CHAPTER 2

Petrography, Petrochemistry and Petrogenesis

2.1 - General statement:

There are seventeen major rock types exposed in the area. Each rock type is described separately. About 450 thin sections of these rocks were examined under the microscope. Important and illustrating photo-micrographs and field photographs are produced (Pl. 9-60). Ninety samples representing all the rock types were analysed. The chemical data is represented in the form of tables (Tab. 1-22) and petrochemical diagrams (Fig. 1-23). The Norms, Niggli values and oxide ratios were calculated, where needed.

2.2 - Gneisses

A vast area of Mysore state consists of gneisses and most of them have been named as Peninsular gneisses. The gneisses of Chitaldrug schist belt also have been considered as one group. These gneisses from Chitaldrug schist belt show some marked petrological and chemical variations.

Petrography

The gneisses in the central part of the Chitaldrug schist belt are exposed on both sides of the NNW trending schist belt. (Pl. 9). The gneisses which are exposed near Malasingahalli village mainly consists of quartz,
plagioclase feldspars; potash feldspars (both orthoclase and microcline), hornblende, green biotite and apatite (Pl. No. 31). The gneissic structure can be seen in hand specimens, but under the microscope it was not observed. Quartz and other mineral constituents of the rock show signs of crushing, and shearing. Sutured boundaries between feldspars and quartz were observed. This type of gneisses are exposed over most of the western side of the Chitaldrug schist belt.

Another type of gneisses are exposed in the North-West of the area (Pl. 1) near Hasanahalli village between the Chitaldrug granite and western limb of the cross-folded anticline. These gneisses are made up of medium to coarse grained quartz, muscovite and sericite (Pl. 32). The typical quartzitic texture, i.e. interlocking sutured boundaries of quartz grains and their elongation was observed (Pl. 33). The texture and mineralogy is of a typical micaceous quartzite, but at certain places the gneissic structure is so well developed that this group is also included in the peninsular gneisses.

The third type of gneisses are exposed in the North-East of the Chitaldrug near Medakeripura village between Chitaldrug granite and the eastern limb of the cross-folded anticline. This is sericite-quartz-feldspar gneiss. It mainly consists of sericite, quartz, potash feldspars, plagioclase and apatite (Pl. 34). Limonite cubes are also observed. Quartz and feldspar grains are mostly elongated parallel to regional schistosity (Pl. 35).
However, some of the grains exhibit their relief angularity. Sericite appears to be authigenic. The potash feldspar fragments show all gradation of sericitisation. Relict feldspar grains were found in between the microcrystalline mass of sericite.

Petrochemistry

Seven representative samples of these three minerologically different gneisses from the central part of the Chitaldrug schist belt were analysed for their major elements (Tab. 1). The chemical data reflects the variation in the mineralogy of these gneisses. It shows that

- all types of gneisses from this area are highly acidic
- all other oxides decrease with the increase in silica content
- alumina content varies from 3.27% to 14.93% and averages at 10.11%
- FeO content varies from 0.08% to 1.22% and averages at 0.53%
- FeO content varies from 0.16% to 1.50% and averages of 0.57
- MgO content varies from 1.30% to 2.57% and averages at 1.47%
- CaO content varies from 0.64 to 4.31% and averages at 1.88%
- Na2O content varies from 0.59% to 4.50% and averages at 1.48%
- K2O content varies from 0.50% to 5.71% and averages at 2.48%
This large scale variation in the Chemistry of these gneisses appear to indicate that probably their mode and time of origin also different. The ternary petrochemical diagrams support this view. In some of the Green and Poldervaart (1954) petrochemical fields and trend diagrams (Fig. 2) position occupied by the sericite-quartz-feldspars gneiss and quartzitic gneiss indicate that they are metasediments. In Ossann's S.Al., F and Al. C. Alk diagrams, (Fig. 8), the position of the ser-qtz-feld-gneiss and quartzitic gneiss was found to lie in sedimentary field, while the gneisses from Malsinganahalli area occupy their position in the igneous field. The Na_2O-CaO-K_2O and MgO-Fe_2O_3-TiO_2 diagrams clearly demonstrate the difference in their chemistry (Fig. 9).

The above study of the gneisses from Chitaldrug schist belt indicates that all the gneisses which have been grouped under Peninsular gneisses do not belong to one petrographic, genetic or perhaps even one stratigraphic group.

Sneath (1916) classified all the gneisses of Mysore State into four separate epochs of granitic intrusion. The peninsular gneiss was considered to form the second epoch of granitic intrusion into the Dharwar schist. B. Rama Rao (1940a) realised that all rocks which are considered as one group actually do not belong to one. He divided the Peninsular gneisses into four groups, i.e., banded gneisses, granitic gneisses, gneissic granites and normal granites. He stated that "Among these, the banded gneisses, form a composite series consisting of a mixed
assemblage of older rocks—igneous and sedimentary—replaced and interbedded with layers of acidic material. The present work supports this view. The peninsular gneisses do not belong to one genetic suite. There are gneisses which are intermediate to acidic in composition and appear to have been derived by the metamorphism of igneous rocks as the granitic gneisses of Chitaldrug (orthogneisses). There are gneisses which might have been derived from the metamorphism of the orthoquartzitic and subarkosic sediments (Paragneisses).

2.3 - The Actinolite-Chlorite-Quartz Schist and Quartzites:

The Actinolite-chlorite-quartz schist is exposed to the east of Talya. It rests directly on the gneisses. Previous workers (Smeeth 1916, Sampat Iyengar 1905, Rama Rao 1960) have named this formation as hornblende schist.

Petrography

It consists mainly of fairly large prismatic and tabular crystals of actinolite and fine grained quartz. In most of the cases, chlorite was associated with actinolite. The tabular and prismatic crystals of actinolite are arranged along the schistosity planes (Pl. 36). Fine grained quartz fragments were found as inclusions in the actinolite. The quartz grains show interlocking sutured boundaries.

Petrochemistry

The abundance of the amphiboles and chlorites
is reflected in the higher percentage of magnesia, iron and calcium (Tab. 2). It contains 1.30% Na₂O, which appears to be present in actinolite, which is not uncommon in regionally metamorphosed actinolite schists. Seki (1958) has reported 1.36% Na₂O from the actinolite of the actinolite-chlorite quartz-albite-sphene schist (Siroisi, Higasi-chichibu-mura Kanto mountain Japan Deer et al 1963). The potash content of the schist is only 0.5% which is also indicated by the absence of muscovite, biotite, and sericite in the rock.

**Genesis**

Deer et al (1963) have stated that the members of tremolite-actinolite-ferroactinolite series are characteristic of the regionally metamorphosed rocks. From the mineralogy and texture of this schist, it appears that the original rock type might be an argillaceous sediment in which the amount of calcium, magnesium and alumina was higher.

The maturity index of this argillaceous sediment (Al₂O₃/Na₂O ratio) is more than 11.0. This high maturity index appears to be related with the provenance. The high magnesia, iron and alumina, low silica and alkali especially K₂O indicate that the source rock was probably basic in composition. The order of the maturity index of the schist (11.0) is more than the maturity index of average sandstone and less than that of average orthoquartzite, (Pettijohn 1957, p. 509). In the presence of higher amount of magnesia and iron the original rock should not be considered as average sandstone as indicated by maturity.
index. In such a case it appears that the alkalies and alumina content represents the composition of the source rock. A source rock with less alkalies and silica and rich in iron, magnesia and calcium may be of basic composition. Furthermore the quartz is also very fine grained. Hence it is inferred that the actinolite-chlorite-quartz schist is a meta-argillaceous sediment probably derived from a rock of basic composition.

**Interbedded Quartzites**

Actinolite chlorite-quartz schist contains two interbedded bands of quartzite. The quartzite bands show faint cross bedding. They consist of coarse grained interlocking quartz fragments having sutured boundaries. (Pl. 37). The bands are only 20 ft. thick. They indicate the Intra-cratic condition of sedimentation.

2.4 - **Talya Conglomerate and the Micaceous schist:**

The Talya conglomerate is named after the village Talya, east of which the conglomerate is exposed. It is a lense shaped body, which persists along the strike for about 15 kms. Only the northern portion of the Talya conglomerate is exposed in this area.

**Petrography**

It mainly consists of pebbles of quartzites and occasionally some pebbles of granites are also found. The matrix is micaceous.
The pebbles are arranged parallel to schistosity (Pl. 11). They are rounded to subrounded. They have been elongated and flattened in the schistosity plane. Some of the pebbles are current bedded (Pl. 10). Pebbles vary in size from 2"-1"-1" to 12"-10"-14" along their a-b-c axes. They do not show any surface texture, except that some of the quartzite pebbles are well polished.

The pebbles of Talya conglomerate are quite close to each other, almost forming a contact framework. But it is very difficult to say (due to the intense deformation) of the pebbles) that this contact framework is a original sedimentary texture or imparted by intense metamorphism. It is possible that the pebbles might have been brought closely to each other by the compression, stretching and flattening during orogenic movements and metamorphism.

Matrix of the Talya conglomerate and the associated Micaceous schist

Matrix of the Talya conglomerate consists of quartz, sericite, muscovite, biotite, microcline and quartzite fragments. Occasionally some plagioclase grains are also seen. The schistosity is developed due to parallel arrangement of micaceous minerals (Pl. 40). The quartz grains are generally of medium size and have typical metamorphic interlocking sutured boundaries (Pl. 38). The modal analysis of the matrix (tab. 3) shows that the main constituents of the matrix are quartz and micaceous minerals. Quartz grains are surrounded by micaceous minerals in some sections while in most of the sections a parallel arrangement of micaceous
minerals and the interlocking quartz grains is found. The microcline grains generally show alteration into sericite. In some sections the matrix has become gritty. The amount of quartz grains has increased at the expense of micaceous mineral content.

Petrochemistry

The chemical analysis of the matrix (tab. 2) reflects the mineral assemblage. The low concentration of Na₂O indicates the absence of the sodic feldspars. The abundance of sericite, muscovite, biotite and chlorite is reflected in the higher concentration of iron, magnesia, calcium and potash. The associated micaceous schist is similar to the matrix of the conglomerate, though its silica content is much higher than the matrix. It appears to be due to increase in the grain size.

Genesis

A comparison of the chemical composition of the matrix and micaceous schist with the chemical analysis of arkoses as quoted by Pettijohn (1957-page 324) shows that the matrix and the micaceous schist from this area are deficient in silica. Most of the arkoses contain more than 70% silica. The lower concentration of soda is found in other arkoses also. (Pettijohn 1957, *Phys* p. 324, table 56, no. of samples B). The higher content of potash is present in the rock in the form of biotite, sericite and microcline etc. These micaceous minerals appear to be derived from the potash feldspar. If so, the higher potash content is an indication of the higher feldspar content of the rock prior to metamorphism and reorganisation. The relict orthoclase and microcline grains support this view. Being the potash content higher than the soda, it may not be considered as
graywackes (Middleton 1960). The only rock type, with which, this formation resembles is Arkose.

Though the pebbles of granites were seen by the author and they have been reported by other workers also (Radhakrishna 1940, Pitchamuthu 1947, Srinivas et al 1968), they are not in abundance. Most of the pebbles are quartzitic. Bands of granitic intrusion were noticed by Radhakrishna (1940) near the occurrence of granitic pebbles. During the course of compressional movements these granitic bands might have provided the granitic fragments due to crushing. The presence of granitic pebbles makes the conglomerate polymictic. The contact framework in the light of association with the micaeous schist, and the well polished surfaces of the pebbles appears to be relict sedimentary structure. The contact framework, the polymictic nature, the matrix of the conglomerate, association with micaeous schist, grit, current bedded quartzite, magnetite quartzite, limestone, and the well-polished surfaces of the pebbles indicate that probably the Talya conglomerate and the micaeous schist were deposited by ordinary water current. These characters when viewed together with the vast extension of the conglomerate indicate that probably this is a petromictic conglomerate. Though most of the petromict conglomerates (Pettijohn 1957- page 257) contain mixture of pebbles of plutonic, eruptive, sedimentary and metamorphic rocks but in some cases one type of class of sediments predominates. Talya conglomerate appears to be a petromictic conglomerate in which the quartzitic pebbles predominate.

The petromict Talya conglomerate and the associated micaeous schist together indicate that they are basin margin accumulation of sediments. Such types of conglomerates have been reported from the Precambrians of Lake Superior region (Pettijohn 1943) also.
Recently Srinivas and Srinivasan (1968) have reported graded bedding from Talya conglomerate. On the basis of the so-called graded bedding they consider that the Talya conglomerate is polymictic geosynclinal type. The present author could not notice graded bedding in the Talya conglomerate. Furthermore even if the graded bedding is assumed its escape from such a severe metamorphism, which has obliterated the shape of the pebbles and the texture between the pebbles, recrystallised the matrix, completely obliterated the sign of the primary bedding and the other sedimentary structures is doubtful. The association with the current bedded quartzites and micaceous schist do not support that Talya conglomerate is a geosynclinal type. All these factors point out that probably it is an orthoconglomerate (petromict conglomerate) of orthoquartzite-carbonate association which represent the early geosynclinal (Peneplanation) stage in the geosynclinal cycle.

2.5 - Magnetite quartzite and sericite phyllites

The formation resting over Talya conglomerate and micaceous schist consists of sericitic phyllites and magnetite quartzite. One layer of the magnetite quartzite, which is repeated on the surface, due to folding, is interbedded with sericitic phyllites.

Petrography

The sericitic phyllite is extremely fine grained and consists of clay minerals (Pl. 41). The individual flakes could not be identified. Occasionally some big quartz grains were also found in the clay.
Magnetite quartzite consists of magnetite, quartz and haematite. The quartz and magnetite grains show interlocking sutured boundaries (Pl. 42). Generally the layers rich in magnetite and layers rich in quartz alternate. The chemical analysis of the two samples of magnetite quartzite is given in table No. 4.

Magnetite quartzites are generally associated with lower division of Dharwars. In the North-Eastern part of the Chitaldrug schist belt (outside from the map produced here) this formation yields a quite good tonnage of low grade Iron ore. In the area surveyed there are many old workings for Iron confined to this formation.

**Genesis**

It looks the silica, Iron and manganese were deposited as chemical precipitates. The recrystallization of magnetite seems to be the result of the low grade regional metamorphism during orogenic movements. The fine grained quartz is considered by many workers as the colloidal silica, which on recrystallization have given rise to fine grained quartz. The silica and Iron is believed to be provided by the weathering of basic rocks.

**2.6 - Limestone**

There is a small patch of limestone exposed in the South-eastern part of the area (Pl. 1). It consists of alternate layers of limestone and argillaceous phyllites. The limestone layers consist mainly of calcite (Pl. 43). The grains of calcite are of medium size. The boundaries of different grains of calcite are interlocking and sutured.
Fine grained quartz and clay minerals are also associated with it. In the light of association with magnetite quartzite and the fine grained sericitic phyllites it appears that the limestone is also a chemical deposit, which has been subjected to low grade metamorphism resulting in recrystallization and formation of bigger calcite grains.

2.7 - Aimangala Conglomerate

The second conglomerate exposed in the area is the Aimangala conglomerate which crops out near the 118 milestone on Bangalore-Chitaldrug road and extends southward upto Mallarasanhalli village.

Petrography

The polymictic Aimangala Conglomerate consists of pebbles of quartzite, granite, banded ferruginous chert, altered basalt, shales and vein quartz in a chloritic, schistose matrix. While the pebbles of quartzite, granite and basalt are rounded, the pebbles of ferruginous chert are angular and subangular. The size of the pebbles varies from 1.5" x 0.5" x 2.5" to 30"-24"-13" along their a-b-c axes.

Aimangala conglomerate has a disrupted framework, i.e., excess of matrix over gravel-sized fragments. The pebbles are randomly embedded in the matrix (Pl. 12).
The matrix is a highly unsorted sediment which consists of angular grains of quartz, clouded feldspars, plagioclase feldspar, ferruginous chert, chert, chlorite, (Pl. 44) and fragments of fine-grained oolites. A general schistosity parallel to the regional foliation (N 170°) has developed. Current bedding or graded bedding as is found in Kaldurga conglomerate (Pichamuthu 1935C) has not been observed.

**Genesis**

The disrupted framework, considerable variation in the size of the pebbles, nature of the matrix and the grain/matrix ratio of the Aimangala conglomerate suggest that it is a paraconglomerate which was subjected to regional metamorphism. This disrupted framework, poor sorting and the absence of any sedimentary structure, indicating the deposition by normal current, suggests that the gravels of Aimangala conglomerate were not collected by ordinary water current. The conglomerates (Orthoconglomerate, Pettijohn, 1956) deposited by ordinary water current, possess an intact framework and a principal mode in the gravel range and a lesser mode in the sand range. The Aimangala conglomerate shows a principal mode in sand grade and lesser mode in gravel range. Such disparity in grain sizes denotes an unusual history and indicates deposition from media of high density and viscosity. The chemical analysis of the Aimangala conglomerate matrix and its modal analysis is given in tables No. 2 and 3 respectively. The chemical analysis resembles the graywackes associated with it.

The most probable mode of deposition of Aimangala conglomerate appears to be subaqueous turbidity flows and
slides. Paraconglomerate can be deposited by turbidity currents, mud flows, ice flows, and subaqueous slumping and slides. The Aimangala conglomerate is associated with the formations which indicate geosynclinal environment of deposition. The $K_2O/Na_2O$ ratio of the matrix of the Aimangala conglomerate and the graywackes (less than one) indicates that they are eugeosynclinal. It appears to grade into graywackes, which at certain places show graded bedding. The next formation Kurmerdikere conglomerate also exhibits graded bedding. Graded bedding is believed to be one of the indications of turbidity currents (Kuenen and Miglionini, 1950). In the light of this indirect evidence, the author believes that probably this conglomerate was deposited by turbidity currents (Section 2.9).

2.8 - Graywackes

The schists exposed to the west of Aimangala conglomerate (Pl-1) were found to be metagraywackes (according to Pettijohn's definition, 1943-1957). It shows the typical graywacke texture and composition.

Petrography

The graywacke from Chitaldrug schist belt varies in colour from blackish green to greenish brown. It is a thick and massive rock formation of the area. At many places alternating layers of graywacke sericitic and chloritic phyllites were also observed. The graywacke layers at certain places show graded bedding. It contains fragments of quartz and feldspars ranging from 0.1 mm to 1 cm. Some quartz grains of 5 mm were also found. The bigger grains are sharply angular, while the smaller grains are angular to subrounded.
These graywackes are metamorphosed to the green schist facies. Fragments and micaceous folia are aligned giving rise to schistosity.

The matrix of the Chitaldrug graywacke consists mainly of a fine-grained mixture of quartz, chlorite and feldspars. An important feature of the matrix of the Chitaldrug graywacke, is the replacement of quartz by authigenic sericite and chlorite, which makes it difficult to get sharp microphotographs. The fine and irregular flakes of chlorite pass out from the surrounding matrix and penetrate the boundaries of the quartz fragment. The original boundaries of the quartz appear to have wholly or partially disappeared.

Modal analysis of ten samples collected from the field (Tab. 6) shows that angular grains of quartz, plagioclase, potash feldspars and chert are the major constituents of the grains of the Chitaldrug graywacke (Pl. 45). The quartz fragments vary in shape from angular to subrounded. Bigger grains are much more angular than the smaller ones. These angular quartz grains show wavy extinction and are fractured to varying degree.

Potash feldspar was identified in two forms. It occurs as microcline and orthoclase as clastic fragment having sharp corners. However the presence of potash feldspar in the matrix is much doubtful.

Rock fragments were not considered separately because most of the rock fragments are of phyllites consisting of exceedingly fine grained chlorite and quartz and all gradations in rock fragments and mineral content of the matrix are present.
In the matrix, chlorite is predominant. It makes 37-42% of the Chitaldrug graywacke. It occurs as recrystallised flakes varying in size, mostly elongated and aligned parallel to regional schistosity. The fact that chlorite flakes embay and penetrate clastic quartz grain indicates that it is of metamorphic origin. In some thin sections minor amounts of epidote, apatite, and zircon were also found. Limes Limonite and pyrite cubes and tetrahedron running along the schistosity planes, together with vein quartz were observed.

**Petrochemistry**

Ten samples from the Chitaldrug graywackes were analysed for their major elements (Tab. 5). Because the samples have been collected from different outcrops, the chemical composition shows variation from sample to sample (Fig. 1). Variation is found to be more in silica and alumina content; silica is varying from 59.55% to 65.58% with an average of 61.86% whereas alumina has an average of 14.56% with a variation from 11.27% to 17.24%. Total iron varies little from 3.32% to 5.72% with an average of 5.08%. Variation in magnesium is not much while the variation in calcium oxide is more. It ranges from 3.72% to 7.63% with an average of 5.74%. The average soda content is 5.10% with little variation. The potash content varies from 1.12% to 2.68% with an average of 1.90. Titania, phosphorous and other constituents of the rock do not show appreciable variation.

**Comparison of Chitaldrug graywacke with other Precambrian graywackes reported from different areas of the world**

Graywackes are the most characteristic rocks in many Archaean terrains (Pettijohn, 1943). Five average chemical
Pettijohn (1957) of the order of 4.8, which is higher than the average $\text{Al}_2\text{O}_3/\text{Na}_2\text{O}$ ratio (3.57) of Chitaldrug graywacke. It may indicate that Chitaldrug graywacke is more immature sediment when compared to other Precambrian graywackes as cited above, except in the case of the graywacke from Ontario which has $\text{Al}_2\text{O}_3/\text{Na}_2\text{O}$ ratio equal to it. This low order of maturity shows that Chitaldrug graywacke contains larger amount of plagioclase than other Precambrian ones.

The average alkalies/alumina ratio (Fig. 5) of Chitaldrug graywacke is 0.41 and varies from 0.31 to 0.50. This value agrees well with values of other Precambrian graywackes discussed here (Fig. 6).

Comparison of Chitaldrug graywacke with graywackes of other than Precambrian times

Eight representative analyses of graywackes of other than the Precambrian ages as reported by Taliferro (1943) Marshall (1918), Henderson (1935), Reed (1957), Bailey et al. (1964), Mattiot (1960), and Whetten (1966) were collected for comparison with the Chitaldrug graywacke (Tab. 8). The comparison shows that all the post-Cretaceous graywackes have higher silica content than that of the Precambrian graywackes of Chitaldrug and of other areas. Post-Cretaceous graywackes are lower in magnesium and calcium. The $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio (Fig. 5 and 6) is less than one and the alumina/soda ratio is almost equal to that of Chitaldrug graywacke and lower than the average value reported by Pettijohn (1957).

Provenance

A great deal of attention has been paid to source rock investigations of graywacke by most of the workers in
analyses of the graywackes from different Precambrian terrains reported by Condie (1967a), Pettijohn (1957), Boyle (1961), Grout (1929) and Todd (1928) were collected from literature (Table 7). From the ternary composition diagrams (Figs. 7 and 11) it is clear that the composition of Chitaldrug graywacke conforms to the chemical composition of above mentioned Precambrian graywackes. However, there is a marked deviation in the CaO content of Chitaldrug graywacke in comparison to the CaO content of the other Precambrian graywackes. The CaO content of the Chitaldrug graywackes varies from 3.89% to 7.63%, while the CaO content of other Precambrian graywackes varies from 2.22% (Condie, 1967) to 4.61% (Grout). It is more than the average CaO content of average granites and granodiorites, which have 1.33% and 3.55% CaO respectively (Nockolds, 1954). It is much less than the average CaO content of Basalts (10.07) and basic volcanic suite (11.53). The lower CaO content of the Wyoming graywackes has been explained by Condie (1967a) by assuming an early diagenetic reaction of clastic calcic plagioclase with Na⁺ ions in sea water and the corresponding release of Ca²⁺ ions. But in Chitaldrug graywacke the calcium content is unusually high, which may be explained in terms of higher calcium content of the plagioclase and attributing some calcium to the chlorite of the matrix. The K₂O/Na₂O ratio of all these graywackes of Chitaldrug and other areas is less than one. Middleton (1960) has stated that the eugeosynclinal graywackes especially differ from other sandstones by their low K₂O/Na₂O ratio i.e., less than 1.0.

The Al₂O₃/Na₂O ratio (maturity index) of Chitaldrug graywacke averages about 3.57 and varies from 2.73 to 4.64. For average graywackes this value was found by
Pettijohn (1957) of the order of 4.8, which is higher than the average $\text{Al}_2\text{O}_3/\text{Na}_2\text{O}$ ratio (3.57) of Chitaldrug graywacke. It may indicate that Chitaldrug graywacke is more immature sediment when compared to other Precambrian graywackes as cited above, except in the case of the graywacke from Ontario which has $\text{Al}_2\text{O}_3/\text{Na}_2\text{O}$ ratio equal to it. This low order of maturity shows that Chitaldrug graywacke contains larger amount of plagioclase than other Precambrian ones.

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Provenance

A great deal of attention has been paid to source rock investigations of graywacke by most of the workers in
this field. It was thought earlier that the graywackes are derived from basalts. However, later investigations by Taliaferro (1943), Helmbold (1958), Mattiat (1960), Mcbridge (1962), Donaldson and Jackson, (1963), and Condie (1967a, 1967b) have shown that most of the Precambrian graywackes were derived from rocks of intermediate composition. (Middleton, 1960), believes that the peculiar characteristics of high rank graywacke are due to partial volcanic province combined with rapid erosion and little chemical weathering.

The low $K_2O/Na_2O$ ratio (Tab. 5, Fig. 5) indicates that either the source rock was soda rich, or the regional soda metasomatism of the graywacke had taken place, or the incomplete weathering of the source rock resulted in this composition.

According to Middleton (1960) the most promising source rocks for graywackes are basic volcanic rocks. Spilites and other basic rocks occur very near to Chitaldrug graywacke. But the fact that this volcanic suite itself does not contain as much soda and potash as the Chitaldrug graywacke rules out the possibility of the former being the source rock. Furthermore the structural evidence (Chapter 4 and 5) do not support the view that volcanic suite is older than the graywackes.

The $Na_2O-CaO-K_2O$ compositional diagram (Fig. 7A) shows that the field of Chitaldrug graywacke falls away from the compositional points of average basalt and from the field of the volcanic suite of Chitaldrug schist belt. This fact together with the occurrence of big fragments of plagioclase, microcline and quartz rules out the possibility of basic volcanics to be the only source rock of the Chitaldrug graywacke. Most of the graywacke
from other areas falls in the field of the Chitaldrug graywacke. The granodiorite composition also comes under the graywacke field. This shows that at least partially the source rock of the Chitaldrug graywacke was either a quartz diorite or granodioritic in composition.

The MgO-Fe₂O₃-TiO₂ compositional diagram (Fig. 7B) shows that all the graywackes and even the granodiorite fall in the compositional field of the Chitaldrug volcanic suite which varies from tholeiitic basalt to andesites and spilites (Tab. 11B) which means a volcanic basic source rock.

The above finding is at variance with what was inferred from Na₂O-CaO-K₂O compositional diagram. This inference should be examined in the light of mineralogy and genesis of the matrix, because the MgO, Fe₂O₃ and TiO₂ of graywackes belong mostly to the matrix, which consists mainly of chlorite and other ferromanganese minerals. These ferromanganese minerals of the matrix are the result of reorganisation of the original interstitial mud. So when only those oxides which are present in matrix are plotted on a ternary diagram they show volcanic rock as a source. In view of the existence of large fragments of quartz, feldspars and the overall composition of the Chitaldrug graywackes, it appears that though the graywackes has been mainly derived from coarse grained rock of quartz diorite or granodioritic composition, at least a partial volcanic provenance cannot be totally ruled out. The widespread distribution of the schists and graywackes having composition equivalent to a basic or intermediate rock throughout the Precambrian period points towards the more basic nature of the Precambrian crust.
Genesis

The origin of the matrix of the graywacke is a controversial problem. Pettijohn (1957) has discussed it in detail. He considers the matrix to be detrital mud. The detrital mud after authigenesis and reorganisation gave rise to most of the present minerals of the matrix. Cummins (1962) in his review of graywackes says that graywackes is a kind of sandstone in which the sand grains are set in a fine muddy matrix, this mud being a post-depositional alteration of sand. Audley Charles (1967) believes that silt clay matrix of the graywacke in the Viqueque formation of Timur (Upper Miocene Pliocene) is an original detrital deposit and not the result of post depositional diagenesis of sand grains.

Regarding the matrix of Chitaldrug graywacke, the present author, on the basis of petrochemical data, believes that originally it was a detrital mud and the reorganisation of present mineralogy took place during metamorphism. The Chitaldrug graywacke which shows graded bedding is associated with a graywacke conglomerate, chloritic phyllite, bedded chert (Naqvi, 1967) and submarine volcanic suite showing pillow structure. This appears to be a eugeosynclinal association (Naqvi, 1967). The eugeosynclinal sedimentary nature of the graywacke is shown in Poldervaart and Green petrochemical fields and trend diagrams (Figs. 2 & 3).

The S, Al, F and Al, C, Alk diagrams (Fig. 3) show the position of Chitaldrug and other graywackes on the boundary of the fields of igneous and other para and meta rocks.
The Kurmardikere conglomerate shows graded bedding and alternate layers of conglomerate graywackes and phyllites (Pl. 14).

The matrix of this conglomerate is highly unsorted and immature (Pl. 46). The texture and mineral composition resembles the lithic graywacke. The modal analysis (Tab. 3) of the matrix of this conglomerate shows 35% of angular coarse grained quartz 14% of chert and quartzite fragments, 2% or even less of plagioclase, 20% of argillaceous rock fragments and 28% of fine grained chlorite and quartz and includes all gradations between rock fragments and chlorite. Potash feldspar was found to be completely absent.

Petrochemistry

Chemical analysis (Tab. 2) show low content of soda. K\textsubscript{2}O/Na\textsubscript{2}O ratio is more than one. The absence of plagioclase in mode is reflected in the chemical analysis in small amount of soda. The overall composition resembles that of lithic graywacke.

Genesis

The disrupted framework, nature of the matrix and the presence of graded bedding suggest that the Kurmardikere conglomerate like the Aimangala conglomerate is a para-conglomerate or a graywacke conglomerate. The para-conglomerates can be deposited by a number of agents of high density and viscosity as mentioned in section 2.7. Graded bedding suggests the deposition by turbidity currents; but the graded bedding alone is not an indication of deposition.
by turbidity current. Dzulynski and Walton (1965, p.8) have stated that "all the structure found in turbidites occur also in non-turbidites sediments. Although there are no sedimentary structures which in themselves are diagnostic of turbidity current action as Kuenen (1951) has insisted, the assemblage of features is noteworthy. The operation of turbidity current is suggested above all by the evidence for deep-water conditions, combined with indications of violent and episodic inflow of coarse clastics". With the absence of fossils, the only evidence for deep water conditions left is the grain size, great thickness (Chapter 4) and the chemical characters of the chloritic schist associated with these conglomerates. These characters along with the graded bedding suggest that the conglomerate was probably deposited by turbidity currents.

The pebbles composition and mineral composition of matrix of the Kurmarkedikere conglomerate indicates the source to be predominantly metamorphic rocks, quartzites and argillaceous schists of basic composition, which contributed to the pebble and matrix.

**Comparison with the other two conglomerates**

Kurmerdikere conglomerate differs in many respects from the Aimbangala and Talya conglomerates. With Talya conglomerate it differs in all these aspects (maturity, mineralogical chemical composition and association) which are the result of the mode of deposition. With Aimbangala conglomerate it differs only in the composition, because both the Aimbangala and Kurmerdikere conglomerate appear to be deposited by the same agency.
Modal analysis of the matrix of these three conglomerates shows (Table 3) that the Aimangala conglomerate consists of 39% quartz, 6% chert and 11% quartzite, 12% total feldspars, 12% argillaceous rock fragments and 30.5% fine grained minerals like chlorite etc. This mineral composition is strikingly different from Aimangala conglomerate in the case of feldspar and rock fragments content. The difference of feldspar rock fragments and chert-quartzite content of these two conglomerate demonstrates that their sources were different and probably they were deposited at different times. The mineral assemblage of the Aimangala conglomerate indicates an intermediate plutonic source rock, while the mineral assemblage of the Kurmerdikere conglomerate indicates a source area of predominantly metamorphic rocks. This indicates that these two conglomerates though deposited by the same agency probably are two different conglomerates and should not be correlated together as one lithological and stratigraphical unit.

2.10 - Chloritic schists and phyllites

Most widespread formations of the area are the chloritic schist and phyllite; generally they are exposed in the gently undulating plains.

Petrography

They are fine grained rocks, rendering the mineral identification difficult. Samples which belong to a coarser variety of the chloritic schist (Pl. 47) show quartz, chlorite, sericite, muscovite and altered plagioclase.
**Chemical composition**

Silica content of these rocks varies from 54.65% to 59.16% (Tab. 10, Fig. 1). The silica content of the coarser schists is higher than the finer ones (Tab. 10). CaO varies from 2.8% to 10.2% sodium content varies from 2.72 to 5.12% K₂O varies from 0.51 to 2.28%. If the higher concentration of alkalies is attributed to the alkali metasomatism the overall composition of the schist suggests a basic or intermediate source rock.

**Genesis**

Like most of the greenschists of eugeosynclinal environment, associated with basic and semibasic subaqueous igneous rocks, the chloritic schist, a green-schist of Chitaldrug also seems to have a doubtful mode of origin. A greenschist can be formed from the low grade metamorphism of both the pelitic rocks and basic and semibasic subaqueous volcanics. Turner and Verhoogen (1962) have stated that spilitic rocks, by reason of their early appearance in geosynclinal belts, are particularly liable to be effected by regional metamorphism and many of the greenschists of orogenic zones undoubtedly are of such origin.

Poldervaart (1953) also suggested that basaltic rocks on low grade metamorphism may give rise to green schists. Turner (in william, Turner and Gilbert, 1965) believes that green-schists are products of regional metamorphism of basalts. Moorehouse (1959) believed that basalts which have been subjected to low grade metamorphism show somewhat a different picture. The meta-basalts on low grade metamorphism show almost complete mineralogical change, which will be reflected in its chemistry by the increase of H₂O, and CO₂, but there will be little
textural change. Many meta-basalts are massive and preserve the original texture. The basic volcanic suite of Chitaldrug schist belt also shows the effects of low grade metamorphic mineralogical changes, but it does not show any textural obliteration or deformation. The green schists formed as a result of metamorphism of pelitic rocks show normal schistosity and undergo little mineralogical changes. The grain size of the chlorite schist from Chitaldrug is smaller than that of the volcanic suite. As compared to basic rocks they contain more silica, ferric oxide, alkalies, less ferrous oxide, MgO and CaO (Tab. 10). These observations indicate that these phyllites and schist may not have originated from metamorphism of basalts.

The association with conglomerates, graywackes and cherts etc, the texture and the variations in chemical composition and the presence of detrital quartz grains in some samples indicate that the chloritic schists are also metasediments. The original sediment appears to be a siltstone or more broadly speaking, shale (Fig. 8, 9 and 10).

The petrochemical trend diagrams (Fig. 10) and Osan's diagrams (Fig. 80 also indicate a sedimentary nature of the original rock.

Interpretation of chemical analysis of a shale is difficult. It becomes more difficult when the shale has been subjected to low grade metamorphism and metasomatism. Chemical composition depends upon grain size, and maturity of the sediment and the chemical processes during and after sedimentation.

Silica content increases with grain size. Pettijohn (1957 p. 345) has stated that "potash always exceeds soda in shales and slates. The few slates in which soda exceeds
potash must be those which contain the products of abrasive action rather than the clay minerals. Chloritic phyllites from this area contain higher soda than potash. It may be mainly due to the addition of soda from the reaction with sea water.

A comparison of the chemical composition of phyllites and schists from Chitaldrug schist belt with those of the Precambrian slates (Nanz, 1953) show that the silica and total iron contents are similar but the soda, magnesia, and calcium contents are higher. Aluminium and potash are considerably lower. This variation of soda, magnesia and calcium may be due to inherent differences of the chemical composition of the argillites which gave rise to slates studied by Nanz and the phyllites and schists from Chitaldrug schist belt, or these changes may have been brought about by metasomatism and metamorphism and reorganisation. However, Nanz and others believe that metamorphism de of shales and their conversion into slates and phyllites do not appreciably change the bulk chemical composition.

The chemical composition of the shales and slates associated with graywackes differs from the chemical composition of shales and slates associated with the more mature sandstones (Nanz, 1953). The average $\frac{Al_2O_3}{Na_2O}$ ratio of two lutites associated with quartzites was 12.5, whereas the corresponding average of two lutites of graywacke affinities was 11 (Pettijohn 1957 p. 359). The average $\frac{Al_2O_3}{Na_2O}$ ratio of the chloritic phyllites (Tab. 10) and schists of Chitaldrug schist belt is 3.69 with a range from 2.95 to 5.61. This lower $\frac{Al_2O_3}{Na_2O}$ ratio is due to both higher soda and lower alumina contents in the schists and phyllites. This average ratio almost equals that of associated graywackes.
Krynine (1948) has attempted to classify the shales with respect to their association. The shales and slates associated with low rank graywackes micaeous while those which are associated with high rank graywacke are chloritic. The schists and phyllites of this area are mainly chloritic and are associated with graywacke and graywacke conglomerates.

A comparison of the chemical composition of the Chitaldrug graywacke (Tab. 5) and these chloritic phyllites (Tab. 10) and schists indicates that increase in silica content with increase in the grain size has resulted and decrease of other oxides in the graywackes. This trend is reversed in the chloritic schist. The alkalies in both the formations show little variation, especially soda content, and the alumina/soda ratio is almost identical. $K_2O/Na_2O$ ratio is less than one in both the formations.

It appears as though that the deposition of graywackes took place at the time of rapid subsidence. Whereby for some time the supply of the coarse clastic material was there and after sometime only exceedingly fine grained material accumulated.

The variations in the petrochemistry of these chloritic phyllites and schists may be due to contribution from volcanics to the sediments, and the reaction with sea water. The soda content of the associated volcanic suite varies very much. The soda content of graywackes has been explained due to the intermediate plutonic rock province and metasomatism. The higher soda content of fine grained rock types (chloritic schists) requires a satisfactory explanation. It appears that a regional soda metasomatism of the shales (phyllites), and graywackes has taken place. This soda
metasomatism due to sea water appears to be in varying degrees in different rock types and varies considerably in the same rock at different places and different samples.

The bulk chemical composition of the chloritic schist indicates that the source rock was dominantly of basic or intermediate composition. The vast amount and the abundance of these schists of basic composition seems to be related to some extent with the composition of the Pre-Cambrian crust.

2.11. The basic volcanic suite

The basic volcanic suite covers a large portion of the area (Pl. 1). Forty two samples of the pillow lava and lava flows devoid of such structures were analysed. Core and rim of the pillow lavas were analysed separately.

Megascopically this suite consists of pillow lava, variolitic lava, massive lava, volcanic agglomerates, orthoamphibolites (meta-basalts) and amygdular basalt.

The volcanic suite show well developed pillow structures (Pl. 15 and 16), individual pillows ranging from six inches to four feet. The pillows are well developed in the north eastern portion of the area surveyed. They are also found near Ingaldhal copper mines, Kurmerdikere and Kennehedlu village. The variolitic structure is well developed int he centre of the area on both sides of the anticlinal axis. The agglomeratic bed is repeated at many places.

The pillows were found generally, varying in shape from ellipsoidal to spherical and are connected with each
other. At Jogimardi hill their convexity was found to be towards south and southeast indicating that the flows are younging towards south and southeast. Each pillow possesses an outer rim showing banded structure (Pl. 16).

**Petrography**

For petrologic description the suite is divided into (i) orthoamphibolites (ii) chloritic pillow trap (iii) chloritic trap without pillows (iv) variolitic trap (v) volcanic agglomerates and tuffs and (vi) amygdular basalts.

(i) **Orthoamphibolites:** The orthoamphibolite is exposed near the southern boundary of Chitaldrug granites. It consists of medium grained plagioclase, bluish green actinolite and magnetite. The texture of this meta volcanic is intergranular holocrystalline. The grain size is larger than the other pillowed and unpillowed traps. The original texture of the rock has not been affected by the metamorphism. The increase in the grain size and the development of the actinolite appears to be due to the contact effect of the granitic intrusion.

(ii) **Pillow lava:** This chloritic trap shows pillow with banded outer rim. The banded nature of the rim was observed under the microscope also. It consists of intergranular chlorite and clouded plagioclase. Magnetite grains are also present (Pl. 48). The outer rim shows devitrified glass. The core of the pillow consists of fine grained intergranular laths of plagioclase, chlorite, epidote and magnetite. In some thin sections relict augite was also observed.
(iii) **Chloritic trap: Without pillow structure:** This is the most widespread group in the Jogimardi area. It shows typical basaltic texture and consists mainly of chlorite, plagioclase, epidote, magnetite. Sometimes minute quartz grains in between laths of plagioclase and chlorite are seen (Pl. 49). Many sections show relict augite. The augite is found in coarser varieties and occurs in the centre of the chlorite. It appears that while the boundaries of augite crystals have been changed to chlorite, the centre has escaped the change. In some sections the phenocrysts of plagioclase (Pl. 50) were also noticed.

(iv) **The variolitic trap:** The variolitic trap is well exposed in the centre of the area. It consists of nodules which vary $\frac{1}{2}$" to 1" in size. Under the microscope these varioles also show the intergranular texture and consists mainly of chlorite, laths of plagioclase, epidote, magnetite and quartz.

(v) **Agglomerate:** The agglomerate bed is seen at many places. It consists of angular and deformed fragments of chloritic trap, and chert of varying sizes (Pl. 17). The fragment size also varies from place to place (Pl. 51). As an effect of the regional metamorphism a schistosity parallel to the regional schistosity has been developed.

Pyroclastic beds are believed to be the product of explosive submarine volcanic eruptions (Williams, 1953). It appears that in this area after sometime the volcanic activity suddenly became explosive. The deposition of chert and other finer clastic sediments was apparently going on at the time of this explosive volcanic activity. The showers of pyroclastic ejection got mixed up with the sediments yielding mixed tuffaceous sedimentary rocks.
(vi) The amygdular trap: Amygdular trap is exposed in the southeastern part of the area near the village Elkereuhalli. It consists of laths of plagioclase, chlorite, augite, magnetite, quartz and epidote. The amygdules are made up of calcite and quartz. Sometimes veins of calcite and quartz are found joining the amygdules.

The major element geochemistry of the volcanic suite

The chemical composition of the Jogimardi trap is given in Table 11 and it is graphically represented in figures 15-22. These chemical data are compared with the analysis of Pichamuthu (1957) from the same suite, average spilites (Sundius, 1930) average andesites and basalts (Nockolds, 1954), Similipal spilites (Iyengar and Banerji, 1964) average Decaan trap (Washington, 1922) and average tholeiitic basalt (Engel, et al, 1965).

A reference to the table No. 11B would indicate the variation and behaviour of different oxides (with respect to SiO₂) present in the volcanic suite. Almost all the oxides except alkalies show a decrease with an increase in the silica content (Fig. 11). Composition of the volcanic suite is seen to vary from tholeiitic basalt to andesite and spilites. The variation in silica and soda content appears to be very important in this connection.

The silica content of the volcanic suite of Chitaldrug schist belt averages 51.83% and varies from 46.50% to 56.91% with 2.0 standard deviation (Tab. 11). The silica content of the core of the pillows was found generally to be greater than the banded outer rim.
The Na$_2$O varies from 0.56% to 3.67%, with an average of 2.20%. A strong positive correlation coefficient (≈ 0.562) was found between silica and soda. Though samples containing Na$_2$O equal to spilites were also analysed the average soda content of the Chitaldrug volcanic suite was found to be less than that of the average spilite, andesite basalt, Similipal spilite and even Deccan basalt and average oceanic tholeiitic basalt.

A positive and good correlation coefficient was found between potash and silica. The average potash content of the volcanic suite was found to be less than that reported by Pichamuthu (1967), almost equal to the average spilite and Deccan basalt, greater than that of average basalt, Similipal spilites, and average oceanic tholeiitic basalt and less than that of average andesites.

**Variation of oxides in the core and rim of the pillows**

Few samples of the pillow lava were analysed for its core and rim separately. Most of the samples analysed show that the banded rim or skin of the pillows contain less silica than the core. It has resulted in the increase of other oxides in the rim except the alkalies which decrease along with silica. This relationship between silica and other oxides present in core and rim indicates that the cooling was from periphery to centre, which is the expected normal case (Macdonald and Ka*tura, 1966) due to the submarine environment of the eruption and subsequent cooling. Hapgood (1962) has reported the radial distribution of soda in a pillow of spilitic lava from the Franciscan California. The soda content of the rim was found invariably less than the soda content of the core of the same pillow, from Jogimardi traps. It appears that being most mobile element the Na$_2$O has been removed from the outer skin of the pillows by
The removal of soda and decrease in silica resulted in a more basic bulk composition to the rim as compared to the core.

The C.I.P.W. Norms

C.I.P.W. Norms (Tab. 13) show that the samples analysed vary from slightly undersaturated to saturated and oversaturated rocks (Tab. 2). The Q-L-M Von Wolf diagram also supports this view (Fig. 17). The normative quartz content averages at 3.54% and varies from 0.00 to 12.48%.

The normative albite content averages at 18.51% and varies from 3.14% to 31.44% with 6.72 standard deviation (Tab. 13). It shows that the albite content in some samples equals the albite content in some samples equals average basalts, and in other samples it equals Similipal spilites and Deccan basalt but is less than that of average spilites in all the samples analysed. The same characteristic of the other normative minerals also may be seen from Table No. 13 and 14.

This shows that the volcanic suite of Chitaldrug schist belt consists of rocks having the composition from tholeiitic basalt (Yoder and Tilley, 1963) to andesites and spilites (Fig. 18).

Niggli values: The si, al, fm, c, alk, qz, k, and mg values were calculated (Tab. 15 and 16; Figs. 14, 15 and 16). The 'si' and 'qz' values indicate that though some of the samples are slightly unsaturated and oversaturated most of the samples belong to just saturated variety. Comparison of Niggli values of volcanic suite and the other basic and
semi-basic rocks also indicates that the composition of
the volcanic suite varies from tholeiitic basalt to
andesite and spilite.

Oxide ratios:

Five oxide ratios have been considered by Godschmidt
(1954) as most important factors for envisaging the magmatic
conditions. These oxide values were calculated for the
Chitaldrug volcanic suite and data collected from literature
(Tabs. 15, 16; Fig. 13).

The average Na$_2$O/CaO ratio of the Chitaldrug volcanic
suite is much less than that of average spilites, andesites,
basalts, Similipal spilites and Deccan basalt (Tabs. 15 and
16). This low Na$_2$O/CaO ratio is mainly due to higher CaO
content of the Chitaldrug volcanic suite. It varies from
0.02 to 0.54, which indicates that some samples of the
volcanic suite show Na$_2$O/CaO ratio equal to that of andesite,
basalts, Similipal spilites and Deccan basalt, and are very
near to the average spilite. The FeO/MgO ratio averages
at 1.54 and varies from 0.95 to 4.91. This variation range
embraces the values of spilites, Similipal spilites, andesites,
basalt and Deccan basalt. The SiO$_2$/MgO ratio averages at
9.58 and varies from 6.23 to 22.17. This range of variation
also embraces the SiO$_2$/MgO ratios of other basic and semi-
basic rocks compared here. The K$_2$O/CaO ratio of the volcanic
suite averages at 0.05 and varies from 0.01 to 0.19. The
variation range embraces the K$_2$O/CaO ratio of all the average
basic and semi-basic rocks considered here for comparison.
The Fe$_2$O$_3$/FeO ratio averages at 0.15 and varies from 0.04
to 0.37. The average Fe$_2$O$_3$/FeO ratio is less than that of all
other rocks. It appears to be due to the lesser amount of
magnetite present in the volcanic suite.
Origin of the volcanic suite

The presence of pillow and spherulitic structure, association with agglomerate and geosynclinal sediments (Narayanaswamy, 1964; Naqvi, 1967) clearly indicates that the Jogimardi trap is a volcanic association of orogenic region. In a geosynclinal volcanic association spilites, normal basalts, andesites and even rhyolites can occur together (Edward, 1965; Knopf, 1948).

Bowen (1928) has explained the chemical, petrographic and associational characteristics of the basalt-andesite-rhyolite association by a simple hypothesis of fractional crystallisation of basaltic magma. This hypothesis has remained widely accepted, but during the last decade opinion against this hypothesis of pure fractional crystallisation has mounted steadily.

But still some workers believe that spilite, keratophyre and andesite association is a result of fractional crystallisation. Edward (1965) has interpreted the petrological, mineralogical and chemical variations in the andesite, spilite, and keratophyre suite of north-central Puerto Rico, as the result of mainly compositional differences and crystallisation history.

Waters (1955) discarded the widely held theory that all volcanic rocks originated by differentiation of basaltic magma. He proposed that tholeiitic magma arises in a deep universal earth shell, but the fissure eruptions do not stop a great molten pool undergoing crystal differentiation. Differentiation occurs after eruption to higher levels. He believes that when a submarine trough is downbuckled into a tectogene, water and other easily removable constituents are distilled from the metamorphosing geosyncline sediments. These mix with the primitive tholeiite, modifying it to a highly explosive steam-rich andesitic magma.
Turner and Verhoogen (1962 p. 270) too do not agree with the view that this association can arise from simple fractional crystallisation of a basaltic magma. On the grounds that such association is not found in differentiated basic sills, they discard Bowen's hypothesis and believe that such association is the result of geosynclinal environment.

Hamilton (1965 p. 350) states that eugeosynclinal basalts in many suites have been converted in varying degrees to spilite. The fact that the clinopyroxenites in such sodic rocks are normal augites and pigeonites, and are not sodic, demonstrates that the rocks crystallised from calc-alkaline magmas, and that the process of spilitisation is not a magmatic process; therefore, spilitisation need not be considered, with the problem of origin of magma.

Iyengar and Banerji (1964) suggests on the basis of petrochemical data of Similipal spilites that these spilites were formed due to albitisation of the parent tholeiitic magma.

The petrochemical features of the Chitaldrug volcanic suite show that the rocks vary in composition from tholeiitic basalts to andesites and spilites (Fig. 7 and 8). They are associated with highly sodic chloritic schists and graywackes (Figs. 8 and 10). It appears that the variation of chemical composition of volcanic suite is a result of varying degree of spilitisation of the parental tholeiitic magma. The tholeiitic magma most probably was held in contact for a period, with Chitaldrug graywackes, highly sodic schists, and geosynclinal waters, which resulted in its spilitization.

The varying and incomplete degree of spilitisation indicates a shorter period of contact between metasomatic liquid and the traps, as the submarine volcanic activity in the Dharwar eugeosyncline appeared at quite a latter stage.
This late stage of volcanic activity is suggested by the youngest and thin phyllites and pyritiferous cherts deposited over it, after which the area witnessed orogenic deformation.

**Metamorphism of the volcanic suite**

In several other areas submarine lavas have been observed to have undergone regional metamorphism. Smith (1968) has studied and described an Ordovician geanticlinal marine sequence exposed in the Central West of New South Wales, Australia. The sequence containing basic lavas, liable sedimentary, and pyroclastic rocks, has undergone extensive adjustment during regional burial metamorphism. Poldervaart (1963) has reviewed the metamorphism of basalts at length. The Chitaldrug volcanic suite which is a submarine lava was buried under a cover of sediments and was subjected to regional metamorphism and deformation together with the associated sediments. Apart from the effect of low grade regional metamorphism of green schist facies it was also effected by granitic intrusion. The effect of the regional burial metamorphism and metasomatism, was the development of chlorite, epidote and plagioclase the original basaltic texture being retained. Near to the granitic contact the basalt got changed into orthoamphibolite consisting of actinolite and plagioclase mainly. In this case also the original basaltic texture was retained.

2.12 - Sericitic-ferruginous phyllites and banded pyritiferous chert

This is the youngest formation in this area and it is exposed on the tops of the synclinal hills (Pl. 1).
It consists of gray-green, white yellow, red and brown coloured phyllites and interbedded chert (Pl. 18), impregnated by pyritic layers (Naqvi, 1967).

**Sericitic ferruginous phyllites:**

**Petrography**

Phyllites consist mainly of extremely fine grained quartz, sericite limonite and hematite (Pl. 52). Sometimes bigger chops of the quartz are also found in between fine grained sericite and quartz.

**Chemical composition**

The silica content of the phyllites varies from 64.26 to 73.64 with an average of 70.82 (Tab. 17; Fig. 17). Alumina varies from 7.33 to 15.64 with an average of 12.71%. A fairly good negative correlation coefficient of the order of $-0.588$ was found between silica and alumina. The ferric oxide content also decreases ($r = -0.746$) with the increase in silica. FeO, MgO, CaO, Na$_2$O, K$_2$O and MnO show $+ve$ correlation to silica. P$_2$O$_5$ and TiO$_2$ show poor negative correlation to silica.

**Genesis**

The grain size index ($SiO_2/Al_2O_3$) ratio; Pettijohn 1957) varies from 4.10 to 10.01. Maturity index ($Al_2O_3/Na_2O$) varies from 10.30 to 21.43. The sample which shows lowest grain size index shows highest maturity index (21.43). A low grain size index means that the sample belongs to a fine grained rock and a fine grained rock is expected to be much more mature than a coarser one. This phenomenon is exhibited by the $Al_2O_3/Na_2O$ and $SiO_2/Al_2O_3$ ratios of these phyllites. The $K_2O/Na_2O$ ratio is always more than one.
The average silica content of shales, phyllites and schists is reported to be 58 percent. The silica content of the sericite and ferruginous phyllites averages 70.85%, which indicates that the original rock might be a siliceous shale. The siliceous character of this type of shales has been considered not only due to small quantities of detrital quartz but rather to be derived from amorphous silica, such as opal or from volcanic ash. (Ruby, 1929; Goldstein and Bendricks, 1953).

In the light of the presence of inorganically precipitated silica in the form of bedded chert (Naqvi, 1967) with these phyllites, it appears that the higher silica content of these phyllites may be due to chemically precipitated silica and detrital quartz. Inorganically precipitated silica might have been deposited with fine detrital material and hence increased the total silica content.

The $\text{Fe}_2\text{O}_3$ was found to vary from 0.52 to 12.15%. It appears that the hydrothermal mineralisation of pyrites and other sulphides and the oxidation of the pyrite resulting in the formation of haematite-goethite has increased the iron content of the phyllites, which are red or brown in colour.

Associated and interbedded with these phyllites is the banded pyritiferous chert, which has been considered by earlier authors (Iyengar 1905) as magnetite quartzite. The phyllites and associated pyritiferous chert were named by Sampat Iyengar (1905) as Guaded Ranganahalli (G.R.) formation.
The banded pyritiferous chert

Petrography

The banded pyritiferous chert generally outcrops on the tops of the ridges forming festoon-like arcs (Pl. 9). The white or greyish coloured chert is found in rhythmically layered forms. The individual layers of chert vary in thickness from one centimeter and less to four or five centimeters (Pl. 19 and 20). On the surface, these chert layers are found to alternate with layers consisting of limonite, haematite and often magnetite. The chert is brittle and closely jointed. The thickness of banded pyritiferous chert varies from 50 to 100 feet and it is embedded in grey, white, pink and brownish coloured clays, shales and phyllites. The study of the core samples from Ingaldhal copper lode reveals that the brown and greyish white banding clearly seen on exposures at the surface disappears at depth. Instead, layers of chert are seen alternating with layers charged with pyrite and other sulphide minerals. This shows that due to surface action like oxidation and leaching, limonite and haematite have formed. At certain places the chert layers are found to pinch and swell (PP. No. ). Chert is also seen interbedded with clay and red shales, at many places (Pl. 20). Brecciation is common (Pl. 19).

Under the microscope, the banded pyritiferous chert is seen to be colourless, and formed of exceedingly fine microcrystalline aggregate of quartz (Pl. 54). Under the highest magnification the individual grains of the chert show fibrous wavy extinction.

Limonitic and haematitic layers on surface and pyritic layers below the zone of oxidation are not persistent. There are places where the limonite layers are reduced to a thickness of a few millimeters or even a thin coating of film in between chert layers. The fractures and joints in the chert are generally filled by limonitic material (Pl. 54)
on the surface and mostly by pyrite and often by chalcopyrite below the zone of oxidation. Cubes and tetrahedrons of pyrite and altered pyrite are very common in the pyrite and limonite layers (Pl. 53). Cubes of pyrite are also found along the schistosity planes in the chloritic schist.

These banded pyritiferous cherts are quite different and should not be put under the same category as the magnetite and haematite quartzites forming part of the iron formation seen in other parts of the state. Rama Rao (1940) has earlier recognised the difference between these two superficially resembling formations.

**Chemical composition**

The partial chemical analysis of the banded pyritiferous chert from Ingaldhal and typical magnetite quartzite from Talya region (Tab. 4) indicates that these two rock types are different and should not be correlated with each other. The absence of sulphur in magnetite-quartzite supports the view that these two formations belong to two different genetic groups.

**Genesis: Origin of chert**

The origin of the banded pyritiferous chert is a complex problem. Two features require explanation, (i) the deposition of chert and (ii) the deposition of pyrite and other sulphides. Various theories have been proposed to explain these features. Biochemical origin of the chert is supported by many workers. On the ground that organisms are today forming pure siliceous deposits, it is supposed that the ancient cherts might have had a similar origin. Since
Chert nodules in limestones are considered as replacement deposits, some workers believe that bedded cherts are formed by an extension of the process of replacement to the whole rock. But majority of workers who have considered the origin of chert, reject both the biochemical and metasomatic origin of cherts and favour the direct precipitation of silica in the form of silica gel.

The banded pyritiferous cherts of Chitaldrug schist belt do not contain remains of Radiolaria, diatoms and siliceous sponge spicules as in some cherts of later periods. It is, therefore, difficult to believe that organisms were responsible for the formation of these bedded cherts.

The aerial extent, the thickness, the texture and rhythmic layering of this chert bed do not support the view that these deposits originated as a result of metasomatic replacement of carbonate rocks like limestone or some calcareous shales.

The banded pyritiferous chert is associated with fine-grained pink, grey yellow and sometimes black coloured phyllites (shales+clays) which have been described by Sampat Iyengar (1905) as G.R. clays. The volcanic suite underlying the phyllites and chert shows pillow structure. In the light of this association, rhythmic layering in the chert, their aerial extent and texture, etc., the present author considers this banded chert as a product of direct precipitation of silica gel in the Dharwarian geosyncline. The existence of pillow lavas indicates subaqueous igneous activity which supplied some part of the silica and initiated its precipitation. The concentration of silica was built up by the subaqueous igneous flows to the extent where inorganic precipitation started. The association with shales and clays
shows that the chert was deposited when relatively little clastic material was being supplied to the Dharwan geosyncline. The silica gel later on underwent dehydration and crystallisation resulting in micro-crystalline chert. Some workers (Correns, 1950) consider acidity or alkalinity as a critical factor in the precipitation of silica, while others (Krumbine and Garrels, 1952) consider silica precipitation to be largely independent of alkalinity or acidity (pH) or (Eh), Oxidation Reduction Co-efficient. Pettijohn (1957, p. 444) has discussed this problem in detail and has concluded that: "chert is a polygenetic rock for which no single mode of origin exists. The origin of a particular chert bed will have to be decided on the evidence at hand".

The evidence at hand, i.e., the association with basaltic pillow lavas and eugeosynclinal sediments supports the view expressed by Davis (1918), Taliferro (1933) and others that volcanism supplied the silica and increased the concentration upto the point where inorganic precipitation started. The fine clay and sericitic shales and schists (G.R. clays) associated with chert bed are most probably the fine clastics. The existence of a graywacke conglomerate and graywackes indicates geosynclinal environment of deposition. The rhythmically bedded chert, clays, para conglomerates, graywackes, chloritic schist and volcanic suite seem to be members of one consanguineous association or facies. This consanguineous association is the characteristic of graywacke suite, i.e., geosynclinal facies. On these grounds the author believes that the chert is a chemical sediment deposited under geosynclinal conditions. The association of the fine clastics, chemical precipitates and volcanics indicates concurrent sedimentation and igneous activity, which is believed to be characteristic of eugeosynclines (Kay, 1947).
The origin of Pyrite

In between the chert layers, pyrite, where unoxidised and all combinations of haematite and limonite where oxidised, is found. Pyrite layers are found varying from a mere film to four or more centimeters in thickness. Sedimentary pyrite, rhythmically interbedded with chert and shales has been reported from Michigan (James, 1951). It can be deposited in reducing and completely oxygen deficient conditions (Krumbine and Sloss, 1963). But the pyrite in pyritiferous chert bed of Chitaldrug schist belt does not appear to be of sedimentary origin. Pyrite, where unoxidised and limonite haematite where oxidised are found along cracks, fractures and joints developed in the cherty layers (Pl. 6). Pyrite cubes and tetrahedrons are found all over the area. In chloritic schists pyrite and limonite cubes and tetrahedrons are found along the schistosity. These cubes found along the schistosity generally are associated with quartz veins which have intruded along the schistosity planes. At depths, in association with pyrite, chalcopyrite, pyrrhotite, galena and other sulphide minerals are also found (Radhakrishna, 1967c). Few samples from Ingaldhal copper lode were analysed over a spectrograph for their trace element contents at the Panh University. The spectrum obtained shows the presence of gold, silver, antimony, bismuth, lead, zinc and arsenic.

In the light of this textural and mineralogical evidence and the association of other hydrothermal sulphide ores, the author believes that the pyrite was not deposited as a chemical precipitate. It appears to be related to hydro-thermal activity. This hydrothermal mineralisation was probably post-Tectonic.
2.13 - Granodiorite

This rock type is exposed in the northeastern portion of the area. It is reported by (Sampat Iyengar, (1950)) as diorite. Hatch, et al, (1956) believes that no granodiorite contains silica less than 66.00%. William (1954) considers that Granodiorite contain less than 1/3rd and more than 1/8th alkali feldspars of the total feldspar. The petrochemical study of the samples reveals that it contains more than 66.00 silica and the alkali feldspar (Normative) content is also less than 1/8th of the total feldspars.

Petrography

It mainly consists of zoned plagioclase, quarts, orthoclase, hornblende, accessory biotite, magnetite, apatite and sphene. Zoning in plagioclase is common (Pl. 56) and the crystals are generally euhedral. The central portion of the zoned crystals of the plagioclase is generally changed to saussuritic aggregate (Pl. 56). Some central zones of the plagioclase crystals are changed to sericite and kaolin while others show hydrothermal alteration. The orthoclase grains also show sericitisation. Some grains of feldspars show reaction rim also.

Chemical composition

Four samples of granodiorite were analysed for their major elements. The chemical analysis (Tab. 18; Fig. 19) shows that the average silica content of the Chitaldrug granodiorite is 68.4% and it varies from 67.4% to 70.52%. The silica content of Chitaldrug granodiorite is higher than the silica content of average granodiorite (Nockolds, 1954) and GSP-1 granodiorite USGS standard (Flanagan, 1967). However the lowest value of the silica
content in samples analysed is almost equal to that of GSP-1.

The alumina varies from 13.26 to 14.63% and averages at 14.01%. The correlation coefficient between silica and alumina was found to be of the order of -0.615. The average alumina content of the Chitaldrug granodiorite is less than that of the alumina content of average granodiorite and GSP-1.

Fe₂O₃ varies from 0.43% to 0.64% and averages at 0.53%. A high positive correlation (+0.748) between Fe₂O₃ and silica was found.

The correlation coefficient between silica and FeO was found to be very poor. The magnesia content of the granodiorite from Chitaldrug schist belt shows strong negative correlation coefficient with silica. The CaO content also decreases with silica. Alkalies shows almost perfect positive correlation coefficient with silica. TiO₂ and P₂O₅ also show positive correlation coefficient with silica while the MnO shows a negative correlation. It indicates that almost all those oxides which are generally present in the mafic minerals decrease with increase of silica.

The oxide ratios of (Tab. 19) Chitaldrug granodiorite, average granodiorite and GSP-1 do not tally fairly with the oxide ratios reported by Goldschmidt (1954) for granodiorites. However, the oxide ratios of Chitaldrug granodiorite show an evolutionary trend.

The normative quartz and feldspar content (Tab. 19; Fig. 22) indicates the intermediate character of the rocks. The Si and other Niggli values (Tab. 19, Fig. 21) are almost similar to the Si and other values reported by Burri (1954) for granodioritic magma.
The presence of the zoned plagioclase when examined along with chemical data and the Niggli values indicates that the granodiorite is probably an intrusive body into the schist belt.

2.14 - Chitaldrug granite

The Chitaldrug granite occupies the axis of the cross folded anticline (Pl. 1). Two varieties of the granites i.e., grey and pink are commonly found in the southern portion of the granite body. Towards north it becomes more and more gneissic. Large caught up patches of amphibolites similar to the orthoamphibolites are found everywhere within the granitic exposures. (Pl. 29). Near the xenoliths the amount of hornblende, plagioclase, and epidote was found to be more than in the portion of the granite away from the xenoliths.

The southern portion of the granite near its contact with the orthoamphibolites (Naqvi, 1969) contains more amphibolite xenoliths than the other portions of the granite. These xenoliths are fairly large. The contact between the amphibolite and granite is sharp and discordant. The granite and quartz veins are found to be entering into the joints and fractures in the amphibolites from the main granitic body.

The contact with the gneisses is seen exposed at only few places. Most of the area between the granites and gneisses is covered by soil and alluvium and the nature of the contact could not be ascertained with certainty. The western and eastern contacts of the granites with gneisses however appear to be gradational.
Petrography

The Chitaldrug granite is hypidiomorphic granular rock. The mafic minerals and plagioclase are generally euhedral (Pl. 57). Most of the orthoclase and microcline is subhedral. Quartz occupies irregular, intergranular, interspaces. It consists mainly of quartz, microcline, plagioclase, orthoclase, hornblende and biotite. Apatite, ilmenite zircon and epidote are found as accessories (Pl. 58). Quartz is present in two generations. One generation is in the form of irregular grains while the other generation is in the form of inclusions in the orthoclase crystals (Pl. 59).

Chemical Composition

Five samples of granite were analysed for their major elements (Tab. 21). The chemical analysis shows the following trends. With the increase in the percentage of silica, alumina, FeO, GaO, TiO₂, P₂O₅ decrease. The negative correlation coefficient between silica and these oxides is shown in Figure 19. With the increase in the percentage of silica Fe₂O₃, MgO, Na₂O, K₂O, H₂O and MnO also increase. The positive correlation coefficient between silica and these oxides is shown in figure 19.

The behaviour of magnesia with respect to silica appears to be erratic. With the increase of silica the magnesia is expected to decrease as reported by Divakara Rao (1968). It may be because of more xenolithic content in the samples (90 and 90B) which have actually resulted in the above reversal trend.
The Norms, Niggli values and the Oxide ratios are given in tables 20 and 21 and they are graphically represented in figures 24, 25, and 26. These data show variation from granodiorite to granite.

**Origin of the granite**

The origin of the granitic bodies has been discussed by a large number of workers. The literature on the granites has been reviewed by H. M. Reed (1957) and more recently by Raguin and Wegmann (1965).

Recently Divakara Rao (1968) has shown by the trace element study of the Closepet, Chitaldrug and Hosdurga granites that the Closepet and Chitaldrug granites may be of metasomatic origin. He proposes that alkali and silica metasomatism of the peninsular gneisses might have resulted in this transformation.

Any theory of the origin of the Chitaldrug granite must explain the following facts:

- The sharp southern contact with the orthoamphibolites.
- The development of orthoamphibolites at the contact.
- The presence of amphibolitic xenoliths.
- The so-called gradational contact with the peninsular gneisses.
- More than 4.5 miles depth of the granitic body (See profile AA' and BB').
- Differences in the density of the granite and associated gneisses.
- Variation in the chemistry of gneisses and Chitaldrug granites.
The sharp and discordant southern contact with the orthoamphibolite and the development of the orthoamphibolite itself indicate that the granite might have been intruded into the schist. The presence of the amphibolitic xenoliths supports this view. The gradational contact between the granites and gneisses appears to be the result of partial assimilation of the gneisses.

The gravity studies show a prominent 'low' on the Chitaldrug granite. Bott (1953) and Qureshy, et al, (1968) have studied the gravity anomalies over the granites. They are of the opinion that the high negative gravity anomalies are located on intrusive granites. Bott (1956) concludes that "metasomatic origin with upward and sideways migration of surplus mass is inconsistent with the shape of observed gravity anomalies of exposed and unexposed granites." The anomaly over the Chitaldrug granite ( - 13 magal; Pl.2) also appears to be inconsistent with the metasomatic origin of the granite.

The chemical analysis of the Chitaldrug granite and the gneisses (Tab. 14 and 21) also do not support the view that alkali and silica metasomatism of the gneisses has resulted in the formation of the Chitaldrug granite. The chemistry of the gneisses shows that the gneisses from Chitaldrug schist belt are not silica deficient. They contain silica more than the granites. Some of the gneisses contain more than 4% Na_2O and some of them contain more than 4% K_2O. It cannot be claimed at present with the available information whether these gneisses existed at the time of the formation of the Chitaldrug granite. Even if it is assumed that gneisses
existed at the time of the formation of the Chitaldrug granite, the chemical data and the geological setting make it difficult to believe that metasomatism is the cause for the development of the Chitaldrug granite.

It is generally believed that the granites are the products of orogeny (Butcher, 1950; Knopf, 1954; Bateman and Eaton, 1967). The existing field, petrological chemical and geophysical evidence indicates that the Chitaldrug granite be an intrusive batholith.

2.15 - Dykes

There is a large number of dykes of varying composition, texture, and dimensions present in the area. Most of the dykes cut across all the formations in the central part of the Chitaldrug schist belt, except two dykes which do not cut across the youngest chert and phyllites. Near the copper mines at Ingaldhal, (Pl. 1) a dyke of gabbroidal composition and texture is not found on the top of the hill while on both the flanks of the hill, below cherts and phyllites, this dyke is visible. Another dyke is seen on both sides of the synclinal hill but it is not found on the top of the hill. It indicates that these dykes might have intruded before the deposition of cherts and phyllites.

There is a marked variation in the texture and mineral composition of the dykes. Some of the dykes are porphyritic having phenocrysts of plagioclase, while others are doleritic showing ophitic texture (Pl. 60). A few dykes show typical gabbroidal texture also. A marked variation in grain size of the dykes can
be noticed even in hand specimens.

Mineralogically also these dykes vary very much. A petrological study of these dykes show that in mineralogical composition they vary from gabbroic to dioritic composition.

It is generally believed that most of the dykes in Mysore are of Duddapah age (Pascoe, 1950) but the fact that some of the dykes do not cut across the youngest formation indicates that probably there was more than one cycle in their emplacement. The mineralogical and textural variation appears to support this view. However, detailed geochemical studies on these dykes are in progress and the results of those studies will be published separately.

2.16 - Conclusion

The above studies indicate that the main rock types of the central part of the Chitaldrug schist belt may be divided into orthoquartzite-carbonate and geosynclinal facies. The chemical composition of metasediments and their distribution shows the abundance of the sediments rich in iron, magnesia and calcium.