GEOLOGY OF THE AREA AROUND PULIVENDLA DISTT. CUDDAPAH, (A.P.)

A DISSERTATION
SUBMITTED IN PARTIAL FULFILMENT
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IN APPLIED GEOLOGY

By

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CERTIFICATE

CERTIFIED that the dissertation entitled "GEOLOGY OF THE AREA AROUND PULIVENDLA, DISTT: CUDDAPAH, (A.P)", being submitted by Sri J. G. Somayajulu in partial fulfilment for the award of the Degree of M.Sc. Tech., in Applied Geology of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

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Date 25/3/'66

(J. G. SOMAYAJULU)

CONTENTS

With 10 figures, 22 photographs and Geological Map.

C H A P T E R - I

INTRODUCTION

INTRODUCTION

LOCATION :-

The investigated area is located in Pulivendla Taluk of Cuddapah District, in Andhra Pradesh (Fig. 1) within latitudes 14°24' to 14°30', and longitudes 78°5' to 78°15'. The area forms part of the Survey of India toposheet Nos. 57 J/7 and is about 40 square miles in extent.

MEANS OF COMMUNICATION :-

Pulivendla, the head quarters of the taluq, is linked to all other important towns within the district by second class but easily motorable roads. The nearest railway station is Muddanur, which lies on Madras-Bombay line and it is 40 Km. from Pulivendla. Cuddapah railway station is 72 Km. from Pulivendla by road.

CLIMATE :-

The annual rainfall is 20-25 inches and the annual range of temperature varies from 40° F to 70° F while the maximum temperature in summer is around 115° F.

SOIL AND VEGETATION :-

There is a general scarcity of green vegetation. Black soil which is a weathering product of basic intrusives is very fertile. Experiments on the possibility of successful cultivation of citrus fruits (Chinas) and grapes have proved much encouraging. Paddy is cul-

THE CUDDAPAH BASIN
ANDHRA

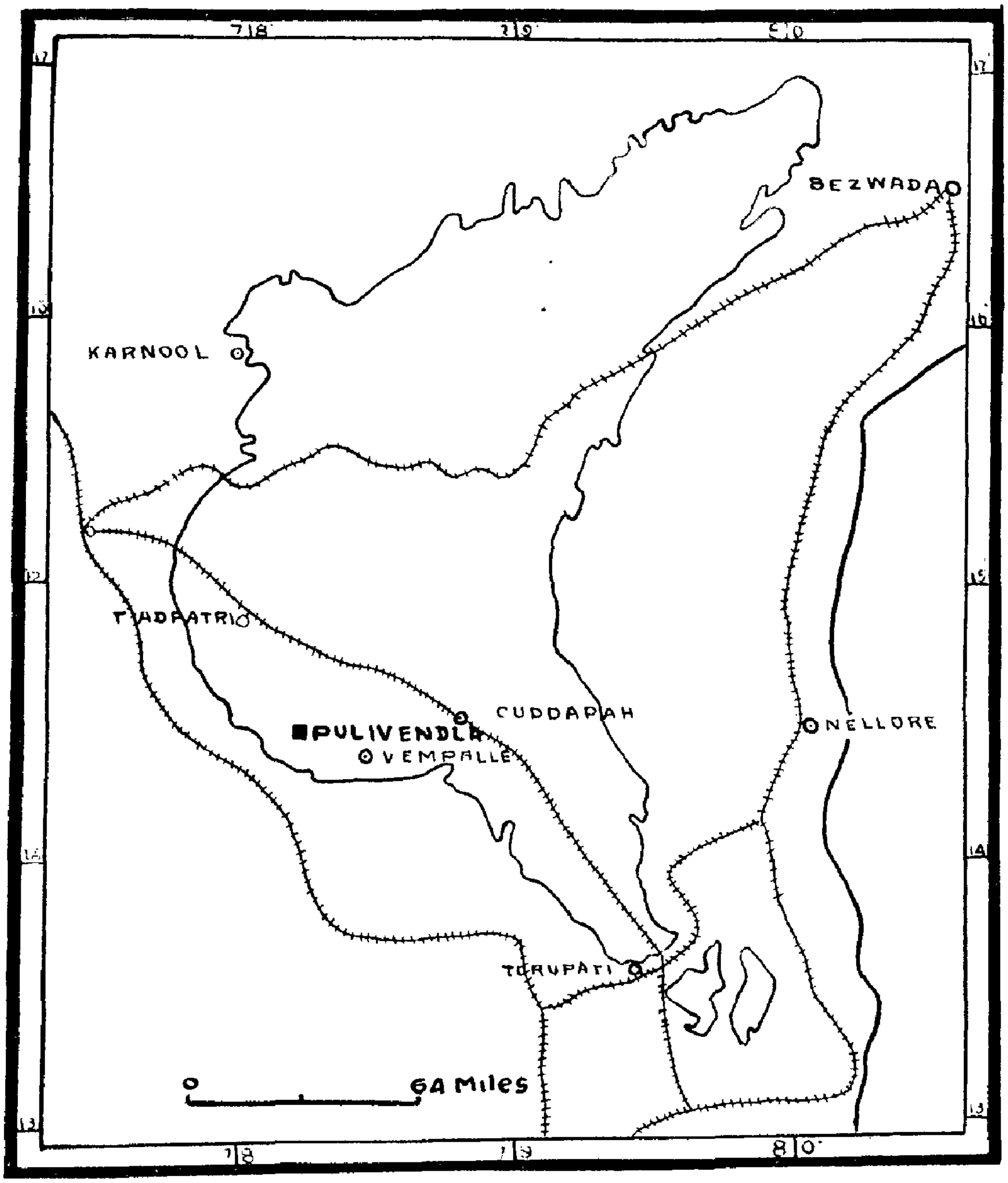

FIG. 1

tivated in alluvial areas

Groundnuts, chillis etc., are very commonly grown in these areas as these crops can easily be grown even in areas of doubtful rainfall.

PREVIOUS WORK :-

The first authentic work is by William King (1872). He mapped the area on the scale 1" = 4 miles and distinguished between the Lower and Upper Cuddapahs and Kurnools based on major breaks in sedimentation. However, he failed to notice the asbestos and barytes occurrences which are associated with Vempalle limestones.

During the early 1920's, the G.S.I. deputed A.L. Coulson to study the occurrence of barytes and asbestos deposits in these areas. He mapped the area on 1" = 1 mile scale and described the geology and asbestos deposits of the area (1933, 1934). Krishnan and Venkatram (1942) also worked in this area, but did not suggest any thing new about the origin of mineral deposits.

Vemban (1946) described the petrochemistry of the basic dykes and sills that are intruded into the Cuddapah rocks.

Venkatram and Balasundaram (1949) studied the Geology of the Vempalli Limestone belt. Murthy (1950) worked on the genesis of asbestos and barytes in this region and came to the conclusion that the former was due to contact metamorphic processes, whereas the later was the result of the interaction between descending barium bearing solutions and ascending sulphate rich water. Rao (1963) worked in this area for his M.Tech. Thesis. In recent years officers of G.S.I. and Andhra Pradesh Govt., have been working in this area on barytes and asbestos mineralisation and their work consists mainly of detailed mapping of mineralised zones but the results of investigations are still not published. In 1964, a symposium was held on "Cuddapah Basin and its Equivalents" under the auspices of the Indian Geoscience Association. Several interesting papers were contributed in this symposium - out of which the papers by Rao, Gokhale and Rao (1964), Vaidyanadhan (1964), Jhamnar, Rajurkar and Phadtore (1964) are worth mentioning.

NATURE AND SCOPE OF THE PRESENT WORK :-

Field investigations were carried out for a period of twenty days during January 1965. Representative samples of various lithological formations were collected for study in the laboratory. Thin section study of basic igneous rocks, limestones, serpentines and other quartzites is carried out and described in Chapter 3.

Four basic rocks, three from Tadpatri sill and one from Lower sill in Vempalles are chemically analysed using the modern methods of silicate analysis. From the chemical composition C.I.P.W. norms and Niggli values are calculated. With the help of variation diagrams the trend of differentiation in the Tadpatri sill is investigated and an attempt has been made to discuss the petrogenesis of basic rocks and the nature of parent magma in chapter 5.

Few limestone specimens are also analysed for insoluble residue, CaO and MgO and the results of analysis are given in Chapter 2.

Differential thermal analysis is carried out for four serpentine samples to get a more reliable information of the minerology of these specimens as described in chapter 4.

The ore minerals associated with serpentines and barytes are studied in polished sections. Based on this and the field observation, the origin of asbestos, barytes and other associated ore minerals is described in Chapter 6.

Wherever possible, quantitative data are substituted for qualitative descriptions as the latter may lead to erroneous conclusions. For example, while describing the petrography in chapter 3 the modes of seven basic rocks are given. Sphericity values are determined for 143 pebbles of Pulivendla conglomerate and with the help of this and other sedimentary data an attempt has been made to determine the framework of sedimentation in chapter 2.

GEOMORPHOLOGY :-

The Cuddapah basin in Peninsular India occupies an area of about 13,500 square miles, in the southern part of Andhra Pradesh. Rocks of Cuddapah and Kurnool systems occur in the basin, the former occupying two thirds of the area. The basin is surrounded by the older Archean rocks.

The Cuddapah basin contains locally folded and faulted semimentary rocks of varied lithology which have been subjected to uplifts and denudation. The geomorphology of the Cuddapah basin has been discussed by Vaidanadhan (op. cit.). He divided the basin into seven geomorphic sections based on topographic differences and found that the different landforms are characterised by typical drainage patterns.

The Cuddapah rocks can be divided into two groups namely Lower and Upper Cuddapahs on the basis of a large break in sedimentation in between.

In the area under discussion, the rocks belonging to the Papaghni and Cheyair series are found as outlined below:

Intrusive sills

Cheyair series	Tadpatri shales which are chloritic (green) and ferrugeneous (red) with intercalotions of limestones.
	Pulivendla quartsose sandstone
	Pulivendla conglomerate
Papaghni series	Vempalle limestones which are at times magnesian and siliceous, containing intercalations of ferrugenous shales.
	Gulcheru quartzites (occur further towards south)

The strike of the rocks of Papaghani and Cheyair series of the Cuddapah system bends round in the form of a bow as it is traced from Vempalli to Pulivendla, being first N.W-S.E. then E.W and finally N.W. - S.E.

<u>TOPOGRAPHY</u> :-

The evolution of the present topography is largely controlled by the difference in the resistanse of the rocks to erosion. Hence the geomorphological characters of the area are based on the lithology and structure of the rock types.

In the present area, the vempalle limestones along with the intrusive sills are fairly conspicuous because they form dark low ridges which are marked by brown coloured soil and thorny shrubs. The vempalle lime-stones have gentle dips ranging from 10°-20° due north east. The ridges accordingly have a low dip slope towards north east and form escarpment opposite to the dip direction. The sills of basic rocks in Vempalles along with lime-stones form a single unit.

The height of the ridges generally does not exceed 200' over the plains. The highest hill present in the area is 1250' above sea level which is situated 2 miles south of Lingaba, while the plains stand at a height of about 900' above sea level.

The faults which have dislocated the Vermpalles and the Pulivendlas have conspicuous effect on topography. The dislocations at Ippatla and Chinnakudala villages have resulted in the discontinuity of the strike ridges as a result of which a large discontinuity appears a mile south of Ippatla while a low land appears S.E. of Ramanutla Palle. The valley south of Ippatla has a width of about 1,000 yards.

Shales form the low lands and are seldom exposed except along the nullah cuttings or in the valleys. They are often covered by alluvium.

Pulivendla quartzite, being more resistant, stand as ridges, but is seen only at few places as thin outcrops.

The sills that intruded Tadpatri shales stand prominently as small ridges. The three E.W. trending ridges, one of them one mile W.N.W of Pulivendla, the second half a mile west of Korapadu, and the third one and half mile N.NE of Pulivendla, are made of the Tadpatri sill. They have a height not exceeding 950' above the sea level i.e., about 50' above the plains. Well developed columnar jointing producing hexagonal blocks is common in these ridges.

The strike of all these hills is more or less parallel to the general strike of different lithologic units i.e., W.NW-E.SE and thus these may be called as strike ridges.

<u>DRAINAGE</u> :-

Small streams cut across the ridges, few of which flow west ward while most of them flow roughly eastward. Some times the rivers take the advantage of fault zones as seen near the village Ippatla.

There is no big river present in the area. A prominent lake is present about 2 or 3 furlongs west of the village Lingala. Small ponds are present at few other places in which rain water accumulates in rainy season. These ponds get dry in summer. No definite drainage pattern could be established.

WEATHERING :-

Both mechanical and chemical types of weathering is seen here. The strike ridges of basic intrusives and Vempalle limestones are marked by brown coloured soil. Basic sills which are intrusive into the Vempalle and Tadpatri stages exhibit spheroidal weathering. Chemical weathering is shown by limestones. Shales form the low lying areas since they are not resistive to weathering. Biscuit and needle like weathering of both Vempalle and Tadpatri shales is common.

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C H A P T E R - II

GEOLOGY AND STRUCTURE OF THE AREA

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GEOLOGY OF THE AREA

The first stratigraphic succession of the Cuddapah rocks was given by King (Op. cit.) which is as follows :-

Cuddapah System

Upper Cuddapahs	Kistna series (2,000 feet)	Srisailam quartzites Kolamnala shales Irlakonda quartzites
	Nallamalai series (3,400 feet)	Cumbum shales Bairenkonda quartzites
Unconformity		
Lower Cuddapahs	Cheyair series (10,500 feet)	Tadpatri shales Pulivendla quartzites
	Papaghni series (4,500 feet)	Vempalle limestones and shales Gulcheru quartzites
Eparchean Unconformity		

ARCHEAN - GNEISSES AND SCHISTS

He divided these rocks into two groups namely Lower and Upper Cuddapahs, where he recognised a large break in sedimentation inbetween.

In the present area only the rocks belonging to the Papaghni and the Cheyair series are found and these are outlined below

INTRUSIVE SILLS

Cheyair series	Tadapatri stage	Shales which are chloritic and ferruginous with intercalations of limestones.
	Pulivendla stage	Conglomerate and quartzose sandstone.

Papaghni series	Vempalle stage	Limestones which are at times magnesian and siliceous, containing intercalations of ferruginous shales.
	Gulcheru stage	Conglomerates and quartzites (occur further towards south of the investigated area)

Eparchean unconfirmity

ARCHEAN ROCKS

The previous authors including King (op. cit) and Coulson (1933) did not recognise major unconformity between Papaghni and Cheyair series, but the persistant conglomerate horizon with well rounded pebbles points to an unconformity. The dips of the two series do not vary much thus representing a disconformity.

GULCHERU STAGE

Gulcheru conglomerate and quartzite which form the base of the Cuddapah group of rocks and lie unconformably above the Archaeans, are not present in the mapped area but occur further towards the south.

VEMPALLE STAGE

In the area under investigation the Vempalles in general form conical rounded hills and their topographic expression in contoured appearance and also their gray to dark gray weathering make them easily recognisable. The Vempalle stage consists of dolomite, chert and mud stone with bands of sandstones and quartzites. The bulk of the formation is dolomite but chert and mudstones are repeatedly interbedded with dolomite. Shales also occur as intercalation in Vempalle limestones more particularly in the upper members of the stage. These are also indurated and compact. In the lower members of the Vempalles bands of quartzite are developed which indicate periods of arenaceous sedimentation. Two sills, one named the Lower sill and the other Upper sill, have intruded in the Vempalles and the description of these sills is given latter in this chapter. Along the upper contact of the lower sill, a zone of asbestos has developed starting from south of Brahmanapalle and extending further northwest of Lopatanutala. Their occurence, origin and economic importance of these deposits have been dealt in chapter 6. The succession in vempalles as observed in the field is given below.

Silicous limestone contains much silica, mostly in the amorphous form and is recognised as chert. The silica often occurs as alternate bands with its calcareous counterpart. Such varieties often show concretionary structures (Plate I, Photo.1 and 2, Plate II, Photo.1) the size of which vary from 2 cm. to 3 meters and these are probably the result of diagenetic processes when the precipitation has taken place around a nucleus which may have been a sand particle. These have been variously described as "algal structures", "cabbage flower" like structures" "concentric structures" etc. It is yet a matter of controversy as to whether they are really algal structures or not. Jhanwar, Rajurkar and Phadtare (op. cit.) p.51, preferred to call them as pseudoalgal structures.

In the present area siliceous and ferruginous limestones occur very locally. The limestones occuring east of Midipenta, south of the Upper sill, are of this type. On weathering, they give rise to yellow ochre when the calcium carbonate and silica are removed in solution.

Oolitic limestones are mainly calceareous and siliceous with oolites having radial as well as concentric arrangement. They are probably inorganic in origin since there are no indications of life in the Cuddapahs. This is also a very local occurrence.

Thin section study of these rocks is given in Chapter 3. From these studies it is clear that the Vempalle limestones and dolomites contain quartz and chert with recrystallized calcite and dolomite.

The present author has analysed four Vempalle limestones from the present area (AP/55, AP/69, AP/61 and AP/51). Their average chemical composition is given below:

Insoluble residue	...	...	11.73
CaO ...	...	...	36.48
MgO ...	...	...	14.97

Based on this chemical composition, it can be concluded that the Vempalle limestones are magnesian rich with considerable amount of impurities and hence may be called as dolomites.

Jhanwar, Rajurkar and Phadtare (op. cit.) pp. 48-49, based on the chemical composition of the Vempalle limestones, have also suggested that the term "Vempalle limestone" be replaced by "Vempalle dolomite".

PULIVENDLA STAGE

Conglomerate :- The lower member of the Pulivendla stage is represented by a quartz pebble conglomerate with pebbles ranging from 2 mm. to 10 cm. embedded in a fine grained quartzose matrix which is some times ferrugenous (Plate II, Photo 2). The Pulivendla conglomerate is not persistant all along but is present only around the village Lingala from where it pinches out towards east. South of Bhrahmanappalle village, there is also a thin outcrop in a nullah.

Few conglomerate specimens with ferrugenous matrix have been polished and studied under ore microscope. It was found that the hematite has partly replaced the intergranular cement. Replacement of the cement by hematite has given rise to cement texture. Thus, this ferrugenous matrix was introduced later during diagenesis.

The pebbles are generally well rounded (Plate III, Photo.1) and are mostly made up of vein quartz, quartzite and chert derived from the Archeans and probably also from the underlying Gulcheru and Vempalle stages. At places the chert pebbles show oolitic structures and these seem to have been derived from the chertification of original vempalle oolitic limestones.

The sphericity values for 143 pebbles are determined. The average sphericity is 0.746 and it ranges between 0.18 to 0.97. Out of these 143 pebbles, 114 pebbles have sphericity values higher than 0.7. This well rounded nature of the pebbles point towards a well worn history of the sediment.

<u>QUARTZOSE SAND STONES:</u> (ORTHOQUARTZITES)

Pulivendla quartzose sandstone overlies the quartz pebble conglomerate at the places cited above. It is about 15 to 25 metres thick and has a maximum thickness of about 30 metres, South of Lingala village. It is a fine to medium grained well sorted sandstone with well rounded grains. Quartz is the main constituent of the rock and the matrix is generally siliceous while ferrugenous matrix is not uncommon. They are hard, compact and brownish gray in colour. These quartzose-sandstones have gentle dips ranging from 25° due N18°E (near the village Chinnakudala).

It exhibits sedimentary features like cross bedding and ripple marks (Plate III, Photo 2 and Plate IV, Photo 1). Current direction as measured from the ripple marks indicate that the current was flowing from N50°W direction. Thin section study (Chapter 3) of these sandstones indicate that the main constituent is quartz with little amount of chert and iron oxide while felspars are practically absent. The constituent grains are generally well rounded and well sorted. Quartz grains at places show authigenic growth. These sandstones are named as orthoquarzites because more than 90% of the rock is composed of quartz grains and matrix is less than 10%.

TADPATRI STAGE

The Tadpatri stage which lies conformably over the Pulivendlas is a dominantly shaly horizon with intercalations of limestone. Unlike the Pulivendlas, they are quite persistant and are traced all through the area.

These shales being softer, form low lying areas and on plains they are weathered. Exposures are mainly seen along the nala cuttings.

The shales in Tadpatri have been intruded by a thick sill (Tadpatri sill) which stands as a low ridge. This sill has been described later in this chapter.

Tadpatris have the same dip (10° to 25° due NE) as the underlying formations.

SHALES :

Two types of shales are mainly recognised in field namely green and red shales. The green coloured shales owe their colour due to the chlorite which is present in abundance. These green shales give a soapy feel on fresh surfaces and the other minerals to be found in these are muscovite and quartz. In some, the constituent grains are of silt size with no prominent bedding and are better termed as siltstone or mudstone. The red coloured shales are mainly ferruginous. They are better laminated and cleaved than the green shale. They occur as alternate bands and these alternations are sometimes very closely spaced. Both green and red shales show biscuit weathering. They also exhibit sedimentary features like shrinkage cracks and penecontemporaneous deformation.

SAND STONE LENSES IN SHALES:

There are only a few sandstone lenses in shales and they are only of local occurrence. They are fine grained sandstone. The constituent grains are cemented by ferruginous matrix. Pellets of iron oxide are often present which show regular to random orientation.

LIMESTONES IN SHALES :

There are a few thin, but persistent bands of limestones in Tadpatri shales and are seen north of Chinnarangapuram, Peddakudala etc. They are thinly bedded and are siliceous in nature with much of chert. Four such limestone bands are met in the mapped area. All these are thin bands except the one that is found north of Chinnarangapuram. This band is mainly silicous limestone with a thickness of about 10 meters. Certain "pesudoalgal structures" are found in this band.

Analysis of the Tadpatri limestones give the following results:-

Insoluble residue	...	...	14.89
CaO ...	...	...	39.52
MgO ...	...	...	9.96

Based on this chemical composition Tadpatri limestones may be described as magnesian limestones with considerable amount of impurities. However the amount of MgO in these limestones is less than in the Vempalle limestones.

Tadpatri shales are usually green and purple while vempalle shales are more ferrugenous. Tadpatri shales show characteristic biscuit like and needle weathering, while this sort of weathering is rather uncommon in Vempalle shales. Tadpatri shales are inter-bedded with siltstone and stromatolitic limestone. Shales dominate the Tadpatri stage while limestones and dolomites dominate the Vempalle stage. Stromatolites are universally seen in Tadpatri limestones while they are rarely seen in the Vempalle limestones.

<u>INTRUSIVES IN THE VEMPALLES AND THE TADPATRIS</u> :

There are three intrusive bodies in the area. Two are within the vempalle stage and the third is in the Tadpatri stage. The two intrusive bodies in the Vempalle stage are named as Lower sill and Upper sill. These are described below:

<u>Lower Sill</u> :- This is a medium grained doleritic sill - grain size being coarser than that of Upper sill. It has generally a uniform thickness of about 10 metres. The general dip of the sill and of the overlying and underlying Vempalles is about 10° to 20° due NE.

This sill has a conspicuous effect on dolomitic limestone towards the top where serpentine and asbestos are developed. Serpentine is black, shades of green and grey or yellowish in colour. Differential Thermal Analysis of serpentines is given in chapter 4. Within the serpentines asbestos of economic importance has developed which is mined at several places as seen in the village Ippatla. The zone of asbestos is only few inches in thickness and the asbestos is of cross fibre nature. Very little asbestos is developed at the lower contact of the sill.

Thin section study (Chapter 3) of the rocks from this sill indicate that the main constituent minerals are plagioclase (labradorite) and clinopyroxene (Augite) with magnetite and quartz as accessories. From the mineral composition as well as the chemical composition (Chapter 6) it is concluded that the rock is a dolerite.

<u>Upper Sill</u> :- This is composed of two sills which follow the same trend as the Lower sill. This sill has been named as Upper sill because it has intruded at a higher stratigraphic level as compared with the Lower sill. The intervening space between the two sills is occupied by Vempalle limestones and shales. The upper part of the

upper sill is either in contact with the Vempalle limestone or with the Pulivendla conglomerate. For this reason, it is regarded that the upper sill is of transgressive nature. The upper sill is much larger in thickness (100 ft.) as compared with the Lower sill. Though it is a sill, it is seen to be discordant locally, sending off-shoots and enclosing larger volumes of country rocks. It has been dislocated by the Ippatla faults and Chinnakudala faults. At Ippatla, the formations have been dislocated towards east while at Chinnakudala the formations have been dislocated towards south. This is because the strata between the two Ippatla faults have gone up with respect to the adjacent formations while the strata between the two Chinnakudala faults have gone down. The fault at Lingala has also effected the Upper sill. Here, the strata north of the fault are the upthrown side since they are dislocated towards the dip direction. The much larger thickness of the upper sill West of Chinnakudala can be explained to be due to the coincidence of the dip and the ground slope.

The upper sill is much fine grained and basaltic as compared with the lower sill. It is black to pinkish black in colour. At places number of vesicles are seen which are usually filled with quartz, calcite, zeolite and chert. At places it shows spheroidal weathering and columnar jointing. The general dip is like that of Vempalles (10° - 20° due E-E). At many places it is observed that the rock is highly epidotised and silicified. Stringers of epidote and veins of quartz are common. No asbestos has developed in its contact with Vempalle limestones.

At village Lingala, the Upper sill shows the presence of volcanic agglomerate. From the fine grained nature, abundance of vesicles and the presence of agglomerate it appears that the upper sill in Vempalles is either an extrusive body or if it is an intrusive body, the thickness of the overburden at the time of intrusion was very little so that the magma crystallised rapidly with escape of gases and this resulted in the fine grained and vesicular nature of the rock.

<u>SILL IN THE TADPATRIS</u> :

It is a thick sill, out cropping for one and half kilometer northwest of Pulivendla dak bunglow.

The upper and lower portions of the sill are quartz dolerites which the central portion is made of picrite-gabbro. Well developed columnar jointing has produced hexagonal blocks at places, particularly in the upper members of the sill. In the middle portion of the sill where it is made of picrite gabbro it has been observed that olivine has changed into asbestos in small amounts. The development of asbestos is very local and is of no economic significance. The middle portion of the sill is at times much coarse grained and dark. Epidotisation is seen at some places but it is not very common.

Detailed petrographic description of various rock types associated with this sill is given in chapter 3. Chemical composition, trend of differentiation and petrogenesis are discussed in Chapter 5.

AGE OF THE SILLS :

It appears that the intrusives in the Vempalles are post Papaghni in age while the sill in the Tadpatris would have intruded during the post - Cheyair period.

S T R U C T U R E

INTRODUCTION :

A look at the Cuddapah basin shows that the structure of these rocks as a whole is interesting in that the rocks in the western part of the Cuddapah basin are disturbed slightly whereas the rocks in the east are highly folded and faulted. The western margin of the basin is a curved one having a WNW-ESE trend in the south, becoming NW at the western part and finally NE-SW in the north. This bend can also be seen at Pulivendla where the rocks assume a trend from EW to NW-SE. The earlier workers mentioned that this trend is not a diastrophic phenomenon but entirely a sedimentary one representing the original shape of the basin.

In the present area five faults and some minor folds are noticed as are described below. All these five faults have a similar trend i.e., E,NE-W,SW and have affected mainly Vempalle limestone and the sills which are intrusive into it. The Tadpatri sill has not been affected by any conspicuous faulting.

The faults in the area are economically important as most of them had served as zones of barytes mineralisation.

IPPATLA DISLOCATION :

The two faults near Ippatla, are named as Ippatla fault and the Brahmanpath fault which taken togethr make one block fault system. The strata that lie in between these two faults are displaced north-easterly for a distance of nearly half a mile. Since this displaceme ent is towards the dip direction, it can be said that the strata in between these two faults represent the upthrown side for each fault. But the prominent drag effect on the strata south of the Brahmanpath fault suggests that there is some amount of strike slip also along this fault. The drag effect is observed on the downthrown side of the Ippatla fault. Thus it can be concluded that the strata in between the two faults moved obliquely upward in which the dip slip is prominent in the case of Ippatla fault while strike slip movement is prominent in the case of Brahmanpath fault. There is no change in dip in the effected strata showing that they have not been tilted.

The Brahmanpath fault has effected the continuation of the asbestos horizon and further towards it is covered mostly by alluvium. However, this fault could easily be traced due to the dislocation of the various sills. The fault runs N80°E-S80°W.

The Ippatla fault which also has the same trend as that of the Brahmanpath fault runs westerly from the Ippatla village and is traced for about a mile. Here the drag effect is not seen on the downthrown side of the fault. This fault is economically important because it is mineralised by barytes accompanied by siderite, dolomite, calcite and quartz.

CHINNAKUDALA - RAMMUTLAPALLE DISLOCATIONS :

Here also there are two faults - one fault runs west of the Chinnakudala village and the other runs west from Rammutlapalle village. Although these two faults run parallel to the previous two faults near Ippatla, here the nature of dislocation is opposite to that of Ippatla dislocation. Here the strata between the Chinnakudala fault and the Rammutlapalle fault are dislocated southwesterly for about a mile.

Since this dislocation is opposite to the dip of the beds, it appears that the strata inbetween these two faults have moved downwards. Whether there is any drag effect or not could not be decided since the area is much covered by alluvium.

LINGALA FAULT :

The Pulivendla quartzose sandstone which has become consistent from west of Rammutlapalle, as well as the Vempalle basic sills are affected by faulting near village Lingala. This fault, which has an east-west trend, has a trend parallel to the previous faults. The strata north of the fault have been dislocated towards east as compared to the strata south of the fault. Taking into consideration the dip direction of the faulted strata and their relative displacement it appears that the southern side of the fault was downthrown.

FOLDS :

It has been observed that the faults at Ippatla, Chinnakudala and Lingala are associated with minor folding. Such folds are seen in south of Ippatla and are also noted near Chinnakudala and south of Lingala. The folds in the Ippatla area are worth mentioning. One anticline and one syncline have been noticed south east of Ippatla and in this region many minor folds are also noticed (Plate IV, Photo 2, Plate V, Photo 1). All of them have got a uniform plunge of 10° towards S70°E. The minor folds vary from 3 meters to 60 meters in diameter and their plunge is in general towards E.SE with a low angle of 10° to 15°. These folds are due to drag effect brought about by faulting.

PATTERN OF SEDIMENTATION

It is possible to determine the environments of sedimentation from the lithologic variation in the stratigraphic sequence, sedimentary features and structures.

The stratigraphic sequence as observed in the present area indicate certain characteristic features. In vempalle stage dolomitic limestones are more prominent with minor bands of shale while in the younger Pulivendla stage conglomerate and orthoquartzites predominate followed by Tadpatri stage in which a thick sequence of alternate shale and limestone is observed.

In Vempalle stage the limestones are mainly siliceous with circular and oolitic markings. Such a character of limestone would indicate shallow water conditions corresponding to platform association.

The sandstone of Pulivendla stage are of orthoquartzite type. They are generally, well sorted and cross bedded with conspicuous ripple marks. These characters of Pulivendla quartzites would indicate deltaic environments. As described earlier the Pulivendlas conglomerate is of oligomictic nature and the pebbles are perfectly rounded with high sphericity (more than 0.7) which indicate a well worn history of the sediments. The matrix of the orthoquartzite is either siliceous or ferrugenous. All these factors i.e., sphericity, sorting, cross bedding, ripple marks and a basal oligomictic conglomerate indicate that the Pulivendlas were deposited under shallow water conditions. The ripple marks in the Pulivendla orthoquartzite indicate that the material was brought from different directions.

Gokhale and Bagchi (1959) from their study of Kolava-Gani area, Kurnool district, have suggested that the Pulivendlas were deposited in a transgressive marine environment.

In Tadpatri stage shale predominate over limestone and as compared with Pulivendla stage there is absence of orthoquartzites. This would indicate that as compared with the Pulivendlas Tadpatris were deposited under comparatively deep water conditions.

From all the above discussion, it can be concluded that the sedimentary rocks of Pulivendla region belong to Orthoquartzite - Limestone series of platform association.

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C H A P T E R - III

PETROGRAPHY

PETROGRAPHY

BASIC INTRUSIVES IN THE VEMPALLES

DOLERITE FROM LOWER SILL (AP/111)

Megascopically, the rock is dark grey in colour, composed of grayish felspars and dark ferromagnesian minerals.

In thin section, the rock is coarse grained, holocrystalline and slightly inequigranular. The constituent grains are subhedral. The main constituents of the rock are plagioclase and augite. Plagioclase felspars make up the bulk of the ground mass in the form of small laths developed in subophitic relation with the pyroxenes which they penetrate from the edges and make the pyroxenes to show angular outlines.

Plagioclase, the most abundant mineral present in the rock forms 47.3% of the total rock constituents as shown by its modal analysis. They occur in the form of well developed laths and show twinning on albite and carlsbad laws. Plagioclase is colourless and shows weak birefringence. Interference colours are first order grays. The maximum extinction angle is 32°, for grains showing twinning on albite law. From Mitchel-Levey's graph, the corresponding composition is Ab_{42} An_{58}. This agrees fairly well with the normative composition of the plagioclase, $Ab_{40.2}$ $An_{59.8}$ and with the composition obtained by plotting K and 2alk/al + alk values in Niggli's diagram (Fig. 3). Untwinned plagioclase is not uncommon. At places plagioclase has altered into patches of sericite.

Augite mostly occurs as subhedral prismatic crystals with four sides and irregular boundaries. They are pale purplish brown in colour and form 38.4% of the total rock mass. Augite crystals are often altered in part into antigorite which is greenish in colour and show weak birefringence. Alteration is more prominent along the margins of the grains. The extinction angle and the birefringence of aughite vary widely, the former varying from 38° to almost parallel. Those grains which show high extinction angle show bright colours of low and middle second order. These are more diagnostic. The low birefringence and low extinction angle is due to their orientation being parallel to one of the optic axes. Augite often shows polysynthetic twinning and herringbone structure (Photo 2 , Plate 5). The twin plane is (100). Some basal sections of augite with cleavages of 87° and 93° are also present. At places, intergrowth between pyroxenes and plagioclase is observed as is shown by the laths of plagioclase present in the plates of augite.

Magnetite is more or less uniformly distributed in the rock. It is black and opaque and form 6.8% of the total rock mass. Most of the magnetite grains are anhedral while euhedral and subhedral grains yielding rhombic, square and triangular sections are also present.

Little interstitial quartz is also present and forms 1.8% of the total rock mass.

In the polished section of this rock magnetite and traces of chalcopyrite are identified.

The modal composition of the rock is as follows :

Plagioclase	...	...	47.3
Augite	...	...	38.4
Magnetite	...	...	6.8
Antigorite	...	...	5.7
Quartz	...	...	1.8
			100.00

EPIDOTISED DOLERITE FROM THE UPPER SILL (AP/142)

Megascopically, the rock is fine grained and dark grayish in colour with epidote which has imparted greenish tinge. Thin veins of epidote are common.

In thin section, the rock is fine grained and merocrystalline. The rock is largely composed of anhedral grains of epidote and quartz, traversed by thin veins of epidote and quartz. Little felspar is present. The rock texture may be described as allotriomorphic.

Epidote is colourless to yellowish in colour and distinctly pleochroic. It is generally fine grained and forms anhedral crystals. At places slightly elongated crystals are present. Epidote shows high relief and strong birefringence with bright upper second order colours - yellow, green, violet and red. Extinction is parallel to cleavage. Vein epidote forms medium to coarse grained subhedral crystals which are more diagnostic.

Quartz and epidote together make up the bulk of the rock mass. Quartz is colourless with low relief and has low birefringence with polarisation colours in yellow and gray of first order. At places narrow quartz veins are present.

Felspars occur in very small amount. Magnetite is more or less uniformly distributed throughout therock mass. This rock is an epidotised Cumb dolerite in which practically no trace of augite is left and even most of the plagioclases are replaced by epidote and quartz. The rock has also lost its original ophitic or subophitic texture.

<u>BASIC INTRUSIVES IN THE TADPATRIS</u>

The Tadpatri sill, intruded in the Tadpatri shales, varies in composition from quartz dolerite to picrite-gabbro. The central portion of the sill is very basic and contains coarse grains of abundant olivine, augite, enstatite, plagioclase, serpentine, iron ore and brown mica and thus differs from the layers above and below it, which are dolerite without olivine. This points to the composite nature of the sill. The picrite-gabbros described below belong to the central portion of the sill while the dolerites are from the layers above and below it.

<u>PICRITE-GABBRO</u> (AP/235)

These rocks are medium to coarse grained in hand specimen and appear darker than quartz dolerites described latter. In thin section, they are medium to coarse grained with olivine, pyroxene (both ortho and clino) and plagioclase as main constituents. The other constituents are chlorite, serpentine, biotite and magnetite. Bigger grains of pyroxene, both ortho and clino, enclose smaller subhedral to anhedral grains of olivine (Photo I , Plate VI) giving rise to poikilitic texture. At places due to the alteration of olivine into serpentine, expansion cracks are developed in the surrounding pyroxene or plagioclase.

Olivine occurs as colourless rounded and polygonal grains traversed by cracks along which alteration into antigorite and iron oxide is prominent. Their strong birefringence, i.e., bright first and second order colours, high refractive index and the absence of cleavage are the other prominent diagnostic features. Sometimes olivine has been completely pseudomorphed by serpentine.

Augite occurs as big colourless to pale purplish brown crystals of subhedral and anhedral nature, and shows moderate birefrigence showing bright yellow, blue and green colours of second order. The maximum extinction angle is 38° with respect to cleavage. Many grains are prismatic while there are few basal sections also.

Enstatite at some places is found surrounding olivine indicating thereby reaction relationship between them. It is distinguished by closely spaced cleavage, parting, alteration to bastite, first order gray colours and straight extinction. In AP/235 enstatite is the dominant pyroxene.

Plagioclase occurs as being big colourless subhedral grains and show twinning on albite and carlsbad laws. The mineral is colourless and show weak birefringence, interference colours being first order grays. The maximum extinction angle is 38° as determined for the grains that show twinning on albite law. The corresponding composition from Michel-Levy's graph is An_{68} Ab_{32}. The plagioclase here is much traversed by cracks which are formed due to alteration of olivine into serpentine. Plagioclase is generally observed in the intergranular spaces between euhedral grains of olivine and can be recognised by its twinning and first order gray colours. The grains are generally cloudy due to alteration. The normative composition of plagioclase in AP/233 seems to be An_{65} Ab_{35}. The composition obtained by plotting k and 2 alk/al + alk values in Niggli diagram together with the values obtained from optical determinations and from C.I.P.W. norm are tabulated in Table 2.

Antigorite is greenish in colour and occurs as shapeless patches but its fibrous nature becomes distinct under crossed nicols.

The accessories are biotite and magnetite Biotite shows strong pleochroism from deep yellowish brown to light brown, moderate birefrengence and straight extinction. Magnetite occurs as small irregular black opaque grains distributed rather uniformly throughout the rock. In olivine it is restricted to cracks and in biotite and augite it occurs along cleavages.

The modal analysis of two rocks, AP/233 and AP/235 are tabulated below.

Constituent minerals	Thin section No. AP/233	Thin section No. AP/235
Olivine	28.8	36.0
Augite	16.9	8.7
Enstatite	5.6	23.4
Plagioclase	23.5	25.2
Antigorite and Chlorite	18.9	4.8
Biotite	3.4	0.7
Magnetite	2.9	1.2
	100.00	100.00

These two rocks when compared with each other points to certain variations. One such variation is in the amount of olivine. AP/235 is richer in olivine by 7.2% and the poikilitic texture is much more characteristically seen in it. Another difference is in the amount of orthopyroxene and clinopyroxene. In AP/233, clinopyroxenes dominate while in AP/235, clinopyroxenes orthopyroxenes dominate. The AP/233, pyroxenes are less in amount (22.5%) while the pyroxenes are comparitively more in AP/235 (32.1%). Inspite of these differences AP/235 could not be named as picrite simply due to its plagioclase content. Alternatively both rocks can better be named as picrite-gabbros.

QUARTZ DOLERITE (AP/234, AP/237, AP/238, AP/239, AP/240)

The term dolerite is usually assigned to those rocks which show a characteristic ophitic texture in which augite encloses disconnected laths of plagioclase and this is explained to be due to an early crystallization of plagioclase. However, in many thin sections we get characters which either point towards the early crystallization of pyroxenes or plagioclases and at times the simultaneous crystallization of both these minerals. For convenience sake, under the term dolerite here are included all those medium grained melanocratic rocks which show the ophitic, poikilitic and porphyritic textures.

Quartz dolerites appear grayish black in hand specimen and contain grayish plagioclases and dark ferromagnesian minerals. In thin section they are holocrystalline and medium to coarse grained. The constituent minerals are plagioclase, augite, enstatite, and little micropegmatite. Accessory biotite, magnetite and chlorite are also present in all the slides. Often plagioclases alter into patches of saussurite while pyroxenes alter into hornblende and uralite. Such alteration is observed to the maximum in thin section No. AP/234 (Photo 2 , Plate VI), in which pyroxenes are altered to hornblende and uralite, felspars are saussuritised, and ilmenite is altered to leucoxene. In some thin sections, orthopyroxene and clinopyroxene are enclosed by plagioclase laths while in others plagioclase laths are enclosed by pyroxenes. This varying relationship between the pyroxenes and the felspars result in the variation of the texture from ophitic and poikilitic to porphyritic.

Plagioclase dominates the rest of the minerals and ranges between 42.7% to 48.8% of total rock mass. The composition of plagioclases based on the extinction angle ranges from An_{51} Ab_{49} to An_{38} Ab_{62}. This coincides markedly with the compositions determined from the norm and by plotting the k and 2 alk/al + alk values in Niggli's diagram. These values are given in Table 5. Plagioclase grains occur as sub-hedral laths and appear cloudy due to saussuritization. It is colourless and show low relief and low birefringence, the interference colours being first order yellows and grays. Plagioclase shows twinning on albite and carlsbad laws. Untwinned plagioclase is not uncommon. In the grains in which alteration is more, the extinction is not clear and the composition is often difficult to determine in such cases. Plagioclases are generally comparitively more altered in the central part than in the margins and this perhaps is due to a difference in the composition of the plagioclase.

Both orthopyroxenes and clinopyroxenes are present, but the latter is more dominant of the two as can be seen from the modal analysis of these rocks given below. Pyroxenes are generally larger in size than plagioclase. The clinopyroxene is augite and is generally pale purplish brown in colour. Purplish and brownish tints indicate that they are titaniferous. The mineral occurs in elongated or stumpy prisms, generally twinned on (100), showing sometimes herringbone structure. Few basal sections show irregular shapes, two sets of cleavage at angles of 87° and 93°, symmetrical extinction and first order colours. The alteration of augite into hornblende is prominent in some thin sections (AP/234, AP/240). Augite shows at places exsolution lamellae of orthopyroxenes which can be recognised due to their straight extinction.

The orthopyroxene (enstatite) occurs as colourless, coarse, subhedral to anhedral grains. It is characterised by low birefringence. Interference colours are of first order greys and yellows and the extinction is straight with respect to cleavage. Alteration into uralite is more prominent along the partings perpendicular to the prismatic cleavages.

Often, in one grain of pyroxene there are numerous grains of felspars without any orientation, showing a typical ophitic texture (Photo 1 and 2, Plate VII) indicating thereby early crystallisation of plagioclases. In others, plagioclase laths enclose augite showing early crystallisation of the latter. Uralitisation is more prominent in orthopyroxenes while clinopyroxenes are comparatively fresh. Uralite has sometimes replaced the original pyroxene in such a fashion, so that the characteristic herringbone structures of the parent mineral (pyroxene) is preserved.

Quartz and micropegmatite are generally restricted to the intergranular spaces. Some of the quartz seems to be of secondary origin, probably on account of the kaolinisation of the felspars. Micropegmatitic intergrowth is also characteristically seen around the margins of calcic plagioclases, resembling myrmekite.

The accessories are magnetite, biotite and chlorite. Magnetite is more or less uniformly distributed and occurs as well developed euhedral and subhedral grains, often altered to leucoxene. The presence of leucoxene in some of the sections indicates that part of the magnetite may be titaniferous. This is confirmed by the observation of the rock under polished section where titaniferous magnetite and traces of chalcopyrite are noticed. Occurrence of biotite is sporadic and presents no difficulty in identification due to their pleochroism, extinction and birefringence. Some phlogopite flakes are present as distinguished by from biotite by their lighter colour and weaker absorption. Greenish coloured and pleochroic chlorite is present in most thin sections.

The modes of four quartz dolerites are given below to show the mineralogic variations.

(Contd.)

Constituent minerals	Rock No. AP/234	Rock No. AP/237	Rock No. AP/238	Rock No. AP/240
Plagioclase	42.7%	44.5%	55.1%	43.5%
Micropegmatite	5.1%	-	1.8%	2.2%
Quartz	4.1%	3.8%	5.2%	6.2%
Augite	20.6%	24.3%	19.4%	27.6%
Enstatite	-	25.2%	16.6%	18.9%
Hornblende	18.9%	-	-	-
Chlorite and antigorite	6.3%	-	-	-
Magnetite	2.3%	1.8%	1.9%	1.6%
Biotite	-	0.4%	-	-
	100.00	100.00	100.00	100.00

<u>PULIVENDLA ORTHOQUARTZITES</u> (AP/130, AP/132)

In hand specimen, Pulivendla quartzites are hard, compact and fine grained and appear dull brownish in colour.

In thin section, the constituent minerals are quartz and chert, the latter amounting to about 10% or less.

Quartz occurs as well rounded grains which are colourless, show low relief and low birefringence; few thicker grains show bright lower second order colours. Quartz grains are clear and show no inclusions. At places secondary authigenic growth is common, yielding well terminated euhedra with detrital nucleus. The cementing material is practically absent, except for a thin film of iron oxide around some grains.

The other mineral is chert and occurs as well rounded to sharply angular grains. Under crossed nicols, chert appears as very fine grained cryptocrystalline granular mosaic mass and shows aggregate polarisation under crossed nicols. It is sometimes coloured in red and brown colours, owing to pigmentation by haematite. In rock No. AP/132 sorting is comparatively better than in AP/130. These rocks are rich in quartz and chert and so they can be named as orthoquartzite. The well rounded nature of bigger grains points towards a distant source area.

<u>QUARTZITE WITH BARYTES</u> (AP/219)

The rock shows granulose texture under thin section. Quartz is the most abundant mineral and appears in the form of bigger and smaller grains.

Barytes has developed along the intergranular boundaries. Barytes shows one or two cleavages nearly at right angles, high relief, first order gray and yellow polarisation colours and straight extinction. Few grains show polysynthetic twinning. From the textural relationship between barytes and quartz, it appears that barytes has replaced quartz.

At other places, barytes is further traversed by veins of secondary quartz.

<u>VEMPALLE LIMESTONE</u> (AP/81, AP/34)

The colour of limestones vary with impurities and composition, generally it varies from dull gray to grayish black.

In thin section they contain calcite as the main constituent. Calcite is colourless and occurs as fine euhedral aggregate. Some dirt like carbonate mass is also present. Calcite shows extreme birefringence and the polarization colours are third order yellows, grays and reds.

Chrysotile has at places, been found to have exotically developed. It is colourless and show moderate birefringence in second order blues. Its fibrous nature is more distinct under crossed nicols. Chrysotile occurs in the form of thin veins with minor plications at places and also as isolated patches within the carbonate mineral.

Little amount of sericite showing second order colours and refractive index higher than serpentine, is also commonly present.

<u>FIBROUS SERPENTINE</u> (AP/78-2)

The constituent minerals of the rock are chrysotile and carbonate mineral. The rock shows fibrous texture.

Chrysotile is fibrous in form and is colourless. It shows low relief, moderate birefringence, the interference colours being second order blues and parallel extinction. It is largely replaced by carbonate minerals.

The carbonate mineral is colourless but cloudy. They occur as fine aggregate fibres and very high birefringence. The interference colours are yellows, greens and reds of third and fourth orders.

The fibrous nature of the carbonate minerals indicate that it is pseudomorph after chrysotile (Photo 1, Plate VIII). The carbonate mineral is most probably calcite.

<u>GREENISH-GREY SERPENTINE</u> (AP/78-1)

Under thin section this rock shows granulose texture with abundance of carbonate minerals and little amount of serpentine.

The serpentine is colourless and has low relief. Interference colours are bluish gray of second order. It occurs as small fibrous aggregates within the carbonate mass.

<u>BLACK SERPENTINE</u> (AP/98)

This rock also shows granulose texture and the constituent minerals are carbonate mineral, iron oxide (Magnetite) and serpentine.

The carbonate mineral generally becomes opaque as it is coated with iron oxide. Black opaque magnetite also occurs in good amount.

Serpentine occurs around carbonate mineral in the form of veins and patches. It is colourless, shows low relief and second order bluish gray interference colours.

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CHAPTER - IV

Differential Thermal Analysis of Serpentines and Associated Minerals.

DIFFERENTIAL THERMAL ANALYSIS OF SERPENTINES AND ASSOCIATED MINERALS

Differential thermal analysis (DTA) has been carried out for four samples of serpentines, (AP/75, AP/78-1, AP/93, AP/78-2), to determine their mineralogy and the changes brought about by heating. Thin section study of these samples shows the presence of serpentine, carbonate minerals and magnetite.

The principle of the differential thermal analysis (DTA) consists in measuring the change in temperature associated with physical or chemical changes during the gradual heating of the substance. Thermal changes due to dehydration, crystalline transition, lattice dehydration, oxidation, decomposition etc., are generally accompanied by an appreciable rise or fall in temperature and hence are amenable for DTA investigation.

DESCRIPTION OF THE APPARATUS AND THE METHOD USED :

DTA has been carried out semiautomatically by raising the temperature of the furnace at a constant rate of 10° C per minute by a Leeds Northrup Controller (U.S.A.). The differential temperatures were recorded by a sensitive galvanometer. Chromel-alumel thermocouples were used for measuring furnace and differential temperatures. The specimen holder was of Grimshaw and Roberts pattern. For the DTA studies 0.5 gram of the sample powdered to - 300 mesh is used. The maximum temperature used is 990°C.

The specimen to be studied is placed in one of the holes of the specimen holder made of silica. In the second hole of the holder is placed α-Al_2O_3 which does not undergo any transformation even at temperatures exceeding 1000°C. The chromel-alumel leg of each couple is connected together and the wires are set free. This constitutes the differential thermocouple. In to the third hole of the specimens holder, containing inert materials, another thermocouple tip is embedded which measures the temperature of the specimen holder. The chromel thermocouple is used because it gives higher e.m.f. than Pt-Rh thermocouple.

The block is placed in a furnace, which is heated at a uniform rate of 10°C per minute by the controller (Leeds Northrup Instrument, U.S.A.). The differential couple records zero e.m.f. as long as the substance under investigation does not undergo any change. Whenever a thermal change occurs there is either absorption or evolution of heat as a result of which the temperature of the substance becomes lower or higher than that of the inert material. A differential e.m.f. is thus set up, the direction of which depends on weather the reaction is endothermic or exothermic. The differential e.m.f. is measured on the sensitive galvonometer.

In the thermograms, the differential temperature (ΔT) and the temperature of the furnace are plotted in such a way so that the exothermal peaks show upwards with respect to the base line ($\Delta T = 0$).

CHARACTERISTIC FEATURES OF THE THERMOGRAMS OF PURE SERPENTINES, CARBONATE MINERALS AND MAGNETITE:

Serpentines :- Deer, Howie and Zussman (1962, Vol. 3 p.180), have mentioned that the D.T.A. curves obtained for many serpentines, although variable according to the grain size of the powder of the specimen and other experimental conditions, are consistent in showing certain characteristic features by which chrysotile and antigorite can be distinguished. One such outstanding feature is that antigorite gives an endothermic peak at about 750 to 780°C while for chrysotile the peak occurs at 680° to 750°C. This endothermic peak corresponds to the expulsion from the serpentine of the structural water, and it is followed closely by an exothermic peak related to the formation of olivine, the latter occurs at about 800° - 820° C but appears with widely varying intensity and sometimes is not present at all. It is possible that the dehydration process is followed so closely by the formation of olivine that in some cases the exothermic peak is overlapped and reduced by the endothermic one. A weak, broad, low temperature endothermic peak is shown by many serpentines at about 100°C corresponding to the expulsion of water which is held on the surface of the grained material. Obviously, this peak is more pronounced in finer grained samples.

DOLOMITE AND CALCITE

Deer, Howie and Zussman (1962, Vol. 5, p. 284) have mentioned that the D.T.A. curve for dolomite shows an endothermic peak at about 800°C due to break down of the Mg CO_3 component and a further endothermic peak at about 940°C due to the dissociation of the Ca CO_3 component.

Webb and Heystek (1957, p.331) have mentioned that Ca CO_3 peak temperature vary from 800°C to 1010°C with a mean of 954°C.

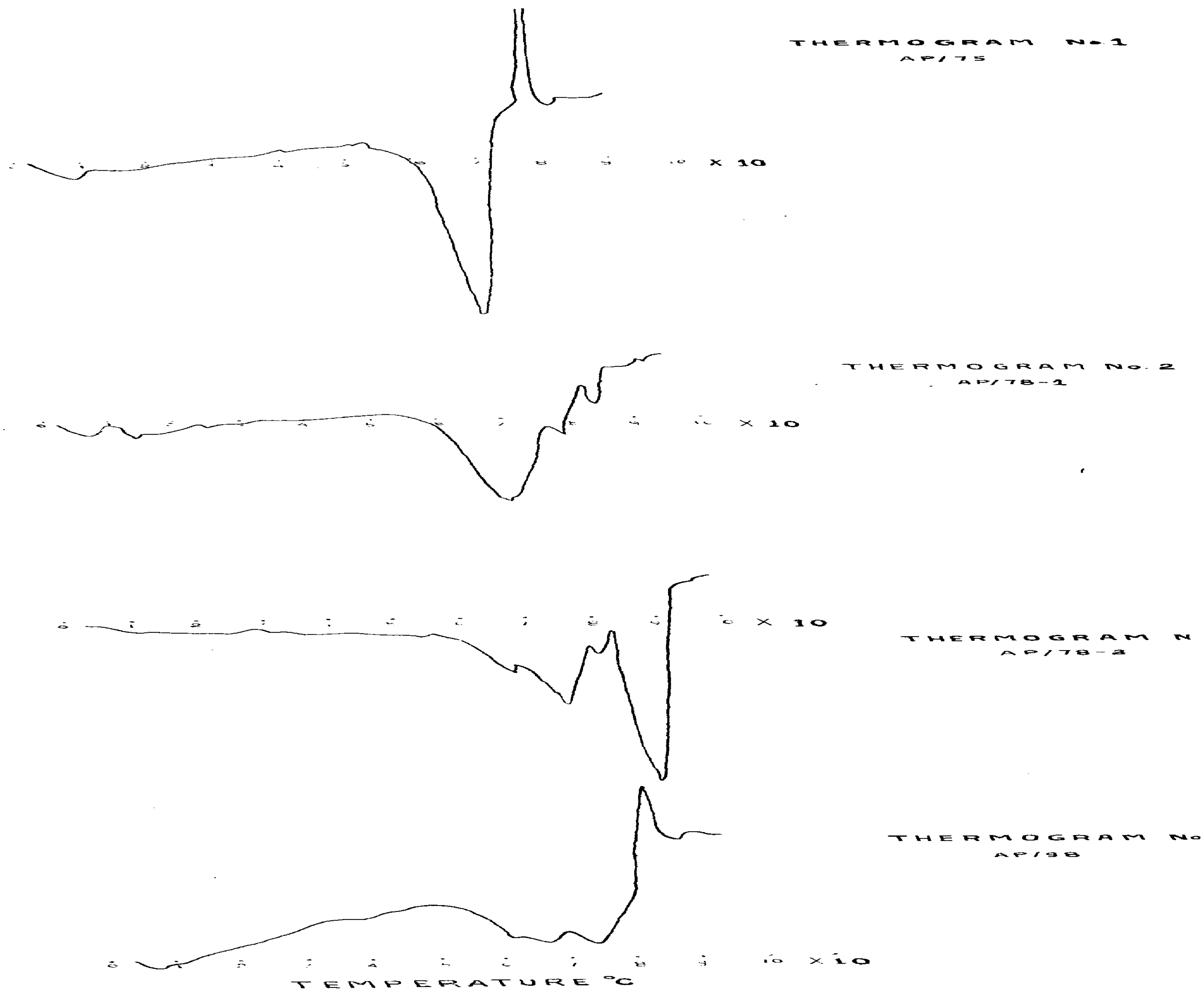
<u>Magnetite</u> :- Mackenzie (1957) has stated that magnetite gives a somewhat featureless curve showing only small exothermic effect at about 350°C - 400°C and a broad exorthermic effect over the 600 - 1000°C range. The first effect is due to oxidation of the surface layers of the magnetite particles, thus the intensity of the effect increases with particle size and may further extend the curve. The second effect is due to the slow oxidation of the remainder of the magnetite and commences once the structure has opened up after the curie point (590°C), which is observable in many curves as a very small endothermic peak.

DESCRIPTION AND INTERPRETATION OF THE THERMOGRAMS (Fig. 2)
<u>FOR THE ANALYSED SAMPLES</u>

<u>THERMOGRAM</u> No. 1 Specimen No. AP/75

It is of greasy whitish yellow brittle serpentine (chrysotile). This thermogram shows typical characteristics of chrysotile. It shows a small endothermic peak at 90°C, a very distinct sharp endothermic peak at 690°C, and an equally distinct and sharp exothermic peak at 790° C.

The small endothermic peak at 90°C is due to the loss of



THERMOGRAM No.1
AP/75
X 10
THERMOGRAM No.2
AP/78-1
X 10
THERMOGRAM N
AP/78-2
X 10
THERMOGRAM No
AP/98
X 10
TEMPERATURE °C

The small endothermic peak at 90°C is due to the loss of hygroscopic water. This peak is prominent in this thermogram when compared to the other specimens. The distinct nature of the curve and the thin section studies show that the sample is of more or less pure chrysotile. The endothermic peak at 790°C is due to the expulsion of the structural water from the serpentine. It is closely followed by an equally distinct exothermic peak at 790°C. This marked prominence of the exothermal peak when it closely follows the endothermal peak has several times been noticed by the earlier workers. The endothermal peak at 800°C is due to the dehydration process that accompanies the formation of olivine.

<u>THERMOGRAM NO.</u> 2, Specimen No. AP/78-1

The specimen is grayish green massive serpentine. Thin section of this specimen shows granulose texture with abundance of carbonate minerals and a little amount of serpentine. The thermogram for this specimen shows an endothermic feature at about 80°C, a distinct endothermic peak at 700°C, and a poor exothermic trend spread over 800°-950°C.

The earlier small endothermic feature is due to the loss of hygroscopic water from the serpentine. The endothermic peak at 700°C is shorter and broader as compared with that of specimen No. AP/75. Further, the exothermic reaction is also not so prominent as that of AP/75.

It appears that the presence of carbonate minerals has not much affected the endothermic peak which is still showing characteristic feature of chrysotile. This appears to be reasonable because pure dolomite also shows endothermic peak at 765°C. In pure serpentines the exothermic peak is related with the formation of olivine. In this specimen, as the amount of serpentine is little, the formation of olivine will also be limited and this can explain the ill defined character of the exothermic peak in the thermogram.

<u>THERMOGRAM</u> No. 3 Specimen No. AP/78-2

The specimen is of fibrous carbonate mineral and serpentine. Under thin section it was found that fibrous chrysotile has been replaced to a large extent by carbonate minerals.

The thermogram of this specimen shows two endothermic peaks, one at 750°C and another more prominent peak at 880°C.

Since the endothermic feature at about 100°C is very small, this shows that the serpentine forms little amount in the sample. The peak at 750°C is due to expulsion of structural water from chrysotile. The endothermic peak at 880°C is due to the dissociation of the carbonate mineral (Calcite).

Thin section studies of this sample markedly support the above observations.

<u>THERMOGRAM No. 4</u> Specimen No. AP/98

This specimen is of Black Serpentine.

The sample when observed under thin section consists of carbonate mineral coated thickly with dark iron oxide, and chrysotile which occurs around carbonate mineral in the form of veins and patches.

The salient features of the curve are a small endothermic peak at 80°C, a broad prominent featureless exothermic effect at about 500°C, another small exothermic peak at 700°C, and another sharp distinct exothermic peak at 830°C.

The small endothermic feature at 80°C is due to loss of hygroscopic water. The broad featureless exothermic effect at 500°C is due to the oxidation of the surface layers of the magnetite particles. This effect is much broad and prominent because the particles are crushed to a much finer size, i.e., -300 mesh. The characteristic small exothermic effect at about 350°C appears only as a trace because this has been further extended by the fineness of the particle size.

The exothermic peak at 700°C is due to the oxidation of the remaining magnetite. The prominence of the earlier peak of the magnetite compared to the lath shows that major portion of the magnetite has been oxidised before the structure has been opened up after the curie point (590°C).

But in the thermogram, the characteristic endothermic peak is not seen for chrysotile. One explanation for this can be that the characteristic endothermic peak which should have appeared between 680° to 750° C range, has been nullified by the exothermic effect of the magnetite. The distinct peak at 830° C, however, shows the presence of chrysotile.

CONCLUSIONS:

The shape and position of the exothermic and endothermic peaks will also be effected by the additional silicate phases which will be formed during the heating of impure serpentines. Which silicate phases are formed due to the heating of samples during D.T.A., could not be determined during the present investigations.

C H A P T E R - V

Petrochemistry and Petrogenesis of basic igneous rocks.

PETROCHEMISTRY AND PETROGENESIS OF THE BASIC IGNEOUS ROCKS

Four basic rocks, three from the Tadpatri sill and one from the lower sill in the Vempallies, have been chemically analysed for SiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5 and H_2O. The results are shown in Table 1.

PREPARATION OF THE SAMPLES

The specimens were washed thoroughly and allowed to dry. Several chips were obtained from different parts of the specimen with a steel hammer and crushed and powdered in a 2" diamond steel mortar to make about 40-60 grams. Of the coarse material 1/8th of the portion (about 5 grams) was collected by quartering and coning. The final pulverising of the material was done in an agate mortar and the material was passed through a 100 mesh sieve.

METHOD OF ANALYSIS

SiO_2, Al_2O_3 and total iron together and CaO were determined by standard gravimetric methods described by Groves (1951). FeO is determined separately by titrating against the standard solution of $K_2Cr_2O_7$.

Total iron, TiO_2, MnO, P_2O_5 and MgO are determined by using a Unicam SP 500 spectrophotometer.

K_2O and Na_2O are determined with the help of a flame photometer (Zeiss model III).

Al_2O_3 is calculated by deducting total iron from Al_2O_3 + total iron which was determined by gravimetric method. Fe_2O_3 is calculated by deducting FeO from total iron.

Chemical Composition of the Basic Rocks :- The chemical composition of the four analysed samples is given in Table 1.

Table 1

Chemical Composition of the Basic Igneous Rocks from Pulivendla and their comparison with similar rock types from other areas.

Constituent.	1	2	3	4	5	6	7	8	9
SiO_2	46.47	49.35	51.68	48.07	49.20	50.61	49.51	50	45
Al_2O_3	10.87	13.89	14.375	14.93	14.59	13.58	13.05	13	15
Fe_2O_3	2.56	4.39	3.94	4.98	3.50	3.19	3.07	13	13
FeO	10.26	8.65	9.12	9.65	9.57	9.92	10.39		
MnO	0.25	0.30	0.20	0.30	0.40	0.16	0.22		
MgO	18.20	9.90	8.20	7.40	6.33	5.46	5.71	5	8
CaO	7.20	8.90	8.90	10.30	9.45	9.45	10.18	10	9
Na_2O	1.40	2.30	2.45	2.30	2.64	2.60	2.25	2.8	2.5
K_2O	0.40	0.75	0.80	0.45	0.63	0.72	0.51	1.2	0.5
TiO_2	0.60	0.80	0.85	0.90	1.34	1.91	2.34		
P_2O_5	0.20	0.20	0.20	0.20	0.17	0.39	0.37		
H_2O	2.17	1.35	1.07	1.23	2.47	2.13	2.31		
Total	100.58	100.46	101.785	100.71	100.29	100.12	99.98	95	95
MgO/CaO	2.53	1.11	0.91	0.71	0.67	0.58	0.56	0.5	0.89
MgO/FeO	1.77	1.10	0.90	0.77	0.66	0.55	0.55		

1. Picrite gabbro, Tadpatri Sill, AP/233. Analysis by the Author.

2. Quartz-hornblende dolerite, Tadpatri Sill, AP/234. Analysis by the author.

3. Quartz dolerite, Tadpatri Sill, AP/237, Analysis by the author.

4. Dolerite, Lower Sill, Vempalle, AP/111, Analysis by the author.

5. Average composition of eight Cuddapah Traps, precambrian in age. N.A. Vemban 1946, Proc. In. Acad. Sci. Vol. 23, p.362. Analysis by N.A. Vemban.

6. Average composition of eleven Deccan Traps. Bull. Geol. Soc. American, Vol. 33, p. 774 (1922). Analysis by H. S. Washington, one of these eleven is from Rajmahal Trap.

7. Average of four analyses of Deccan Traps close to the parental magma, suggested by W.D. West. Trans. Natl. Instt. Sciences, Vol. IV, No. 1 p.29 (1958)

8. Tholeiitic magma type (W.Q. Kennedy, Trends of differentiation in basaltic magmas, Am. Jour. Sci., Vol. 25, p.241, 1933.

9. Olivine - basalt magma type (Kennedy, Op. cit, p.241, 1933).

From the chemical composition, C.I.P.W. norms were calculated as shown in Table 2.

See next page

Table - 2

C.I.P.W. NORM

NORMATIVE COMPOSITION OF THE BASIC IGNEOUS ROCKS, PULIVENDLA.

Constituent	AP/233	AP/234	AP/237	AP/111
Quartz			1.74	
Orthoclase	2.22	4.19	4.45	2.71
Albite	12.05	18.46	19.93	19.12
Anorthite	22.24	24.52	26.16	26.46
Diopside	10.26	13.81	14.05	17.26
Hyperesthene	20.28	21.73	26.23	20.76
Olivine	26.04	8.66	-	4.78
Magnetite	3.71	6.03	5.58	7.09
Ilmenite	1.22	1.52	1.52	1.67
Apatite	0.34	0.33	0.33	0.33
H_2O	2.17	1.35	1.07	1.23
Total:	100.53	100.80	100.80	101.41

Contd.

The modal composition for the four (chemically analysed) samples as determined by a swift point counter is given in Table 3.

Table - 3

Modal composition of the basic igneous rocks, Pulivendla.

Constituent	AP/233	AP/234	AP/237	AP/111
Plagioclase	23.5	42.7	44.5	42.0
Olivine	20.8	-	-	-
Quartz	-	4.1	3.8	1.0
Micropegmatite	-	5.1	-	-
Augite	16.9	20.6	24.3	38.4
Enstatite	9.6	-	25.2	-
Hornblende	-	18.9	-	--
Biotite	2.9	-	0.4	-
Magnetite	3.4	2.3	1.8	6.8
Antigorite and Chlorite	18.9	6.3		5.7
Total:	100.00	100.00	100.00	100.00

Contd.

From the chemical composition, Niggili values are also calculated and these are shown in table 4.

Table - 4

NIGGILI VALUES OF THE ANALYSED SAMPLES OF THE BASIC IGNEOUS ROCKS, PULIVENDLA

Constituent	AP/233	AP/234	AP/237	AP/111
si	87	107	124	106
al	12	18	15	19.3
fm	71	55.4	55	50.7
c	14	20.8	23	24.4
alk	3	5.8	7	5.6
ti	0.9	1.305	1.44	1.46
p	0.115	0.1305	0.114	0.136
k	0.148	0.178	0.17	0.119
mg	0.72	0.585	0.5385	0.485
qz	-25	-16.2	-4	-16.4
2 alk/al + alk	0.4	0.49	0.607	0.45

Contd.

COMPARISON OF THE NORMATIVE COMPOSITION WITH THE MODAL COMPOSITION OF THE ROCKS

COMPOSITION OF THE PLAGIOCLASE :

The composition of the plagioclase is obtained from :

1. optical determination.

2. C.I.P.W. norm

and 3. by plotting the calculated k and 2 alk/al + alk values in Niggli's diagram. (Fig.).

On comparing the composition of the plagioclase, obtained from these three methods, it is noted that they agree with each other to a fair extent as shown in table 5.

Table - 5

COMPARISON OF THE COMPOSITION OF PLAGIOCLASE OBTAINED FROM DIFFERENT METHODS

Method of determination	AP/233	AP/234	AP/237	AP/111
Optical determination	An 68 Ab 32	An 56 Ab 44	An 54 Ab 46	An 56 Ab 42
C.I.P.W. norm	An 64.9 Ab 35.1	An 57.3 Ab 42.7	An 56.76 Ab 43.24	An 59.8 Ab 40.2
By plotting k and 2 alk/al + alk in Niggli diagram	An 57 Ab 43	An 54.5 Ab 45.5	An 46 Ab 54	An 55.5 Ab 44.5

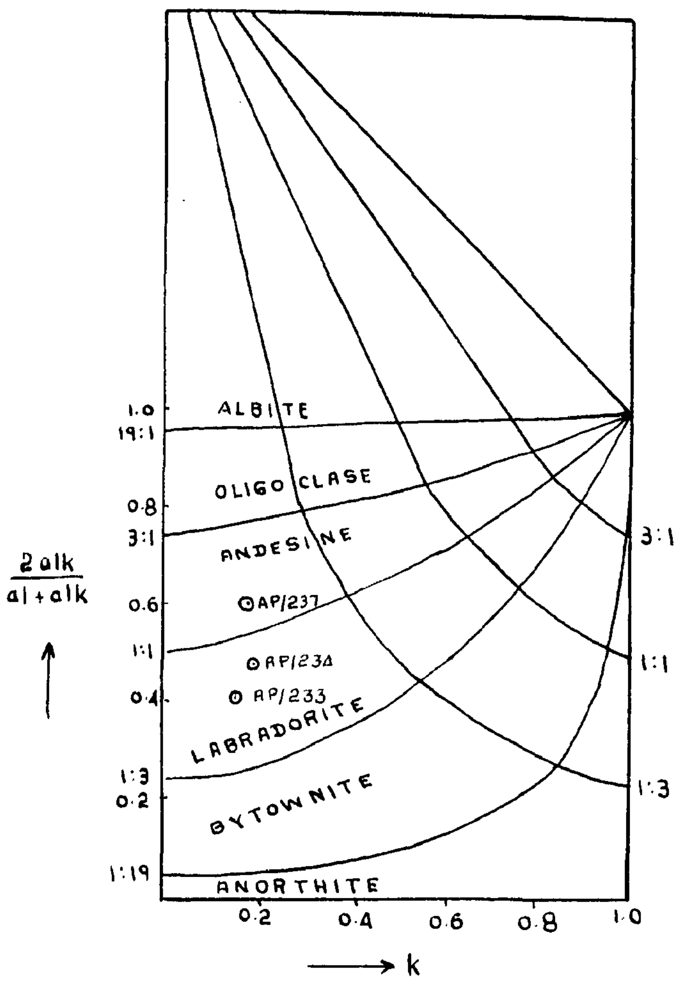


FIG. 3 $k - \frac{2alk}{al+alk}$ DIAGRAM FOR THE BASIC IGNEOUS ROCKS OF PULIVENDLA.

Plagioclase composition obtained by plotting k and 2 alk/al + alk in Niggli diagram are generally lower than the values obtained from the first two methods in the table. This difference is markedly seen in the case of AP/237.

PICRITE GABBRO :

The olivine content as obtained from modal analysis markedly agrees with the normative value. Plagioclase and pyroxence have higher percentage content in the norm while this deficiency is made up by antigorite and chlorite in the mode. Otherwise it appears that both the normative composition and the modal composition agree to a marked degree.

QUARTZ DOLERITES :

One of the characteristic features of quartz dolerites is that they show the presence of quartz in the modal composition, but in the norm quartz does not appear except in one case and on the other hand olivine appears which points towards the undersaturated nature of these rocks i.e., according to mode they appear to be over saturated rocks but the norm points towards their undersaturated nature. Iyer (1932, p. 527) has described a similar character in the quartz dolerites of Ranchi and Singhbhum districts of Bihar.

The modal and normative values for plagioclase agree to a marked degree of accuracy both in amount as well as in their composition. The other constituents, especially pyroxenes also agree with each other.

VARIATION DIAGRAMS :

Four types of variation diagrams are plotted, three are based on the weight percentage of oxides and the fourth on the Niggli values.

In fig. 4 weight percentage of silica is plotted against weight percentage of other oxides. The curves for K_2O, Na_2O, CaO, Al_2O_3 are more or less sympathetic while the curve for Fe_2O_3 shows an increase from AP/233 to AP/234 and from AP/234 it further shows a slight decrease. The curve for MgO shows a distinct decrease with increase in weight percentage of SiO_2. It may be noted here that in this diagram and also in the other three variation diagrams only the rocks from Tadpatri sill have been plotted and that of Vempalle sill have been excluded because there may not be any genetic relationship between the rocks of the Tadpatri sill and the Vempalle sill.

In fig. 5, the variation in the Niggli values as given in Table 6 are plotted to indicate the trend of differentiation in the rocks of the Tadpatri sill. The curves for c and alk are sympathetic and show a general increase with an increase in si value. The curves for fm shows, a distinct decrease with an increase in si value. The latter part of this curve (fm) i.e., from AP/234 to AP/237 show a further gentle increase with increase in si content. The curve for al is similar to the curve for c from AP/233 to AP/234, but therefrom it further shows a decrease in al value with increase in si value.

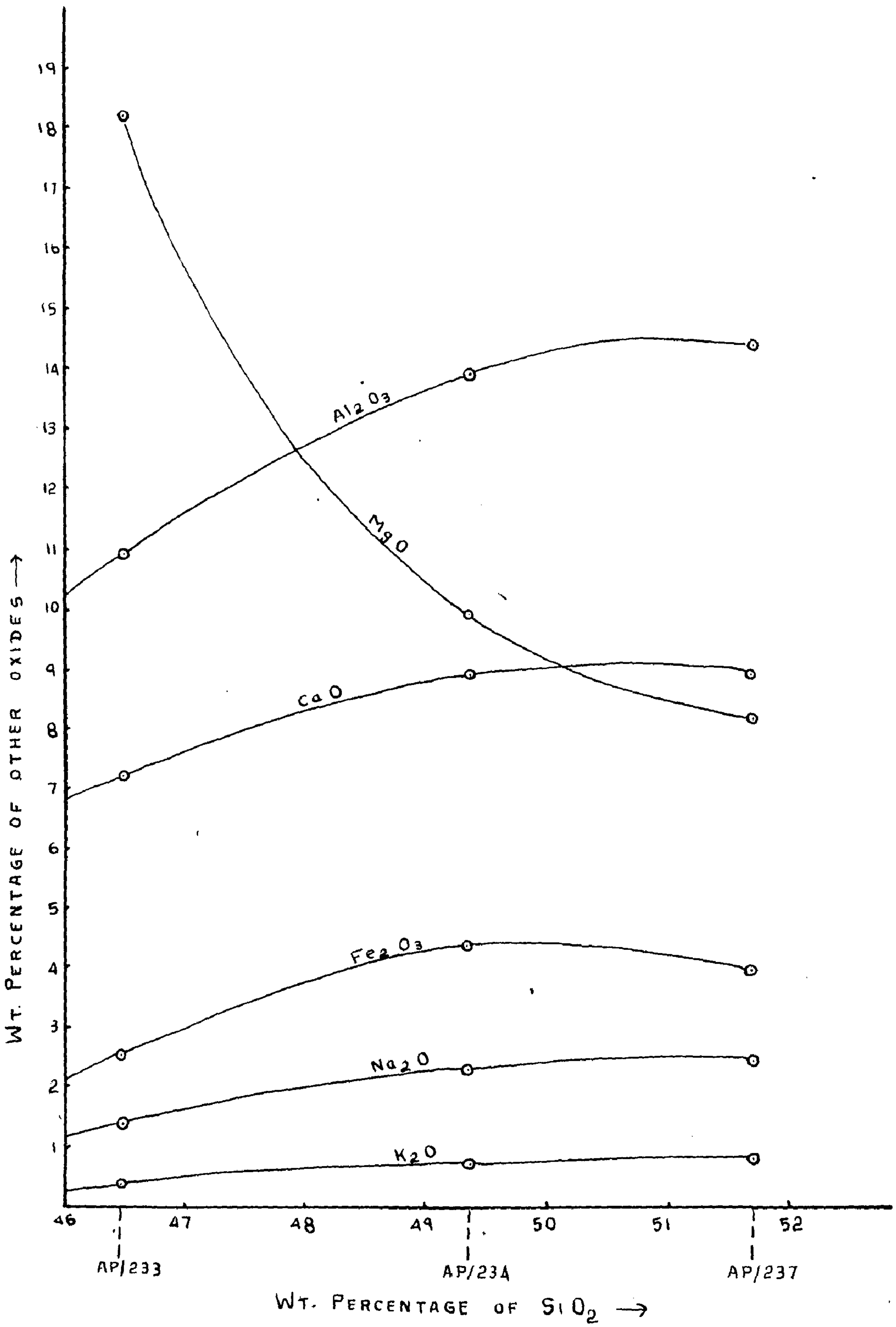


Fig. 4 Variation Diagram With Respect To Wt. Percentage Of Oxides For The Rocks Of Tadpatri Sill.

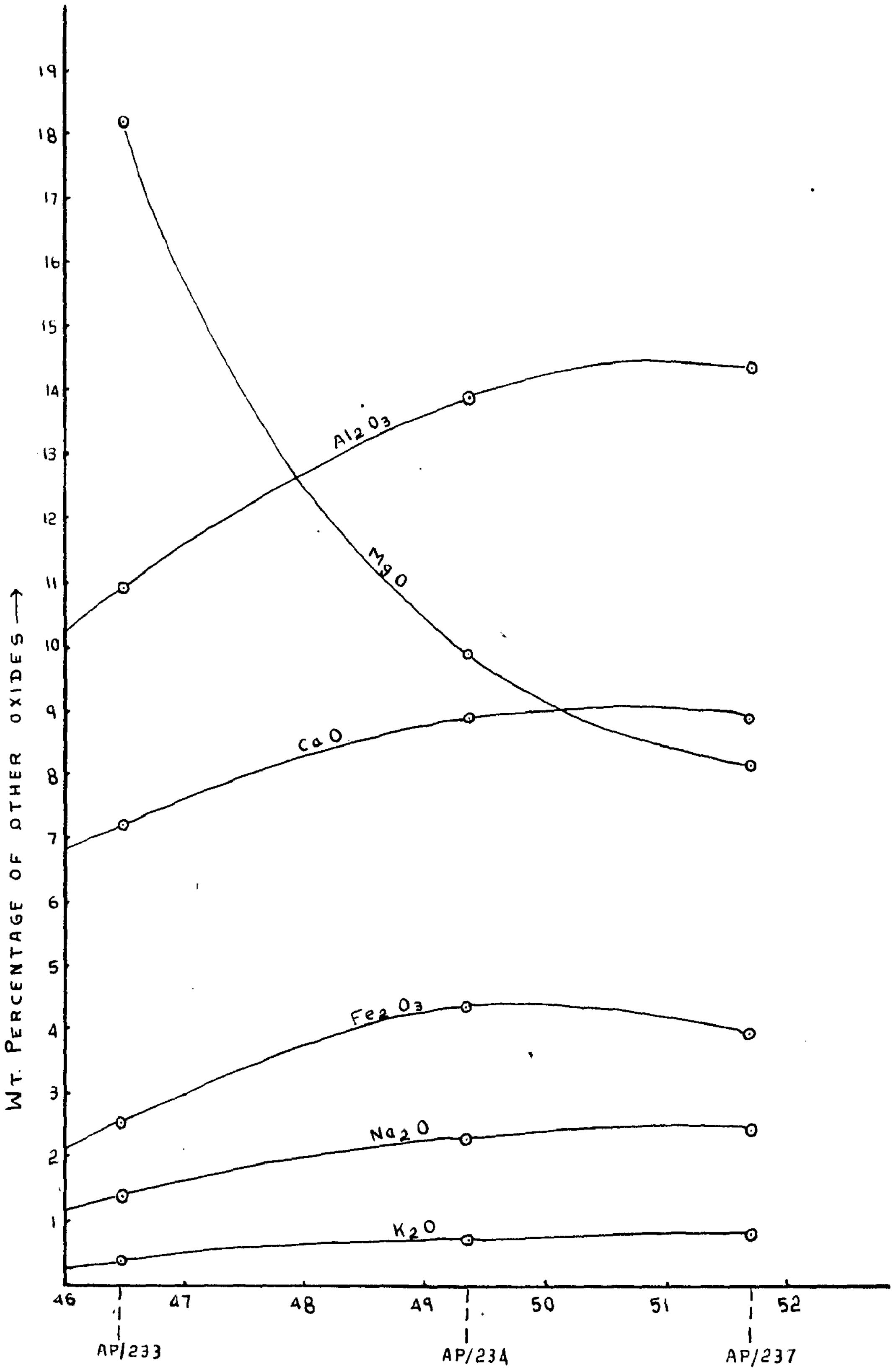


Fig.4 Variation Diagram With Respect To Wt. Percentage Of Oxides For The Rocks Of Tadpatri Sill.

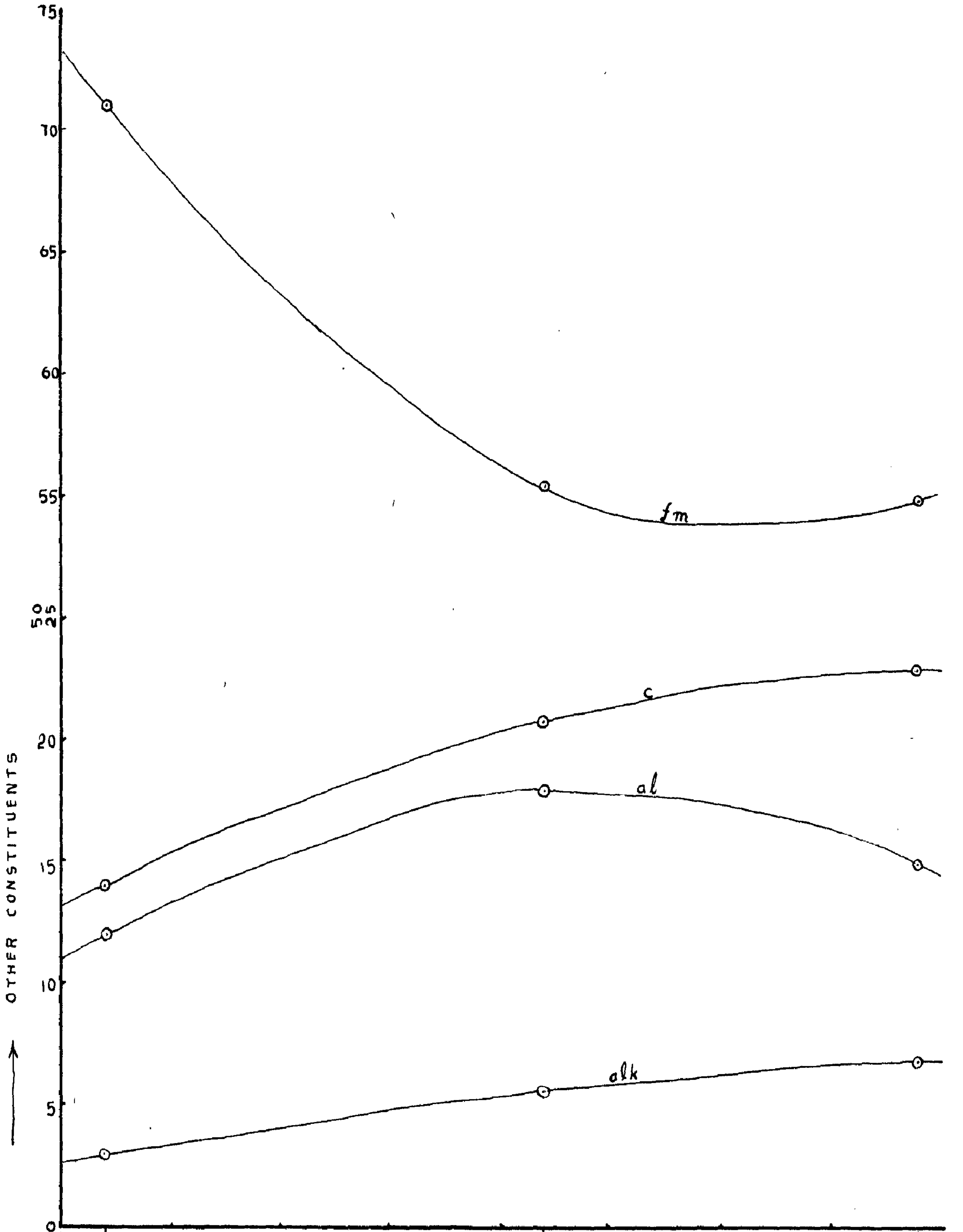


FIG. 5 VARIATION DIAGRAM WITH RESPECT TO NIGGLI VALUES FOR THE BASIC ROCKS OF TADPATRI SILL.

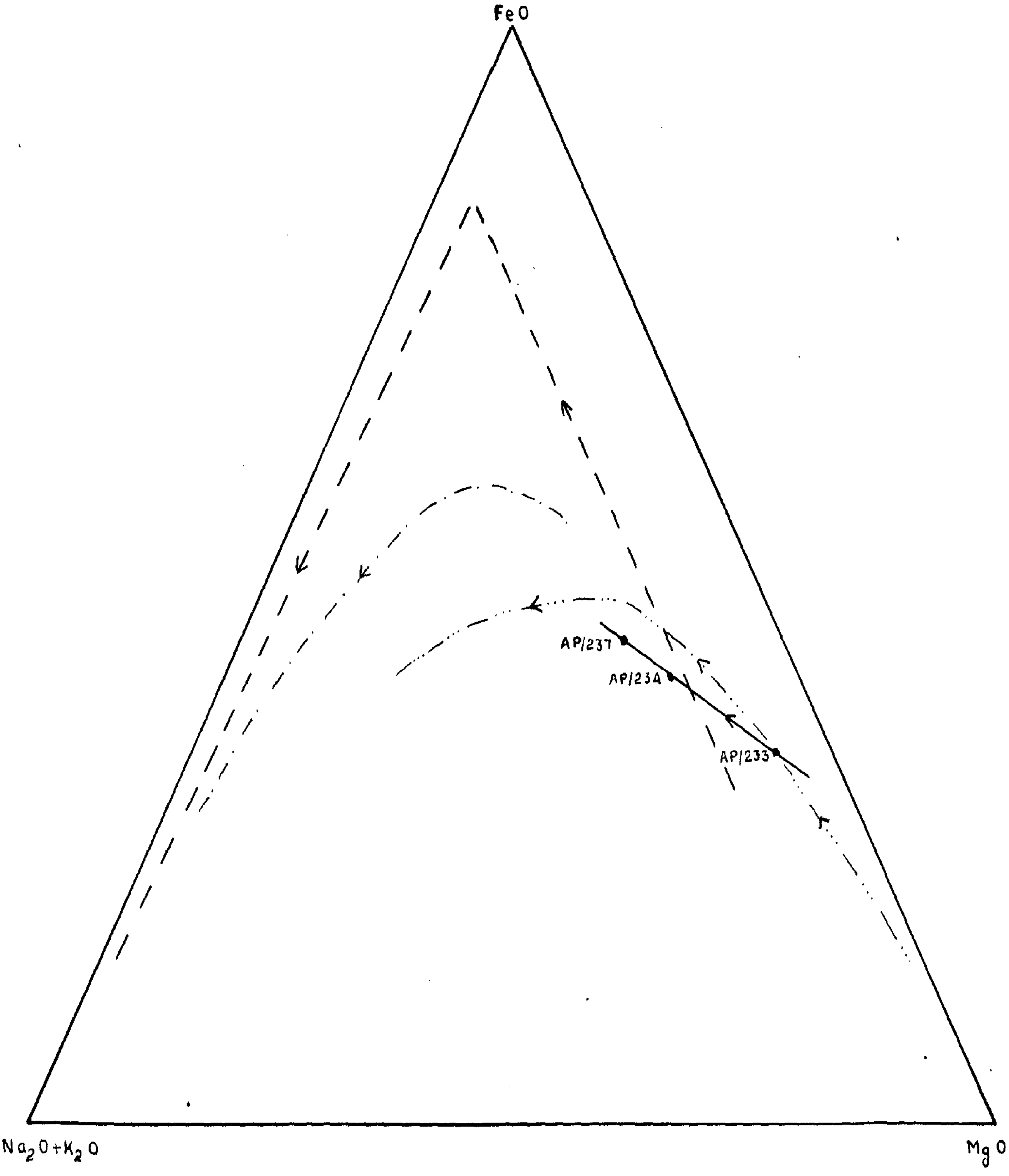


FIG. 6 TRIANGULAR VARIATION DIAGRAM

— Tadpatri Igneous Suit
— — Skaergaard Ferro-gabbro Series
—·—·— Alkaline Basalt → Trachyte Series, Hawaii
——··——··— Amjori Sill.

In fig. 4 a triangular variation diagram is shown in which is indicated the trend of differentiation in the Tadpatri sill and its comparison with the Skaergaard ferrogabbro series and the alkaline basalt - trachyte series, Hawaii. From this figure, it appears that the trend of differentiationin the Tadpatri sill was towards enrichment in FeO and alkalies with impoverishment in MgO. This trend is neither similar to the Skaergaard trend nor to the alkaline basalt trend but it is very similar to the trend of differentiation of Anjori sill of Orissa as mentioned by Iyengar, Venkatraman and Banerjee (1964, plate 5).

DIFFERENTIATION INDEX :

Thornton and Tuttle (1960) have expressed the chemical characters of igneous rocks in terms of Differentiation Index (DI). The concept of Differentiation Index is based on the experimental studies of in the crystallisation behaviour of silicate melts as revealed by the "petrogeny's residua system' of Bowen. Differentiation Index is a measure of the basicity of the rock and is expressed as the sum of the normative percentage of quartz, orthoclase, albite, nepheline, leucite and kalsilite.

As no more than three of these normative minerals will appear in any given norm, thus the D.I. is simply the sum of the percentages of three normative minerals. D.I. is not a measure of silica saturation. In the basic rocks it is less than 50 while in salic rocks it is more than 50.

In as much as the D.I. is a measure of the basicity of an igneous rock, it is an ideal quantity for illustrating the variation in the chemistry of igneous rocks. Thornton and Tuttle (op. cit.) have plotted the variation diagrams for various igneous suite in which D.I. is plotted against the weight percentge of various oxides. Such a type of variation diagram for the rocks of Tadpatri sill is given in fig. 7.

ORDER OF MINERAL CRYSTALLIZATION :

Based on the study of the texture of the rocks, it is possible to decide with fair accuracy, the order in which the various silicate minerals have crystallised out. In picrite-gabbros, as described earlier, olivine grains are poikilitically enclosed within orthopyroxenes, clinopyroxenes and plagioclase felspars. This indicates that the olivine was the first mineral to crystallise, followed by other silicate minerals.

Among pyroxenes and plagioclase, textural relations indicate that in some cases pyroxenes crystallised earlier while in other they crystallise later than the plagioclase.

Barth (1952, pp. 120-123) has suggested a method to determine the relationship between the order of crystallisation of plagioclase and pyroxene in a basaltic magma. It is based on the position of the boundary surface which separates the pyroxene field

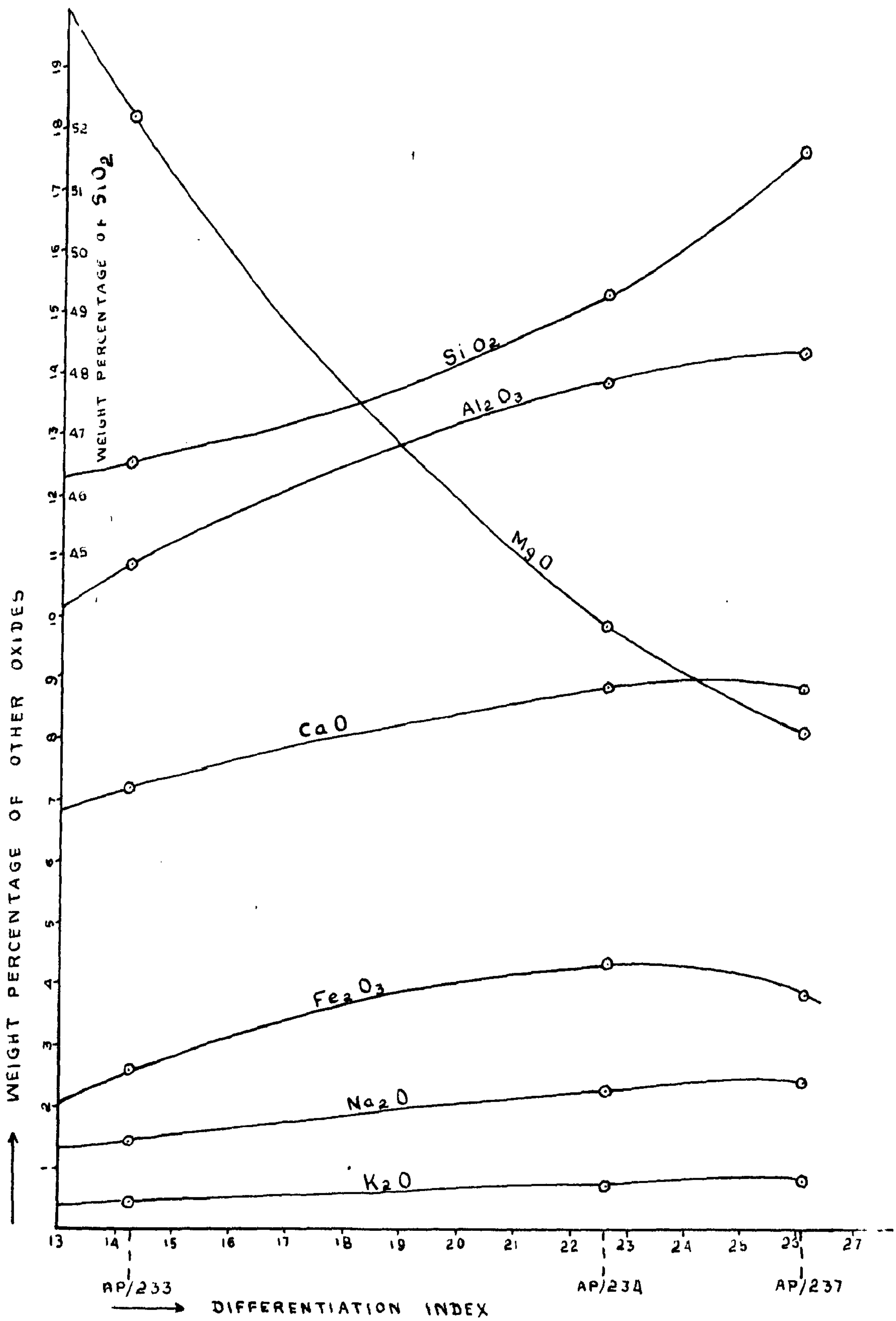


FIG.7 VARIATION DIAGRAM OF OXIDES VS. DIFFERENTIATION INDEX FOR THE ROCKS OF THE TADPATRI SILL.

from the plagioclase field in the four component system Ab - An - Di -Hy. The equation which defines the boundary surface is

ab' + 2 di' + 2.3 hy' = 123, where ab', di' and hy' are calculated from the C.I.P.W. norm. If ab' + 2di' + 2.3 hy' which is called the f(norm) is near about 123, it would indicate that the composition of the basalt falls on or near about the boundary surface and therefore it would indicate simultaneous crystallisation of both pyroxenes and plagioclases. If the f (norm) is smaller or greater than 123, the basalt falls in the plagioclase field or in the pyroxene field respectively. The f (norm) values for the four analysed samples of the basic igneous rocks are given in table 7.

Table - 7

f (norm) for the basic igneous rocks from Pulivendla area.

Specimen No.	ab'	an'	di'	hy'	f(norm)
AP/233	18.6	34.2	15.8	31.4	122.4
AP/234	23.5	31.3	17.6	27.6	122.2
AP/237	23.15	30.15	16.50	30.40	125.65
AP/111	22.8	34.1	20.65	22.45	121.2

This table shows that the value of f (norm) for the analysed rocks, fall near to 123. Thus, from the value of f (norm), it appears that in these rocks there was more or less simultaneous crystallisation of pyroxenes and plagioclases.

PETROGENESIS :

Tadpatri sill is a differentiated igneous intrusive body and is of composite nature. The rocks at the bottom and the top of the sill are quartz dolerites while the central portion is of picrite-gabbro in composition. It appears that the parent magma was of basaltic composition from which picrite gabbro was the first to form by fractional crystallisation brought about by gravitational differentiation. Due to this mode of differentiation, the upper part of the intrusive body got deficient in those constituents which had already crystallised out and by the crystallisation of the remaining liquid fraction, quartz dolerite was formed. The occurrence of quartz dolerite at the bottom of the sill is a little problematical and it appears that it is not a normal insitu differentiation product of the same magma which has given rise to the middle and upper portion of the sill. Quartz dolerites from the Tadpatri and the Vempalles are quite similar in their mineralogical and the Vempalles are quite similar in their mineralogical and chemical composition; but picrite-gabbro is restricted only to the Tadpatri sill. Quartz dolerites of this region show the presence of micropegmatitic intergrowth between quartz and felspar which indicates that the latter Sector fraction of the differentiating magma got enriched in silica and this can be explained due to early separation of olivine from the parent magma and its incomplete reaction with the remaining liquids as the olivine crystals settled due to gravity.

The rocks of Tadpatri sill (picrite-gabbro-quartz-dolerite) show not only a change in chemical composition as shown by the variation diagrams but also a variation in the amount and composition of the various minerals. With respect to plagioclase felspars it has been observed that in picrite gabbro the plagioclase felspars, as determined by optical data, from norm and also by plotting calculated k and 2 alk/al + alk values in Niggli's diagram (Fig. 1), are more calcic than the plagioclases of the quartz dolerites (Table 5).

The normative composition and the metasilicate proportion of pyroxenes, as calculated from the average chemical compositions are given in Table 6. In this table, the normative composition and the metasilicate proportion of pyroxenes of dolerites and basalts from other areas are also included for a comparative study.

Table - 6

NORMATIVE COMPOSITION OF PYROXENES OF THE BASIC IGNEOUS ROCKS FROM PULIVENDLA AND THEIR COMPARISON WITH DOLERITES AND BASALTS FROM OTHER AREAS.

No.	Di	Hy	$CaSiO_3$	$MgSiO_3$	$FeSiO_3$
AP/233	10.26	20.58	17.48	60.91	21.48
AP/234	13.81	21.73	19.60	54.61	25.59
AP/237	14.03	26.23	17.89	50.94	31.17
AP/111	17.26	20.76	23.24	46.00	30.76
A	13.84	22.33	19.60	53.12	27.24
B	17.54	21.22	22.6	41.8	35.6
C	17.41	17.78	24.6	44.3	31.1
D	16.76	23.74	19.6	46.6	33.8
E	13.14	15.90	22.3	52.3	25.4
F	14.71	21.03	20.3	53.9	25.8

A - Average of AP/233, AP/234, AP/237 and AP/111

B - Newer dolerite. Average of 3 analyses of Newer dolerites, Singhbhum (L.A.N. Iyer, 1932) and 2 of Keorijhar state (M.S. Krishnan, 1936)

C - Average of 11 analyses of Deccan traps (H.S. Washington, op. cit.)

D - Average of 5 analyses of Karroo dolerites (Daly and Barth, 1930, Geol. Mag., Vol. 67, pp.97-110)

E - Average of 6 analyses of Whin sill (Holmes and Harwood, 1928, Min. Mag. Vol. 21, pp. 493-542)

F - Average New Jersey Basalt (Anderson, 1940, Am. Journ. Sci., Vol.238, pp. 477-92).

The average basic igneous rock from Pulivendla (Table 6) when compared with the 'Newer dolerites', Karroo dolerites and the New Jersey basalts show similarity in the dippside and hypersthene molecules and also in having more hypersthene than diopside. But, in contrast to this, the Deccan trap shows equal amount of both these molecules. The Whin Sill, though containing more hypersthene than diopside, their total amount is less than the other rocks.

The metasilicates in the average of these rocks are remarkably uniform in showing a lower proportion of Ca SiO_3 and higher proportion of Mg SiO_3, while Fe SiO_3 is intermediate between these values. On a careful scrutiny it would appear that there is a reciprocal relationship between Mg SiO_3 and Fe SiO_3, for a decrease in Mg Si O_3 results in the increase of $FeSiO_3$. but such a notable change is not observed with respect to $CaSiO_3$. The explanation for this can be had from the phase diagram for the system, $CaSiO_3$ - $MgSiO_3$ - $FeSiO_3$.

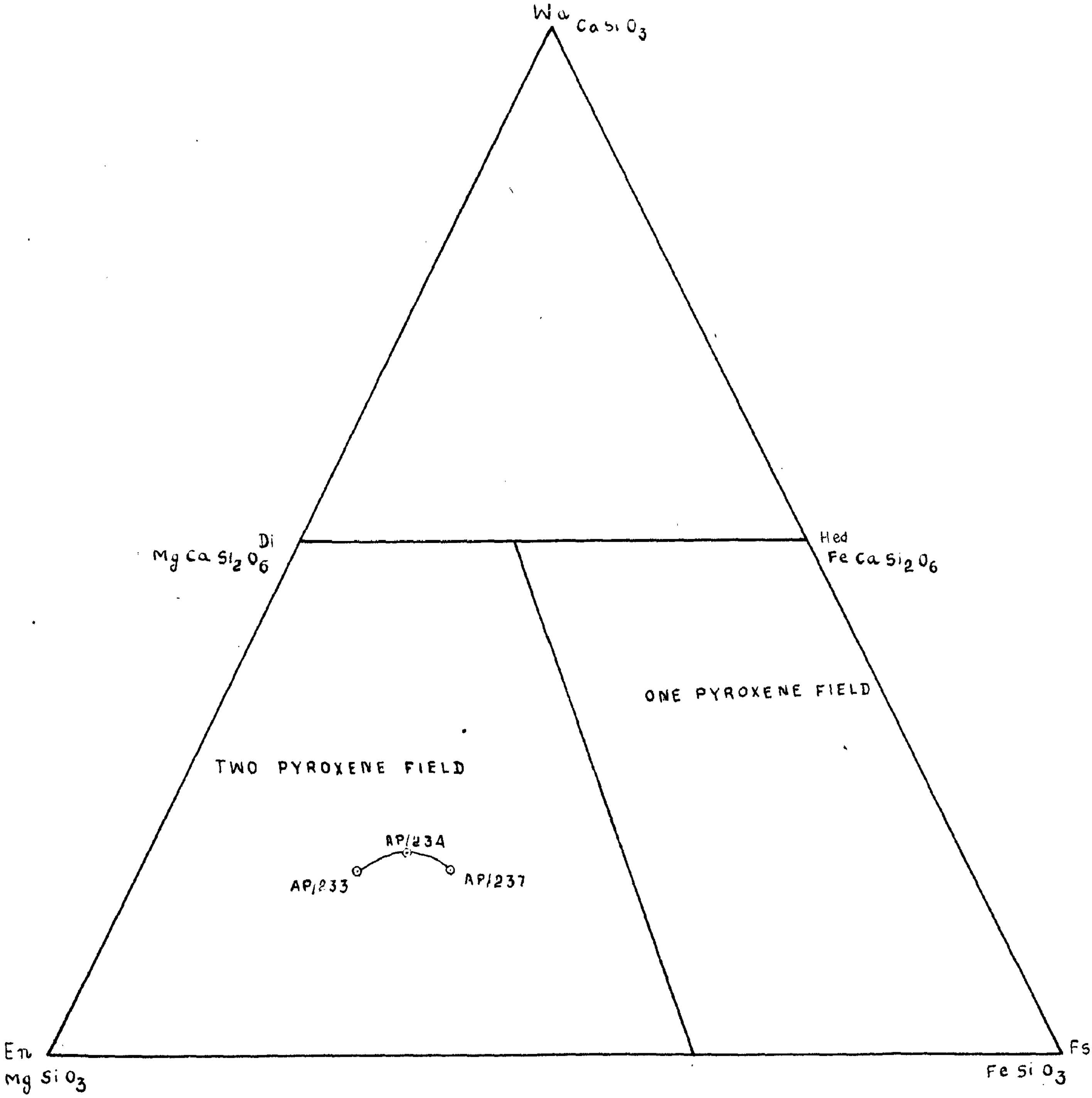


FIG. 8 TREND OF CRYSTALLISATION OF PYROXENES

The metasilicate proportions of rocks analysed from Tadpatri sill are plotted in the above figure (Fig. 8). Picrite gabbro (AP/235) is more rich in enstatite and diopside molecules as compared with the pyroxenes of quartz dolerites (AP/234, and 237) which got enriched in Fs. and Hed. molecules indicating thereby enrichment of pyroxenes in iron with successive fractional crystallization. Thin section study of these rocks indicate that picrite-gabbro has a good amount of orthopyroxenes which decrease in amount or completely disappears in quartz dolerites.

Another conspicuous feature of these rocks is the presence of micropegmatitic intergrowth in quartz dolerites. It is generally believed that the presence of micropegmatite in basic rocks results due to the crystallization of acidic residum formed by the early separation of olivine in excess of its stoichiometric proportion. Such an origin was suggested by Bowen (1928, pp. 70 to 74). But Fenner (1929, 1931) objected to this theory and concluded that micropegmatite does not result from the process of crystallization differentiation, but as a secondary product of hydrothermal activity after the rock has completely solidified.

Changes in the composition of the individual mineral groups and their relative percentages indicate that the rocks of the Tadpatri sill are a product of differentiation from basaltic magma. The variation in the chemical composition and the mineral composition is of a normal nature as can be expected during differentiation brought about by fractional crystallisation.

pigeonite and hypersthene are found together.

The average chemical composition of a tholeiitic magma type and that of an olivine basalt type, as suggested by Kennedy (op.cit.) are given in Table 1. The tholeiitic type is said to be distinguished by notably higher SiO_2, higher K_2O and lower Al_2O_3, and much lower values for MgO/CaO and MgO/FeO ratios. These differences as suggested by Kennedy are not always true in distinguishing between these two magma types. This led Daly (as cited by Turner and Verhoogen, op.cit.) to oppose the concept of Kennedy and conclude that there is no essential consistent chemical difference between the two types. Turner and Verhoogen (op. cit.) have suggested that a tendency for SiO_2 to be higher and for Na_2O, K_2O and MgO to be lower in tholeiites than in alkaline olivine basalts can be the distinguishing characters, but in some cases, a transitional relation rather than a sharp difference between the two magma types exist. C.I.P.W. norms and Niggili values are also considered to indicate the difference between the two magma types. A high vlue for normative hypersthene is characteristic of tholeiites and also the appearance of normative quartz and the exclusion of olivine and nepheline with respect to Niggili values, the tholeiite basalt will show a positive value for quartz number.

In table 8, an attempt has been made to determine the nature of the parent magma for the basic rocks of Pulivendla area based on the distinguishing mineralogical and chemical character of the two magma types.

<u>NATURE OF THE PARENT MAGMA</u> :

Any discussion on the petrogenesis of the rocks of basaltic composition without a mention of the magma type will be considered as incomplete. Two types of basaltic magmas are generally recognised i.e. alkaline olivine basalt and Tholeiitic basalt. These two basalts which represent two different parent magmas on differentiation give rise to two different rock suits. One is represented by olivine basalt - trachyte - phonolite and the other by tholeiitic basalt-quartz diabases. Green and Poldervaart (1955) have suggested that there are no distinct types of basalt magmas but rather a continuous series from silica saturated (tholeiitic) to silica under saturated (olivine - baslat) rocks.

Yoder and Tilley (1962) which aggreeing to the two fold classification of basaltic magmas into tholeiitic and alkaline olivine types, have suggested a third type also which is called as high-alumina basalt and this is also supported by Kushiro and Kuno (1963).

Turner and Verhoogen (1962, pp. 205-209) while supporting the views of Kennedy, Kuno and others have mentioned that there are distinct mineralogical and chemical differences between the two types of basalts. According to these authors, two distinctive and persistant criteria of the tholeiitic basalts as contrasted with olivine basalts are prevalence of pigeonite and the common presence of an acid residuum which is commonly quartzofelspathic. Olivine is a rare constituent of tholeiitic basalts, and , if present, it is unzoned. The pyroxene of the alkaline olivine basalt is generally augite which in tholeiites, pigeonite and hypersthene are found together.

The average chemical composition of a tholeiitic magma type and that of an olivine basalt type, as suggested by Kennedy (op.cit.) are given in Table 7. The tholeiitic type is said to be distinguished by notably higher SiO_2, higher K_2O and lower Al_2O_3, and much lower values for MgO/CaO and MgO/FeO ratios. These differences as suggested by Kennedy are not always true in distinguishing between these two magma types. This led Daly (as cited by Turner and Verhoogen, op.cit.) to oppose the concept of Kennedy and conclude that there is no essential consistent chemical difference between the two types. Turner and Verhoogen (op. cit.) have suggested that a tendency for SiO_2 to be higher and for Na_2O, K_2O and MgO to be lower in tholeiites than in alkaline olivine basalts can be the distinguishing characters, but in some cases, a transitional relation rather than a sharp difference between the two magma types exist. C.I.P.W. norms and Niggli values are also considered to indicate the difference between the two magma types. A high vlue for normative hypersthene is characteristic of tholeiites and also the appearance of normative quartz and the exclusion of olivine and nepheline with respect to Niggli values, the tholeiite basalt will show a positive value for quartz number.

In table 8, an attempt has been made to determine the nature of the parent magma for the basic rocks of Pulivendla area based on the distinguishing mineralogical and chemical character of the two magma types.

TABLE - 8

COMPARISON OF THOLEIITIC BASALTS AND ALKALINE-OLIVINE-BASALTS WITH THE BASIC IGNEOUS ROCKS FROM PULIVENDLA AREA.

Distinguishing character	Tholeiitic basalt.	Alkaline Olivine basalt	Basic rocks from Pulivendla area	Nature of the parent magma for basic rocks of Pulivendla.
I. MINERALOGICAL COMPOSITION				
Olivine	Generally absent, when present, unzoned.	Usually present but commonly zoned.	Sometimes present but unzoned.	Tholeiitic
Pyroxene	Two pyroxene (Augite + Pigeonite or hypersthene	One pyroxene (Augite)	Two pyroxenes and also one pyroxene. Pigeonite and Hypersthene are absent.	Tholeiitic
	Later pyroxenes are richer in Fe.	-	Later pyroxenes are richer in Fe.	Tholeiitic
Nature of ultimate differentiation	Micropegmatite	Alkali rich	Micropegmatite	Tholeiitic

(Contd)

TABLE 8 CONTD.

Distinguishing character.	Tholeiitic basalt	Alkaline Olivine basalt	Basic rocks from Pulivendla area	Nature of the parent magma for basic rocks of Pulivendla.
II. Chemical composition				
Weight percentage of SiO_2	50	45	46.47 to 51.68	Intermediate
Weight percentage of Al_2O_3	13	15	10.87 to 14.93	Intermediate
Weight percentage of K_2O	1.2	0.5	0.40 to 0.80	Intermediate
MgO/FeO	0.50	0.89	2.53 to 0.71	Alkaline-olivine - basalt.
III. C.I.P.W. Norm	Presence of normative quartz and exclusion of olivine and nephelene	Absence of normative quartz and presence of olivine and nephelene	Olivine is present in three rocks but nephelene is absent in all cases	Intermediate
	High values for hyper-othene	-	High values for hyper-othene	Tholeiitic
IV Niggli values for [illegible] qz.	Positive value	Negative value	Negative value	Alkaline Olivine basalt.

From this comparative study, it can be concluded that the basic igneous rocks from Pulivendla area show some characters which are characteristic of the tholeiitic basalts and others which are characteristic of alkaline - olivine - basalt. But ingeneral they show greater affinity with the tholeiitic suit except that the MgO/FeO ratio is high. Hence the parent magma for the various rocks of Tadpatri sill can be regarded to be magnesium rich tholeiite.

It may be mentioned here that Iyengar, Venkatraman and Banerjee (op.cit.) have assigned a similar composition to the magma for the Anjori sill in Orissa. West (1958, pp 34 to 35) and Roychoudhury and Saha (1954, p. 492) also reported magnesian rich phase in the Deccan Trap. The triangular variation diagram (Fig. 4) indicates that the trend of differentiation in the Tadpatri sill is neither exactly parallel to the Skaergaard (Tholeiitic series) nor to alkaline olivine basalt series. However, as mentioned earlie., the trend of the basic rock series from Tadpatri sill is very similar to the trend of Anjori sill where the parent magma is regarded to be magnesian rich tholeiite by Iyengar, Venkataraman and Banerjee (op.cit.).

Vemban (op.cit., p.376) also concluded that the Cuddapah magma belongs to the tholeiitic type and the trend of differentiation is similar to that of Calc. alkaline suit of rocks.

ooOoo

CHAPTER - VI

ASBESTOS AND BARYTES DEPOSITS

A S B E S T O S A N D B A R Y T E S D E P O S I T S

INTRODUCTION

The asbestos deposits of this area were for the first time investigated by Coulson (1936).

In the area under investigation, asbestos has two different mode of occurrences. Important deposits of asbestos occur at a number of places along the lower and upper contact of Lower doleritic sill in Vempalle dolomites and limestones while sporadic occurrence of asbestos is within the Tadpatri sill. These two occurrences are described below:

ASBESTOS IN TADPATRI SILL

Small development of Chrysotile asbestos is seen in the picrite-gabbro exposed on the south side of the ridge N.W of Pulivendla Dak Bungalow. This asbestos is not of commercial significance as it occurs in theform of small fibres within the fractures which traverse the picrite-gabbro. It seems to have originated by the alteration of olivine in these rocks by the action of water which permeated through the fractures. Such an alteration takes place at comparatively low temperatures.

Experimental studies on the system $MgO - SiO_2 - H_2O$ by Bowen and Tuttle (1949) have indicated that serpentines can not be formed at temperatures above 500°C and that formation of serpentine by the action of water on forsterite can occur only below 400°C.

ASBESTOS IN VEMPALLE STAGE

Asbestos occurs at a number of places at both lower and upper contacts of the Lower sill which has intruded the Vempalle limestone and dolomites and these occurrences constitute the main asbestos deposits of the area.

The Mysore Asbestos Mines Ltd., worked these deposits between 1924 to 1931 and opened a number of mines in which the asbestos zone was followed down the dip (10° to 18°) upto 200'. Since May 1964, these deposits are being investigated by the Andhra Pradesh Government and the mining of asbestos is being carried out near the village Brahmanapalli.

The best mineralisation has taken place along a 9 mile long zone extending from Brahmanapalle to Lingala along the Upper contact of the sill while at the lower contact the development of asbestos is sporadic. This will be discussed in more detail when the origin of asbestos is described. Asbestos (Chrysotile) has developed in the form of thin veins within the serpentines. The serpentine zone varies in thickness from 3' to 15' but the main asbestos zone is confined within 2' to 3' from the contact.

Chrysotile bands vary from 1/4th of an inch to 3" in thickness and it is of cross fibre nature (Plate VIII, Photo 1). The individual veins are not of uniform width but they show thickening and thinning which indicates that chrysotile has developed due to the replacement of serpentine. The asbestos zone has been effected by faults as described in chapter 2. The serpentine associated with the asbestos deposits is of varied colour and texture. The colour of the serpentine vary from light yellow to shades of green and black. The black colour of the serpentine is due to abundence of iron oxide which is revealed by the thin section study. Thin section study of serpentines is given in chapter 3, and the D.T.A. is discussed in Chapter 4.

Asbestos is generally found within the black serpentine and within the asbestos band small angular pieces of black serpentine can be observed (Plate IX, Photo 1) which would indicate that the crysotile has developed due to replacement of serpentine and these enclosed pieces of serpentine are the remnants of the unaltered serpentine. Magnetite and pyrite are associated with serpentine. Under polished section (Plate IX, Photo 2) the magnetite is fresh and tends to take idiomorphic character. Few grains show well developed forms like cubes and rectangles while irregular grains with one or two well developed faces are more common. Pyrite occurs as coarse euhedral and anhedral grains. Both magnetite and pyrite occur as disseminated replacement bodies.

Associated with serpentine are also fibrous carbonate minerals (calcite and dolomite). The fibrous nature of these carbonates indicate that they are pseudomorph after asbestos.

BRAHMANAPALLE ASBESTOS MINE

In the Brahmanapalle area the asbestos zone is nearly one metre in thickness and is made up of numerous cross fibred chrysotile veins varying from a minute size to about 8 cm. thick anastomosing through the serpentinous dolomitic limestone. Above the serpentinous rock containing the asbestos is dolomitic limestone. The dolomitic limestone is fairly massive but it is sometimes more finally massive bedded. Its thickness varies from 5 to 10 metres. The dolomitic limestone is succeeded by a series of blocky shales which in turn is succeeded by dolomitic limestone. Plan of the leased area of the Reddy Asbestos Mine is shown in fig.9 which indicates the above sequence.

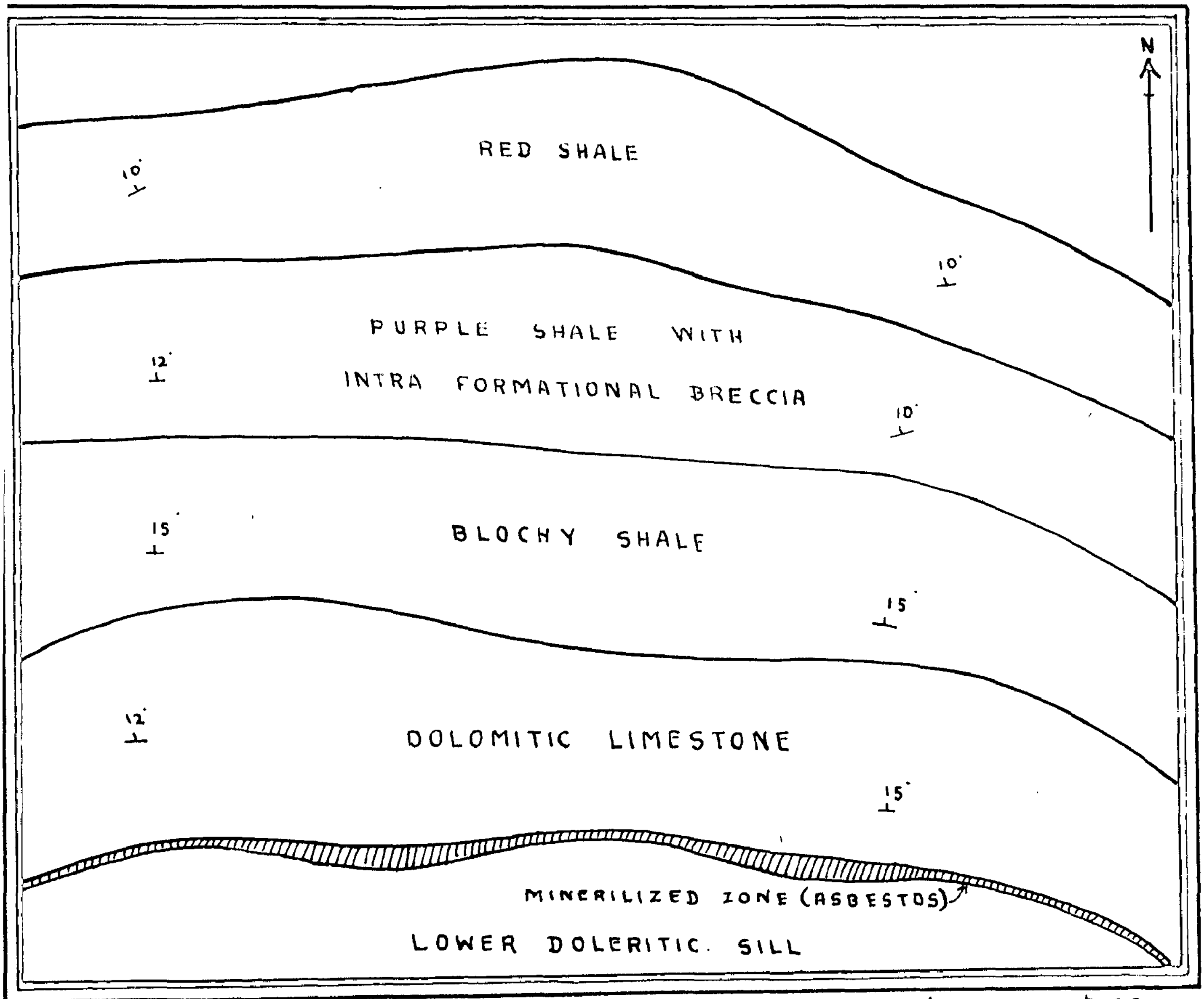
MINING AND BENEFICIATION

The proposed method of mining at Brahmanpalle is to go along the dip direction for a certain distance and then to make strike galleries at a regular interval. The underground water problem is solved by pumping out the water. The mining scheme of the Reddy Asbestos Mine is shown in fig.10.

The asbestos bearing rock is broken by explosives and is transported to the surface where the asbestos is sorted by manual labour with the help of hammer and hand. If the asbestos fibres are smaller, making it difficult to sort by hammer and hand, the rock is crushed with hammer and asbestos is separated by sieving. If the fibres are still smaller, they are pounded along with the attached

PLAN OF THE LEASED AREA

REDDY ASBESTOSE MINE, PULIVENDLA

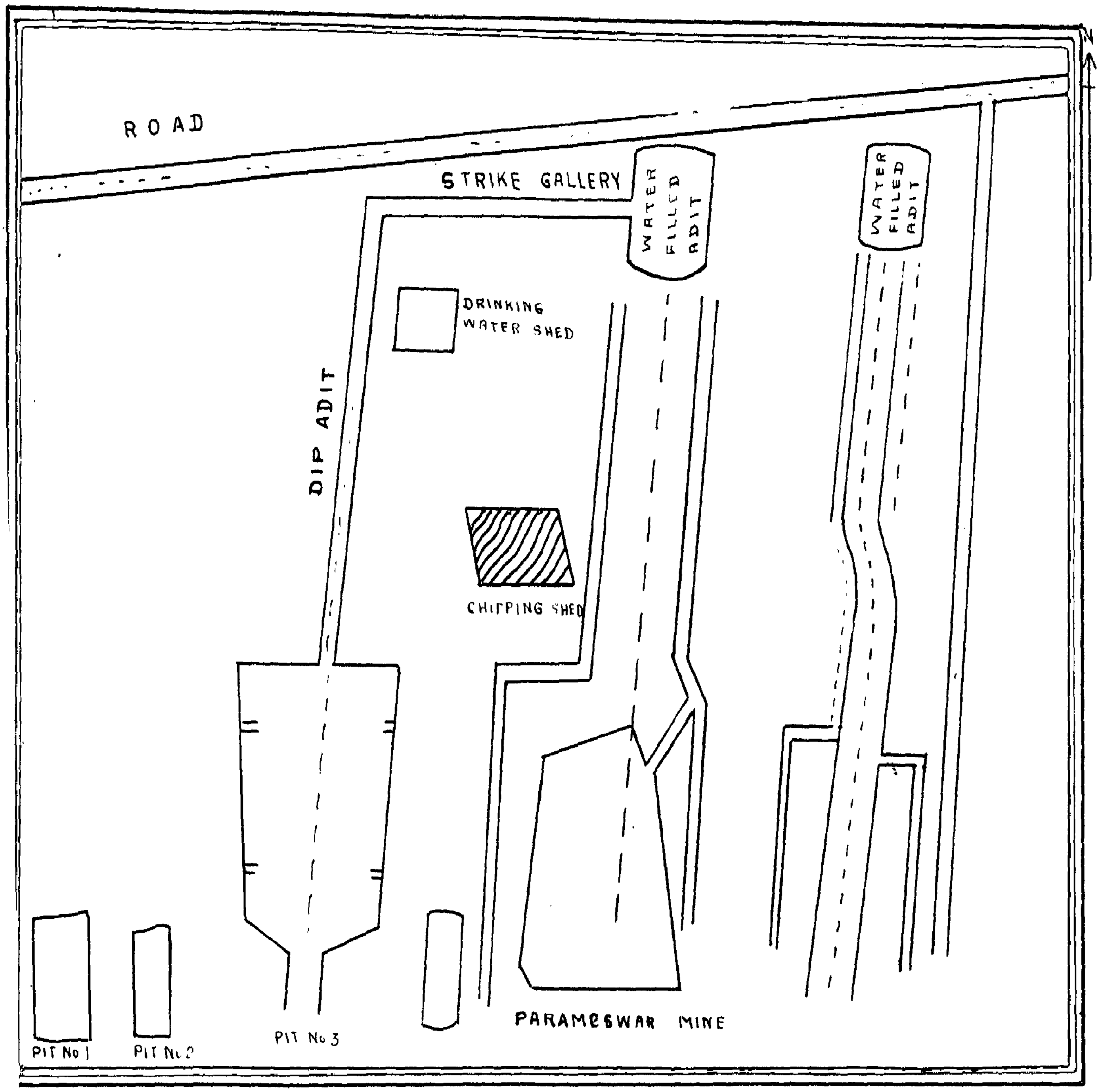


SCALE: 1 cm = 15 metres

FIG. 9

REDDY ASBESTOS MINE, PULIVENDLA

MINING SCHEME



SCALE: 1 cm : 15 metres. (APPROX.)

FIG. 10

rock mass and then mixed with water. The lighter asbestos fibres float over the water and are separated with a sieve.

GRADING

The sorted out asbestos is graded according to the fibre length into A, B and C grades. The grade size and the approximate price is given in the following table:

Grade	Fibre length	Price
'A' special	More than 1"	Rs. 8,000 to 10,000 per ton
'A'	3/4" to 1"	Rs. 6,000 per ton
'B'	1/4" to 3/4"	Rs. 3,000 per ton
'C'	less than 1/4"	Rs. 1,000 per ton

The maximum fibre length ever recovered from this area was 7".

The reserves of all the grades of asbestos to a length of 3 miles along the strike and one furlong along the dip are of the order of 2,50,000 tons.

ORIGIN OF ASBESTOS

Coulson (1934) while discussing the asbestos in the Ceded districts of the Madras Presidency concluded that the asbestos veins found in the serpentinised magnesian Vempalle limestone close to their contact with intrusive dolerite sills owe their origin to the hydrothermal solutions accompanying the dolerites. He further mentioned that the first effect of the intrusion was the formation of serpentine, the hydrothermal solution assisting the reaction between the dolomitic portion of the magnesian limestone and the silica with the additional formation of calcite and CO_2 and the second effect, perhaps slightly later, was the penetration around cracks in the serpentinised rock by the serpentinising waters and the deposition therein, under pressure of the chrysotile asbestos, the vein increasing in thickness possibly by partial resolution of the serpentine bordering fissures. The fissures and fractures in the limestone were formed due to heat of intrusion. Other conditions being equal, magnesian limestones have a better predisposing influence for the formation of the Chrysotile asbestos than dolomites.

Poldervaart (1950) has discussed the formation of serpentine by dolerite intrusion in dolomite. He suggested that a rise in temperature in the dolomite results in concentration, along bedding planes, of vadose water which dissolved material from the dolomite and gave rise to saturated aqueous solutions of calcium and magnesium carbonates and silica. Subsequent cooling of magnesium rich fluids resulted in the crystallisation of Chrysotile.

Another type of contact effect of dolerite on a siliceous dolomite can be the formation of forsterite and calcite and the equation for this reaction can be written as follows:

$$\underset{\text{(dolomite)}}{2CaMg(CO_3)_2} + \underset{\text{(Silica)}}{2SiO_2} \rightarrow \underset{\text{(Calcite)}}{2CaCO_3} + \underset{\text{(Forsterite)}}{Mg_2SiO_4} + 2CO_2$$

Forsterite will subsequently be serpentinised at lower temperatures and asbestos will be found by the replacementof the massive serpentine material by aqueous solutions.

In Pulivendla area, the dolerite intrusion has not caused the development of olivine (forsterite) as it is not observed in any thin section of either serpentine rock or crystallised dolomite from the contact nor the serpentine shows any character which would indicate that it is pseudomorph after olivine. Hence the possibility of the formation of olivine due to contact effect and the subsequent formation of serpentine in this region can be ruled out. It appears that the water vapours and other hydrothermal solutions, which were introduced by the dolerite intrusion permeated through the dolomitic limestone and this caused the development of serpentine which later on was replaced by Chrysotile asbestos along fissures and fractures. Hence the dolerite was the source of the water vapour and other hydrothermal solutions.

Another interesting feature which has been also mentioned earlier is the predominance of the asbestos zone along the upper contact of the sill as compared with its lower contact. This can be explained on the basis of the difference in the contact effect on the rocks which overlie and underlie the intrusive body. From a crystallising igneous intrusive, the water vapours and hydrothermal solutions would have a tendency to move upward under the influence of pressure gradients and hence the country rocks which overly the intrusive body would be more effected by these vapours and solutions as compared with those which underline it.

Carbonate minerals which are found associated with the serpentines and asbestos are of secondary origin released during the change of dolomite into asbestos. Magnetite and pyrite which are found associated with asbestos and serpentine appear to be of hydrothermal origin introduced into the country rock from the magmatic source as is indicated by the ore microscopic studies.

BARYTES DEPOSIT

Barytes occurs in this region as fine fissure vein deposits along the fault zones which traverse the basic sills as well as the Vempalle limestone. Faults at villages Ippatla and Lopatanutala have been mineralised. Barytes vein at Ippatla cuts across the lower dolerite sill and also Vempalle limestone. It dips with an angle of 80° due W.S.W. i.e. opposite to the dip direction of the Vempalle limestones. Along with baryte, calcite, quartz and some ore minerals (magnetite, pyrite and chalcopyrite) are also seen. In Ippatla region, the mining of baryte is abandoned due to the poor quality of baryte and also water hazards during mining (Plate X, Photo. 1 and 2)

Polished section study of the ore minerals associated with barytes is described below (Plate XI, Photo. 1.)

CHALCOPYRITE

Chalcopyrite occurs sparodically in small amounts. Quite often, islands of pyrite are observed within chalcopyrite. It takes good polish and shows high reflectivity. Its bright yellow colour, weak anisotropism and weak bireflection are diagonostic. No twinning is present in any of the observed polished sections. Yellowish green colour is observed under oil immersion when nicols are crossed.

PYRITE

Pyrite is the next abundant ore mineral. Most commonly it occurs as fine rectangular euhedral grains disseminated in barytes or occasionally as islands in chalcopyrite. Hardness is very high and takes moderate polish. It displays pale yellow colour, high reflectivity and isotropism in air, but a distinct green anisotropism in oil.

COVELLITE

Occurs as thin films along the borders and fractures in chalcopyrite forming rims around chalcopyrite. Its deep blue colour with a shade of slight violet tint, enormous anisotropism with reddish orange and reddish brown colours, and strong bireflection are diagonostic.

TEXTURES

The following textures are observed in the polished section.

REPLACEMENT TEXTURE

Chalcopyrite has replaced baryte sporadically and form shapeless masses. The veins have unmatching walls.

AUTOMORPHIC REPLACEMENT

Pyrite which replaced baryte shows well developed rectangular forms giving rise to automorphic replacement texture.

ISLAND TEXTURE

Islands of pyrite appear in chalcopyrite.

RIM TEXTURE

The formation of covellite around chalcopyrite in thin films has given rise to rim texture.

Euhedral crystals of pyrite appear in barytes as well as chalcopyrite. Subhedral and anhedral pyrite is also common. The chalcopyrite veins are irregular with unmatching walls.

PARAGENESIS

Barytes is the first to form and is earlier to the sulphides. Islands of barytes are not observed in pyrite or in chalcopyrite. Barytes is followed successively by pyrite and chalcipyrite. The early crystallisation of pyrite than that of chalcopyrite is evident from the following points:

1. Euhedral forms of pyrite in baryte
2. Euhedral grains of pyrite in chalcopyrite also.

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A little chert is observed in most polished sections which is indicative of relatively low temperatures of deposition. The presence of chert has been confirmed under thin section.

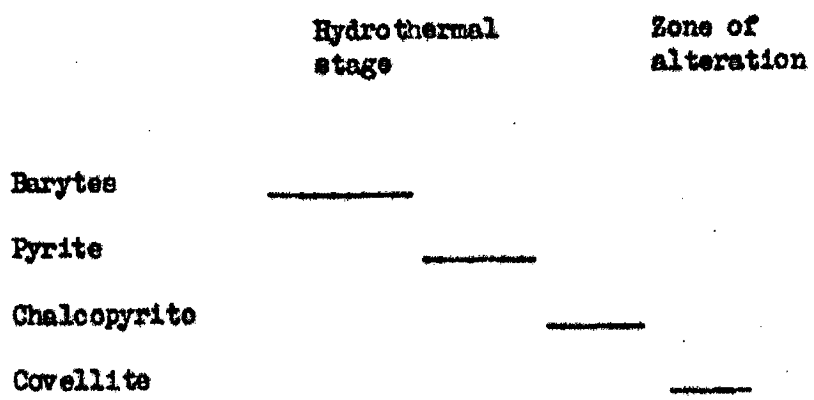
The illdefined boundary between covellite and chalcopyrite, and the rim texture shows that covellite has formed after chalcopyrite as a result of alteration.

ORIGIN

The origin of barytes in this area has been generally ascribed to the interaction of two solutions - namely barium solution derived from the trap and the sulphate ion derived from the oxidation of the limestone. Coulson (1933) and Murthy (op.cit.) agreed to this popular view. Coulson (op.cit.) quotes "The fact that the majority of barytes occurrences are in Vempalle shales and limestones or in the associated traps is certainly suggestive that these shales and limestone have a predisposing influence for the precipitation of barytes. Exactly similar basalts and dolerites are intrusive as sills in the Tadpatris, but not in one single case barytes was noted associated with these rocks". From this he concluded that Vempalle limestones and shales have been in part at least responsible for some of the sulphuric acid which precipitated the barytes.

To the present author it appears that the main source of baryte deposits was from the Vempalle intrusives and the nature of the country rocks did not have much influence on the formation of barytes.

This conclusion is further verified by the study of barytes deposits at Vemula, nearly 16 miles due east of Pulivendla town, (not included in the area under investigation). At Vemula, the barytes deposition is not only restricted to the sill but also the overlying Pulivendla conglomerate (Plate XI, photo 2). So it can be concluded that the solutions which were responsible for the formation of barytes were genetically related with the Vempalle sills. Ore microscope study of the polished sections indicate that the formation of barytes, was followed by the formation of pyrite, chalcopyrite and covellite as indicated below :



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PHOTOGRAPHS

PLATE - I

Photo - 1 Field photograph of Vempalle limestone, showing "cabbage flower" like structure. Locality 2½ miles from Pulivendla on Pulivendla - Lingala road.

Photo - 2 Vempalle limestone (AP/71) showing banded structure.

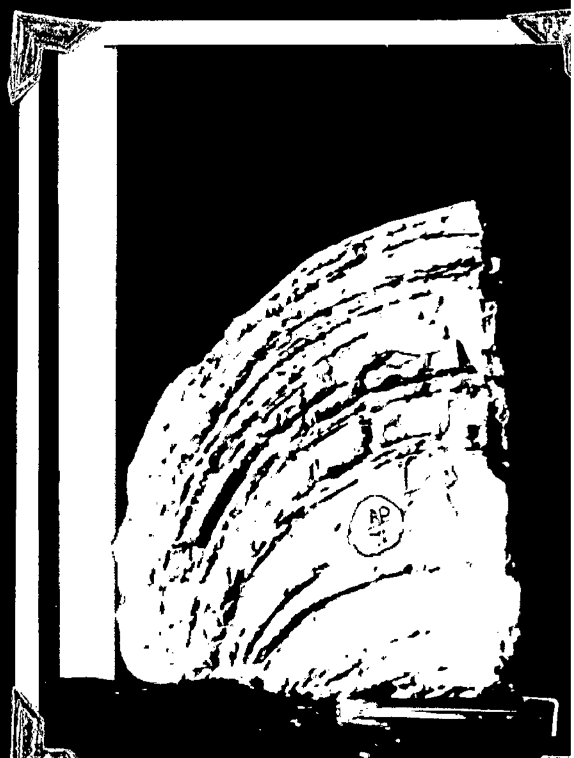

Plate - II

Photo - 1 Stromatolytic character in Vempalle limestone.

Photo - 2 An outcrop of Pulivendla conglomerate.
Locality - Village Lingala.

Plate - III

Photo - 1 Pulivendla conglomerate showing well rounded nature of the constituent pebbles.

Photo - 2 Cross bedding with thin quartz veins in Pulivendla orthoquartzite. Locality-village Lingala.

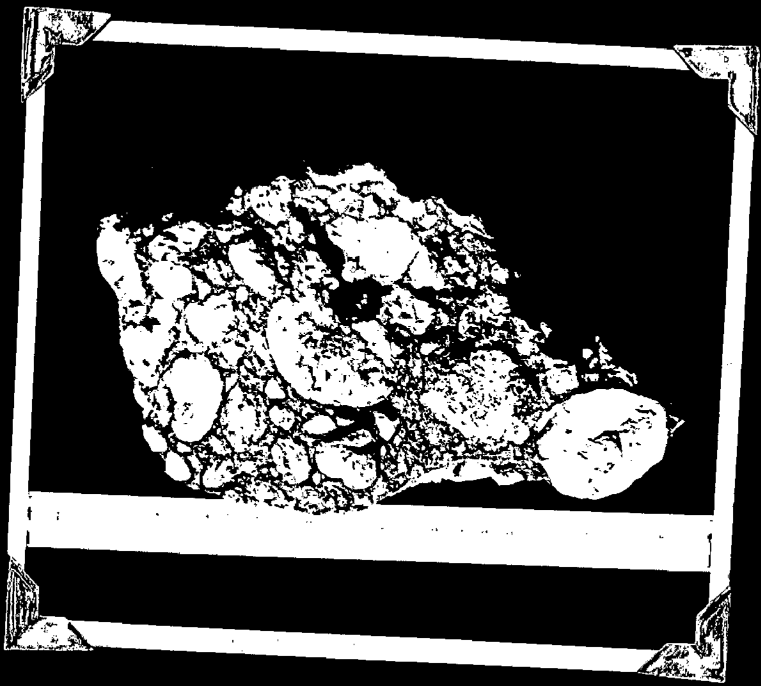

Plate - IV

Photo - 1 Ripple marks in Pulivendla orthoquartzite in Specimen No. AP/134.

Photo - 2 Minor anticline in Vempalle limestone. Locality - near village Ippatla.


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Plate - V

Photo - 1 Minor folding in the limestone band.
Locality near the village Ippatla.

Photo - 2 Photomicrograph (X 50) of dolerite showing herringbone structure in augite.

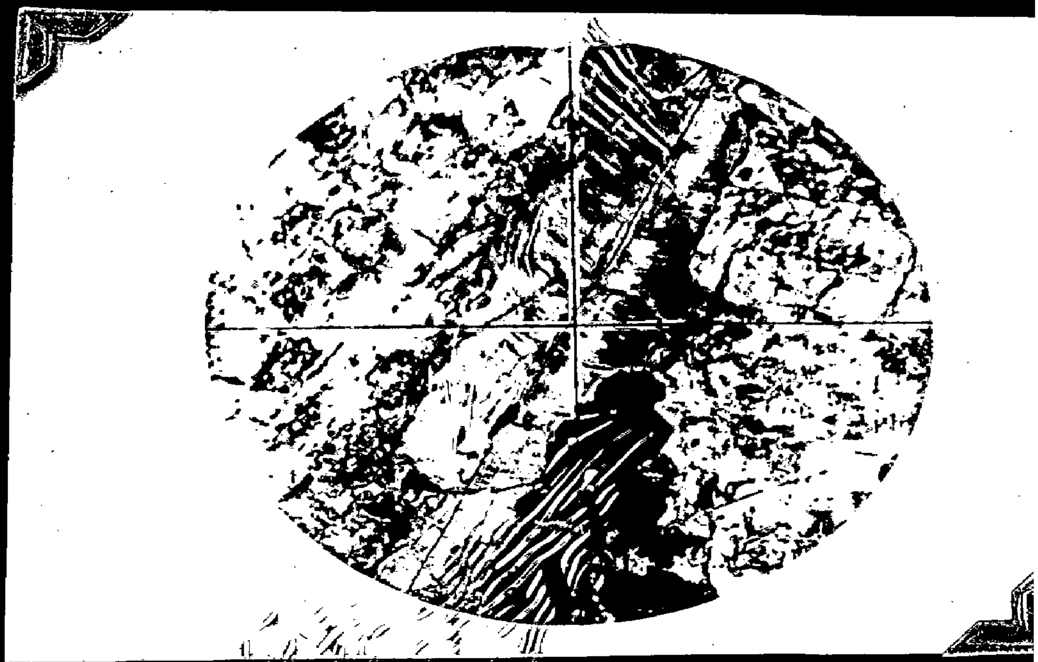


Plate - VI

Photo -1 Photomisrograph (X 50) of Picrite - gabbro showing grains of olivine surrounded by augite. Olivine grains show presence of cracks along which magnetite has developed.

Photo - 2 Photomicrograph (X 50) of specimen No. AP/234 (dolerite) showing alteration of augite into hornblende and saussuritisation of plagioclase.

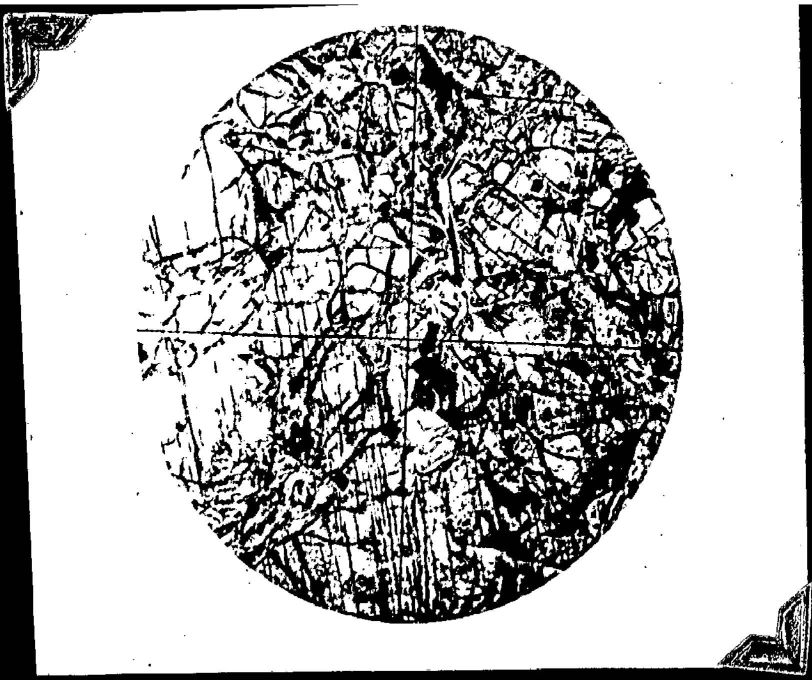
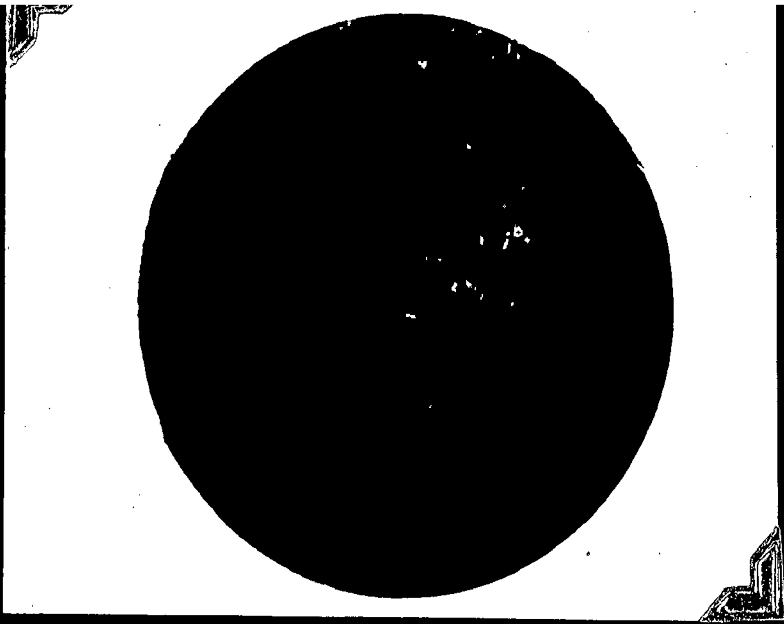


Plate - VII

Photo - 1 Photomicrograph (X 50) of dolerite,specimen No. AP/240,showing ophitic texture. Plates of augite enclose disoriented and isolated laths of plagioclase.

Photo - 2 Same as above in specimen No. AP/237. Plagioclase grains are highly saussuritised.



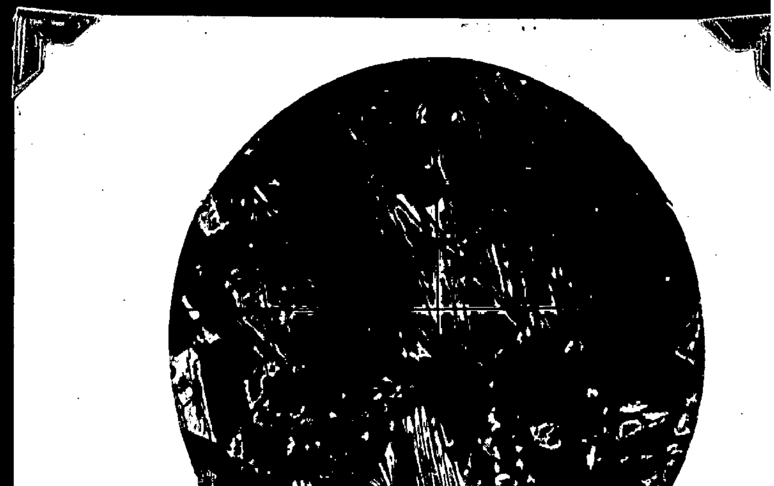


Plate - VIII

Photo - 1 Photomicrograph (X 50) of banded serpentine carbonate rock in which the carbonates (calcite) shows fibrous texture.

Photo - 2 Black serpentine with thin veins of chrysotile showing cross fibre structures.

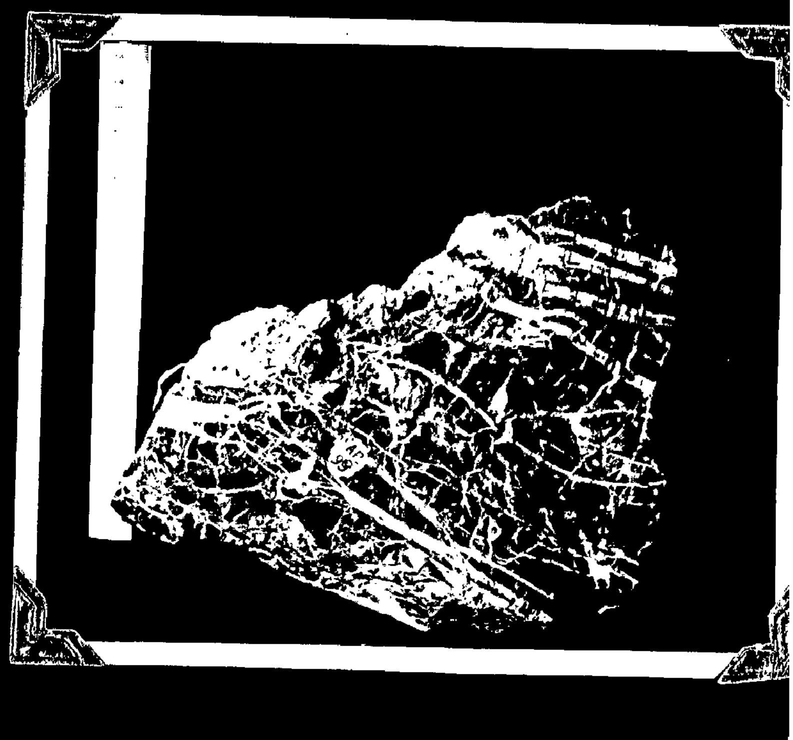


Plate - IX

Photo - 1 **Vein of chrysotile asbestos with angular grains of black serpentine.**

Photo - 2 **Photomicrograph (X 50) of a polished section of serpentine in reflected light.**

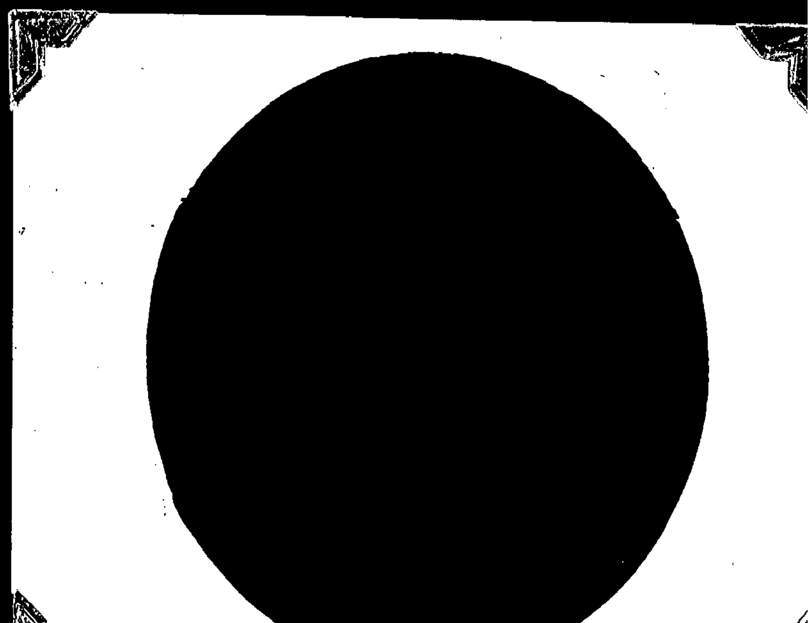


Plate - X

Photo - 1 Abandoned barytes quarry near village Ippatla. The barytes is associated with Vempalle limestone.

Photo - 2 Same as above

PHOTOGRAPH No1

PHOTOGRAPH No2

PLATE X

Plate - XI

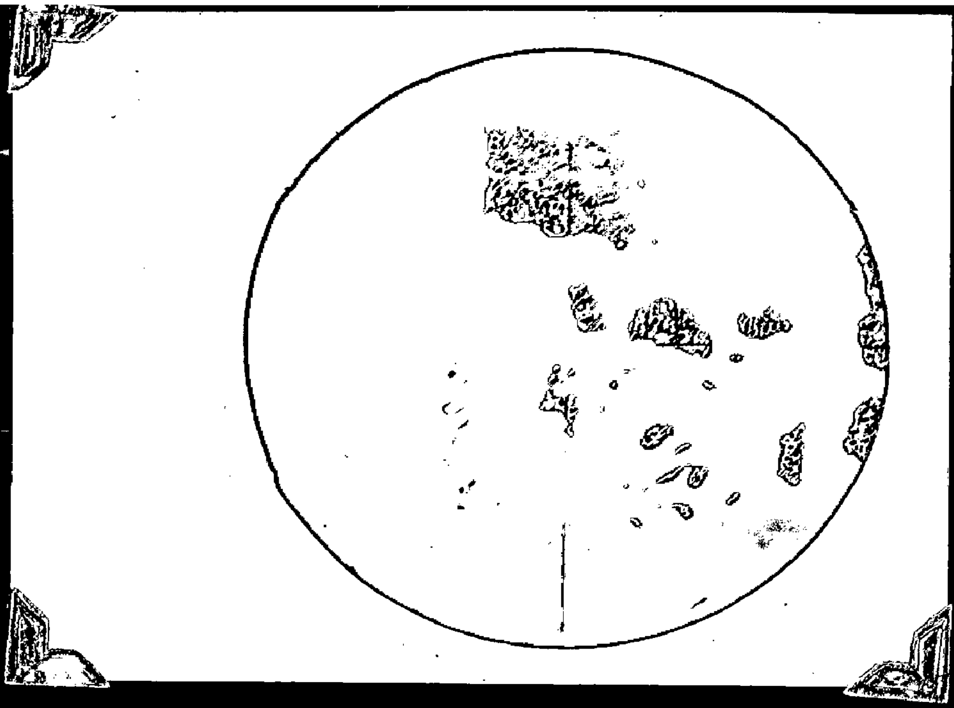
Photo - 1 Photomicrograph (X-50) of a polished section of ore minerals associated with barytes. Euhedral crystals of pyrite appear in barytes. At themargins of chalcopyrite covellitehas developed.

p = pyrite

cp= chalcopyrite

cv= covellite

Photo - 2 Pulivendla conglomerate with barytes Locality - Vemula.



PHOTOGRAPH No 1

PHOTOGRAPH No 2

PLATE I