti. The gneisses at Gobbagurti show a deep cataclastic imprint. The contact between gneisses and granulites is sharp when the outcrops are well exposed. These rocks reveal the presence of clinopyroxene, plagioclase and hornblende as essential minerals and quartz, orthopyroxene, biotite, garnet, zircon and opaques as accessory minerals. Subhedral crystals of hypersthene show feeble pleochroism from colourless to pale green. Clinopyroxenes are predominant over orthopyroxenes and are represented by diopside and augite. Rounded crystals of zircon with high relief are seen in minor amounts.

Pyroxene Granulites:

The conspicuous development of these bodies is seen in the Gobbagurti hills and the southern adjoining plains. They are seen as cross cutting dykes into the meta-anorthosites, calc-gneisses, banded magnetite quartzites, charnockites, and other gneisses and at places occur as sheet like bodies running parallel to the trends of these rocks in the Wyra and Gobbagurti areas. Hornblende-pyroxene-granulites, chlorite-talc-tremolite schist and amphibolites with or without corundum are younger rocks, which are medium to coarse grained, dark coloured, hard and compact. They trend along NNW-SSE to NW-SE and E-W directions. These rocks are essentially composed of hypersthene, diopside, plagioclase, brown hornblende, and actinolite-tremolite. Biotite, garnet, scapolite, zoisite and quartz occur in varying amounts. However, it is reported that the amphiboles derived almost entirely from the pyroxene show xenoblastic to granoblastic, ophitic to sub-ophitic texture are rich in hypersthene. and such features are occasionally observed in the study area.

Hornblende Granulites:

These are predominantly seen in the southern part of the area, to the west of Wyra Lake and occur in profusion with dykes and lenses. They trend in NW-SE direction. These are mostly fine grained, dark and massive rocks and garnetiferous at places. Exposures are seen South and South-East of Gobbagurti hills on the West of Wyra Lake. These rocks are granoblastic, composed of highly pleochroic, dark green hornblende, and plagioclase together with minor amounts of epidote, magnetite diopside and quartz.

Garnetiferous – Pyroxene – Amphibole Granulites:

These occur as intrusives in the form of thin sheets, cross cutting dykes and lenses into the meta- anorthosites, and the dharwarian schists and gneisses. The rocks are melanocratic, hard, compact, jointed, medium to coarse grained, and are invariably garnetiferous. In the Wyra area, granulitic rocks are confined to the narrow zone in the amphibolite facies rocks. These rocks reveal xenoblastic/ophitic texture. Light green diopside, greenish brown hbl, garnet and plagioclase are the major constituents. Scapolite, zoisite, epidote, magnetite and quartz occur in varying amounts. Hornblende is seen as rims around pyroxene. Hypersthene is not found which is conspicuous of pyroxene-granulites. (Babu, et al, 1972)

Amphibolites:

The amphibolites are granular and streaky in nature. Based on mineralogical variations they are categorized into: Normal amphibolites, pyroxene-plagioclase amphibolites, and garnet-pyroxene-plagioclase amphibolites. The amphibolites show hornblende, plagioclase and quartz as main constituents and pyroxene and garnet as accessories. Idioblasts of garnet display sieve structure (Fig.4.7) because of hornblende and quartz inclusions. The amphibolitic sections showed the presence of hornblende with good cleavage, and pleochroism, presence of biotite, plagioclase in small amounts and opaques. in accessory amounts.

Garnetiferous Amphibolites:

The highly garnetiferous, coarse-grained rocks occurring as dykes and lenses are well exposed in most parts of the study area. They form a number of low mounds. These ramify as apophyses and tongues into the dharwarian gneisses and meta-anorthosites. They sometimes show a typical Salt and Pepper texture, made up of white felspars and black amphiboles. (Fig.4.8 and 4.9) These rocks show coarse aggregates of greenish-brown hornblende, and abundant pink garnets together with minor amounts of alkali felspar, biotite, and quartz compared to the hornblende-granulites. These are coarse grained and lack plagioclase and pyroxene which suggest that these rock types could be meta-eclogites. Presence of porphyroblasts of garnet is reported in some sections.

Host rocks:

The amphibolite suite of rocks with distinct variation in mineralogical phases, exhibit a variety of host rocks in the study area. The amphibolites are observed in the form of hornblende-schist, quartz-sericite schist, quartzite with occasional quartz. The suite of rocks at number of places has been subjected to shearing which controls the drainage along the zones of least resistance. The gabbroic anorthosites is emplaced and subjected to post anorthositic movements that produced changes in the mineralogical contents and texture. The corundum mineralisation is invariably associated with such settings, generally seen along NNE-SSW trending zones, dipping with varying angles towards NNW or NW. The amphibolites show crude gneissosity. Amphibolites are found as sill like bodies in the banded biotite gneisses, all along the Wyra river section. These rocks show intermediate plagioclase, green hornblende and biotite which form large plates with a brown-green pleochroism along the periphery. Hornblende alters to biotite or chlorite. Sphene, epidote, apatite and opaques are seen in variable amounts as accessory minerals. Migmatisation is indicative of the presence of quartz and K-felspar.

Anorthosites:

Anorthosites are predominantly gabbroic and occasionally banded. They contain 10-20% of mafics while plagioclase accounts for 80-90%. Hornblende is an important mafic constituent and occurs as secondary mineral after the pyroxenes. Small amounts of scapolite, zircon, sphene and zoisite are present. Traces of hypersthene are noticed. Plagioclases occur as plates and as small grains. The mineral is twinned. Most of the grains show Carlsbad twinning. Zoning is observed. Inclusions of pyroxene and hornblende are observed. Hornblende is secondary and strongly pleochroic in nature. Both clinopyroxe and ortho-pyroxene occur together but clinopyroxene (augite) is dominant. It is also a domainal rock, consisting of lenticular regions dominated by **alkali feldspar** (orthoclase) with a little **quartz** and **biotite**, set in a matrix dominated by **cordierite**. The K-feldspar domains may represent veinlets of syenitic melt, either intruded into or melted out from the rock. The cordierite-rich zones with in this rock type contain **cordierite** + **K-feldspar** + **corundum** + **spinel** + **opaque** assemblage. Clear K-feldspar is interstitial to cordierite, and shows lower refractive indices. The high-relief colourless mineral is corundum. **Biotite** is concentrated along the margins of the k-feldspar. There is a little white mica (retrograde) and andalusite (not in all sections). This rock composition is somewhat depleted in silica and alkalis, and relatively enriched in Al_2O_3, FeO and MgO, compared with a typical metapelite, which is consistent with the removal from it of a partial melt fraction. Inclusions of rutile are observed along with the presence of garnet which are similar in chimalpahad area (Leelanandam, and Narsimha Reddy, 1988).

Meta Anorthosites:

Meta anorthosites occur as detached patches within the study area. The smaller patches of the rock type are seen near Jannaram, and two detached outcrops are observed East of Gobbagurti. The Meta-anorthosites are hard, massive, jointed, craggy and at places gneissose. They are medium to coarse grained, leucocratic to melanocratic rocks with a characteristic pearly sheen on fresh surfaces. Plagioclase, hornblende and occasionally garnets are the main constituents of these rocks, which may be classified into anorthosites, gabbroic anorthosites, and anorthositic gabbros depending on the proportion of the mafics to the felsics. They exhibit at places coarse banding due to alternate layers rich in dark coloured hornblende and grey coloured plagioclase. The outcrops near Jannaram are pegmatitic, being the coarsest and are very rich in plagioclase with very little mafics. These rocks vary in composition from plagioclase rocks to plagioclase-hornblende gneisses and hornblende-plagioclase gneisses. Meta-anorthosites are surrounded by dharwarian schists and gneisses. The contact between them is sharp. The trend varies from NE-SW to ENE-WSW with very steep dips to the SE or SSE. These rocks reveal the xenoblastic texture, of which plagioclase and blue-green hornblende are the essential minerals. Diopside, garnet, scapolite, zoisite, hypersthene, sphene and zircon are the important accessory minerals. Rims of Hornblende are seen round the pyroxenes. Plagioclases show alteration to sericite (Fig. 4.10).

4.2 MODAL ANALYSIS

Modal analysis of 32 samples comprising different rock types (Gneisses, 5 No.s, Normal amphibolites, 5 No.s, Pyroxene Plagioclase amphibolites, 5 No.s, Anorthosites, 5 No.s, Granulites, 7 No.s, and Hornblende Schists, 5 No.s) were studied for their mineral assemblage which are revealed in the following tables.

Table 4.1 Modal analysis of Gneisses

Mineral Name	Sample1	Sample2	Sample3	Sample4	Sample5
Plag	11.59	11.35	11.65	11.5	11.68
Hbl	0	0.05	0.06	0.04	0.05
Cpx	1.82	1.6	1.75	1.75	1.66
Qtz	64.33	65.8	64.8	65.7	66.3
Zircon	0.33	0.28	0.22	0.3	0.26
Bt	3.7	3.5	3.8	3.94	3.77
Orthoclase	10.05	9.7	9.85	9	8.48
Opx	7.07	6.9	6.76	6.82	6.8
Apatite	0.66	0.5	0.68	0.55	0.55
Sphene	0	0	0	0	0
Epidote	0	0	0	0	0
Opaques	0.44	0.4	0.42	0.4	0.45
Garnet	0	0	0	0	0
Muscovite	0	0	0	0	0
Total	99.99	99.98	99.99	100	100

No. 1 Gneiss, Gobbagurti Hills, Near Pangidi. No. 2 Gneiss, Tallada area.

No. 3 Gneiss, Lakshmipuram area. No.4 Gneiss, Pangidi area

No. 5 Gneiss, Lakshmipuram area. No. 6 Gneiss, Irlapudi area.

Table 4.2: **Modal analysis of Normal Amphibolites**:

Minerals	**Sample1**	**Sample2**	**Sample3**	**Sample4**	**Sample5**
Cpx	4.26	3.08	3.5	3.8	3.8
Opx	0.31	0	0.2	0.3	0.3
Plag	17.3	23.55	23	22	22
Qtz	3.14	10.97	8.5	7.5	8
Opaques	0.52	0.98	0.7	0.8	0.6
Garnet	0	0.23	0.1	0.2	0.1
Hbl	72.1	61.2	68	66	66
Zoisite	-	-	-	-	-
Scapolite	2.41	-	-	-	-
Total	100	100	100	100	100

No. 1 Amphibolite, Gobbagurti area. No. 2 Amphibolite, Donabanda area. No. 3 Amphibolite, Lakshmipuram area. No. 4 Amphibolite, Mekalkunta area. No. 5 Amphibolite, Pallipadu area.

Table 4.3: **Modal analysis of Pyroxene-Plagioclase Amphibolites**:

Minerals	**Sample1**	**Sample2**	**Sample3**	**Sample4**	**Sample5**
Cpx	6.07	8.18	17.20	9.89	12.00
Opx	0.00	0.92	1.12	1.28	0.80
Plag	27.45	21.15	37.70	36.21	30.55
Qtz	4.94	3.53	1.01	3.02	3.30
Opaques	1.00	0.51	0.39	1.92	0.75
Hbl	60.54	65.72	42.58	47.66	52.60
Total	100.00	99.98	100.00	99.98	100.00

No. 1 Pyx -Plag amphibolite, Gobbagurti area. No. 2 Pyx - Plag amphibolite, Donabanda area. No. 3 Pyx - Plag amphibolite, Lakshmipuram area. No. 4 Pyx - Plag amphibolite, Mekalkunta area. No. 5 Pyx - Plag amphibolite, Pallipadu area.

Table 4.4: **Modal analysis of Anorthosites**

Minerals	Sample1	Sample2	Sample3	Sample4	Sample5
Plag	66.86	88.36	93.89	83.04	84.00
Hbl	29.82	5.54	3.09	12.82	10.70
Cpx	3.31	3.89	0.39	2.53	2.50
Scapolite and Sericite	0.00	2.03	2.10	1.38	1.50
Zircon	0.00	0.16	0.00	0.05	0.08
Zoisite	0.00	0.00	0.26	0.09	0.12
Sphene	0.00	0.00	0.26	0.09	0.10
Total	99.99	99.98	99.99	100.00	99.00

No. 1 Anorthosite, Jannaram area. No. 2 Anorthosite, Kodaratimetta area.

No. 3 Anorthosite, Lakshmipuram area. No. 4 Anorthosite, Mekalkunta area.

No. 5 Anorthosite, Pallipadu area.

Table 4.5: **Modal analysis of Granulites (Gobbagurti)**

Minerals	Sample1	Sample2	Sample3	Sample4	Sample5	Sample6	Sample7
Cpx	40.03	47.16	29.57	33.04	27.45	32.70	29.53
Opx	1.64	5.75	1.43	3.38	3.29	2.86	1.74
Plag	31.86	39.81	41.27	34.74	46.96	37.96	41.60
Qtz	5.31	3.38	3.71	5.26	2.26	3.16	4.89
Opaques	1.31	0.08	2.47	1.93	0.97	1.65	2.23
Garnet	0.00	0.00	0.00	10.11	0.38	8.74	3.23
Hbl	19.86	3.81	20.13	11.58	18.69	12.93	16.77
Biotite	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zircon	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	99.99	98.58	99.99	100.00	100.00	99.99

No. 1 Granulite, Gobbagurti Complex. No. 2 Granulite, West of Anjanapuram area.

No. 3 Granulite, Lakshmipuram area. No. 4 Granulite, Mekalkunta area.No. 5 Granulite, Lakshmipuram area. No. 6 Granulite, Pallipadu area.No. 7 Granulite, Pallipadu area.

Table 4.6: **Modal analysis of Hornblende- Schists**:

Minerals	**Sample1**	**Sample2**	**Sample3**	**Sample4**	**Sample5**
Quartz	27.86	21.81	24.84	25.60	25.75
Hbl	58.56	61.20	59.88	59.75	59.50
Plag	13.17	16.99	15.08	14.70	14.57
Apatite	0.14	0.00	0.07	0.05	0.08
Opaques	0.27	0.00	0.03	0.00	0.10
Total	100.00	100.00	100.00	100.00	100.00

No.1 Hbl- Schist, Gobbagurti area. No.2 Hbl- Schist, Tallada area. No.3 Hbl-Schist, Lakshmipuram area. No.4 Hbl- Schist, Mekalkunta area. No.5 Hbl- Schist, Lakshmipuram area.

4.3 SEM STUDIES:

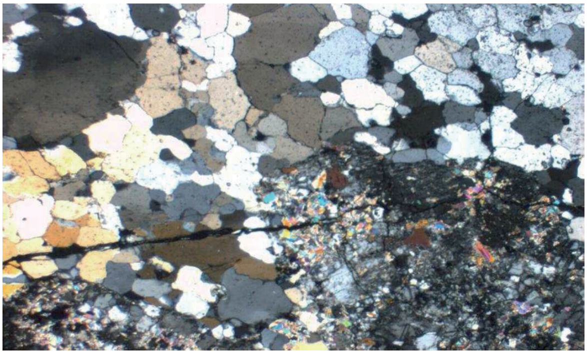
In earlier days, for conducting SEM studies, Ruby (Al_2O_3: Cr) layer was successfully grown on a wall surface of an aluminum oxide crucible by isothermal evaporation of molybdenum trioxide (MoO_3) flux. The growth was conducted by heating a mixture of MoO_3 and an oxide dopant (Cr_2O_3) at 1100 °C, for 5 h at this temperature without adding any reagent grade aluminum oxide. The ruby layers, obtained with a thickness up to 100–300 µm, were transparent-red. The layers consisted of ruby crystals having flat surfaces. This technique was found to be a very suitable method for coating ruby layer on aluminum oxide materials. (Katsuya Teshima et al, 2005)

The “alpha” -phase of aluminium oxide (aka a -alumina, a -Al_2O_3 or corundum) is used in a wide variety of applications, mainly due to its chemical stability and high hardness even at high temperatures. This study deals with the growth and fundamental physics of “alpha” -alumina thin films, which have applications in wear resistant coatings and diffusion barriers.

Although alumina has drawn tremendous interest over the years, research on the low-temperature growth of the stable “alpha” phase has begun fairly recently, along with the development of new deposition techniques and the industrial interest in coatings for mechanical applications. Low growth temperatures are needed not only for deposition on temperature-sensitive substrates, e.g. tool steel, but also to prevent high-temperature reactions during growth, reactions that could degrade the properties of both film and substrate. However, growth of a -alumina has, until fairly recently, only been possible at a substrate temperature of above 1000^{o}C.

Results demonstrate the growth of hard, single phased “alpha” -alumina at substrate temperatures as low as 280^{o}C. This is achieved by aid of an *in-situ* pre-deposited chromia (Cr_2O_3) template layer. Chromia has the same crystal structure as corundum with a relatively small lattice mismatch. It also forms easily even at low temperatures, it is chemically very stable and forms a complete solid solution with alumina. TEM results show that the corundum grains grow with local epitaxy on the polycrystalline chromia layer, copying the crystal structure and orientation of the underlying grains and thus that chromia works as a template to promote corundum growth. The temperature dependence of the film microstructure has been investigated and further investigations on films and growth physics are underway (Anderson, 2004).

SEM studies were carried out on the samples of corundum collected from the study area. (Fig.4.15)



Fig, 4.1 Tonalite Gneisses showing typical granular texture with equant mineral grains

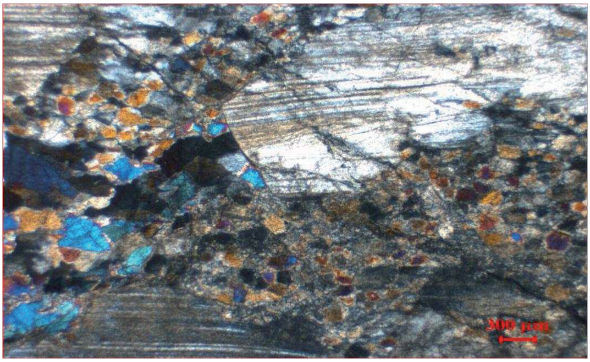


Fig.4.2 Fine recrystallised quartz occurring as micro veins within the plagioclase feldspar

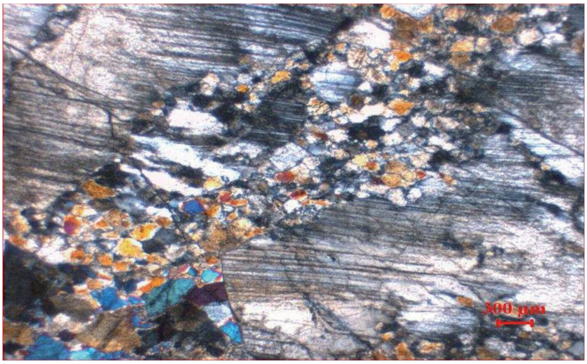


Fig.4.3 Section showing coarse grained plagioclase with bent twin lamellae

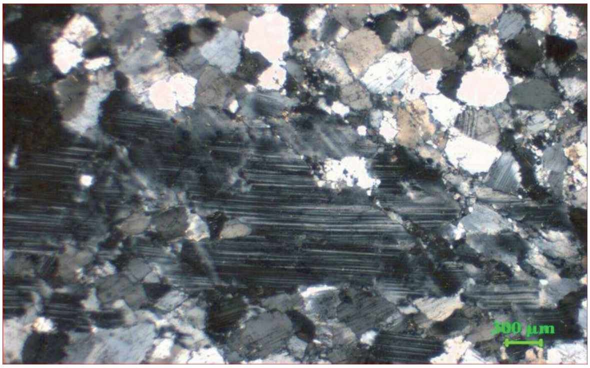


Fig.4.4 Section showing Mortar texture (Peripheral granulation of Quartz Porphyroblasts)

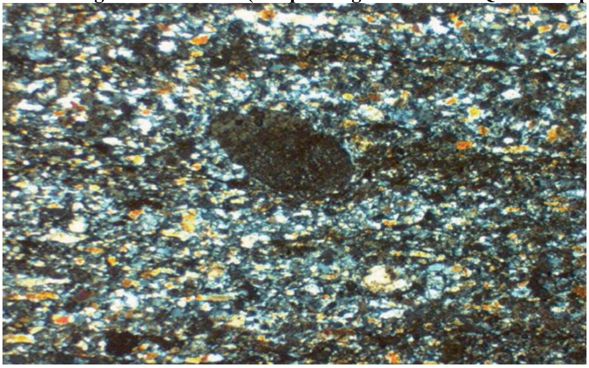


Fig.4.5 Section showing Quartz, and Biotite and high shearing effects (40x)

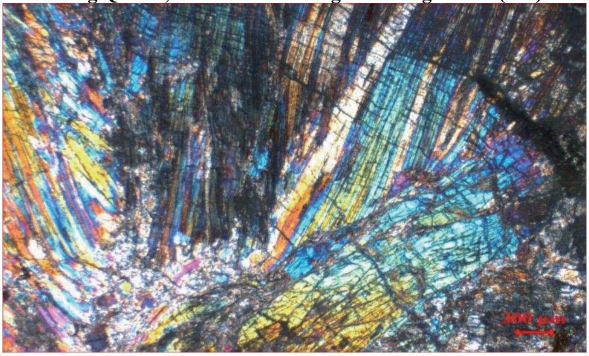


Fig.4.6 Section showing Sillimanite with characteristic sugarcane structure and schistose texture

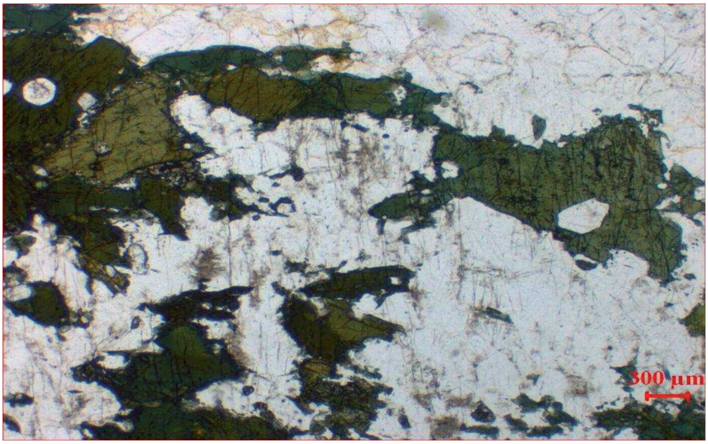


Fig.4.7 Section showing Sieve Structure (Inclusions of Hbl & Qtz in amphibolite)

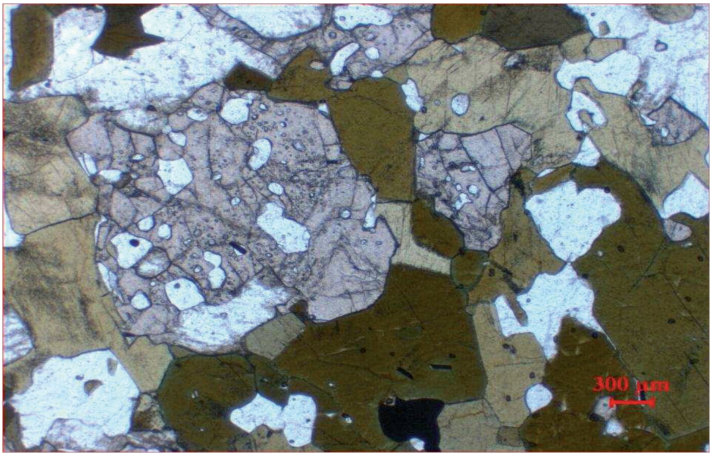


Fig.4.8 Section showing Porphyroblasts of Garnet and a typical salt and pepper texture with White feldspars & Black amphiboles (Plane Polarised Light)

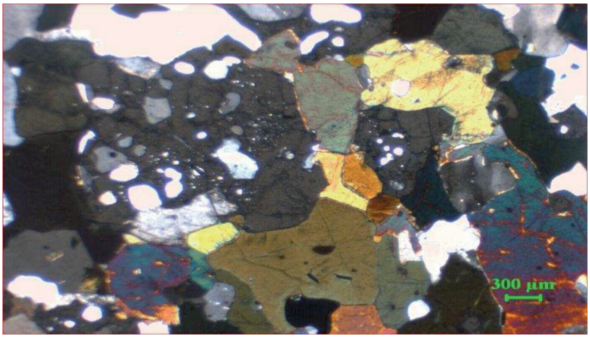


Fig.4.9 Section showing Porphyroblasts of Garnet and a typical salt and pepper texture with White feldspars & Black amphiboles (Crossed Nicols)

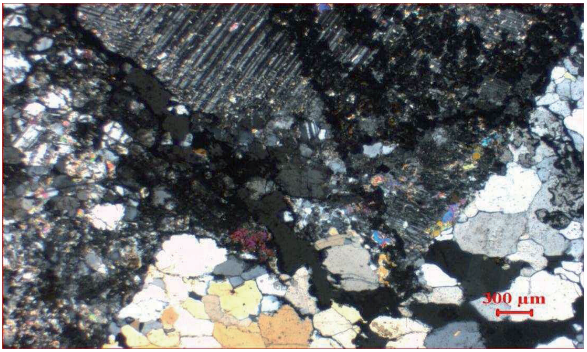


Fig.4.10 Section showing alteration of Plagioclase to Sericite

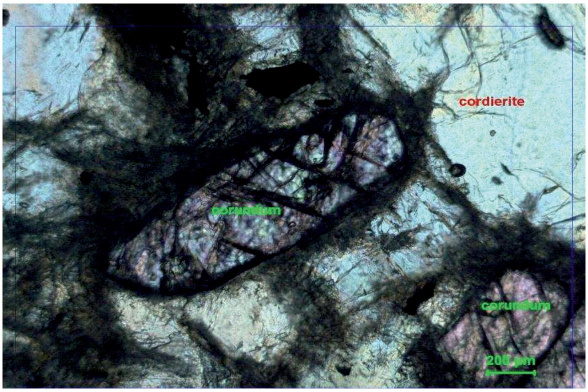


Fig.4.11 Section showing Corundum associated with Cordierite

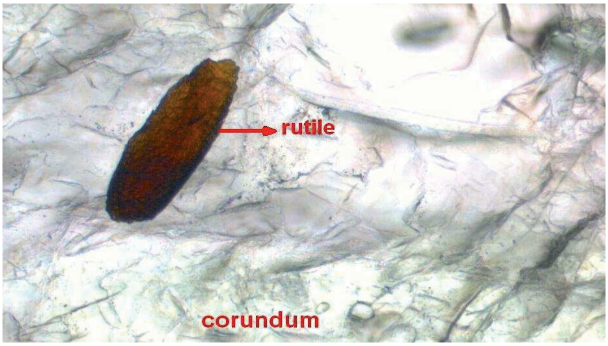


Fig.4.12 Section showing Rutile inclusions in Corundum (40x)

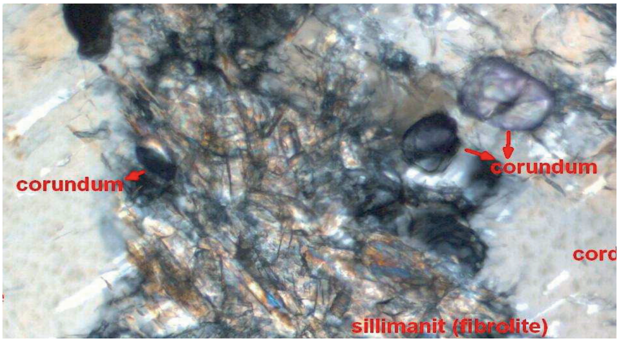


Fig.4.13 Section showing Corundum in Cordierite-Sillimanite Gneiss(40x)

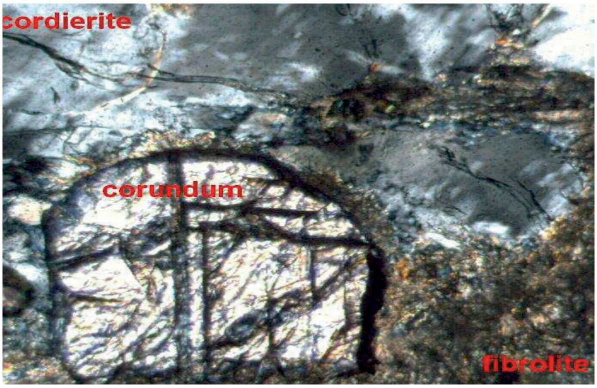


Fig.4.14 Section showing Corundum in Cordierite and the altered mineral fibrolite(40x)

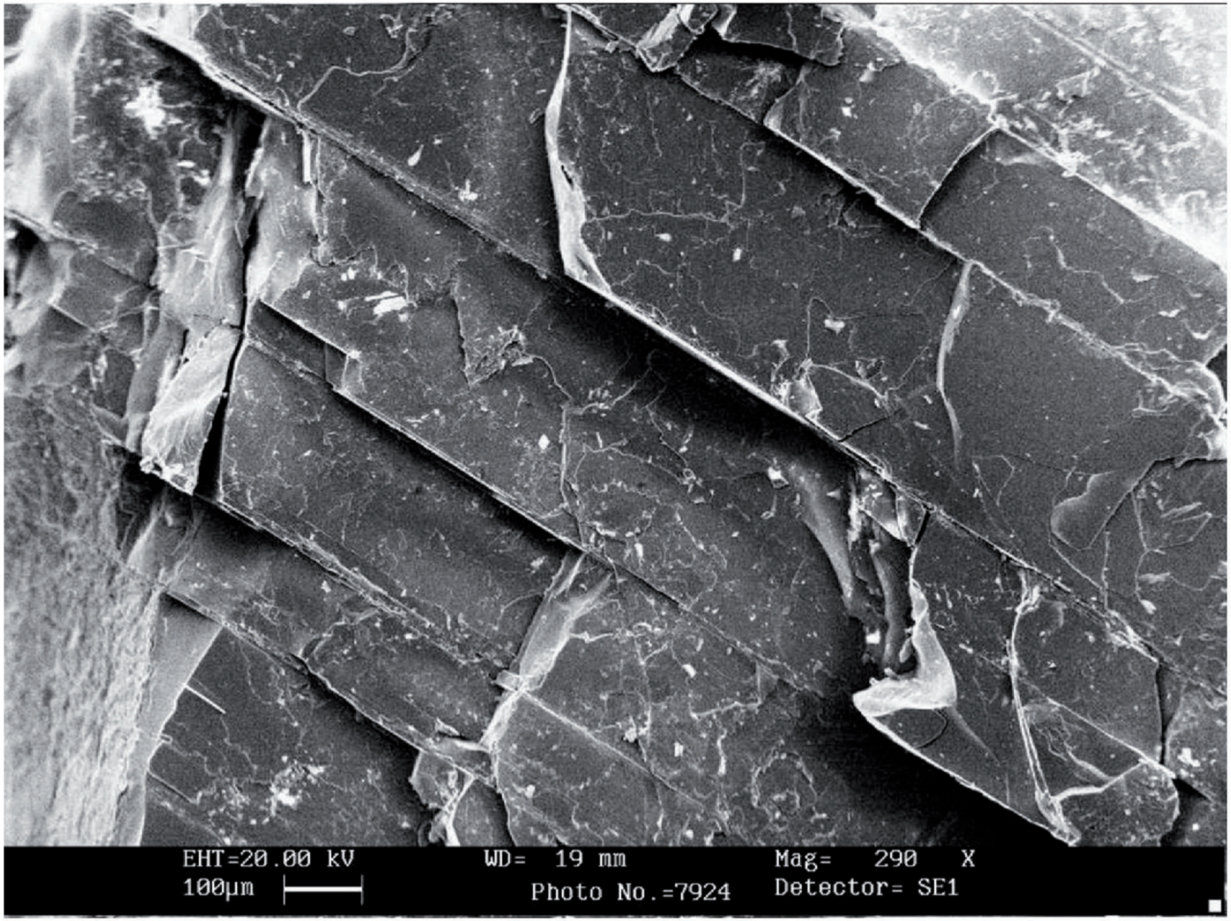


Fig. 4.15 Photograph related to SEM Studies

CHAPTER - 5

GEOCHEMISTRY

Geochemical studies in recent years have acquired considerable importance as the results produce meaningful interpretations. The studies not only help in classifying the rock but also understand the various discriminants which take part in the formation of different minerals.

There is an accumulating evidence of the importance of knowledge on the chemical composition of igneous and metamorphic rocks and the origin and formation of ores. This is based only on the inherent characters of the rock-mass, which is more an essential factor in deducing the purposeful conclusion. The geochemical studies also help in formulating the origin and formation of the ores (Stanton, 1972).

Keeping in view of the above, a few check samples of representative lithologies of the study area have been analyzed for Major/Trace elements based on the megascopic identification of rock type in the field.

5.1 MAJOR ELEMENTS OF LITHO UNITS:

The important litho units and variation in the rock formations (litho-units) of the Khammam Schist Belt which enclose corundum mineralisation have been studied. They comprises of garnet-kyanite bearing schists, hornblende schists, actinolite-tremolite schists, sillimanite schists, normal Amphibolites, garnetiferous amphibolites, basic granulites & felspathic gneisses (tonalites) along with intrusive quartz veins. Representative samples (16 No's) including amphibolites: 6 No's, metapelites: 6 No's, granulites: 3 No’s and gneiss: 1 No. have been chemically analysed for major oxides and 6 check samples which includes amphibolites, 3 No’s, basic rock, 1 No. and pegmatite, 2 No’s have been analysed for both the major & trace elements. The major elements determined (in percentages) are SiO_2, TiO_2, Al_2O_3, Cr_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O & P_2O_5. in all the rock types. Trace elements, viz: Ag, Li, Rb, Cd, Cu, V, Te, Sr, Pb, Zn, Ni, Co, Cr, Mo were determined in hornblende schists, actinolite-tremolite schists, normal amphibolites, garnetiferous amphibolites, basic granulites and felspathic gneisses (tonalites). In Garnet-Kyanite bearing Schists, Zn, Cu, Pb, Ni, Co, Sn were also determined.

5.2 METHODS OF SAMPLING:

There are different procedures in vogue in the investigation of geochemical studies. The first method was advocated by Hillebrand and employed in the laboratory of the United States Geological Survey. It involves first crushing the rock fragments by means of a hardened steel hammer on a hardened steel plate. The plate used by Hillebrand is 4J cm. thick and 10 cm. square, and the rock fragments are surrounded by a steel ring 2 cm. high and 6 cm. internal diameter to prevent the flying and loss of small rock fragments. After reduction in this way to very small particles and powder, the whole sample is ground down by hand in an agate mortar in small portions at a time.

In the second method, the rock is broken into small pieces and is crushed in a specially hardened steel mortar, of peculiar shape, somewhat resembling a “diamond" mortar, but with a tall cylinder and loosely fitting pestle. The crushing is done by the pestle alone, without the aid of a hammer. The material is then ground in an agate mortar mechanically.

In the third method the rock is broken into small pieces, and these pieces are crushed in a steel mortar. The resultant mixture of small fragments and powder is sifted through a silk-gauze sieve, the part which does not pass through being once more crushed in the steel mortar and again sifted, and this operation repeated till only very small portion is left, which is pulverized by hand in an agate mortar (Washington, 1899).

Based on the above, the following procedure was adopted for Whole Rock Analyses (Determination of both Major Oxides and Trace Elements) of 16 representative rock samples and also 6 check samples.

Fresh representative rock samples, 6 No's (3 Samples of Amphibolites, 1 sample of Basic Rock, and 2 samples of Pegmatite) were selected which were from among the collected samples from the field. They were broken into small pieces of 3mm size with the help of Jaw Crusher consisting of iron mortar and pestle. Later these 3mm size samples were thoroughly washed with distilled water and dried under a light source. Subsequently these 3mm size samples were powdered to –200 mesh size with the help of Vibratory Cup/Disc mill with Tungsten Carbide.

These were analysed using XRF for determining the percentage of major oxides and trace elements contained in 6 representative check rock samples, which were subjected to analyses and are given separately (Tables 5.5 & 5.7).

5.3 XRF ANALYSIS:

X-ray fluorescence (XRF) is an elemental analyses technique, which provides (1) highly accurate determinations for major elements and (2) a broad elemental survey of the sample composition without standards. For example, XRF is used in analyses of rocks and metals with an accuracy of ~0.1% of the major elements. A technique known as Fundamental Parameters can estimate the elemental composition of unknowns without standards. And to top it all off, sometimes the analyses requires minimal sample preparation. Detection limits for XRF are generally in the 10-100 ppm range for heavy elements, and elements lighter than Na are difficult to detect (Johnson, et al, 1999). XRF analysis was carried out for one powdered rock sample which revealed the presence of cordierite as the major mineral and talc in trace amounts.

Procedure of XRF (Pelletisation Technique):

X-ray fluorescence spectrometry requires the sample to be in a homogeneous powdered form and comp-ression of the powder in a pellet die yields a denser, flatter surface that provides greater analytical accuracy and sensitivity, especially for wavelength XRF. The representative quantity of the sample is first pulverized and then split to obtain enough powder for an XRF sample disc, usually 6 to 10 grams. That powder is blended with a binder and placed in a pellet die (with or without a Spec-Cap) to be pressed into a sample disc, which will hold together and has a flat, compositionally uniform surface. The Spec-Caps aluminium cups are used for reinforcing the pellet samples. The sample disc is then placed in the sample holder of the XRF spectrometer. The sample disc is handled with care and anti sticking agents is used for safe removal of the disc. This is followed by the fusion of the sample by employing Borate Fusion. For this purpose, a suitable fusion flux and additives for fusion are selected. The process of fusion is carried out in Graphite Crucibles and Accessories or Katanax Automated Electric Fluxers. Thus, a fused sample is prepared in this way (Obenauf, et al., 1991).

5.4 CHEMICAL ANALYSIS OF ROCKS

TABLE 5.1: Chemical Analysis of Metapelites:

Oxides	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
SiO_2	68.64	61.09	56.97	49.32	56.21	58.45
Al_2O_3	18.30	24.75	30.70	23.73	24.44	24.38
TiO_2	1.13	1.13	0.82	1.31	0.80	1.04
FeO	3.28	4.23	4.14	14.04	8.01	6.74
Fe_2O_3	1.60	2.00	1.61	1.91	4.27	2.28
MnO	0.01	0.03	0.06	0.27	0.09	0.09
CaO	0.19	0.29	0.15	1.42	0.22	0.45
MgO	0.97	1.22	0.93	1.89	1.43	1.29
Na_2O	0.56	0.38	0.38	0.60	0.30	0.44
K_2O	3.75	2.90	2.90	3.62	1.90	3.01
P_2O_5	0.80	0.94	0.83	1.29	0.78	0.93
Total	99.23	98.96	99.49	99.40	98.45	99.10

No. 1 Metapelites, Gobbagurti Hills, near Pangidi. No. 2 Metapelites, Tallada area.

No. 3 Metapelites, Lakshmipuram area. No.4. Metapelites, Pangidi area.

No. 5 Metapelites, Lakshmipuram area. No. 6 Metapelites, Irlapudi area.

TABLE 5.2: Chemical Analysis of Amphibolites:

Oxides	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**
SiO_2	47.34	47.53	48.65	47.17	49.61	48.06
Al_2O_3	14.46	15.76	16.43	15.71	13.56	15.18
Fe_2O_3	3.26	2.86	3.26	3.32	3.93	3.33
FeO	12.42	11.45	12.37	11.56	12.23	12.01
MgO	6.41	7.10	7.70	7.04	6.92	7.03
CaO	10.35	10.75	10.04	9.56	9.14	9.97
Na_2O	2.51	2.19	2.12	2.16	2.74	2.34
K_2O	1.26	0.64	0.82	0.56	0.88	0.83
TiO_2	0.35	0.69	0.05	0.71	0.33	0.43
P_2O_5	0.25	0.25	0.05	0.44	0.38	0.27
MnO	0.16	0.15	0.17	0.15	0.06	0.14
H_2O	0.60	0.50	0.60	1.40	0.50	0.72
LOI	0.79	0.50	0.30	0.20	0.20	0.40
Total	100.04	100.37	102.56	99.98	100.48	100.71

No.1 Amphibolite, Gobbagurti area. No.2 Amphibolite, Donabanda area.

No.3 Amphibolite, Lakshmipuram area. No.4 Amphibolite, Mekalkunta area

No.5 Amphibolite, Pallipadu area. Sample No.6 Amphibolite, Irlapudi area.

TABLE 5.3: Chemical Analysis of Granulites

Oxides	Sample 1	Sample 2	Sample 3
SiO_2	50.89	50.07	50.70
Al_2O_3	13.62	14.10	14.76
Fe_2O_3	3.61	3.06	3.82
FeO	11.53	12.89	11.65
MgO	2. 71	4.16	4.76
CaO	12.33	10.22	10.10
Na_2O	2.56	1.95	1.77
K_2O	0.86	0.93	0.68
TiO_2	0.46	1.40	1.32
P_2O_5	0.37	0.25	0.23
MnO	0.18	0.08	0.09
H_2O	0.80	0.80	1.00
LOI	0.30	0.30	0.30
Total	100.22	100.21	100.18

No.1 Granulite, Gobbagurti Complex. No.2 Granulite, West of Anjanapuram area. No.3 Granulite, Lakshmipuram area.

TABLE 5.4: Chemical Analysis of Gneisses (Gobbagurti)

Oxides	Sample1
SiO_2	71.81
Al_2O_3	12.50
Fe_2O_3	1.47
FeO	4.10
MgO	0.58
CaO	0.94
Na_2O	4.60
K_2O	1.60
TiO_2	1.14
P_2O_5	0.01
MnO	0.03
H_2O	1.10
LOI	0.20
Total	100.08

Sample No.1 Gneiss, Gobbagurti Complex.

The check analysis repeated on some selected samples confirmed to close range of the analyses. (Table 5.5 and Fig 5.7)

TABLE 5.5: Whole Rock Analyses (Major Oxides)

Lab No	**H-50**	**H-51**	**H-52**	**H-53**	**H-54**	**H-55**
SiO_2	52.96	58.54	45.75	46.16	76.01	76.73
TiO_2	0.48	0.69	0.57	0.36	<0.1	<0.1
Al_2O_3	8.54	12.32	21.59	22.45	11.61	10.99
Fe_2O_3	4.71	1.24	0.17	1.04	0.04	<0.01
FeO	5.00	5.12	5.62	5.28	0.32	0.56
MnO	0.11	0.07	0.04	0.04	<0.01	<0.01
CaO	10.51	8.76	11.10	12.15	1.85	2.46
MgO	14.40	8.32	10.31	8.59	0.07	0.03
Na_2O	2.46	2.93	1.80	2.35	7.42	6.68
K_2O	0.36	0.72	0.33	0.54	0.84	0.78
P_2O_5	0.11	0.18	0.08	0.19	0.04	0.06
LOI	0.88	0.73	1.14	1.26	0.25	0.54
Total	100.52	99.62	98.50	100.41	98.50	98.95

H-50, H-51 and H-52: Amphibolites, H-53: Basic Rock, H-54 and H-55: Pegmatite

5.5 NORMATIVE CALCULATIONS OF MAJOR OXIDES:

However, the normative calculations on the check samples not only suggested the existence of felsic rocks (Tonalites) but also the basic diorites. (Table 5.6)

TABLE 5.6: Normative Calculations From Major Oxides

Lab No	**H-50**	**H-51**	**H-52**	**H-53**	**H-54**	**H-55**
Quartz	0.14	8.89	0.00	0.00	31.79	34.36
Orthoclase	2.12	4.23	1.94	3.18	4.94	4.59
Anorthite	11.19	18.32	49.82	49.08	0.00	0.00
Albite	20.80	24.77	15.22	14.84	54.99	52.14
Diopside	31.73	19.23	3.77	7.99	1.21	1.82
Hypersthene	25.64	18.87	4.12	0.00	0.00	0.00
Magnetite	6.84	1.80	0.25	1.51	0.00	0.00
Ilmenite	0.91	1.31	1.08	0.68	0.19	0.19
Apatite	0.24	0.39	0.17	0.41	0.09	0.13
Olivine	0.00	0.00	20.92	18.64	0.00	0.00
Nepheline	0.00	0.00	0.00	2.73	0.00	0.00
Rock	Diorite	Qtz-Diorite	Troctolite	Nepheline-Gabbro	Tonalite	Tonalite

5.6 PETROCHEMISTRY OF MAJOR LITHO UNITS

Garnet-Kyanite bearing Schist's (Metapelites): The Garnet-Kyanite bearing Schists (metapelites) are rich in SiO_2 which ranges from 49% to 68% and Al_2O_3 ranges from 18% to 30%. The FeO content ranges from 3.2% to 14%. The K_2O content ranges from 1.9% to 3.7% .The MgO content ranges from 0.9% to 1.4%. The CaO content ranges from 0.1% to 1.4%. The chemical data of these rocks show lower percentage of MnO (0.01% to 0.2%). High percentages of Al_2O_3 (24.38%), FeO (6.74%), & Fe_2O_3 (2.28%) and lower percentage of MnO (0.09%) suggests a higher metamorphic status to the metapelites suggesting that the original argillaceous sediments had higher Fe, Mg & Al contents. The higher percentage of Al_2O_3 could be due to the presence of kyanite and partly to almandine garnet, which is rich with Fe and Al molecules. The higher percentage of Al_2O_3 is also suggestive of argillaceous nature of original material.

Hornblende Schists: In Hornblende Schists, SiO_2 content ranges from 48% to 52% and Al_2O_3 ranges from 12% to 15%. The FeO content ranges from 8% to 12%. The MgO content ranges from 5% to 9%. The CaO content ranges from 6% to 10%. The chemical data of these rocks show moderate Na_2O (2.2% to 2.6%) and lower average percentages of MnO (0.05% to 0.09%) and K_2O (1.0% to 1.4%). However, the Al_2O_3 content is significant.

Amphibolites: In Amphibolites SiO_2 content ranges from 41.7% to 49.6% and Al_2O_3 content ranges from 14% to 17.3%. The FeO content ranges from 11.4% to 12.4%. The MgO content ranges from 6.4% to 7.7%. The CaO content ranges from 9.1% to 10.7%. The Na_2O content ranges from 2.1% to 2.7%. The amphibolites show higher CaO/ Na_2O values. The difference between MgO/ FeO ratio is less than 1% in amphibolites. The values are suggestive of slow depletion of SiO_2 and increase in Al_2O_3

Basic Granulites: In Basic Granulites, SiO_2 content ranges from 50% to 52% and Al_2O_3 content ranges from 14% to 15%. The FeO content ranges from 11.5% to 12.9%. The CaO content ranges from 10% to 12.3%. The Na_2O content ranges from 1.6% to 2.9%. The MgO content ranges from 2.7% to 4.7%. The basic granulites are relatively poor in K_2O (0.6% to 0.9%).

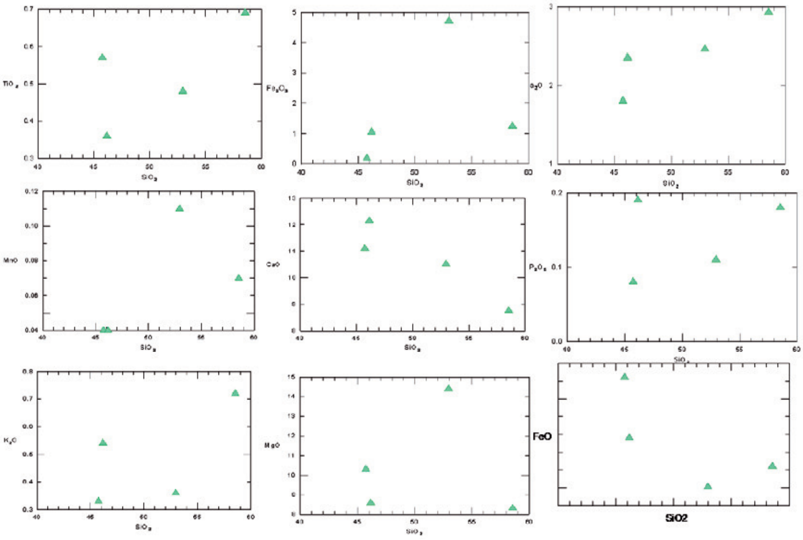
Gneisses: In Gneisses SiO_2 content ranges from 69% to 72% and Al_2O_3 content ranges from 10% to 15%. The FeO content ranges from 2% to 6%. The Na_2O content ranges from 4.2% to 4.8%. The MgO content ranges from 0.2% to 0.6%. The K_2O content ranges from (1.4% to 1.9%). The basic granulites are relatively poor in CaO content which ranges from 0.9% to 1.3%.

The overall regional geochemistry points out that from gneissic end of the rocks towards metapelites, there is a decrease in SiO_2 content suggesting the effects of desilication. The progressive increase in Al_2O_3 content points to the addition of Al_2O_3 where the increase in critical composition might lead to the formation of corundum.

The variations in the percentages of different oxides with respect to the check samples have been revealed in the following variation diagrams.

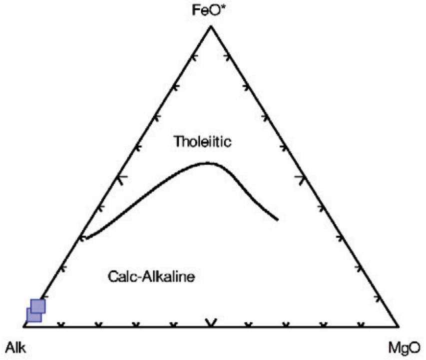
5.7 HARKARS VARIATION DIAGRAMS

Fig 5.1 HARKAR'S VARIATION DIAGRAMS



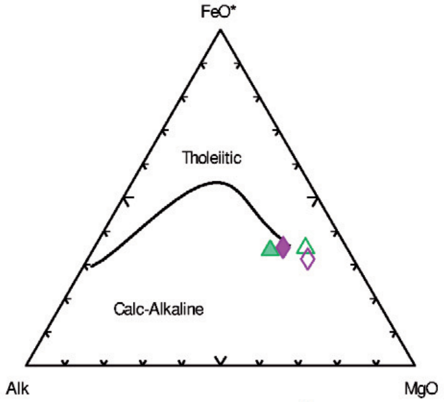
5.8 MAJOR ELEMENT PLOTS OF ANALYSIS

Fig. 5.2 AFM Diagram for Granitic/Pegmatite rocks (after Irvine and Baragar 1971)



1. Granite/Pegmatite, Ganesharam Area, 2. Granite/Pegmatite, Ganesharam Area

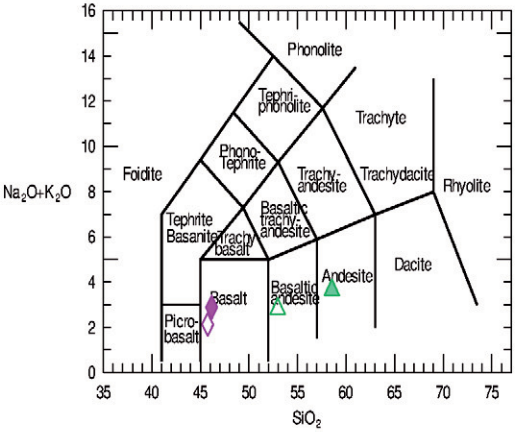
Fig. 5.3 AFM Diagram for Basic rocks (after Irvine and Baragar 1971)



No.1 ▲ Amphibolite, Gobbagurti area. No.2 △ Amphibolite, Donabanda area.

No.3 ◊ Amphibolite from Lakshmipuram area No.4 ♦ Basic Rock, Lakshmipuram area

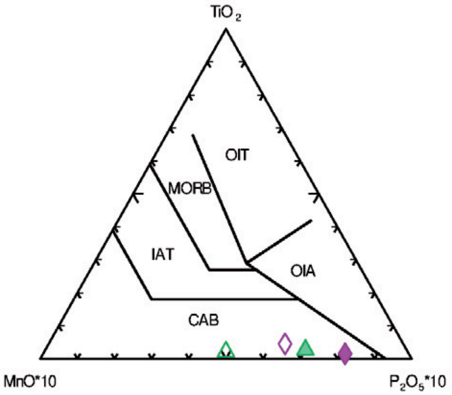
Fig 5.4 TAS diagram for basic rocks (after Le Maitre et al 1989)



No.1 ▲ Amphibolite, Gobbagurti area. No.2 △ Amphibolite, Donabanda area

No.3 ◇ Amphibolite , Lakshmipuram area. No.4 ◆ Basic Rock, Lakshmipuram area

Fig 5.5 Tectonic discrimination diagram for Basic rocks (after Pearce and Gale, 1977)

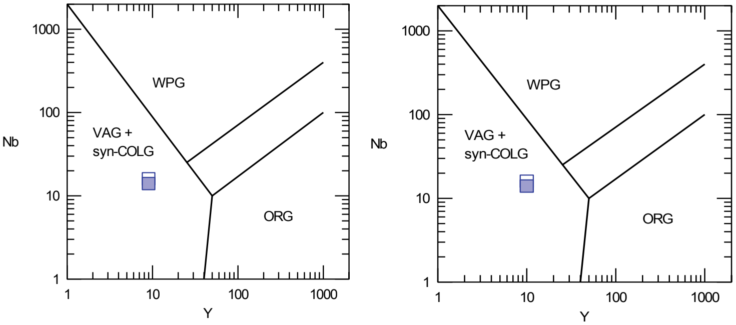


No.1 ▲ Amphibolite, Gobbagurti area No.2 △ Amphibolite, Donabanda area

No.3 ◆ Amphibolite, Lakshmipuram area No.4 ◇ Basic Rock, Lakshmipuram area

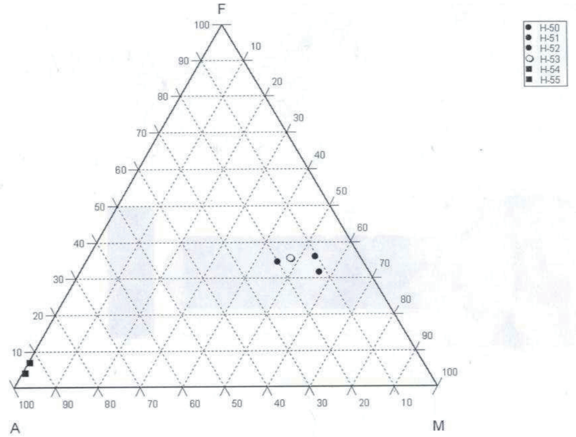
Tectonic Classification based on Nb/Y ratio given by Pearce, 1977 has been utilized to determine the nature of occurrence of these rock types.

Fig 5.6 Tectonic discrimination diagrams for Granite/Gneiss rocks (after Pearce, 1977)



1. Granite/Gneiss, Ganesharam Area 2. Granite/Gneiss, Ganesharam Area

Fig. 5.7 AFM Diagram for Check Samples



5.9 TRACE ELEMENT STUDIES:

Increasingly, developments in analytical techniques have been made in order to obtain recise and accurate trace element abundances at in rocks using inductively coupled plasma mass spectrometry (ICP-MS).The application of ICP-MS for rapid and precise measurement of a wide range of elements has been successful (Eggins et al., 1997;

Makishima and Nakamura, 1997). However, high field strength elements and elements present at ultra low levels in rocks are still not easily measured by ICP-MS for routine analyses because of difficulties in sample preparation, complicated matrix/ interference effects, and sensitivity limits of the instrument. Recent advances in ICP-MS technology, such as the development of a chicane lens system and micro sample introduction methods have significantly improved its performance in trace element quantification and is being used universally (Chang Quing et al., 2000).

Method:

Approximately 100 micrograms of chips from the smashed discs are weighed accurately into Savillex teflon vessels. Five ml of internal standard, one ml of HF and five ml of HNO_3 are then added. The vessels are sealed and heated for 12 hours overnight at 120^0 centigrade on a timed hotplate, such that cooled samples are ready the following morning. The digests are then transferred to volumetric flasks and made up to volume as per the procedure (Pyke, 2000) ready for the ICP–MS.

TABLE 5.7 TRACE ELEMENT ANALYSiS OF CHECK SAMPLES (in ppm**)**

Lab No	**H-50**	**H-51**	**H-52**	**H-53**	**H-54**	**H-55**
Ti	2046	2672	2463	2411	107	296
V	172	136	166	183	5	7
Cr	2890	159	477	418	19	11
Mn	1692	930	713	432	92	133
Co	119	35	52	48	<5	9
Ni	777	84	189	157	27	34
Cu	75	70	84	45	35	36
Ga	19	22	27	25	24	20
Y	20	19	20	15	<10	<10
Zr	52	61	29	38	12	323
Nb	11	16	11	<10	16	14
Pb	10	16	11	8	52	14

Be, Mo and Sn <10 ppm, Li and La <100 ppm and Ag <2 ppm in all the samples

H-50, H-51 and H-52: Amphibolites, H-53: Basic Rock, H-54 and H-55: Pegmatite

Distribution of Trace Elements:

Rubidium: The amount of Rubidium present in the major litho units is as follows: Metapelites (<10 ppm), Hornblende Schists (15-16 ppm), Amphibolites (12-15 ppm), Basic Granulites (13-18 ppm) and Gneisses (35-80 ppm). The higher percentage of Rubidium in Gneisses is due to the presence of K-Feldspars and Biotite.

Barium: The amount of Barium present in the major litho units is as follows: Metapelites (<10 ppm), Hornblende Schists (185 ppm), Amphibolites (181 ppm), Basic Granulites (182 ppm) and Gneisses (210 ppm). The higher percentage of Barium in Gneisses is due to the presence of K-Feldspars and Biotite.

Strontium: The amount of average Strontium present in the major litho units is as follows: Metapelites (<10 ppm), Hornblende Schists (650 ppm), Amphibolites (580 ppm), Basic Granulites (505 ppm) and Gneisses (760 ppm). The Plagioclase and K-Feldspars are the hosts for Strontium.

Lithium: The amount of average Lithium present in the major litho units is as follows: Metapelites (<10 ppm), Hornblende Schists (6.5 ppm), Amphibolites (4.6 ppm), Basic Granulites (6.5 ppm) and Gneisses (8.2 ppm).

Chromium: The amount of average Chromium present in the major litho units is as follows: Metapelites (<10 ppm), Hornblende Schists (224 ppm), Amphibolites (409 ppm), Basic Granulites (390 ppm) and Gneisses (195 ppm). Goldschmidt opines that the basic rocks in general have higher content of Chromium, which normally appears in early crystallites rich in magnesium. (Olivine and Pyroxenes). The higher values of Chromium obtained in metabasics is due to the presence of Femic minerals. As the gneisses contain less percentage of Femic minerals, they also contain less percentage of Chromium.

Nickel: The amount of average Nickel present in the major litho units is as follows: Metapelites (163 ppm), Hornblende Schists (163 ppm), Amphibolites (175 ppm), Basic Granulites (275 ppm), Gneisses (117 ppm) and Pelitic Schists (83 ppm).

Cobalt: The amount of average Cobalt present in the major litho units is as follows: Metapelites (79 ppm), Hornblende Schists (79 ppm), Amphibolites (83 ppm), Basic Granulites (84 ppm), Gneisses (24.8 ppm) and Pelitic Schists (<125 ppm).

Vanadium: The amount of average Vanadium present in the major litho units is as follows: Metapelites (253 ppm), Hornblende Schists (253 ppm), Amphibolites (341 ppm), Basic Granulites (259 ppm), and Gneisses (124 ppm). The lower values of Vanadium obtained in gneisses is due to the less representation of Femic minerals, mainly Pyroxene.

Copper: The amount of average Copper present in the major litho units is as follows: Metapelites (57 ppm), Hornblende Schists (57 ppm), Amphibolites (134 ppm), Basic Granulites (102 ppm), Gneisses (12 ppm) and Pelitic Schists (249 ppm). The higher percentage of Copper in the Pelitic Schists suggests that the original argillaceous sediments were higher in Copper and the sediments were derived from basic rocks.

Lead: The amount of average Lead present in the major litho units is as follows: Metapelites (37 ppm), Hornblende Schists (37 ppm), Amphibolites (44 ppm), Basic Granulites (42 ppm), Gneisses (34 ppm) and Pelitic Schists (<125 ppm).

Zinc: The amount of average Zinc present in the major litho units is as follows: Metapelites (183 ppm), Hornblende Schists (183 ppm), Amphibolites (135 ppm), Basic Granulites (127 ppm), Gneisses (59 ppm) and Pelitic Schists (201 ppm).

5.10 CHEMICAL MINERALOGY

Electron Probe Micro Analyses (EPMA):

EPMA is non-destructive, so that in situ analyses of minerals in polished thin sections are obtained while retaining textural relationships among coexisting minerals. This also preserves the same sample for analyses by other measurement techniques, such as ion microprobe

Raimond Castaing first presented his idea to use secondary X-rays excited by a focused electron beam from a polished solid sample for microanalyses in 1949 at the First European Regional Conference on Electron Microscopy in Delft, the Netherlands (Castaing and Guinier, 1950).

Studies of zoning, exsolution, inclusions, or other compositional variations within minerals require electron microprobes with high spatial resolution, a highly stable beam (both spatially and with respect to current output), and automated spectrometers for multi-element analyses in precisely controlled spots. These requirements led to improvements in spectrometer and stage precision, beam control, and more thorough software automation systems for instrument control and data collection. (James et al 2001)

Electron microprobe designs allowed several wavelength dispersive spectrometers (WDS) to be attached to the electron column. This provided multiple-element data acquisition in short time intervals.

It has been recognized that EPMA provided a powerful interactive research tool for characterizing the compositional behavior of the minerals as a function of texture and mode of occurrence of the mineral within the rock matrix. Thus rapid quantitative results were critical in efficiently and completely identifying the systematics of the mineral chemistry within a rock sample. This provided an impetus for faster, more thorough online quantitative corrections of the microprobe measurement data. Improvements in computer memory and processing speed enabled real-time data corrections and recalculation of analytical results into mineral formulas to assess the quality of the analytical results. Correction procedures were continually refined to produce more accurate analytical results (Armstrong, et al 1991).

Therefore, EPMA became common for major and trace element analyses in minerals. The powerful advantage of speed (relative to other chemical techniques), in situ non-destructive analyses, and a nearly “complete” quantitative chemical analyses combine to make EPMA a valuable technique for trace element analyses, down to routinely attainable detection limits of 10–50 ppm, and in some cases below 10 ppm. There have been several studies of trace elements in geologic materials, both in individual minerals. (Ramsden and French, 1990). Studies of metamorphic minerals, particularly garnets and other minerals and the distribution of trace elements in them have received considerable focus utilizing EPMA, as have studies determining trace element partition coefficients in minerals.

Although Corundum has been identified megascopically in the field, associated with distinct gneissic and schistose rocks, exact chemical nature and the associated minerals could not be well established.

Chemical mineralogical characterization has been carried out with EPMA Studies. The studies indicated compositions obtained by EPMA for minerals, which also includes a considerable amount of Corundum.

Procedure:

A thin polished section of the sample has been selected and EPMA was conducted. The following data has been taken into account for the conduct of this analyses.

1. Machine, make and model: Cameca SX100 EPMA
2. Analytical Conditions
   a) Wavelength Dispersive Spectrometry. (WDS)
   b) 20 Kv accelerating voltage
   c) 20 nA beam current, 1 micron beam diameter on silicates except feldspars which are analysed with diffuse beam (5-10 micron beam diameter)
3. Other Parameters
4. Standards: Supplied by MAC Analytical Standards, UK
5. The data reduction carried out by PAP corrections on line. Cations proportions calculated using AX program of Dr. T.J.B. Holland, Cambridge University, U.K. by stoichiometry.

Table No. 5.8 Table Showing EPMA parameters

Element	**X-ray line**	**Crystal**	**Standard**
Si	Si Ka	TAP	Andradite
Ti	Ti Ka	PET	MnTio3
Al	Al Ka	TAP	Corundum
Cr	Cr Ka	LiF	Cr
Fe	Fe Ka	LiF	Andradite
Mn	Mn Ka	LiF	MnTio3
Mg	Mg Ka	TAP	Periclase (MgO)
Ca	Ca Ka	PET	Wollastnite
Na	Na Ka	TAP	Jadeite
K	K Ka	PET	Orthoclase
P	P Ka	PET	GaP
Ni	Ni Ka	LiF	Ni metal

Standards:

Homogeneous, well-characterized standards are the foundation of quantitative EPMA. The importance of such materials, preferably including minerals with compositions similar to the materials to be analyzed, cannot be emphasized enough. The use of standards in quantitative EPMA was also discussed by earlier geoscientists. The geologic and planetary science community has benefited greatly from the characterization and availability of a variety of mineralogical standards. Those distributed by Jarosewich and Boatner , 1991, for example, have proved to be invaluable in mineralogical applications.

Electron probe microanalyses were carried out for the corundum-bearing sample collected from Gobbagurti & Lakshmipuram areas , part of the study area. The analyses results are shown in the following table.

From the analytical results, it is observed that the silica percentage varies between 45 & 52 %, which indicates that the original rock steadily got reduced in the silica content.

(Desilicification). The analyses also reveal the presence of Rutile, Zircon, Chrome Spinel & Talc as the minor minerals apart from Cordierite, Corundum, Sillimanite & Opx (Magnesium-Cummingtonite gedritite) as the major minerals. The increasing proportion of MgO compared to FeO, Na_2O, K_2O & P_2O_5 suggests that the rock is definitely a desilicified metamorphic rock with Corundum & Cordierite minerals, suggesting reconstitution of its mineral content. (Table 5.9)

Table No. 5.9 EPMA Analysis

Point#	Sio2	Tio2	Al2o3	Cr2o3	Feo	Mno	Mgo	Cao	Na2o	K2o	P2o5	Zro2	Hfo2	Total
1	49	0	33.08	0.03	0.89	0	13.1	0	0.22	0	0.03	-	-	96.39
2	49	0	33.51	0.04	0.97	0.1	13.1	0	0.26	0	0.04	-	-	96.99
3	31.8	0.02	19.01	0	0.93	0	4.19	1.6	0.26	0.5	0.02	-	-	58.24
4	49.1	0.01	33.35	0	0.89	0	13.2	0	0.19	0	0	-	-	96.79
5	36.2	0.02	62.54	0.02	0.13	0	0	0	0	0	0.02	-	-	98.98
6	34.6	0	61.04	0	0.14	0	0.02	0	0.02	0	0	-	-	95.81
7	36.4	0	62.21	0	0.14	0	0.04	0	0.01	0	0.05	-	-	98.88
8	49.2	0	33.52	0.01	1.03	0	13.1	0	0.21	0	0	-	-	97.1
9	34.6	0	60.22	0.03	0.1	0	0.04	0	0	0	0.01	-	-	95.1
10	62	0.04	2.44	0	1.44	0	29.1	0	0.09	0	0.01	-	-	95.14
11	47	0	33.4	0.04	0.98	0	13.2	0	0.29	0	0	-	-	94.88
12	59.8	0.05	17.56	0	1.05	0	23.8	0.3	0.75	0.3	0.04	-	-	103.6
13	58.6	0	2.91	0.07	1.58	0	27.1	0.1	0.17	0	0.01	-	-	90.5
14	29.8	0.02	0	-	0.01	-	0.01	0	-	-	0	68.5	1.46	99.83
15	36.3	0.05	62.71	0.05	0.13	0	0.03	0	0	0	0.01	-	-	99.31
16	0.21	99.03	0	1.02	0.07	0	0.04	0	0	0	0.02	-	-	100.4
17	44.9	0.07	19.62	0.02	5.41	0.1	23.9	0.1	2.04	0	0.06	-	-	96.24
18	37.1	0.02	63.23	0	0.17	0	0.01	0	0	0	0	-	-	100.6
19	36	0	62.4	0.01	0.17	0	0.02	0	0.01	0	0	-	-	98.67
20	43.7	0.06	20.52	0.04	5.7	0.1	23.5	0.2	2.17	0	0.05	-	-	95.9
21	42.9	0.04	21.44	0.04	5.55	0.1	23.4	0.2	2.31	0	0.01	-	-	95.85
22	36.6	0.01	62.66	0	0.13	0	0.03	0	0	0	0.03	-	-	99.53
23	0.2	3.32	0.88	32.44	21.8	0	8.86	0	0.02	0	0	-	-	97.5
24	0.21	3.11	29.82	33.25	22.3	0	8.37	0	0.01	0	0.01	-	-	97.03

Point#	Sio2	Tio2	Al2o3	Cr2o3	Feo	Mno	Mgo	Cao	Na2o	K2o	P2o5	Zro2	Hfo2	Total
25	0.11	100.2	0	1.32	0.06	0	0	0	0	0	0	-	-	101.7
26	17.8	0.02	29.9	0.11	0.01	0	0.01	0	0	0	0.01	-	-	47.86
27	49	0	33.21	0	0.86	0	13.1	0	0.26	0	0	-	-	96.52
28	43	0.1	19.17	1.48	5.52	0	23.4	0.2	2.06	0	0.04	-	-	94.92
29	41.5	0.12	19.19	1.69	5.55	0.1	23.5	0.2	2.07	0	0.04	-	-	93.94
30	42.9	0.14	20.15	1.07	5.56	0	23.4	0.2	2.25	0	0	-	-	95.69
31	44	0.12	19.19	0.9	5.5	0	23.3	0.2	2.1	0	0	-	-	95.35
32	36.4	0.16	62.09	0.75	0.13	0	0.02	0	0	0	0.01	-	-	99.6
33	0.18	0.02	99.58	0.31	0.1	0	0.01	0	0	0	0	-	-	100.2
34	0.14	0.02	99.08	0.29	0.09	0	0.02	0	0	0	0.01	-	-	99.67
35	0.13	0.04	98.47	0.24	0.09	0	0	0	0	0	0	-	-	99.03
36	0.12	0.03	99.31	0.47	0.09	0	0.01	0	0	0	0	-	-	100.1

Points 5, 6, 7 15,18, 22, 32,33, 34, 35 and36 indicate Corundum and points 23,24 indicate Chrome-Spinel Point 25 indicates Rutile and Points

CHAPTER - 6

NATURE OF OCCURRENCE

Semi-precious-commercial grade corundum (Ruby Variety) is localised in and around Gobbagurti area, Khammam District, Andhra Pradesh. Unscientific exploitation of corundum over few decades and improper open pit mining activity without understanding of the nature of mineralisation is being carried out around Gobbagurti and Wyra areas.

Corundum mineralisation is essentially controlled by lithology and structure of the host rocks of Khammam Schist Belt. The prime mineralised area is in close proximity to the Wyra lake and the incoming drainage carry considerable quantities of transported corundum. Lithologically, the area is comprised of hornblende schists, schistose amphibolites, garnetiferous-amphibolites, tremolite-actinolite-talc-chlorite schists, tonalite gneisses and pelitic gneisses, younger anorthosites, amphibolite dykes, mafic and felsic granulites, meta-dolerites, tonalites and cordierite-sillimanite-quartz-schists/gneisses, are intruded by gabbroic cryptic anorthosites, aplites, granites and pegmatites.

The association of corundum both with pelitic schists and tonalites suggests its intimate lithological control with the SiO_2 depleted rocks and its occurrence along well defined planes of structural weakness is noteworthy. Corundum is observed in association with felsic rocks in these areas and suggests its affiliation to primary nature and reflects its occurrence and origin from felsic rocks and metamorphosed pelitic schists. The occurrence of corundum along the contacts between the intrusives (felsic rocks) and the schists and gneisses is generally observed. Garnets in association with amphibolites are commonly observed.

Prospecting activity by panning along the structurally controlled nallas (drainage) is the testimony to the wide spread placer concentrations of corundum in this area.

Ruby Corundum (semi-precious) occurs in the areas of Lakshmipuram, Gobbagurti, Singaraipalem, Lalapuram, Mekalkunta, Tumallepalle, Wyra and adjoining areas of Khammam District, Andhra Pradesh. (17^o 10’ – 17^o 20’: 80^o 15’- 80^o 25’)

The occurrence of corundum in these areas has attracted the attention of a number of prudent entrepreneurs since few decades and exploratory mining is the order of the day. However, there is no proper scientific method of extraction and open pit mining activity was observed in these areas without proper understanding of the nature of mineralisation.

6.1 MODE OF OCCURRENCE CORUNDUM:

Based on the nature of occurrence of corundum (all varieties) it can be categorized into three different types, namely, float, insitu, and placer occurrences.

Float occurrences are observed in close proximity to the primary occurrences and are admixed with soil within the weathered profile of the rocks. They are also observed as colluviums mixed with pebbles of quartz and it is very difficult to identify these deposits unless the eyes are properly trained as they are coated with films of ferruginous material. They generally occupy gentle slopes and sheet wash areas. (Fig 6.1)

Insitu occurrence of corundum is noticed in association with felsic, gneissic rocks and along the contact zones of weak structural planes of amphibolites which appears to be the controlling factor that localized the mineral corundum (Fig 6.2 and 6.3).

The contact between felsic rocks and garnetiferous amphibolites forms major insitu occurrences. The dug material shows the presence of weathered felsic rock associated with the amphibolites. Petrographically, corundum with lamellar twinning is associated with coarse-grained felsic rock. (Fig 6.13)

Placer concentrations are worked out along the nalla courses. Large scale panning of alluvium is observed and the recoveries are also encouraging particularly during rainy season. It is conspicuously observed along the culverts where prospecting pits by the local people amply justify the transportation of corundum from the upper reaches of the stream network. (Fig 6.4, 6.5 and 6.6)

The significant feature of corundum occurrence is its localisation along the structural trends, which also control the drainage pattern. Corundum is intimately associated with pebbles of quartz in the stream sediments. Placer accumulations with thickness of about 10 cm lying below a thick soil cover of about 1 m spread over a large area is under active exploitation. Corundum is reported (Appavadhanulu, et al., 1976.) to occur in association with ultramafic bodies at Gobbagurti. Its occurrence as euhedral crystals in sillimanite bearing schists. (Pelitic Schists) is also note worthy. Ruby variety corundum occurs in association with talc-chlorite schists and sporadically in amphibolites in Khammam schists (Dharwarian rocks) at Lakshmipuram, Lalapuram and Singaraipalem villages which are located in close proximity to Gobbagurti area. Corundum also occurs within the micaceous felsic rock, which is devoid of quartz and enriched in muscovite in the adjoining areas. Corundum occurs in corundum bearing sillimanite schist at Lakshmipuram.

CORUNDUM AND KYANITE:

Rubble of corundum kyanite bearing schist, containing tiny crystals of red-opaque corundum is observed in association with blue bladed kyanite 4 Kms NW of Papkal. Corundum is occurring in the cultivated lands SE of Gobbagurti hill, around the villages of Lallurgudem, Singaraipalem, Mekalakunta, Lalagudem and Lakshmipuram, in the form of strewn crystals. (Dark red to honey yellow in colour). The terrains around these areas enclose biotitic gneisses, amphibolite gneisses, calc-silicate rocks, pyroxene granulites, hornblende granulites, pegmatite veins and hornblendite. Corundum occurs in kyanite schists, 2 Kms NW of Singaraipalem and East of Pallipadu-Gobbagurti area. (Appavadhanulu, et.al. 1976.)

6.2 CONTROLS OF MINERALISATION OF CORUNDUM:

Distinct controls of corundum mineralisation manifested in geomorphology, structure and lithology is observed in this area.

Geomorphologic Controls: The **geomorphologic controls** are manifested in structural hills, denudational hills, residual hills and pediment areas. The elevated reaches are occupied by thick thorny and bushy vegetation and sometimes inaccessible. The available map on land use/land cover studies indicated built-up land, forest, gullied land and water bodies. The gullied land with moderate slopes in continuation of the known corundum lithological signatures forms an important area for prospecting. The study area possesses dendritic to subdendritic drainage (Fig. 1.2). Majority of the streams drain along NW-SE and N-S trending major stream and enter into the pediment area and finally discharge into the Wyra Lake. They lose their velocity as they approach the lower reaches and thus help in continuous deposition of their content in the meanders and confluence points of different nallas. They carry along with them colluvial corundum and all the culverts are the focal points for active exploitation of placer accumulations in this area (Fig. 6.6). Felsic intrusive are observed along the Nagarjunasagar Right Canal (Fig. 6.7)

STRUCTURAL CONTROLS:

The Structural controls are envisaged in three major prominent trends along the directions NW-SE to N 35° W-S35° E, N-S with few degrees variations towards E-W and NE-SW to N 30° E-S30° W. The NNW-SSE or NW-SE trend generally coincides with the plane of schistosity of the amphibolites, which seldom possess mineralisation of corundum. The N-S structural feature is the important and significant structure in the amphibolites which facilitated the emplacement of granite / pegmatite / aplitic intrusions. They form the loci of mineralisation of corundum. The NE-SW (joints) structures indicate the post-mineralized effects in the formation of en-echelon lensoidal occurrences in this area. In addition to the above, WNW-ESE and ENE-WSW trends are also observed which also localize corundum (Fig 6.8)

LITHOLOGICAL CONTROLS:

Lithology plays a protracted and dominant role in the mineralisation of corundum. The contact zones between the felsic intrusions with schistose amphibolites localized the rich concentrations of corundum.(Fig, 6.10, 6.11,6.12, 6.13). Generally the quartzo-felsic rocks do not enclose corundum. Perhaps, the tectonic elements, which facilitated the emplacement of quartzo-felsic and related rocks such as aplites, pegmatites and tonalites must have also acted as carriers of corundum and localised them with desilicified rocks along the contact zones as insitu occurrences in the study area (Fig. 6.7).The garnetiferous amphibolites along their contacts with the felsic and pelitic schists enclose rich occurrences of corundum (Fig. 6.9). However, the amphibolites as such do not exhibit mineralisation of corundum. Occurrences of sillimanite-corundum and kyanite-corundum rocks in the study area only substantiate the contact zones where sillimanite schists and kyanite schists as a contact rock with the quartzo-felsic intrusive (Pegmatite, tonalites, Cordierite-corundum gneiss) hosting mineralisation of corundum. Kasipathi, and Bhaskara Rao, 1998 studied variety of corundum from different areas within the vicinity of Wyra, at Pallabhavi, Kodaratimetta, Lakshmipuram, Mekalkunta and Pallipadu areas and based on XRD studies, they were identified as potential resource for abrasive industry. The XRD data confirmed their potentiality.

TABLE 6.1 XRD Data of very Coarse, Platy, Xlline, Opaque, Light pinkish corundum (after Kasipathi, and Bhaskara Rao, 1998)

Sample	2 0	d(A)	l	hkl	Remarks
KH-1	25.505	3.4895	96.1	12	Abrasive variety
KH-2	35.05	2.558	37	104	Abrasive variety
KH-3	43.24	20,906	100	113	Abrasive variety
KH-4	52.545	17,402	46.4	24	Abrasive variety
KH-5	57,450	16,027	42.9	116	Abrasive variety
KH-6	61,160	15,141	3.4	122	Abrasive variety
KH-7	66,650	14,021	10.2	124	Abrasive variety
KH-8	66,650	14,056	10.2	124	Abrasive variety
KH-9	68,050	13,766	22.1	30	Abrasive variety
KH-10	70,340	13,373	1	125	Abrasive variety
KH-11	74,255	12,762	0.4	208	Abrasive variety
KH-12	77,195	12,378	7.5	1.0.10	Abrasive variety
KH-13	77,425	12,347	4.2	119	Abrasive variety
KH-14	80,775	11,888	6.4	220	Abrasive variety
KH-15	83,155	11,607	0.4	306	Abrasive variety
KH-16	84,125	11,498	3.5	223	Abrasive variety
KH-17	86.285	11,264	3.3	312	Abrasive variety
KH-18	89.14	10,976	8	0.0.12	Abrasive variety

6.3 METHODS OF EXTRACTION:

The common extraction practice for corundum in the study area is mostly **unscientific-strip quarrying** or pitting. Primitive open pit mining, burrow mining and rat hole mining (Fig 6.15) has been carried out for the extraction of corundum in this area. The mineral is collected from shallow surface by diggings in the soil to a depth of 0.3 to 0.6m. Light Pink to Dark Purple corundum of translucent variety is picked by handpicking. Stray pieces of corundum are seen in the area between Tummalapalle on the West to Singaraipalem in the East and from Lakshmipuram in the North to Pallipadu in the South indicating enormous extraction activity. The corundum is also collected from the cultivated lands soon after the monsoon rains, particularly in close proximity to the periphery of the basic rocks such as amphibolites. The grain size of corundum is large and also small grains of corundum are picked up over gently raised outcrops of hornblende granulite. The detrital corundum occurs as worn out crystals of 0.25 to 0.5 x 1.0 m in size, but well developed prismatic crystals as big as 2cm x 4 cm are not uncommon indicating their liberation from the weathered rock without much transportation. It is observed that the top layer of the soil (black soil) of thickness up to 0.15 m approximately is generally barren of corundum. Where the black soil is underlain by brownish secondary zone, consisting of very small fragments of sillimanite, ferruginous matter and quartz are observed in matrix of brown soil, which contain corundum. The thickness of this corundum zone varies from 0.15 to 0.30 m.

Some of the prominent areas of extraction activity are given below

NNE OF MEKALKUNTA:

Abandoned pits & dumps of about 30m x 60m in the area comprise quartz-sillimanite gneisses. Insitu corundum occurs in trenches at 1.50 m below the surface. Trenches exposed weathered schists and gneisses where the corundum bearing zone is 0.60 m. The corundum is reddish brown to purple in colour, seldom translucent and 0.5x1.0cm in size.

SALEBANJAR AREA:

NW of Salebanjar and 5 Kms, S of Salebanjar, old workings 30 x 40m dumps comprise altered basic rocks and politic schists. Corundum is extracted from these dumps and perhaps the source could be the contact zone containing pelitic schists.

TUMMALAPALLE AREA:

Located 1.5 Kms, N 65^{o}E of Tummalapalle, small outcrops of pyroxene granulite and gneisses are present. Mined out dumps comprised of hypersthenes / hornblende granulites and gneissic rocks. Corundum is extracted from this area and it is transparent to translucent in nature.

SINGRAIPALEM – LAKSHMIPURAM AREA:

Higher incidence of corundum over an area of 1.5 Km x 0.75 Km (53 hectares) area is observed which includes cultivated lands. South of Lakshmipuram village, old pits and dumps with altered basic rocks, white mica and acicular sillimanite is observed. Trenches expose biotite gneisses, quartz sillimanite gneisses, mica-schists and amphibolites. Here the corundum-bearing zone is 1 m wide. Corundum is of white to light pink colour, translucent in nature. One of the trenches exposes sillimanite corundum rock where the corundum sillimanite horizon starts at 2.20 m and continues upto 4.90 m in depth. Corundum is of translucent to semi-transparent variety and light pink to dark purple in colour.

LALAGUDA (Lallugudem): Located 1.5 Kms. NNW of Lalaguda Village, Corundum extraction is observed in the cultivated lands. Here light pink, purple and translucent corundum of superior quality is found compared to that of other localities. Corundum is recovered from the soil by manual breaking, panning and washing. Distribution of corundum in host rock is irregular. Incidence of corundum is 2 to 3 % of host rock by weight in this area. Corundum is mostly transparent and rarely translucent. Detrital corundum is yellowish to reddish brown. Insitu corundum is pink to dark purple and white in colour. Imperfect crystals (hexagonal) of corundum measuring 0.5 x 0.5 cms to 1.0 cm are observed. All the trenches used for corundum extraction are shallow with maximum 6 m depth (Fig 6.14).

PALLIPADU – LAKSHMIPURAM AREA:

The area lies between Pallipadu and Gobbagurti, near Lakshmipuram where corundum extraction is mainly carried out in soil cover which is devoid of rock outcrops. Pebble bed containing corundum pieces is 10 to 15 cms thick (1 m weathered zone and at places 2 to 3 m). The main components of pebble bed include pebbles of quartz, felspar, lime, kankar, along with pieces of corundum occurring over the gneisses and schists in the weathered zone. Old workings of corundum extraction up to 8 m depth are observed. Pebble bed is the host horizon and contains corundum which exhibits brown to violet colour, with cleavage partings and is occasionally fractured (Fig 6.16).

Corundum is mined by shallow pits and trenches. Placer accumulations of 10 cm thickness lying below a thick soil cover in the weathered mantle of 3 m is spread over a large area. 5-7 % of the pebble bed material is contained of corundum pieces.

Similar structurally controlled cordierite corundum occurrances have been reported in close proximity to the Palghat-Cauvery Shear Zone in Kerela (Santosh, et al, 2004).

Fig 6.1 Large Spreads of Float Deposits of Corundum

Fig 6.2 Waterlogged Abandoned Exploration Pit exhibiting Insitu Corundum

Fig 6.3 Insitu working Pit for Corundum

Fig 6.4 Placer Concentrations of Corundum along the stream course

Fig 6.5 Placer Concentrations of Corundum along the Wyra Lake

Fig 6.6 Placer Concentrations of Corundum along the Sheet wash areas

Fig 6.7 Felsic intrusive exposed along Nagarjunasagar Canal

Fig 6.8 Linear felsic intrusive serve as structural guides

Fig 6.9 Conract zones of Pelitic schists and amphibolite exposed in a pit.

Fig 6.10 Occurrence of corundum along contact zones of Pelitic schists and Amphibolites

Fig 6.11 Contact zones where intense silicification is seen with occurrances of corundum.

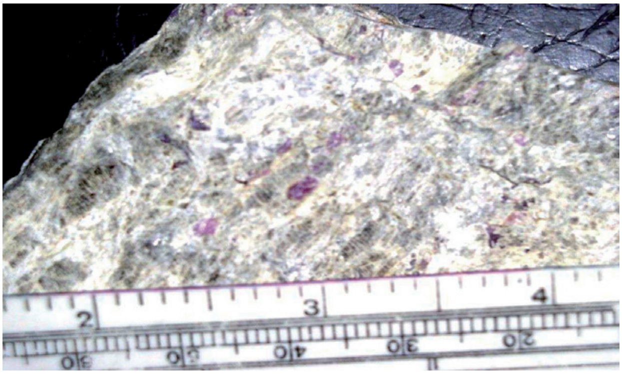


Fig 6.12 Corundum in Pelitic Schists along the contact zones.

6.13 Granules of Corundum in coarse grained felsic rocks.

6.14 Detritus of Corundum (pink and white) and Garnet.

Fig 6.15 Rat Hole Mining for Placer Concentrations

Fig 6.16 Pebble Bed hosting Corundum in Pelitic Schists.

CHAPTER - 7

REMOTE SENSING AND GIS STUDIES

In recent years, large and voluminous information is available on the management and use of remote sensing and GIS techniques and several websites of leading agencies are providing distinct analyses with the available geodata sets and their applications in different fields of earth sciences. There are a number of websites that deal exclusively with remote sensing studies for instances: (http://terra.nasa.gov,http://www.nima.mil, http://infoserver.ciesin.org, http://www.geographic.com, http://www.landinfo.com, http://www.grida.no, http://www.geospatial.online.com, http://www.ogis.org, http://www.asprs.org)

7.1 REMOTE SENSING IN MINERAL EXPLORATION:

Remote Sensing is a technique in which acquisition of data for deriving information about objects or materials (targets) located on the earth surface or on its atmosphere is made without any direct contact. (Lillisand, and Keifer, 1979) However, innovations in this field by using sensors mounted on different types of platforms located at a distance from targets have been made to collect precisely accurate data. The platforms are generally aircrafts or satellites. MSS (Multi Spectral Scanner), TM (Thematic Mapper), LISS (Linear Image Self Scanner) are some of the examples of sensors. Measurements are made in different spectral regions on interactions between the targets and EMR (Electromagnetic Radiation) Spectrum. The information from the object to the sensor is carried by the electro magnetic energy and these are encoded in the form of frequency or intensity or polarization. The values of spectral reflectance of objects arranged over different well-defined wavelengths comprised the spectral signature of the objects. These are the characteristic features by which the objects can be uniquely distinguished. The output of satellite remote sensing is generally in the form of an image. Visual or Digital interpretation of these images will be used in various application areas.

Remote sensing is generally described as the measurement of reflected or emitted electromagnetic radiation (EMR) in the range of about 300 nanometers (nm) to 1 meter (m) in wavelength. The use of remote sensing in mineral exploration began about 60 years ago with the help of hand held cameras, and has since evolved through stereoscopic aerial photography to sophisticated space age technology with satellite and air borne multispectral and digital imaging systems (Stettler, 2007).

Remote sensing is applied in the field of exploration, which directly maps the broad range of alteration minerals associated with ore deposits. Satellite systems have evolved to provide higher spatial and spectral resolutions, essential for mineral exploration. Manual interpretation of the remote sensing results on printed maps is rapidly giving way to full digital integration of data and use of Geographical Information Systems (GIS) for statistical based analysis and interpretation.

7.2 APPLICATIONS OF REMOTE SENSING:

The applications of air photo interpretations on a variety of areas, viz, land cover mapping, soil and geologic mapping, zones of mineralisation, agriculture, forestry range, land management, water resources, urban and regional planning, wet land mapping, wild life ecology, archaeology, environmental assessment, land form identification and evaluation is the real time programme of different agencies. With the help of remote sensing, geological contacts, faults, and fractures are brought out clearly which help in prospecting mineralized areas (Gold, 1980). Air borne satellite hyper spectral data has been used for mapping mineral abundance (Hewson et al 2005). Synthetic Aperture Radar (SAR) is an important tool in lineament mapping. Lineaments give information about the strike direction and foliation trends of geological structures like faults, joints, shear planes, fractures, gneissosity etc.

Remote sensing has proven to be a valuable tool in exploring the mineral resources and isolating the favourable areas from unfavourable areas. Remote sensing data provide the litho logical, geomorphological and structural guides essential for understanding various parameters responsible for localization of most of the ore deposits. (Rawashdeh, 2007).

Table 7.1: Electromagnetic Spectrum used for mineral exploration.

EM Region	Minerals
Visible and Near Infrared region. 400-1000 nm (Very Near Infrared)	Iron oxides, REE's, Vegetation
Short Wave Infrared region (1000-2500 nm)	(OH) bearing minerals, Clays, Phyllosilicates, Amphiboles, Sulphates, Carbonates.
Mid or Thermal Infrared (8000-12000 nm)	Silicates, Quartz, Feldspars, Garnet, Pyroxenes, Carbonates.

Table 7.2: IRS Satellites and their Resolutions

Resolution (m)	Sensor	Satellite
2.5	PAN Stereo	IRS-P5
5	PAN	IRS-1C, IRS-1D
24	LISS-III	IRS-1C, IRS-1D and IRS-P6
36.25	LISS-II	IRS-1A, IRS-1B
56	AWiFS	IRS-P6
72.5	LISS-I	IRS-1A, IRS-1B
180	WiFS	IRS-1C, IRS-1D and IRS-P3
360	OCM (Multispectral)	IRS-P4

7.3 GEOGRAPHICAL INFORMATION SYSTEM (GIS) IN MINERAL EXPLORATION:

The thematic maps (completed) brought out using parts of the Survey of India Toposheets of 65 C/7 and 65 C/8, IRS 1C/ID LISS III geocoded False Colour Composite (FCC) image (1:50,000 scale) and existing maps / literature were scanned at appropriate dots per inch. (DPI). The scanned resource maps were digitized in Auto Cad (point, line and polygon features). The digitized resource maps were edited, and later the process of map composition was executed. (Arc View GIS). Finally each thematic map with details of respective units and legend was brought out using Arc View GIS 3.2. The resulted thematic maps contains the title of the map, latitude / longitude values (Study area), scale of map, north direction, map units and legend with description of units.

GIS is a digital database, which facilitates the integration of various datasets for spatial analysis and modeling with a common spatial coordinate system. GIS is highly useful for handling images, maps, data tables, visualization, analysis, modeling and spatial decision support. GIS is used to identify mineral potential zones. GIS is a tool for analyzing geological, geochemical, remote sensing data etc. It is extremely useful in generation of mineral potential maps. In recent years, few authors have discussed the role of GIS in mineral exploration. (Bonham-Carter, 1994)

GIS also facilitates in organizing several variable datasets for querying, analysis and is thereby helpful in drawing meaningful inferences from the data generated. It is also useful in the identification of various parameters, which help in decision-making. It also emphasizes on the spatial context by focusing on geological features that may have localized mineral deposition.

Several authors have studied on the importance of GIS in mineral exploration (Wilkinson, et al, 2001).

7.4 MINERAL MAPPING ON GIS PLATFORM:

The generation of thematic maps requires data from different disciplines which needs to be integrated for this purpose. The zonation, integration and modelling of geoscientific data is useful for preparing the thematic layers. The technology is coherently utilised for ground based data acquisition, information extraction and analytical GIS.

It develops theoretical understanding of those fundamental geologic processes, which control the nature of the Earth's surface and near surface environments depending upon the preparation of different layers.

It contributes to rapid and efficient mapping of geology, structure, and geomorphology in the area with limited IT infrastructure and data using modern methods and using geoinformation technologies (Chung et al., 1992).

Remote sensing, and GIS have played an important role in the study of mineralized areas by evaluating different thematic layers (Viz., geology, structure, and geomorphology) using spectral anamolies.

It helps extrapolate surface exposures to underneath covered areas making logical deductions as to which hidden units are likely to occur below the surface.

In the exploration stage, GIS forms the perfect tool in integrating and analyzing various georeferenced geosciences data and selecting the best sites of mineral deposits as practiced in the present area (Konijerla, Khammam, Andhra Pradesh).(Fig 7.1, 7.2 and 7.3)The above technique was ably supported by AUTOCAD and techniques in digitization.

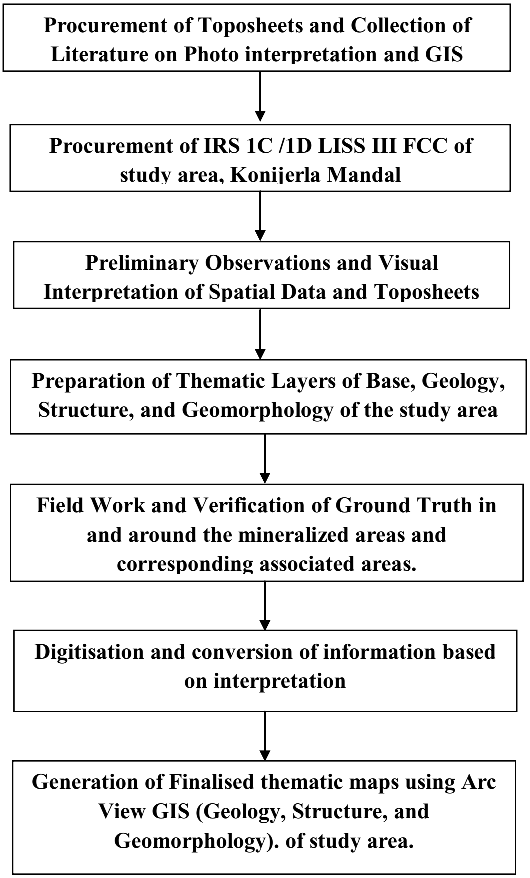
7.5 PROCEDURE **FOR GENERATION OF THEMATIC MAPS**

The following steps were taken in the preparation of thematic layers (geology, structure, and geomorphology) of the area:

1. Preparation of base layers using SOI toposheet (1:50,000 scale) and updation of additional features using IRS 1C/ID LISS III geocoded FCC (1: 50,000 scale)
2. Visual interpretation of each thematic layer (lithology, geomorphology, and structure) using both SOI toposheets and IRS 1C/ID LISS III FCC.
3. Collection of data on existing maps/ remote Sensing data on the study area.
4. Quality check-I involved in scrutinizing the available data of thematic layers prepared earlier.
5. Field verifications of ground truth for each thematic layer and also collection of information on the area from D.M.G office, Konijerla Mandal, Khammam District Andhra Pradesh.
6. Updating additional information in the thematic layers, after field observations and verifications.
7. Quality checks II involving cross checking the remote sensing data and field observations in each thematic layer from the ground truth.
8. Scanning of final thematic layers, digitization of features, integration, map composition and output of the thematic layers using Arc View GIS 3.2.

7.6 FLOW CHART FOR GENERATION OF THEMATIC MAPS

The activities for generation of GIS based maps of the area.



7.7 GEOLOGIC MAPPING, GEOMORPHOLOGIC MAPPING AND STRUCTURAL MAPPING

GEOLOGIC MAPPING:

It involves identification of rock types and configuration of geologic units on a map in their correct spatial relationship with one another. Corundum occurrence and exploration is an important activity in the area as there is no definite methodology so far adopted for geologic mapping.

The geological map of the study area was prepared using the SOI Toposheet Nos.65 C/7 and 65 C/8 on 1:50,000 scale, and IRS 1C/ID LISS III geocoded FCC image. The various rock types / geological units were marked using the SOI toposheets and IRS 1C/ID LISS III geocoded FCC image. Field verification / ground truth with respect to the rock types was carried out in detail to establish the correctness of the interpreted geological units and broad correlations were made with the existing maps. The lithological units thus interpreted out from the detailed studies are granite gneisses / biotite gneisses, amphibolites. anorthosites, gabbroic anorthosites, pegmatites, schistose rocks of various types and basic rocks as pyroxene granulites and metadolerites (Fig 7.1 & 7.2)

GEOMORPHOLOGICAL MAPPING:

From the Air photo interpretation, landform identification and evaluation was made and studied stereoscopically for topography, drainage pattern and texture, erosion, photo tone, and vegetation.

TOPOGRAPHY:

Each landform and bedrock type has its own characteristic topographic form including a typical size and shape. There is often a distinct topographic change at the boundary between two different landforms.

PREPARATION OF GEOMORPHOLOGICAL MAP:

The Geomorphological Map of the study area was prepared through an analysis of the elements of photo interpretation (topography, drainage pattern and texture, erosion, photo tone, and vegetation) using the SOI toposheet, IRS 1C/ID LISS III and existing maps / literature. The various landforms were interpreted and verified through field verifications / ground truth. The geomorphological units thus derived include hills (Denudational, Residual and Structural hills), pediplains (shallow weathered and moderately weathered), inselbergs and valleys (Shallow fill material) (Fig 7.3)

STRUCTURAL MAPPING:

Tonal features in many areas are the surface expressions of fractures or fault zones. Major lineaments range from a few to hundred of kilometers in length. The mapping of lineaments is important in mineral resources studies because most of the mineral deposits are localized along structural traps. Several factors influence the detection of lineaments. One of the most important is the angular relationship between the linear fracture and the illumination source. In general, features that trend parallel to the illumination source are not detected as readily as those that are oriented perpendicularly.

PREPARATION OF STRUCTURAL MAPPING:

A Structural Map of the study area was prepared using the IRS 1C/ID LISS III geocoded FCC image and the various structural trends were marked. Field verifications / ground truth was carried out in establishing the presence of all the structural features in the study area. The structural units observed included lineaments (major and minor), fault zones, fractures, joint patterns, structural trends, and zones of mineralisation of corundum. (Fig 7.4)

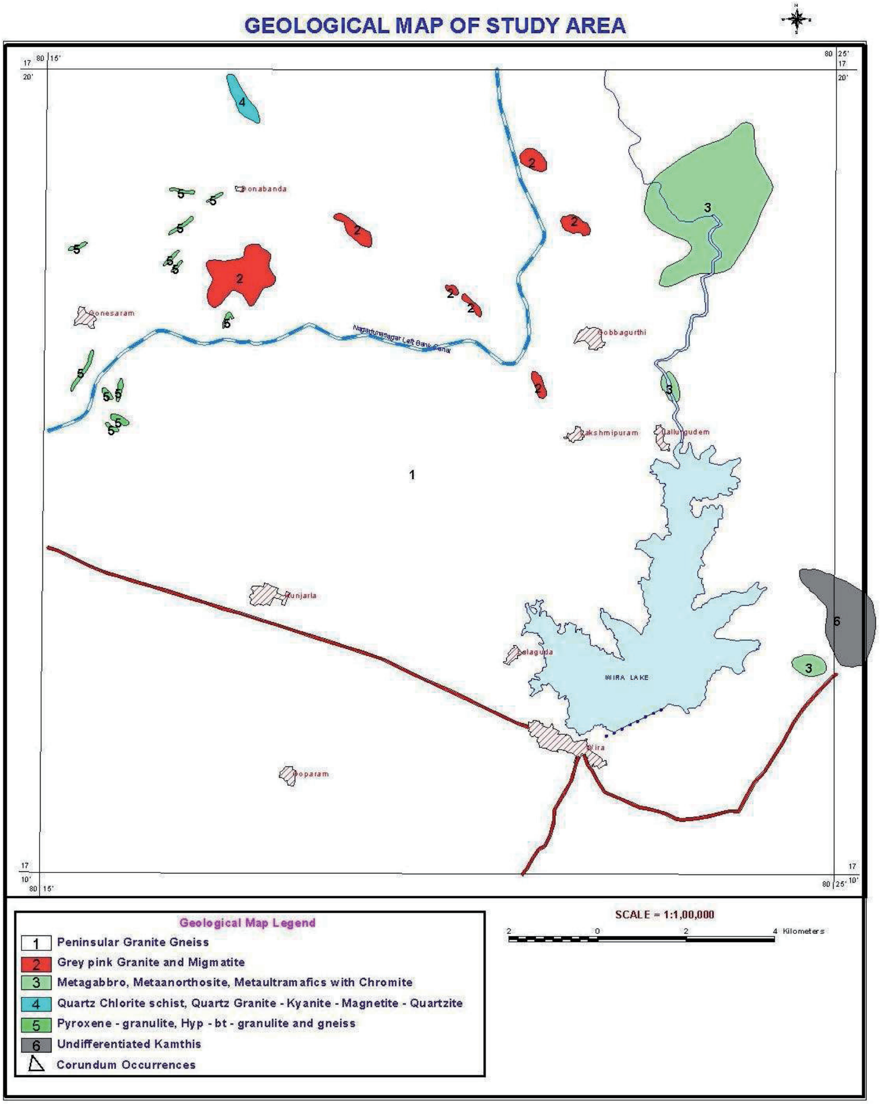


Fig. No. 7.1 Geological Map of the Study Area

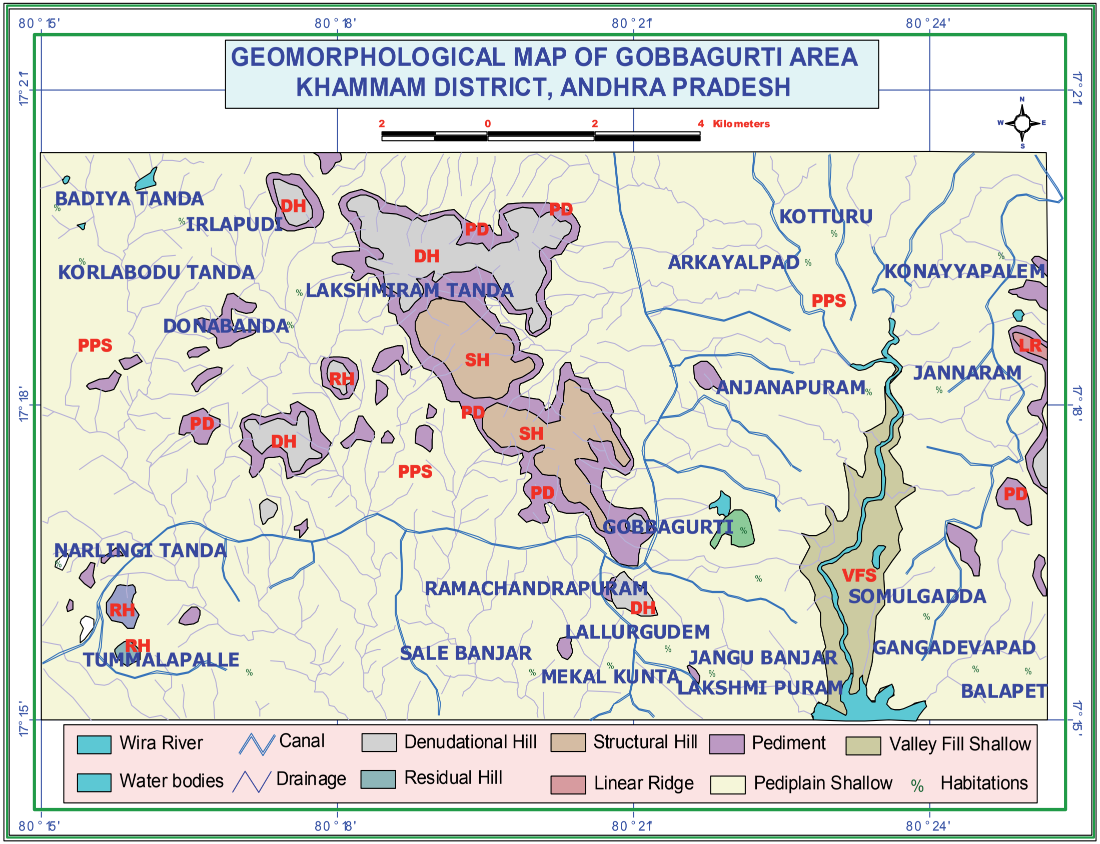


Fig. No. 7.2 Geomorphological map of Gobbagurti Area

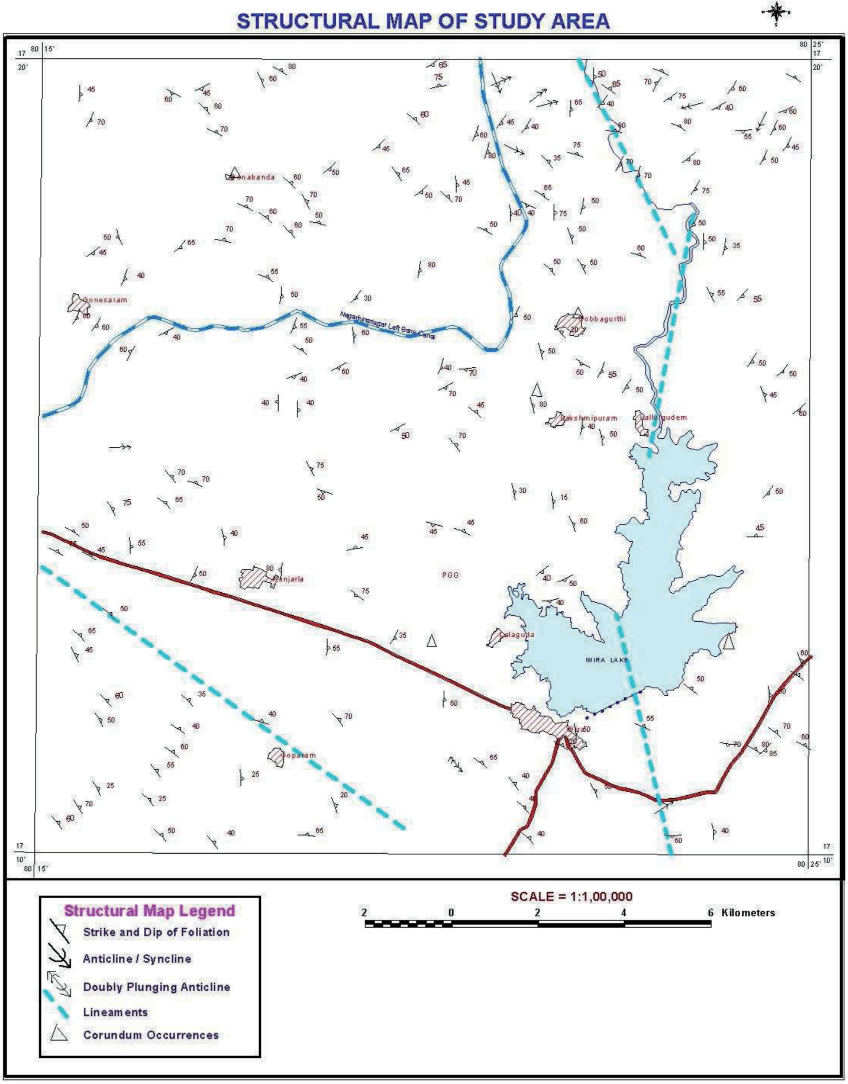


Fig. No. 7.3 Structural Map of the Study Area

CHAPTER - 8

DISCUSSION

The corundum mineralisation in Gobbagurti/Konijerla area is associated with biotite gneisses, tonalitic gneisses, and amphibolites. The relatively higher grade metamorphic rocks such as sillimanite schists and corundum bearing sillimanite rock form small lenticular bodies. Seldom, at places the host rocks for corundum are also cordierite bearing gneisses and all these litho-units are part of the Nellore Schist Belt. The rocks are occasionally intruded along weak planes, by felsic magmatic rocks such as granites, pegmatites and aplites. These rock types are sporadically exposed as most of the area is covered by soil cover. (Appavadhanulu et al., 1976)

The petrography of the rock types is predominantly characterised by varieties of gneisses and schists of distinct mineralogy. The ortho-gneisses include amphibole gneisses and metamorphosed pelitic rocks which are represented by garnetiferous biotite- muscovite-kyanite-chlorite- schists, kyanite and sillimanite bearing meta-pelitic schists, calc-silicate rocks, quartzites, fuchsite quartzite, and magnetite quartzite. Based on the regional geological set-up, it is observed that the rocks of the Khammam Schist Belt have a complex deformational and metamorphic history and were intruded by basic dykes, gabbro anorthosite complex and pink granites (Ajit Kumar, et al., 1976).

On the basis of regional geological studies, five periods of deformation and two periods of metamorphism have been deciphered in the area. Migmatisation of the meta-sediments and meta-basics (amphibolites) appears to have been later to the second period of folding in NW – SE direction.

Regionally, Gobbagurti area in Khammam district, hosting corundum mineralisation, is a part of a NW-SE trending cratonic fold belt and occupying the major fracture developed normal to the axis of the Chimalpahad Anothositic Gabbro Complex (Babu,. 1998). The NW – SE trending Gobbagurti hills may represent a major fracture that resulted from the NE-SW trending fold. The pyroxene granulites were developed along NW-SE and E-W trending fractures at the time of their emplacement. The mineral assemblages of the rock types belonging to the Dharwars viz. hypersthene, diopsides, hornblende, biotite, kyanite, muscovite, garnet, scapolite and plagioclase bearing schists indicate that the rocks were metamorphosed under the conditions of hornblende – granulite sub-facies of the granulite facies of the regional metamorphism.

The garnetiferous amphibolite with abundant greenish brown hornblende and garnet indicate almandine amphibolite facies, Further, retrogression of the green schist facies is indicated by the quartz-chlorite-biotite-schists and talc-actinolite-tremolite schists. The major element studies endorse the same.

The metamorphic grade of meta-sediments and meta-volcanics of Khammam Schist Belt ranges from amphibolite to green schist facies. Based on the analysis of the regional structure and igneous activity, the following sequence of tectonic events is inferred (Subbaraju, 1976).

The initial folding (F1) and the development of foliation along N.E-S.W direction reveal:

1. Injection of basic igneous dykes now represented by amphibolites and hornblende gneisses.
2. Folding along N.W-S.E axis (F2) resulting in the development of strong local axial planar foliation and shear zones.
3. Regional metamorphism producing the schists and gneisses form the folded sequence.
4. Influx of granitic fluids causing extensive migmatisation.
5. Folding along N.E-S.W axis (F3) and development of shear zones parallel to fold axes.
6. Emplacement of Gabbro Anorthosite Complex syntectonic with F3.
7. Injection of the gabbros, dolerites and the ultramafics with the chromite mineralization.
8. Folding along N.N.E-S.S.W axis (F4) and development of shear zones in N.N.E-S.S.W or N-S direction.
9. Folding along E-W axis (F5)

The N.E-S.W and N.W-S.E trends are the dominant structural elements exhibited by the schists and gneisses. The lithological assemblage together with migmatisation, complex deformational history and intrusion of the anorthosite-gabbro complex suggest that the schistose rocks of this area bear ample testimony with the lithology of the Precambrian rocks from Southern India.

Distinct controls of corundum mineralisation are manifested in geomorphology, structure and lithology.

The geomorphologic controls are manifested in structural hills and denudational hills. The settlements are observed in pediment areas. The structural controls are envisaged in three major prominent trends along the directions NW-SE to N 35° W-S35° E, N-S with few degrees variation towards E-W and NE-SW to N 30° E-S30° W. The NNW-SSE or NW-SE trend generally coincides with the plane of schistosity of the amphibolites, which seldom possess mineralisation of corundum

The K-feldspar domains (Gabbro-Anorthosite Complex) may represent veinlets of syenitic melt, either intruded into or melted out from the rock. The cordierite-rich domains contain the assemblage cordierite + K-feldspar + corundum + spinel + opaque oxide. Cordierite commonly makes up aggregates up to 2 mm across, composed of subgrains in similar optical orientation. The elongate aggregates show up well when the sensitive tint plate is inserted (length fast) and reveal that cordierite has alpha parallel to Z. They are dotted with small dark inclusions of dull green isotropic spinel. Coarser grains of spinel (hercynite) occur outside cordierite. Clear K-feldspar is interstitial to cordierite, and shows lower refractive indices. The high-relief colourless mineral is corundum. (Roopkumar, et al 1981)

The important litho-units and their variation in the Khammam Schist Belt which enclose corundum mineralisation have been studied and they include Garnet-Kyanite bearing Schists, Hornblende Schists, Actinolite-Tremolite Schists, Sillimanite Schists, Normal Amphibolites, Garnetiferous Amphibolites, Basic Granulites and Felspathic Gneisses (Tonalites) along with intrusive quartz veins. All these rocks are deformed and metamorphosed under Upper amphibolite to lower granulite facies conditions

The petrographic characteristics of garnet-kyanite bearing schists, hornblende schists, actinolite-tremolite schists, sillimanite schists, normal amphibolites, garnetiferous amphibolites, basic granulites and quartzo-felspathic gneissic rocks have been studied for evaluating corundum mineralisation in the KSB**.**

SEM Studies has indicated that Ruby (Al_2O_3: Cr) layer was successfully identified on a wall surface of an aluminum oxide. The layers consisted of ruby crystals having flat surfaces. (Fig 4.11). This technique was found to be a very suitable method for coating ruby layer on aluminum oxide materials.

Representative samples of the rock types associated with mineralization have been chemically analysed for the major and trace elements. The major elements determined (in percentages) are SiO_2, TiO_2, Al_2O_3, $Cr_2 O_3$, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O & P_2O5. LOI & H_2O has been determined in all the rock types, except in metapelites.

Trace elements, viz: Ag, Li, Rb, Cd, Cu, V, Te, Sr, Pb, Zn, Ni, Co, Cr, Mo were determined in Hornblende Schists, Actinolite-Tremolite Schists, Normal Amphibolites, Garnetiferous Amphibolites, Basic Granulites and Felspathic Gneisses (Tonalites). In Garnet-Kyanite bearing Schists, Zn, Cu, Pb, Ni, Co, Sn was also determined and was interpreted accordingly.

The overall geochemistry points out that from gneissic end of the rocks towards metapelites, there is a decrease in SiO_2 content suggesting the effects of desilication. The higher percentage of Al_2O_3 could be due to the presence of kyanite and partly to almandine garnet, which is rich with Fe and Al molecules. The higher percentage of

Al_2O_3 is also suggestive of argillaceous nature of original material. The progressive increase in alumina content points to the addition of Al_2O_3 and the increase in critical composition might lead to the formation of corundum.

Studies on zoning, exsolution, inclusions, or other compositional variations within minerals and their exact chemical nature with the associated minerals warrant **electron microprobe** studies (Armstrong, et al 1991). The present study with the help of EPMA confirmed considerable amount of corundum with the host rocks (Fig 6.8).

The Geochemical studies indicated consistent decrease. The analyses also reveal the presence of Rutile, Zircon, Chrome Spinel and Talc as the minor minerals apart from Cordierite, Corundum, Sillimanite and Opx (Magnesium-Cummingtonite gedritite) as the major minerals. The proportion of increase in MgO and Al_2O_3 suggests that the rock is desilicified and facilitated the appearance of corundum and cordierite minerals suggesting mineral reconstitution during metamorphism, perhaps at >8 k.bars and $>1000^0$C temperatures as deduced by the previous workers (Sengupta, et al., 1999) on the stability of metamorphic events. Hence, Corundum mineralisation is essentially controlled by lithology and structure of the host rocks of Khammam Schist Belt. The association of corundum both with pelitic schists and tonalites suggests its intimate lithological control with the SiO_2 depleted rocks along well defined structural planes of weakness. Primary nature of corundum with felsic rocks and reconstituted pelitic schists is observed. The presence of corundum in contact zones reveals its occurrence and mineralisation along the contacts between the intrusives (felsic rocks) and the schists and corundum concentration as alluvial mechanical concentrations is observed along the structurally controlled nallas. Garnets in association with amphibolites are commonly observed.

Therefore, Lithology played a protracted and dominant role in the mineralisation of corundum and its concentration after its liberation from the host rocks.

Generally the quartzo-felspathic rocks do not enclose corundum. Perhaps, the tectonic elements, which facilitated the emplacement of quartzo-felspathic and related rocks such as tonalitic gneisses must have facilitated mineralisation of corundum and localised them along the contact zones as in situ occurrences in the study area.

Workable corundum and kyanite are developed in high grade precambrian metamorphic terrains, particularly, in rocks originally enriched in alumina. Crystalline corundum deposits owe their origin to the desilication of intrusive pegmatites and associated metamorphism and granitisation of amphibolites, basic schists, serpentinites and fuschitic mica schists

The host rocks for corundum mineralisation are essentially highly weathered amphibolites, seldom ultramafic rocks (Talc-Actinolite-Tremolite Schists) and pegmatite veins. Corundum is typically found in aluminous metamorphic rocks and it also occurs in under saturated rocks with respect to silica such as nepheline syenites and aluminous xenoliths in igneous rocks. Corundum is known to occur in corundum-bearing schists and para-gneisses (Simandl, et al 1999).

Universally, it is observed that the principal controls are the chemical composition (high alumina and low silica content) of the protolith and a high regional metamorphic grade, typically granulite facies. Most of the gneiss hosted corundum deposits contain industrial grade corundum with little or no high quality (gem quality) stones.

Mining is typically by open pit type. Residual and placer deposits are not only less expensive to exploit, but typically contain a higher proportion of gem quality material due to the break-up of micro-fractured stones during stream transport. It is also true to the present area.

Corundum can be found in several different types of silica deficient rocks. These include syenites with much feldspar, amphiboles and limestones, as well as a few more exotic types. Corundum is very hard, and it is often mined from so-called secondary deposits like river gravels, where the corundum is preserved even if the rest of the rock has decomposed. As a matter of fact, only very little corundum is mined from primary rocks.

Corundum porphyroblasts and quartz coexist with porphyroblastic almandine-rich garnet, hercynite spinel, ilmenite and magnetite. Corundum and quartz are separated by sillimanite or a composite corona consisting of sillimanite and garnet, where corundum shows sharp grain boundaries with spinel, ilmenite and magnetite. Porphyroblastic corundum contains prismatic sillimanite inclusions in which irregularly shaped quartz is enclosed. Two distinct reactions are inferred from the textural features: corundum+quartz=sillimanite and spinel+quartz=garnet+sillimanite. (Shaw and Arima, 1998)

Similarly, many identical occurrences have been observed in Andhra Pradesh i.e., for instance the semi-precious corundum occurrences at Anantapur District where corundum bearing syenitic pegmatites intrude the biotite gneiss, talc-tremolite-chlorite schist and amphibolites. These corundum diatreme tracts show a trend of N 30° W to S 30° E to N-S and are sub parallel to schistosity. The narrow linear pegmatoidal tracts delineated and spread over 100m to 2500m wide zones are:

Mauktapuram Corundum diatreme,Kurlapalli-Jallipalli corundum tract., Melkunta-Kuralorapalli-Kammula shedlu tract, Honnurunahalli-Agharam, Dommarahatti-Honnurunahalli-Agharam, Honnurunahalli (east) - Agharam. Janganmaranahalli–ommarahatti (West), Hunikunta to Gantikallu-Bairanhalli tract.in the vicinity of Rolla Mandal. 15 Km SE of Kalyandurg and south of Gangavaram.

Alternate linear bands of amphibolites, pegmatoid gneiss and granite are noticed in these tracts. Systematic assessment of material from corundum diatremes/colluvium found has been recommended (Kazimi, 1994).

Occurrence of corundum is also reported in metapelites and meta-bauxites in British Columbia - Canada/International): Blue Star (082FNW259); Elk Creek, Bozeman and Bear Trap deposits (Montana, USA), Gangoda and Tannahena occurrences (Sri Lanka). Formation of corundum in metapelites around ultramafic bodies has been reported from the Saualpe region, Eastern Alps (Stüwe, et al., 2005).

Rich corundum bearing placer deposits have been reported from Southern Vietnam, (Sutherland, et al 1988). East Australia and South East Asia also exploit rich corundum deposits from their basalt fields and support significant mining, processing and cutting industries (Mumme, et al., 1988).

Corundum is resistant to chemical and mechanical weathering. Weathering facilitated crystal recovery from the hard rock as mechanical concentrates. Corundum may be enriched in residual soils or eroded and deposited as placer type deposits. A large proportion of alluvial gem corundum is sometimes interpreted to be derived from corundum layers within garnet sillimanite biotite gneisses (Dahanayake and Ranasinghe, 1981). Ruby is noted from parts of Thailand and Burma, India, Russia, Norway, Madagascar and elsewhere. Sapphire hails from Sri Lanka, Kashmir, Eastern Australia, Montana and beyond. Boulders of the assemblage Ruby-Sapphire corundum, chromian muscovite, margarite and tourmaline (chromian chlorite, Zn-Mn chromite & Mn-Ti magnetite) occur in glacial moraines and rivers of North Westland, South island of New Zealand. Corundum – Cr silicate rocks are the products of extreme metasomatic alteration of quartzo felspathic schist enclaves in serpentinites (Rodney Grapes & Ken Palmer, 1995).

Corundum-bearing silica-under saturated granulites are reported from the In Ouzzal granulitic unit (NW Hoggar). They have also been reported in Central Australia, the Gruf complex, Italian Central Alps, the Wilmington complex, USA, the Limpopo belt, Namaqualand, South Africa and Central Sri Lanka. Massive sillimanite-corundum rock and the quartz-sillimanite schist in Sonapahar, Meghalaya could have resulted after isochemical metamorphism. (Golani, 1989)

Corundum+quartz-bearing assemblages occur in small lenses in granulite facies metapelites in Rayagada, North-central part of the Eastern Ghats Granulite Belt, India.

Metasomatic deposits (Mangare Ruby mineralisations) results from the introduction of reactive fluids along a tectonic structure (channelised metasomatism), or from the accidental contact between two chemically different rocks (contact metasomatism). Sharp mineral zonations with limits parallel to the mineralization plan characterize this type of deposits. Small scale metasomatic events responsible for the formation of gem-corundum deposits are usually due to desilication phenomena. They involve a silico-deficient rock and a silica- and alumina-rich rock or fluid (silico-aluminous term). The silicodeficient term can be an ultramafic rock (serpentinite or sagvandite), a mafic rock, a metacarbonate, or a fluid equilibrated with ultramafic rocks. The silico-aluminous term can be an intrusive granitic or syenitic pegmatite, gneiss, or a fluid equilibrated with acidic rocks (metapelite, granite, etc.). In most cases, the silico-aluminous term undergoes a desilication, the silica being "pumped out" by the silico-deficient term. Alumina, which is less mobile, remains in the protolith and recrystallises as corundum, spinel, kyanite and other alumina-rich silicates. The most common geological settings are

- Plumasites and related rocks.

Plumasites are the most typical example of corundum-bearing metasomatic rocks. They result from the desilication of pegmatites that have intruded the ultramafic rocks. Desilication leads to the disappearance of quartz and the crystallization of corundum in the pegmatite.

Small occurrences of chromite and corundum within anorthosite are reported southwest around Karungalpatti. A number of occurrences of precious and semi-precious stones are reported from the Gemstone Belt of Eastern Ghats Belt in parts of East Godavari, Vishakhapatnam and Vizianagaram districts.

As no systematic work has so far been carried out in respect of the occurrences associated with the KSB, particularly, the commercial ruby occurrences at Konijerla and associated areas, a multi-dimensional approach has been contemplated towards tangible and geoscientific evaluation of corundum occurrences at Singaraipalem, Ratnapuram, Lakshmipuram, Nallagutta, Tummalapalle, Lallurugudem, Mekalkunta, Wyra and Tallada villages in and around Gobbagurti area belonging to Konijerla mandal. The mineralised area with scanty outcrops possesses, among different varieties of corundum, the pink variety as the most precious one. In the old workings, association of corundum within the contact zones of felsic rocks and schistose amphibolites reflects its distinct affinity to metamorphic assemblages. Sillimanite/kyanite and sericite bearing schists are occasionally observed in close proximity with the mineralisation. The petrographic studies of host rocks confirmed the occurrence of corundum with felspathic tonalites which are migmatised and sillimanite schistose rocks. However, corundum is not found within amphibolites. As mentioned earlier, there is a preferential structural control of their occurrence along N-S trend with variations of 5^o due east and west. Detrital corundum in the colluviums particularly along the meander points of the drainage pattern in the Gobbagurti area is endowed with both float and placer concentrations (Fig, 6.14).

CHAPTER 9

CONCLUSIONS

1. The area, part of the Khammam Schist Belt, hosting corundum mineralisation, predominantly consists of a wide variety of schists and gneisses namely; garnetiferous biotite schists, quartz -biotite schists and gneisses, garnet -muscovite chlorite- schist, garnet –kyanite- muscovite schist (metapelites), Calc silicate rocks, hornblende schists and felsic gneisses (tonalite), and quartz chlorite schists.(metavolcanics). Besides these, there are streaky biotite gneisses, hornblende gneisses (migmatites) and talc- tremolite -actinolite schists.
2. The area is endowed by economically viable corundum and garnet occurrences which are significantly controlled by both lithology and structures. (Shears fractures and faults).
3. Structurally, the area exhibits. N.E-S.W and WNW-E.S.E, trends which dominantly control the mineralization of corundum at Gobbagurti and the contact zones of gneisses and amphibolites form the loci of mineralisation.
4. Petrographically, the tonalitic gneisses possess primary corundum and the reconstituted metamorphic assemblages also enclose corundum in schistose rocks.
5. Geochemically, the increasing proportion of MgO compared to FeO, Na_2O, K_2O & P_2O_5 and the reduction in SiO_2 content suggests desilication with the appearance of corundum and cordierite suggesting reconstitution of its mineral content.

6. The felspathic intrusive (tonalite, corundum syenite) hosting mineralisation of corundum is observed along the contact zones of sillimanite-corundum and kyanite-corundum rocks.
7. Unscientific exploitation of corundum over few decades and improper open pit mining activity without understanding the nature of mineralisation is observed around Gobbagurthi and Wyra areas.
8. Thematic layers of geology, geomorphology and structure were prepared with the help of Remote sensing and GIS techniques which facilitated to delineate the favourable extended areas of mineralisation to explore full potential of mineralisation.
9. Detailed petro-chemical studies of the different rocks helped in unraveling the genetic aspects of mineralisation in the area. Studies on prospecting exploration pits from shallow surface diggings in the soil to a depth of 0.3 to 0.6m helped to locate the host rock for corundum in the vicinity of Laxmipuram and Singarayapalem areas and confirm the nature and controls of mineralisation.

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