A REPORT ON STRUCTURAL GEOLOGICAL FIELD WORK IN ANGUL REGION.

Submitted in partial fulfilment of the requirements for the degree of Masters of Science in Geology by Group 5.

UNDER THE SUPERVISION OF:

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We would also like to convey our wholehearted thanks to all the Research scholars for their help in clearing the doubts and guiding us during the field trip. We would like to thank aur batchmates from other groups who worked together and supported us in various situations which made our days memorable during the field trip. We are also grateful to the management of Hotel Santi for ensuring our safe and comfortable stay along with proper hygiene. Their warm hospitality was very comforting.

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GROUP 5

Report on Geological fieldwork in Angul, Odisha.

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CHAPTER 1: INTRODUCTION

1. Introduction:

As a part of the curriculum of MSc. Degree in Geology offered by the Indian Institute of Technology Kharagpur, a geological fieldwork to Angul district in Odisha was arranged from 5th December to 16th December 2024. Geological data reconnaissance, independent mapping of a region, detailed mapping, strain analysis and estimating the tectonic and deformation history of the area using the evidence found on field were some of the primary exercises that were conducted during this field work. This report gives a detailed account of all the exercises carried out on the field, their procedures, outcomes and the traverses.

1.1 Objectives of this fieldwork:

Majority of the fieldwork focused on the structural geology and its controls on various aspects of the regional scale of deformation and its overall effect combined with the tectonic history of the region. To integrate these aspects, following were the objects of this fieldwork:

a. Identifying the structures on the field and their significance in the deciphering the deformation history.
b. Different mapping techniques.
c. Regional Mapping of a given area.
d. Preparing lithological map of the Angul region.
e. Detailed Mapping of an outcrop.
f. Strain and kinematic analysis.
g. Taking oriented samples from an outcrop.
h. Observing the fabric and its importance in understanding the deformation history.
i. Reconstruction of various folded surfaces from data gathered from the field.
j. Understanding the fractal nature

1.2 Location and Accesibility:

Odisha has a wide geographic extent from the eastern coast of India, covering an area of about 1,55,707 km^2 which approximates to 4.87% of the total area of the country. This vast expanse is then further divided into 30 districts, 58 Sub-divisions and 317 Tahasils. One of these districts is Angul District which covers and area of 6232 km^2 and is located at the centre of the state. It lies between latitudes of 20º40'N and 21º40' and longitudes of 84º15'E and 85º23'E. Being at the centre, the district is surrounded by Dhenkanal and Cuttack districts in the east; Deogarh, Kendujhar and Sundargarh district in the north and Sambalpur and Sonepur in the west while the Boudh and Nayagarh lie to the south of the Angul district.

Angul is enriched in various economic deposits which makes it very important locality for mining of various deposits like coal, kyanite, graphite, dimension stones and various quarries of pegmatites, charnockites, etc. The Talcher coal field lies in this district which has the coal beds belonging to Karharbari and Barakar formations or the Damuda series. Due the presence of these economic deposits, the district hosts various industrial plants like National Aluminium Company Limited (NALCO, Mahanadi Coalfields Limited, Indian Aluminium Product Limited and National Thermal Corporation, etc.

Being the centre of the state, Angul has very connected railway and roadway network which facilitates the transportation efficiently. Angul station is one of the most important railway stations of the East Coast Railway as the coal and other economic deposits mined here are transported further. Furthermore, it falls on the Bhubaneshwar-Talcir-Sambalpur railway track. The district headquarter of Angul is located about 150 kilometres from the state capital, Bhubaneshwar. Bhubaneshwar Airport is the closest airport from Angul district. Bus is one of the most efficient and vastly connected means of transport. Although not commonly preferred, water transport across the Mahanadi and Brahmani rivers is an option. Cuttack is also one of the important and closest main cities that one can take a stop at so as to reach Angul.

Train from Hijli station to Bhubaneshwar was taken and further, another train from Bhubaneshwar was taken to reach Angul for this fieldwork. Accommodation provided was Hotel Santi which is located near the Old Bus Stand.

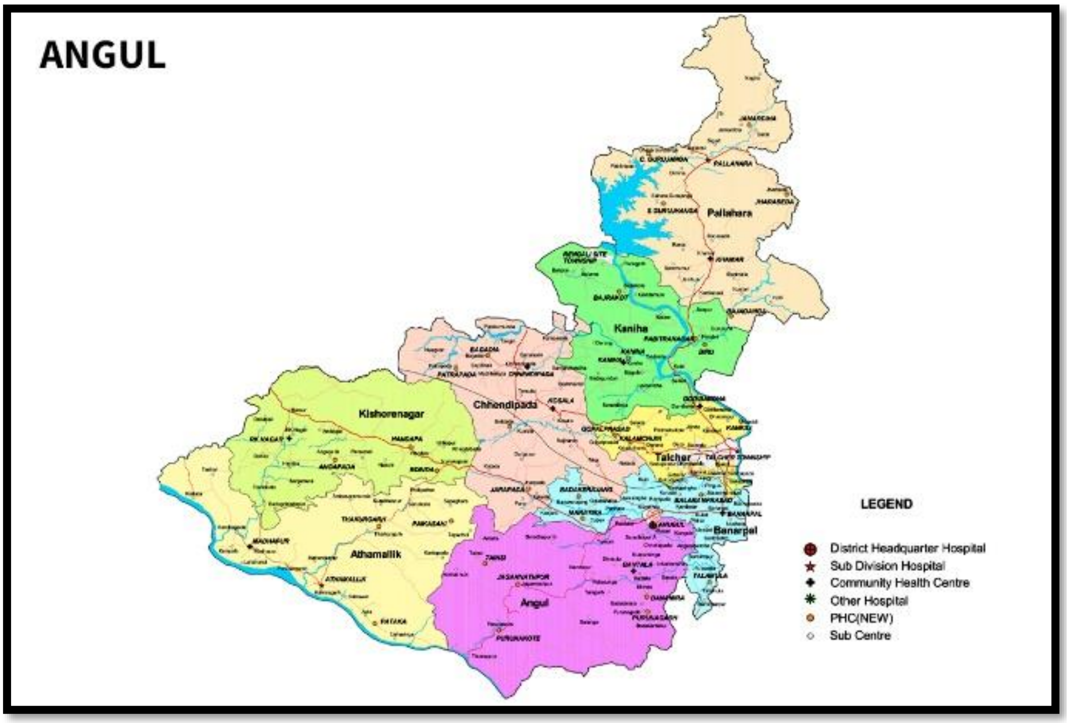

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Fig. 1 Map of Angul district.

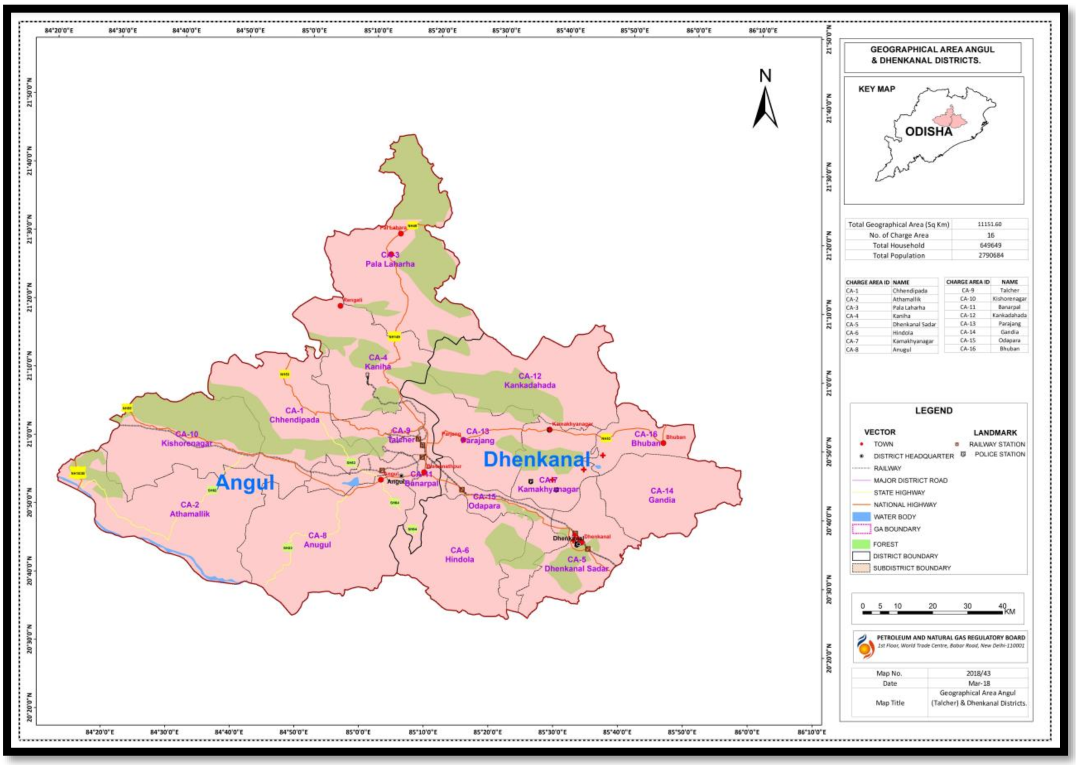


Fig. 2 District map of Angul and Dhenkanal.

1.3 Physiography and Topography:

Angul shows variety of terrains starting from low-lying flatlands to hillocks, ridges and undulating lands with and average elevation of 875m. River Mahanadi passes through Angul in the southern boundary while to north lies the river, Brahmani. Their respective tributaries drain the area. Broad classification of the area is done as follows: Eastern Ghat Supergroup and Old Metamorphic Group towards the Southern and Western part; Coal bearing sedimentary deposits of Talcher basin to the North and the Satpura-Mahanadi sediments in the Graben at the central part. Moving along the north of the Talcher basin, the faults become prominent along with the north-westerly plunging syncline on a regional scale. This structure hosts varied coal seams and number of these coal seams increase along the west direction and the basin then outcrops along the western part. Iron Ore Supergroup that trends almost N-NE is seen along the northern part. Malaygiri of Pallahara is the highest peak of the district with an elevation 1186m above the mean sea level which is also a small tourist attraction followed by the Banamadali peak with 790m elevation above the mean sea level. These hill ranges run along the north-eastern boundary; southwestern boundary. The valley of river Brahmani runs along the boundary of Talcher through Kaniha and Pallahara.

This varied topography, terrains of different ages and evidences of intense events of deformations in the form of constantly changing physiography make Angul an ideal place for structural geology studies and in understanding the stratigraphical makeup along with the events of tectonics.

1.4 Climate:

Climate of Angul shows extremes in the two seasons of summer with temperatures going up to 47ºC and in the winters going as low as 10ºC. The hot summers start around march and come to an end around June. From the month of June, monsoon takes over with significant amount of rainfall, enough for agriculture to be one of the main occupations of the people residing in the area. The months from November to February experience the chilly winters. The humidity is seen to be high all through out the year. This varied climate makes Angul a home for varied species of flora and fauna.

1.5 Vegetation:

The vegetation of the Angul region can be classified as tropical dry deciduous forest which covers around 44% of the district. The valleys of the rivers are particularly fertile. The prominent soil type is red lateritic soil along with sandy and alluvial in nature. Due to this, paddy fields are very commonly seen along with pulses, vegetables, spices etc. Teakwood is very commonly seen in the areas with dense vegetation.

1.6 Drainage:

Two major rivers that flow through Angul are Brahmani and Mahanadi along with their respective tributaries. Large part of Angul is covered by the Brahmani basin and the Mahanadi covers the southern part of the area. Brahmani river is the second longest river of the state and follows a general South-East direction which is the broader trend of the regional rocks which is further dictated by the joints and faults. Mahanadi flows along the South-West boundary of the district which goes along the parallel to the strike of Khondalites and shear zones. Apart from these major rivers, Angul is dissected by various canals that expose beautiful outcrops for geological studies.

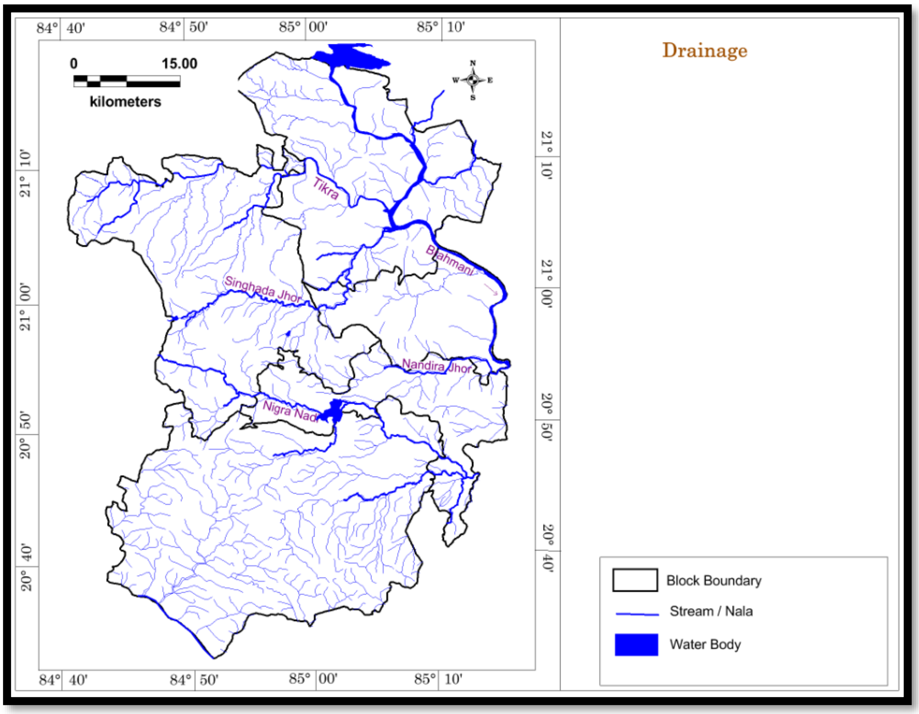


Fig. 3 Drainage in NAQUIM area, Angul District.

1.7 Equipment used:

Throughout the fieldwork various equipments were used to take geological data which was later inferred on an outcrop and regional scale.

- Clinometer compass: Consists of graduated scale and magnetic needle. Used for taking various data sets like strike direction, dip amount, front bearing, back-bearing and orientation, etc.

- Brunton Compass: Consists on magnetic needle, bull's eye, clinometer tube, two graduated scale: one for measuring dip and one for measuring the azimuth. Brunton compass is used for taking trends, bearings (fore bearing and back bearing), strike direction, dip amount and dip direction. It also helps in taking oriented samples.
- Hammer and chisel: Used for breaking and splitting rock samples. Often used to break a fresh piece of the rock so as to look for the minerals which have not undergone weathering. Used to breaking oriented samples. Also used as scale for pictures.
- Measuring tape: Used to measure the distance between two points. Preferably used during detailed mapping to calculate the distance between the pivot and the point of interest.
- Mapping board: Used to mount toposheets, graphs and tracing papers for various exercise like detailed mapping, regional mapping and strain analysis, etc.
- Diagonal scale: Used to measure the rake of lineation and long and short axes of the porphyroclasts.

Chapter 2: Geological Background and Regional Geology

Odisha as a region falls under one of the most tectonically deformed parts of the country with the ages of rocks ranging right from the Archean metasedimentary and igneous rocks to the Quaternary sediments and laterites. Being the host to Eastern Ghat Mobile Belt, the Singhbhum Craton, and parts of Bastar craton, Odisha's districts show a variety of geological and topographical features. As stated earlier, Angul falls at the approximate centre of the state which makes it very structurally and geologically complex regions.

The metasediments of the Singhbhum groups like Gorumahisani consists of quartzites, hornblende schist, quartz-mica schist, chlorite schist and meta-basic rocks; Bonai Group: biotite gneisses, biotite-hornblende gneisses and granodiorite along with metasediments like shale, phyllite, sandstone and conglomerates; are exposed in the area around the study area.

The EGMB lithologies consists of Khondalites, garnetiferous quartzo-feldspathic gneiss, charnockites, leptinites, augen gneisses mafic dykes metamorphosed to amphibolite facies and pegmatites, etc. All of these lithologies preserve the polyphase deformations that affected the terrain. The Eastern Ghats that run parallel to the Eastern Cost of India are seen exposed in Angul along the southern part. The Eastern Ghats are made up of the high-grade metamorphic rocks going up to upper granulite facies and the at places up to migmatites. The zircon dating ages of these rocks comes up to 1000 million years. The Angul domains lies to the north of the Mahanadi and by some is considered to be the part of the East Antarctica. The granulite facies are the indicatives of high temperatures which are more than 700-770^{o}C. The mineral assemblages that are stable at these temperatures indicate elevated temperature conditions. Thus, some geologists call it Ultra High Temperature terrain. These elevated temperatures are of the indicators of the intense deformation and metamorphism conditions. These conditions correspond to the middle crustal conditions. Thus, the study of this domain can aid in understanding the structural and regional trends that correspond to these conditions.

North of Angul town, bands of garnet-sillimanite gneisses and schist quartzites and charnockites group rocks are exposed along with mafic granulites, metapelites, graphic granite intrusions are some of the lithologies that can be regionally traced on a larger scale while some outcrops have been subjected to urbanization and can no longer be seen on field or traced on map. Amongst these, quartzo-feldspathic gneisses and khondalites are very prominent. These lithologies take a regional turn along the northern part of the town which is inferred from the turning of the earlier foliation drastically. Charnockites exposed are a part of charnockite suite. Enderbite is the variety of the charnockite exposed near Jharasingha. Contact between the Khondalites and the quartzites are seen along the north of Jharasingha Arts College which forms the S_0.

The Talcher Basin famous for the coal bearing horizons also lies on the northern part of the Angul region. Gondwana group of sediments are separated by the EGMB is separated by fault that runs along east-west. Gondwana sediments consist of conglomerates, shales and sandstones. Major part of Rengali province is exposed near the Rengali Dam. The main lithology consists of granulite facies of rocks with charnockites of two different ages. The one to the north of River Brahmini are of Archean age and the one south of the river are Proterozoic in age. The major lithology of the area is cut across by mafic dykes which have been metamorphosed to the amphibolite grade of facies. These dykes that trend WNW-ESE preserve the evidence of shearing that took place during the deformation events. The shear zone between Rengali Province and Eastern Ghat Mobile Belt is observed near Kanihan which is called Kerajang Shear Zone. The area in and around the Budhapal region expose a beautiful section of quartzite ridge which contains the XZ section i.e. kinematic frame of reference for structural analysis.

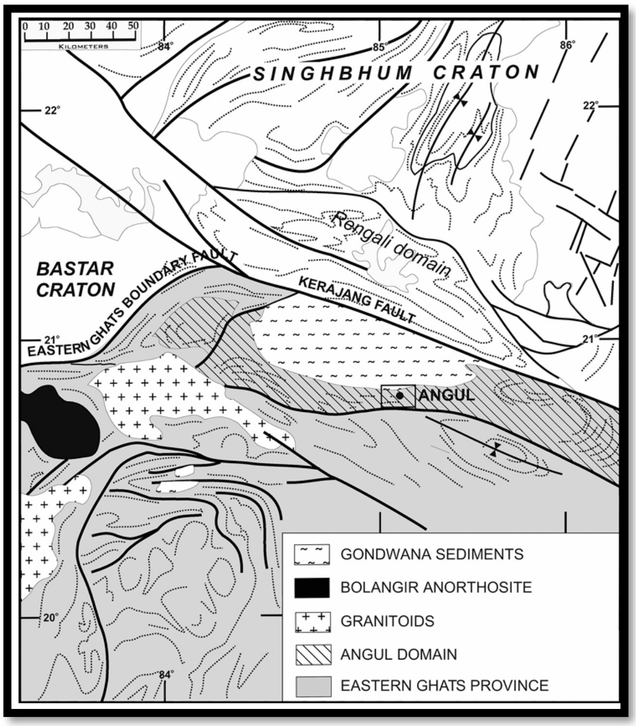


Fig. 4 Geological Set-up of Angul Domain.

Stratigraphy:

Age	Group/Supergroup	Formation	Lithology
Holocene	Quarternaries	Brahmani/Mahanadi formation Kaimundi formation	Alluvium Grey sandy clay
Pleistocene to Holocene	Tertiaries		Laterite
Permian to Triassic		Mahadeva formation	Sandstone, shale
Permian	Gondwana Supergroup	Barakar, Barren Measures , Raniganj and Damuda formation	Conglomerate, Sandstone, Shale and coal
Carboniferous to Permian		Talcher formation	Sandstone , shale and tillite
Archean to Paleo-Proterozoic		Lower Bonai Group	Gabbro, metavolcanics, granite , biotite gneiss biotite hornblende granite gneiss and granodiorite
		Gorumahisani Group	Ferruginous shale, cherty shale, gritty sandstone, orthoquartzite, conglomerate, metabasics
Archean		Granitoids	Augen gneiss, garnetiferous gneiss, biotite gneiss and migmatised khondalite

	Eastern ghat group	Charnokite group	Acid and intermediate charnockite, Basic charnockite, pyroxene granulite Quarzto-feldspathic gneiss
		Khondalite group	Coarse crystalline quartzite, quartz-silimanite schist, garnetiferous quartzite

Chapter 3: Lithology and Structural elements.

Angul Domain has variety of lithologies exposed as beautiful outcrops for structural analysis and studies which help in decoding the deformation history of the area and understanding the regional tectonic make up. The following chapter explains the presence of the these various lithologies, their outcrop exposures, the different planar fabrics, the inferred structural make up and their relation to the deformation history.

Khondalites

Khondalite is a high-grade metamorphic rock, typically classified within the granulite facies. It represents metamorphosed aluminous sedimentary rocks having a composition of garnet, sillimanite, quartz, feldspar. The presence of sillimanite is characterised by its needle like habit. Protolith: Khondalite originates from aluminous sedimentary rocks, such as clay rich shale or argillaceous sediments. It is prominently associated with Precambrian terrains, especially in the Eastern Ghats Mobile Belt. It is believed to have formed during regional metamorphism associated with tectonic processes, such as continental collision, crustal thickening, or rifting.

a) Location 1: Near Amalapada, beside the road

Coordinates: 20° 50’46”N and 85° 05’ 56”E

A small two metre outcrop of Khondalite was exposed near the Amlapada. Two distinct limbs of a fold were observed. One limb was trending NNW-SSE and another limb was trending NNE-SSW. The axial plane of this forl was trending North-South. These observed foliations were the planar fabrics S_{n+1} and S_{n+2}. The planar foliation fabrics in the folded limbs S_{n+1} indicates primary foliation formed due to deformation D_{n+1} and followed by deformation D_{n+2} forming S_{n+1}. S_{n+1} and S_{n+2} may become parallel when tightly folded.

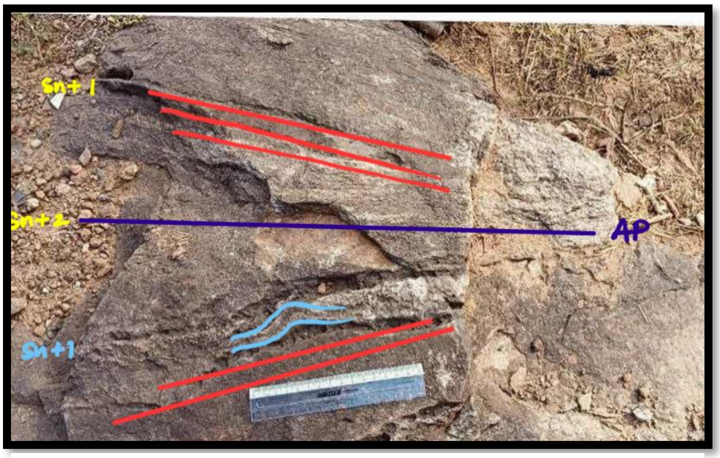


Fig. 5 Sn+2 foliation trending North-South.

b) Location 2: Near Ramachandi temple

Coordinates: 20°51’35’’N and 85° 06’11’’E

Towards the north eastern part of the Ma Ramachandi Mandir behind the railway colony, an outcrop of Khondalite showing evidences of superposed deformation was seen. The outcrop revealed lineation and foliations which were trending in various directions with different generations of foliation that were curved. Along with preserving the superposed deformation in the khondalite, melt of the same composition also shows the imprints of these deformation. Boudins were also observed.

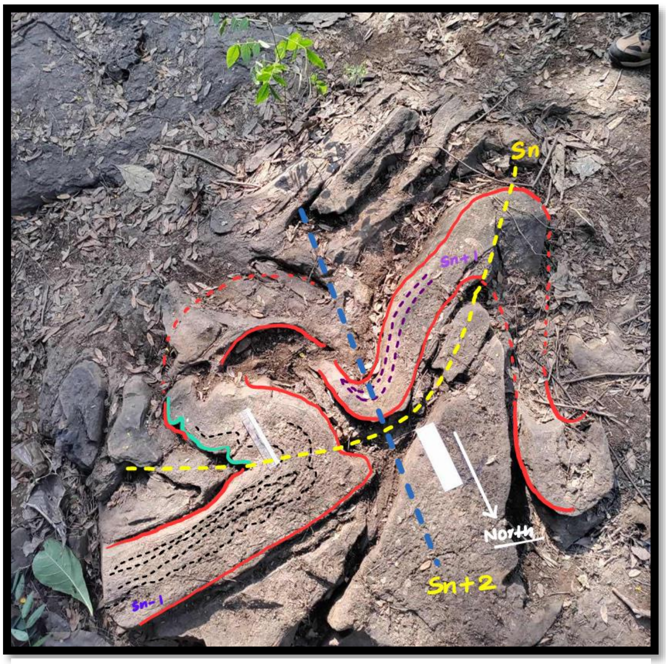


Fig. 6 Foliations demarcated of Type 2 pattern.

Two metres apart from this outcrop, another outcrop preserving Type 2 super-posed deformation is seen. The two foliations curving along with the lineations are seen. The outcrop shows isoclinal folds with well-preserved Type 2 and Type 3 interference patterns. It consists of S_1 foliation formed due to deformation D_1. The traces of S_2 on S_1 can be observed, the S_2 traces indicate the lineation formed by the deformation event D_2. Type 2 and Type 3 interference patterns have suffered weathering but the interference patterns are clearly visible. Isoclinal fold provide the evidence for the occurrence of D_{n+2} deformation. For Type


Fig. 7 Type 2 fold interference pattern.

2 at least S_{n+3} foliation can be observed. The southerly plunging fold can be seen. In Type 3 deformation S_{n+1} and S_{n+2} foliation can be observed whereas L_1 and L_2 lineations are parallel to each other. The characteristic mushroom geometry is observed. Detailed explanation on this is in chapter 4.

Few meters away from this a small outcrop of refolded fold in khondalite is seen.

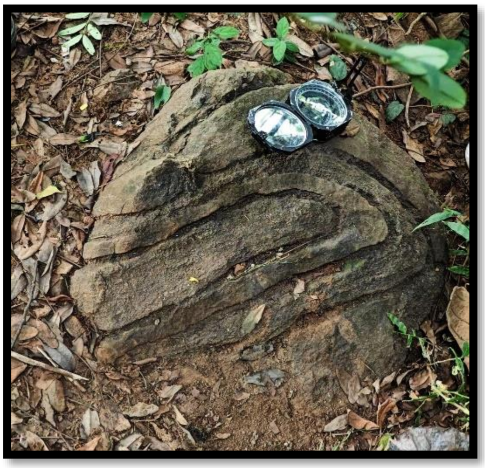


Fig. 8 Type 3 fold interference pattern.

Cross-sectional view of the outcrop is seen which shows the isoclinal folds forming the S_{n+1} foliation which, if seen from above constitutes to the mushroom geometry.

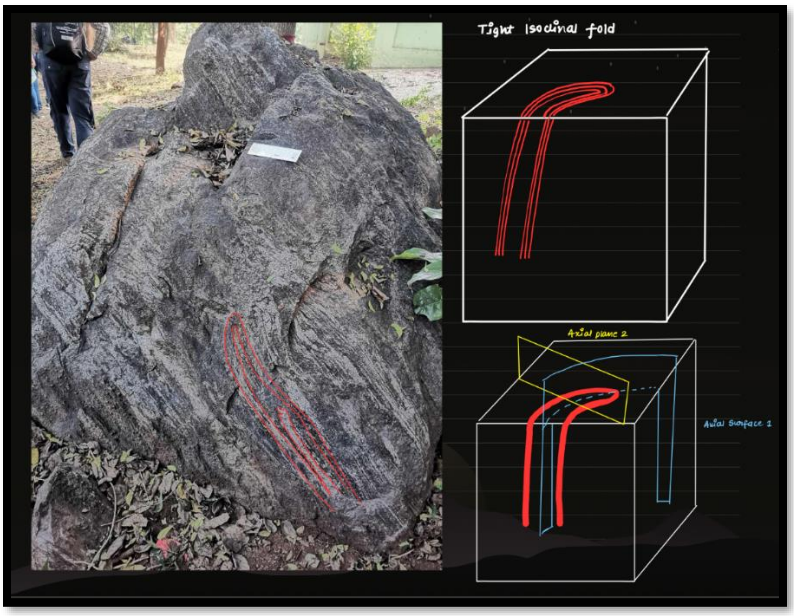


Fig. 9 Crossectional view of type two-fold showing tight isoclinal folds.

c) **West along Petrol Pump and Sakasingha**

Coordinates:20° 51’08.4”N and 85° 05’19.0”

Attitude: Strike **-**N54°E and Dip -39 SE

A slightly weathered Khondalite outcrop was observed. The sillimanite needles were clearly visible upon breaking a fresh piece of sample. The lineations and foliations were very well developed.

The lineation was plunging towards south. On the surface tight fold can be observed which had 90 degree rake with lineation.

Fig. 11 Reclined folds.

This meant that the folds were reclined folds which were tightly folded and their intersection with the plane gave rise to intersection lineation or the fold axis lineations. The trend and pitch of the lineations were measured to be: N54/90^{o}. The red colour of the khondalite in this exposure is likely due to the iron leaching. Aluminium rich minerals like garnet and sillimanite indicate rock’s protolith may be shale.

Fig. 10 Attitude of the intersection lineations.

d) Near Jorasingha Arts College

Coordinates:20° 51’29” N and 85° 4’23” E

The contact i.e. S_o between Khondalite and Quartzite can be observed which signifies that earlier a fold was present which was later eroded and other limb of the fold was also preserved.

On one outcrop at the same place culminations and depressions can be observed which indicates dome and basin features.

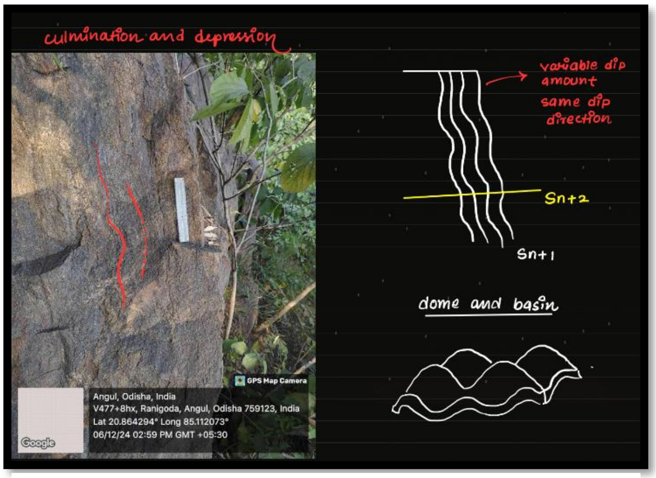


Fig. 12 Culmination and depression pattern.

These features are characteristic of Type-1 fold interference pattern. Here dip amount changes but dip direction remains same. This is prominent evidence of the fact that the limbs of the folds itself show curving due to the super-posed deformation. S_{n+1} foliations and S_{n+2} foliations were prominent.

e) Jorasingha (Ahead of the petrol pump)

Co-ordinates:

Distinct type 2 folding was observed in the khondalites on the top of the hills. This outcrop holds a special significance as the primary foliation S_{n+1} itself is seen turning. This indicates that takes a regional turn. This is inferred from the fact that if the earlier strike of the S_{n+1} is followed from this outcrop onwards, khondalite beds will no longer be encountered. This indicates the regional

Fig. 13 Type 2 fold interference in Khondalite.

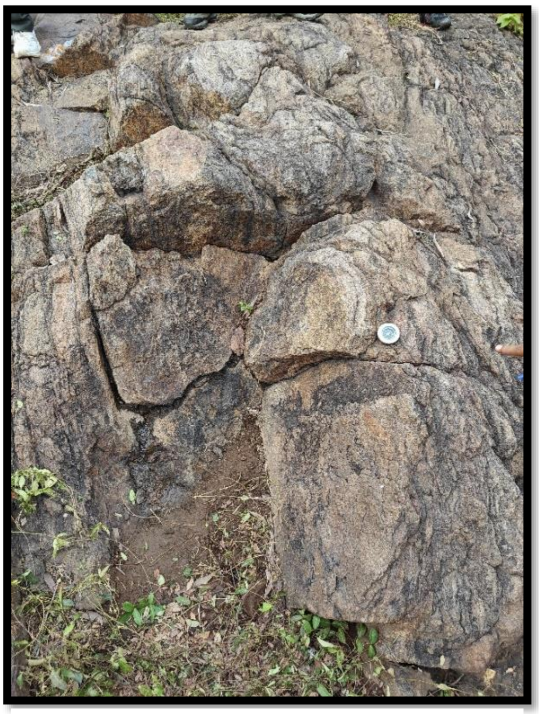


Fig. 14 Folded Sn+2 surface.

scale turning of the beds. The S_{n+2} formed due to the curved axial plane strikes North South. And the general plunge of the fold axes is along the dip of the outcrop which is towards the south. The strike of the S_{n+1} changes from NNE-SSW to 295/30º.

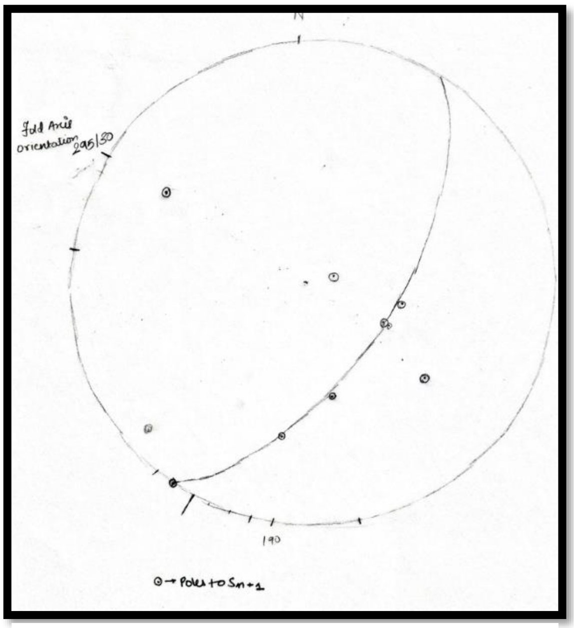


Fig. 15 Reconstruction of the fold using stereonet.

f) Behind Railway electric loco-shade

Co-ordinates: 20° 51' 44.56" N 85° 06' 5.23"E

Scattered exposures of Khondalites were observed from the Loco-shade to the Sidheshwar temple. These exposures showed Type 2 folding which were similar to the folds observed at the outcrop behind the Ramachandi Mandir. The changing strike of the beds indicate a fold that can be inferred by tracing these scattered outcrops. The khondalites near the Sidheshwar Temple point towards a possible hinge of the regional fold that started from the change of the Sn+1 foliation of the Jorasingha Khondalites and which continues ahead (discussed in the independent mapping chapter.)

Fig. 16 Type 2-fold resembling the Ramachandi outcrop fold.

Quarztofeldspathic gneiss

Quartzofeldspathic Gneiss is a metamorphic rock primarily composed of quartz and feldspar, with minor amounts of mica, amphiboles, and other minerals. It is a high-grade metamorphic rock formed under conditions of intense pressure and temperature. Mineralogically, it is predominantly made up of quartz, feldspar, garnet, biotite. Gneissic banding is the most characteristic feature that is made up of alternating light-colored (quartz and feldspar-rich) and dark-colored (mica or mafic mineral-rich) bands. Depending on the protolith, gneiss can be classified as orthogneiss when the parent rock is igneous rock like granite, granodiorite; or paragneiss if the parent rock is sedimentary in nature. Generally, the gneisses can undergo high-grade metamorphism (**granulite facies**). It is often found in ancient cratonic shields and high-grade metamorphic terrains.

Gneisses are important in studying the structural make up of the terrain and the deformation history. This is due to the fact that the foliation seen in the rock is a result of segregation of the minerals which is their way of accommodating the applied strain. The foliation develops perpendicular to the shortening and is seen throughout the body which makes it a 'fabric'. If the foliation is visible in every part of the rock, then it is called 'Penetrative Foliation'. The quartzo-feldspathic gneisses seen in and around the Angul area are strongly foliated with the foliation fabric being penetrative and preserving the deformation history.

a) **Location: GRIDCO Exposure**

Coordinates: 20º51'08" N and 85º05'90" E

The two outcrops can be observed adjacent to each other. One of the boulders is tilted as a result of blasting which makes its orientation different as compared to the in situ one. This outcrop shows evidence of at least four deformations. The stress acting on the rock leads to plastic flow in the minerals which aids in accumulating the strain and leads to foliation/segregation. As a result of this phenomenon the minerals within the rock recrystallize and the rock behaves in a ductile manner.

Feldspar augen-shaped grains were observed and were distinguished from quartz grains due to their pearly lustre and cleavages. The foliation is seen wrapped around the porphyroclasts. The recrystallized feldspar grains were observed in the pressure shadows of the porphyroclasts. This bimodal grain size of feldspar indicates to a granitic protolith and is thus an orthogneiss.

Fig. 17 Isoclinal folds of S1 and axial planar foliation of S2 along S1.

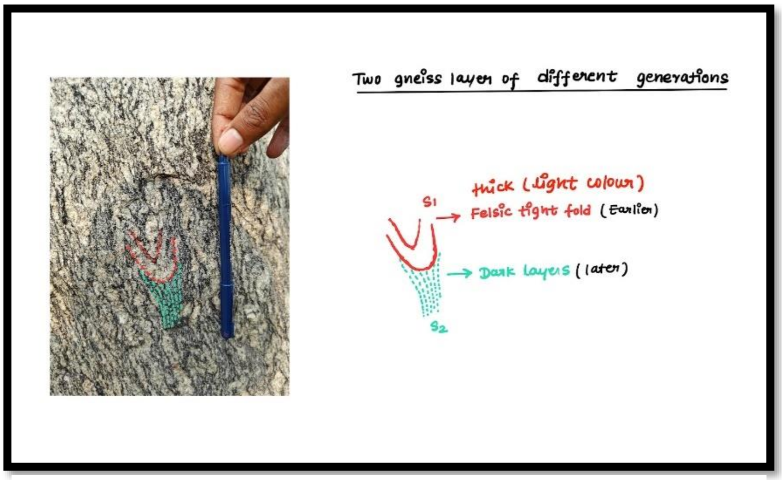


Fig. 19 S1 and S2 along the gneissic layers.

Along with the gneissic layering of leucocratic and melanocratic layers, coarse and fine layers can be identified easily. The black layer i.e, finer gneissic layer does not show folding whereas coarse layer shows prominent folding. The coarser foliation is seen isoclinally folded and the dark coloured finer layers are seen along the axial plane of these isoclinal folds. The intersections of these two foliations forms the fold axis. The trace of S_2 i.e. the finer bands is seen on the S_1 i.e. the coarser band which makes up the fold axes. The general trend and rake of the fold axis is N350/14^o.

On the other side of the outcrop, shearing of the foliation is observed which indicates a shear plane that cuts across the foliation thus making it younger than the earlier foliations. This shear plane trends N70 and has sinistral sense of shear. The traces of this shearing plane are seen on the other plane of the outcrop. This shear plane makes a trace on the plane having strike N190/50^o towards East with the rake of 68^o.

Fig. 18 Shear plane.

Type 1 pattern of culmination and depression is seen on one of the exposed face of the outcrop.

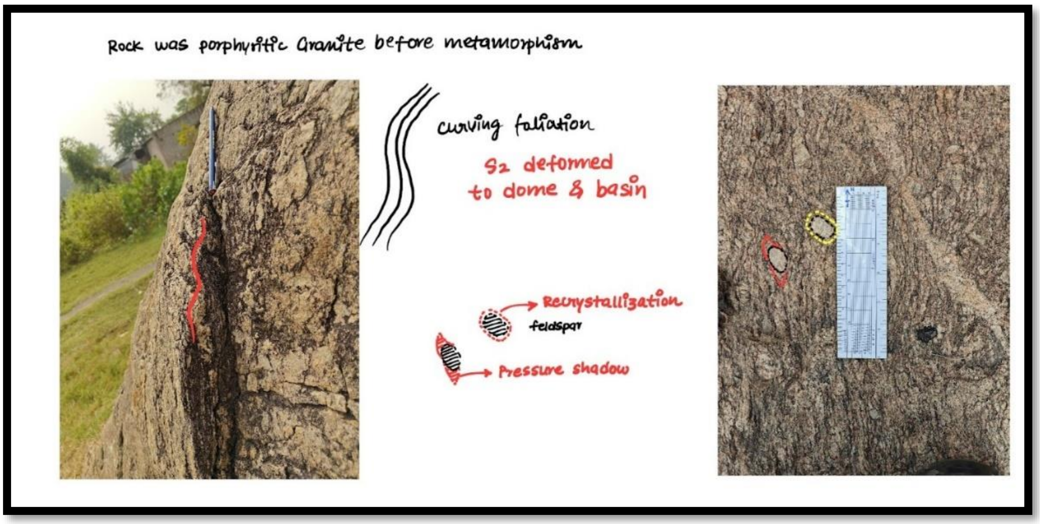


Fig. 20 Culmination and depression pattern in quartzofeldspathic gneiss.

The deformation history can be easily reconstructed by observing the foliations carefully. The coarser foliation can be considered as the first formed foliation S_1 formed due to D_1. The later foliation developed can be described as S_2 which forms along the axial plane of S1 isoclinally folded folds which accounts to D3 and D2 respectively. The culmination and depression pattern corresponds to at least two more deformations that gave rise to these characteristic patterns. Lastly, the youngest shearing activity cutting across both foliations can be termed as a separated event of deformation. Thus, minimum of five events of deformation can be inferred from this outcrop of quartzo-feldspathic gneiss.

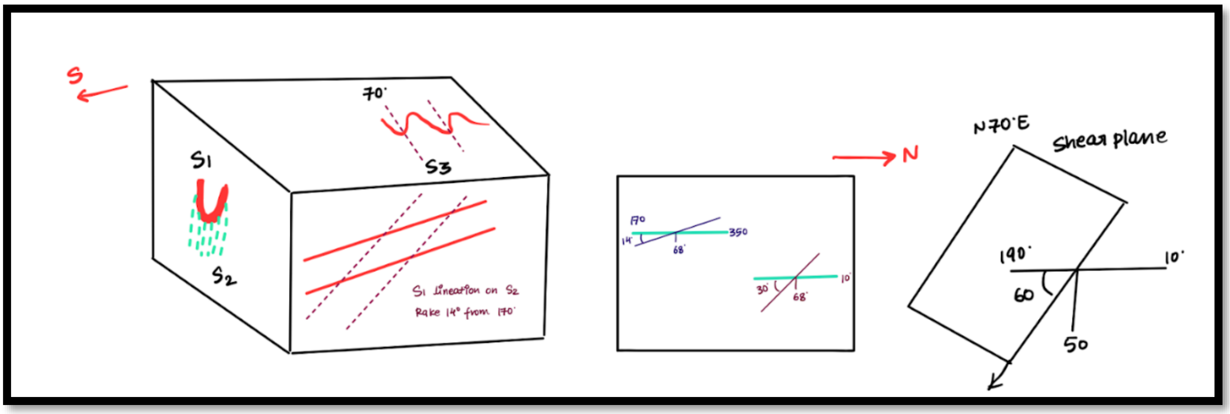


Fig. 21 Block diagram of the outcrop.

b) **Location:** Railway cutting section

Coordinates: 20 51’ 50” N , 85 06’42”E

The outcrop reveals post-deformational melts aligned along east-west direction forming crenulations. The gneissic banding is seen tightly refolded and almost striking North-South. This foliation is seen curving into the crenulation which indicates the crenulations are younger i.e. they post-date the North-south striking foliation. The crenulations and the curving of the earlier foliation indicate ductile behaviour. The crenulations are made up of melts.

Notably, these melts lack substantial amounts of biotite or other large mineral crystals. Intense strain in the region has almost entirely obliterated the original S1 and S2 planes. Instead, east-west trending shear planes disrupt the melt layers, exhibiting a sinistral sense of motion. Deformation associated with D3 is

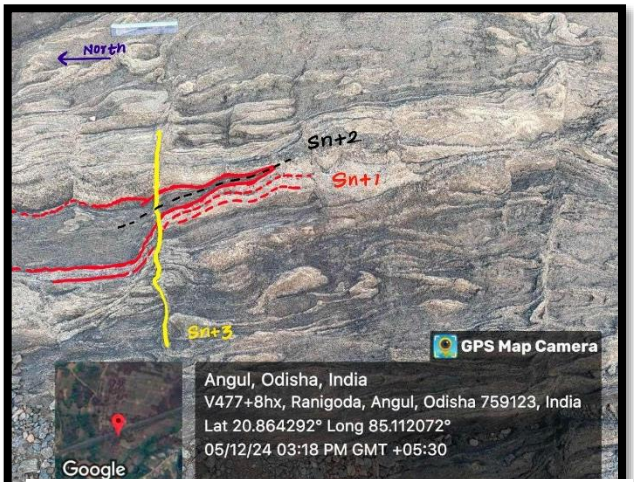


Fig. 22 Quartzofeldspathic gneiss showing crenulation and two sets of foliation.

predominantly north-south, while D4 is characterized by east-west trending structures, indicating superposed deformation events.

Fig. 23 Distortion in the melt layers seen.

One section of the outcrop displays numerous tight folds within felsic layers. In contrast, another part shows felsic banding devoid of isoclinal folds. This variation in structural features is a result of intense shearing, which has erased all structures at the boundary between the two sections. Another evidence of intense shearing is the distortions seen in the melt layers.

Moving along the strike of the earlier foliation, boudins are seen which indicate extensional regime. Further details of quartzofeldspathic gneisses are discussed in chapter 7, Independent mapping.

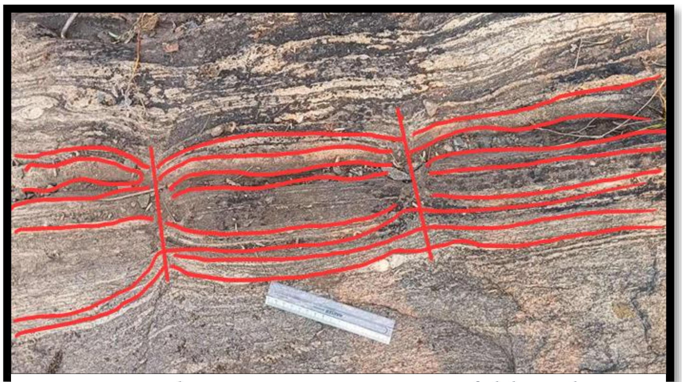


Fig. 24 Boudinage seen in quartzo-feldspathic gneiss.

Quartzite

a. Location: Budhapal Quartzite Exposure
Coordinate: 21°12'1''N and 84°52'49''
Stretching lineations were prominent on the outcrop. The foliation planes were dipping steeply towards north. The lineation trend was east-west. The section which is parallel to stretching lineation and perpendicular to foliation is XZ section. This section was exposed on the outcrop. XZ Section forms a very integral part of the strain analysis and always used to study the kinematics of the region.

The foliation plane is identified as S1 and refers to D1 deformation. The strike is around 110°-290° and the dip is 70°**.** A small exercise on taking oriented samples was conducted.

Fig. 25 Stretching lineation on quartzite (Strike marked on the outcrop).

Fig. 27 XZ Section.

Fig. 26 Oriented sample.

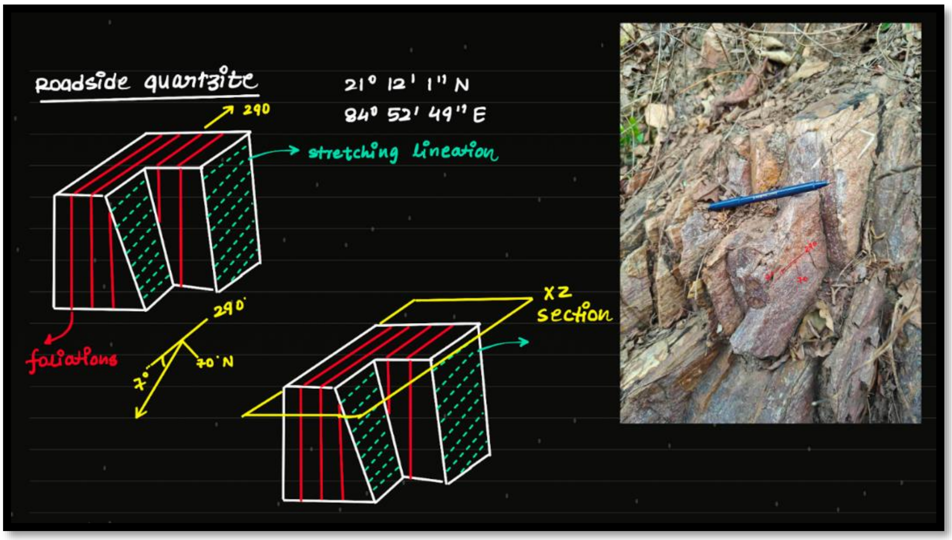


Fig. 28 Block diagram of the quartzite section near Budhapal.

b. **Location:** near Jarasingha Arts College
Coordinate: 20°51’27’’N and 85°04’17’’E
Strike:35°-215°
Dip:49° SE
Rake:90°

The faulting was clearly observed on the quartzite outcrop 1 i.e. the faulted quartzite was present. The presence of chatter marks which were convex up was clearly visible which depicts thrusting was prominent on this outcrop 1.The outcrop 2 shows joints ,three joint planes were clearly visible here. The lineation plunges towards 49°NW**.** On the surface the plane is curved so the joints are also curved. At this outcrop the S_0 i.e. the contact between two lithologies can be observed clearly. This contact was between Khondalites and Quartzite. The orientation of Khondalite beds was N70°E and dipping 15°SE and Quartzite beds dipping towards NE. This depicts that there was a fold present which later got eroded.

Fig. 29 S0 between Khondalites below and Quartzites above.

Mica-schist:

Location: Budhapal Mica Schist
Coordinates: 21°12’0.6’’ N and 84° 52’52.2’’E

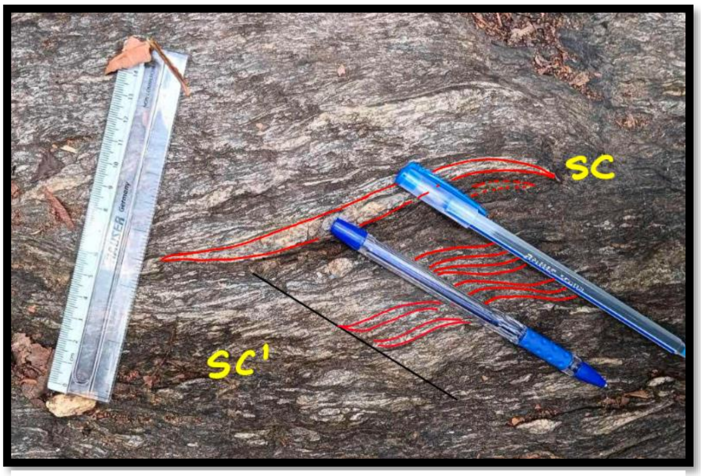


Fig. 30 SC and SC’ Fabric in mica schist.

Mica schist is the common metamorphic rock and the most common schistose rock. It has a foliated appearance and platy mica crystals, and is medium-grained. The area can be identified as Strike Slip Shear zone with clockwise rotation. Stretching Lineations can be observed on the mica schist outcrop and they were steeply dipping.

Tightly folded structures with quartz veins can be seen on the outcrop. Quartz veins could have accumulated between the gaps during the time of formation. Sheath like geometry was found which was formed due to extension, fractures were developed perpendicular to extension direction. Hinge was curved and also perpendicular to direction of movement and the circular pattern was also observed on the cross section.

SC and SCC’ shear bands were observed on the XZ section. SCC’ shear bands are at low angle to the main plane and formed due to high strain conditions. SC developed due to mylonitization as the shearing continues, a small another plane is created at low angles to the C fabric which is synthetic to the sense of shear, that is if SC fabric shows dextral shear sense, then SCC’ shows the same sense of shear. Sheath fold and SC fabric formed due to same deformation and shows same shearing.

Chapter 4: Fold Interference and Detailed Mapping

Fold Interference:

Location: Behind the Ramachandi Temple:

Outcrop 1

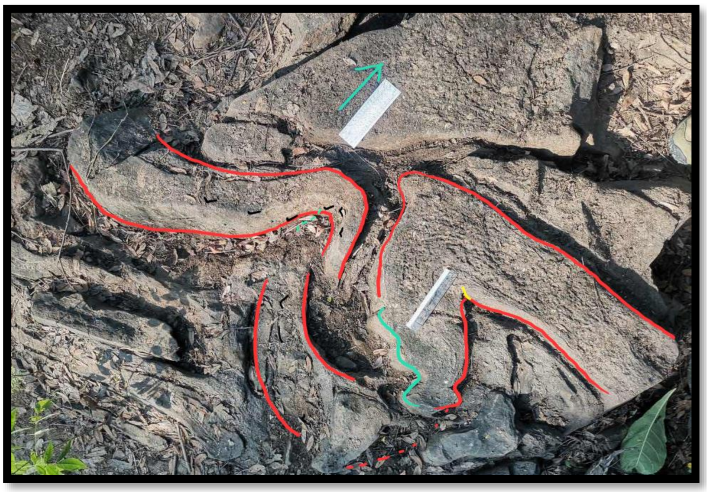


Fig. 31 Superposed deformation seen in Khondalites and melt.

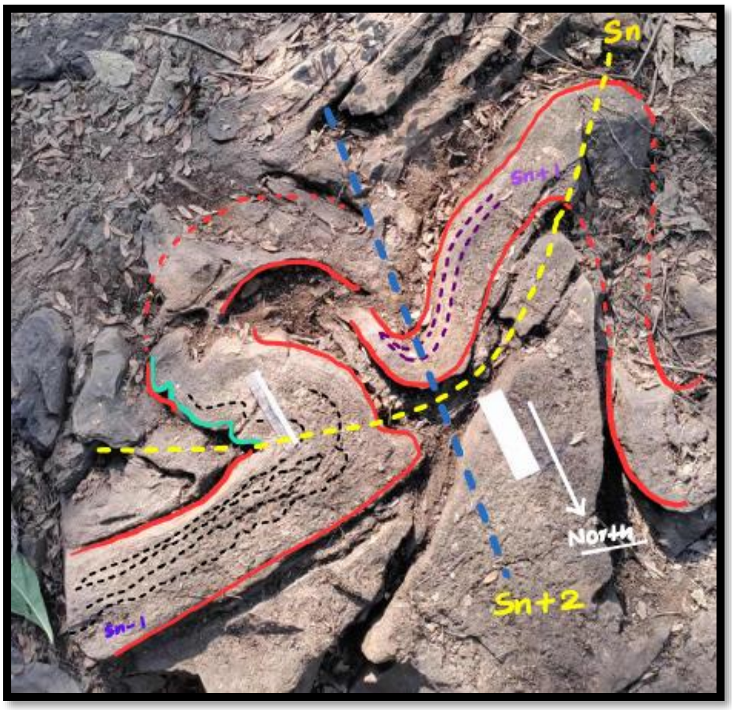


Fig. 32 Three generation of foliations observed on the outcrop.

The primary foliation or the S_{n-1} is seen along the limbs of the folds. This foliation is curved and is made of tight isoclinal folds which aids in naming it as S_{n-1}. The axial plane of the major fold which is formed by the limbs that contain this S_{n-1} is curved; corresponds to S_n. These folds are further refolded which give rise to the S_{n+1} foliation and the axial plane of these foliations give rise to the S_{n+2} foliation.
The nomenclature of these foliations can change if the isoclinally folded foliation is taken S_{n+1} which will then give the foliation order to S_{n+3}.
These generations of the foliations indicate to at least three events of deformation. That is the Sn-1 foliation as per earlier nomenclature was formed due to Dn+1 deformation which led to the isoclinal folds. The Sn was formed due to the folding of Sn-1 which was the effect of Dn+2 deformation. The further refolding of these folds which formed the Sn+1 was caused due to Dn+3 deformation and the axial plane of these folds have rise to Sn+2 which is also an effect of Dn+3. Thus, minimum of three events of deformation can be decoded from this type 2 interference fold pattern seen.

Outcrop 2

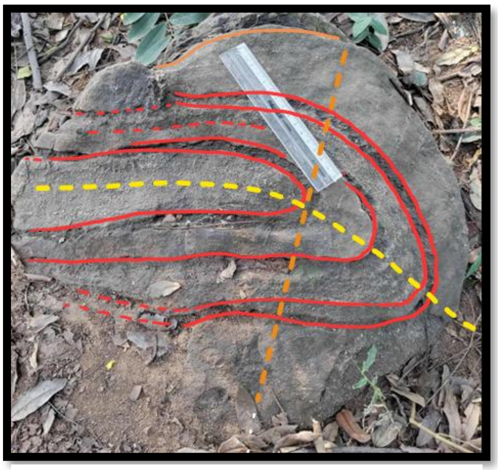


Fig. 33 Type 3-Fold interference pattern.

Type 3-fold interference pattern is seen in the outcrop. At least two events of deformation can be inferred from this pattern. The primary foliation S_n is folded to a recumbent fold. The axial plane of this forms Sn+1. This recumbent fold is then refolded to form Sn+2.

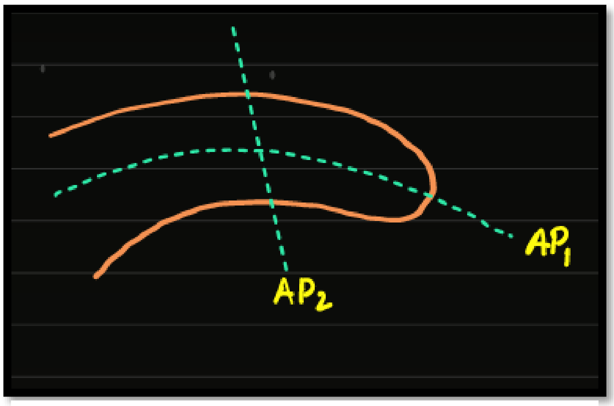


Fig. 34 Two generations of foliations observed in the refolded folds,

During this refolding which is Dn+2 deformation, the folding of Sn+1 or the axial plane of the recumbent fold is curved. But the fold axis of booth the folds are almost parallel. Thus, at least two events of deformations can be explained by this outcrop showing type 3-fold interference.

Detailed Mapping of an Outcrop

Site Selection and Setup:

An area was selected near the northern side of Ranigora Minor, close to Ramachandi Temple (N 20°51’39”, E 85°5’51”), for detailed structural mapping. The process began by selecting a pivot point at the eastern corner of the outcrop, which served as the reference point. This pivot point was plotted on a graph sheet, and a scale of the graph defined for mapping was 1cm=12cm.

Mapping Procedure:

1. **Boundary Definition:** The outcrop boundary was drawn, and its length and width were measured.
2. **Orientation Marking:** The geographic north was marked on the graph sheet as well as the outcrop to ensure proper orientation.
3. **Distance Measurements:** Using a measuring tape, the distances of various observable features from the pivot point were recorded.
4. **Data Collection:**
    - **Foliation (S1):** Observable foliations were identified on the outcrop and measured for their orientations, bearings from the pivot point, and distances.
    - **Lineations:** Plunge amounts and directions of lineations were directly measured using a clinometer and a Brunton compass.
5. **Data Plotting:** The collected data for foliations and lineations were plotted on the graph sheet based on the scale and orientation.
6. **Tracing and Finalization:** The outcrop pattern, along with the attitudes of foliations and lineations, was traced onto tracing paper to document the structural features.

Observations:

- **Folding Pattern:** The outcrop features a boudinage structure with khondalitic composition boudins defining a folding pattern. The spaces between these boudin surfaces are filled with mafic granulite melt, identified as the S1 foliation surface.
- **Foliation and Lineation Attitudes:**
  - The strike of the S1 foliation varies across the northern semicircular part of the stereonet, while the dip direction predominantly trends towards the southern semicircular part.
  - Lineations associated with the S1 foliation exhibit consistent attitudes, plunging southward with plunge angles ranging between 45^o and 55^o.
- **Rock Composition:**
  - **Mafic granulite melt:** Composed of two pyroxenes and plagioclase feldspar.
  - **Khondalitic boudins:** Consisting of plagioclase feldspar, quartz, sillimanite, and garnet.

Deformational History:

The observed S_n foliations, formed during D_n deformation, show strong folding attributed to subsequent D_{n+1} deformation. This is evident from the lineations present on the S_n surfaces, which suggest later deformation phases. The curving of first formed axial plane is also a strong indication of D_{n+1} deformation. Further, the S_{n+2} is seen cutting across the edges of the mushroom geometry.

Conclusion from Stereo Plotting:

The stereoplot analysis revealed that the folding pattern corresponds to a Type 2 "mushroom fold." This classification reflects the deformation geometry, where the folding indicates a complex history of strain distribution and tectonic processes.

Overall Conclusion:

The detailed mapping of this outcrop successfully reconstructed its structural geometry. The folding patterns, foliation characteristics, lineation orientations, and stereo-plot interpretation provide critical insights into the deformational history and tectonic evolution of the region.

Serial No.	DISTANCE	Back Beari	Front Bear	Strike(Azin	Dip amour	Dip Directi
1	260	165	345	265	50	SE
2	253	168	348	289	30	SE
3	246	168	348	300	27	SE
4	241	167	347	334	28	SE
5	226	168	348	341	57	SE
6	212	170	350	340	67	SE
7	200	174	354	281	36	SE
8	215	175	5	263	41	SE
9	198	164	16	284	29	SE
10	230	165	15	342	61	SE
11	260	163	17	33	83	SE
12	320	161	19	210	77	SE
13	354	159	21	194	51	SE
14	390	163	17	21	50	SE
15	416	162	18	6	22	SE
16	410	158	22	67	22	SE
17	432	159	21	77	25	SE
18	447	157	23	69	20	SE
19	462	153	27	125	25	SE
20	446	149	31	183	70	SE
21	393	148	32	35	77	SE
22	367	150	30	75	60	SE
23	340	155	25	58	80	SE
24	305	158	22	55	70	SE
25	270	159	21	23	69	SE
26	245	155	25	335	79	SE
27	201	144	36	15	58	SE
28	165	139	41	20	30	SE
29	135	139	41	42	43	SE
30	106	151	29	97	43	SE
31	102	172	8	80	29	SE
32	100	180	0	120	45	SE
33	110	178	358	152	48	SE
34	112	171	351	308	50	SE
35	117	174	354	287	48	SE
36	140	171	351	342	53	SW
37	200	175	355	67	43	SE
38	205	172	8	139	57	SE
39	210	166	14	30	60	SE
40	285	164	16	42	60	SE
41	338	159	21	190	66	SE
42	380	161	19	185	67	SE
43	406	161	19	195	88	SE
44	418	159	21	296	70	SE
45	420	154	26	12	46	SE
46	440	153	27	240	80	SW
47	460	150	30	262	57	SE
48	455	148	32	343	87	SE

Fig. 35 S1 Foliation data.

Serial No.	DISTANCE	Back Beari	Front Bea	Strike(Azir	Dip amou	Dip Directi
48	455	148	32	343	87	SE
49	415	145	35	27	72	SE
50	380	144	36	68	70	SE
51	380	148	32	11	53	SW
52	385	152	28	72	47	SE
53	382	153	27	16	54	SE
54	320	154	26	47	60	SE
55	294	157	23	60	52	SE
56	245	157	23	333	70	SE
57	245	149	31	332	36	SE
58	220	145	35	19	29	SE
59	180	138	42	12	35	SE
60	153	135	45	58	36	SE

Serial No.	DISTANCE	Front Bea	Strike (Azimuth)	Dip Amount	Dip Direction
63	125	330	192	41	SE
64	144	326	159	37	SE
65	167	324	119	41	SE
66	184	320	167	38	SE
67	198	312	219	33	SW
68	204	307	233	35	SW
69	205	301	183	42	SW
70	210	349	213	67	SW
71	224	348	217	57	SW
72	240	347	200	28	SW
73	245	350	235	27	SW
74	254	348	200	30	SW
75	260	345	204	50	SE
76	275	339	187	56	SE
77	319	335	229	69	SW
78	338	334	243	68	SW
79	350	335	272	75	SW
80	364	334	146	68	SE
81	374	336	219	50	SW
82	362	331	107	78	SE
83	3448	329	97	48	SE
84	324	328	296	65	NW
85	337	324	219	50	SW
86	330	321	201	53	SW
87	329	318	232	56	SW
88	347	315	286	40	NW

Fig. 36 S1 Foliation data.

Serial No.	DISTANCE	Front Bearing (in degree)	Strike (Azimuth)	Dip Amount	Dip Direction
89	347	311	253	39	NW
90	269	307	230	45	SE
91	280	306	209	43	SW
92	288	336	234	51	SW
93	204	332	228	55	SE
94	220	327	240	52	SW
95	246	325	241	61	SW
96	263	326	178	52	SE
97	281	321	147	55	SW
98	298	317	218	46	SW
99	282	318	188	42	SW
100	240	315	162	53	SW
101	258	317	230	40	SW
102	265	315	170	45	SW
103	280	317	169	47	SW
104	276	315	209	43	SE
105	306	313	171	65	SE
106	299	311	173	45	SE
107	320	310	265	47	SE
108	334	308	213	71	SW
109	324	307	231	71	SE
110	270	305	162	54	SE

Fig. 37 S2 foliation data.

S2 Data:

Serial No.	DISTANCE(in cm)	Front Bearing (in degrees)	Strike (Azimuth)	Dip Amount	Dip Direction
1	430	27	26	78	SE
2	350	24	25	83	SE
3	322	23	35	86	SE
4	275	19	58	79	SE
5	230	15	16	88	SE
6	154	21	47	76	SE
7	138	347	20	88	SE
8	235	337	4	86	SE
9	160	335	329	54	SW
10	197	317	293	74	SW
11	220	313	342	72	SW
12	243	328	32	78	SE
13	261	328	324	74	SW
14	311	322	336	81	SW
15	330	326	328	84	SW
16	410	334	0	86	SE
17	435	22	252	68	SE
18	435	22	271	33	SE

Fig. 38 S2 Foliation data.

Lineation Data:

Serial No.	DISTANCE	Front Bear	Trend	Plunge Amount
1	220	176	264	72
2	232	165	196	43
3	274	162	243	64
4	282	162	217	63
5	306	158	208	48
6	323	156	225	49
7	160	335	224	44
8	160	335	229	45
9	197	317	93	81
10	243	328	260	72
11	261	328	275	74
12	311	322	11	50
13	330	326	185	58
14	410	334	163	41
15	168	24	212	44
16	435	22	196	52
17	435	22	199	58
18	450	24	203	64
19	154	21	188	57
20	154	22	201	51
21	156	23	198	54
22	156	24	201	48
25	138	347	207	35
29	138	347	333	63
30	138	347	199	42
31	138	347	197	45
32	255	339	339	74
33	255	339	208	46
34	255	341	201	48
35	258	339	196	46
36	342	339	209	53
37	343	337	207	57
38	282	335	259	59
39	430	27	214	67
40	430	27	204	63
41	430	27	213	50
42	430	27	208	50
43	430	27	215	44
44	430	27	209	47
45	282	335	259	59

Detailed Map Generated using the data:

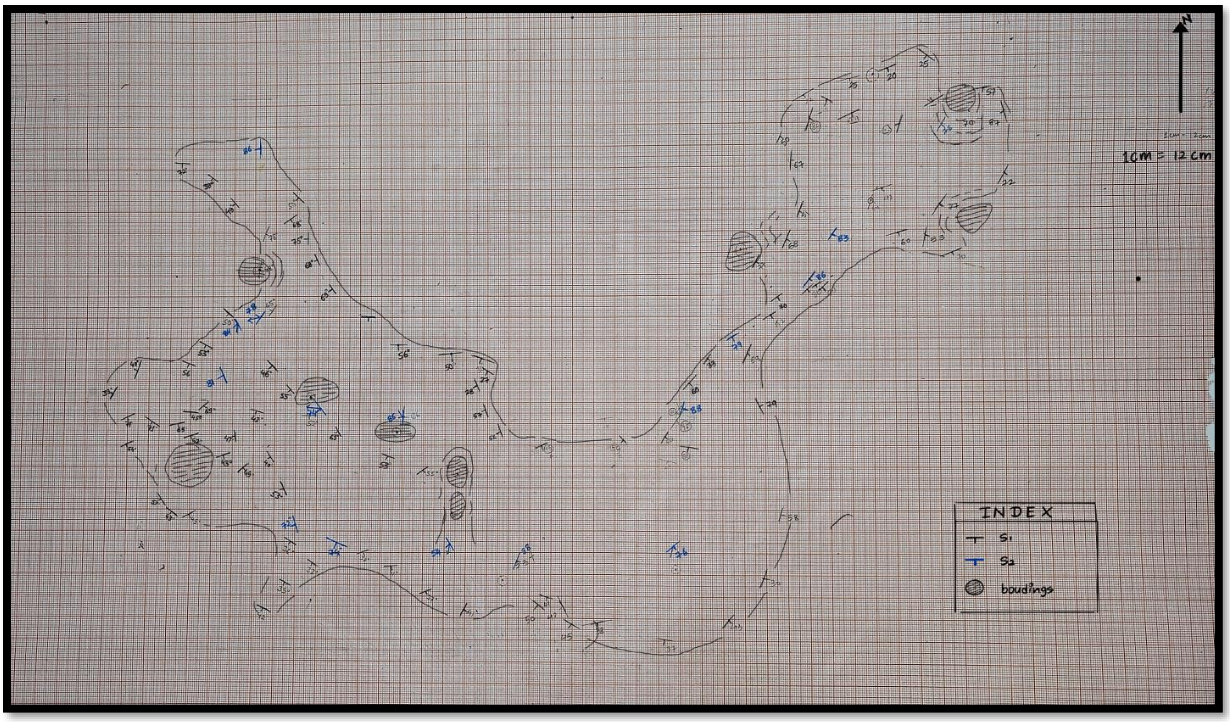


Fig. 39 Detailed Map of Type 2-fold interference observed in Khondalite and its melt.

Stereonet Plotted:

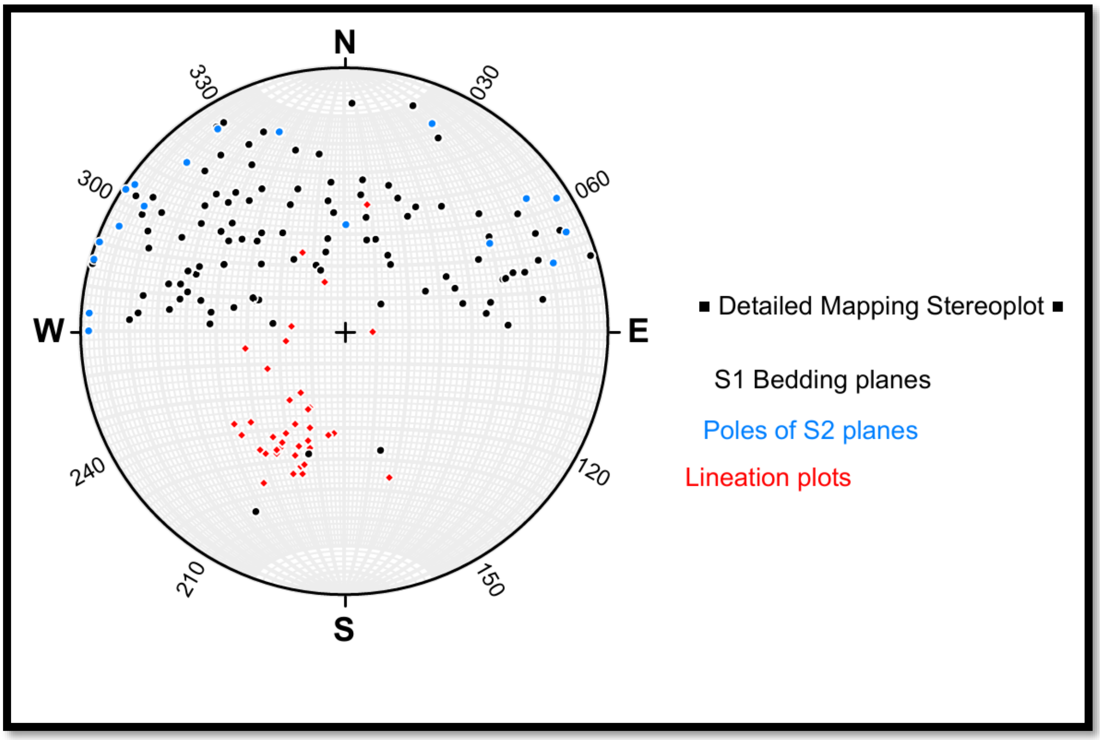


Fig. 40 Setreoplot of S1 and S2 data indicating type 2 pattern.

Fig. 42 Outcrop mapped.

Fig. 41 Student performing detailed mapping.

CHAPTER 5: STRAIN ANALYSIS

Strain analysis is a structural geology technique that measures the change in shape of natural rocks to understand the deformation history and tectonic structures. It involves analysing strain variations in rocks to determine the deformation mechanisms, such as pure shear or simple shear. Strain, reflecting the deformation of a material in response to stress, is a crucial indicator of its strength and toughness

Outcome of strain analysis:

- Shape and orientation of strain ellipse or ellipsoid: This can provide information about the overall deformation of a region.
- Whether deformation was simple shear: In a sheared zone setting, strain analysis can help determine if the deformation was simple shear.
- Fold mechanisms: In folded layers, strain analysis can provide ideas about how the folds happened in the past.

Techniques used in strain analysis for this exercise.

The Fry method:
This centre-to-centre technique plots the average centre to centre vectors of grains.

The Rf/ φ Method:

- The Rf/φ method is a graphical technique for estimating the finite strain of deformed elliptical objects. It can be used when the only available markers are elliptical, rather than circular, even before deformation. This gives insights of the aspect ratio and orientation of the total strain experienced by a rock mass. To conduct the strain analysis of elliptical porphyroclasts whose initial state was circular.
- In this field study we observed Augen Gneisses which involved selecting different porphyroclasts. Measurements of long axis and short axis were taken then their aspect ratios were calculated (RF) and their orientation (Φ) with respect to North was taken.

Augen gneisses are one of the most important lithologies found in and around the Angul region. The word 'augen' means eyes, thus a gneiss with eye-shaped porphyroclasts is called as Augen gneiss. The feldspars form this augens in these gneisses and can be used for strain analysis. Depending on the shape, porphyroclasts can be of different types:

- Theta: **θ**
- Sigma: σ
- Delta: δ
- Phi: Φ

The mantle and tail that make up the porphyroclast help in determining the sense of shear as dextral, sinistral or top towards (direction).

Location: Near GRIDCO

Co-ordinates: 20^{o}51’08” N and 85^{o}05’90” E

Augen gneisses with all the different types of porphyroclasts were exposed. Exercises of Strain analysis were performed.

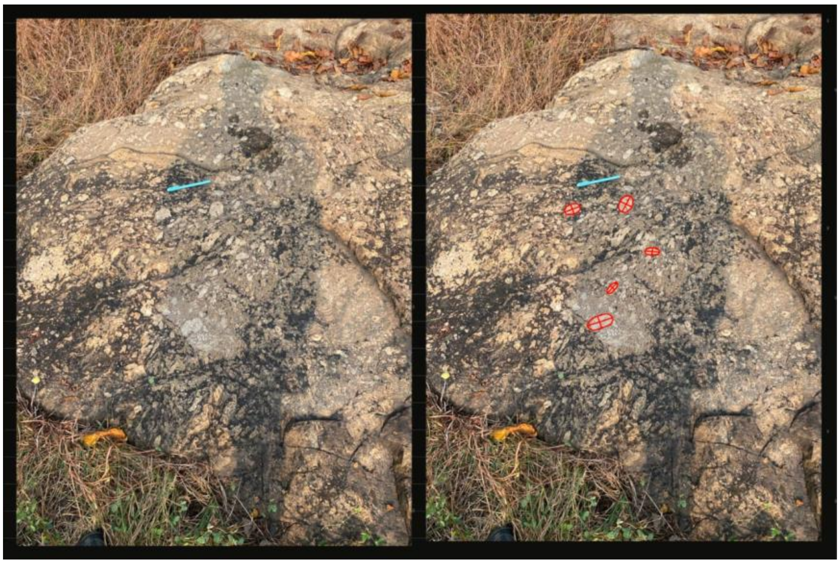


Fig. 43 Augen gneiss outcrop on which strain analysis was performed.

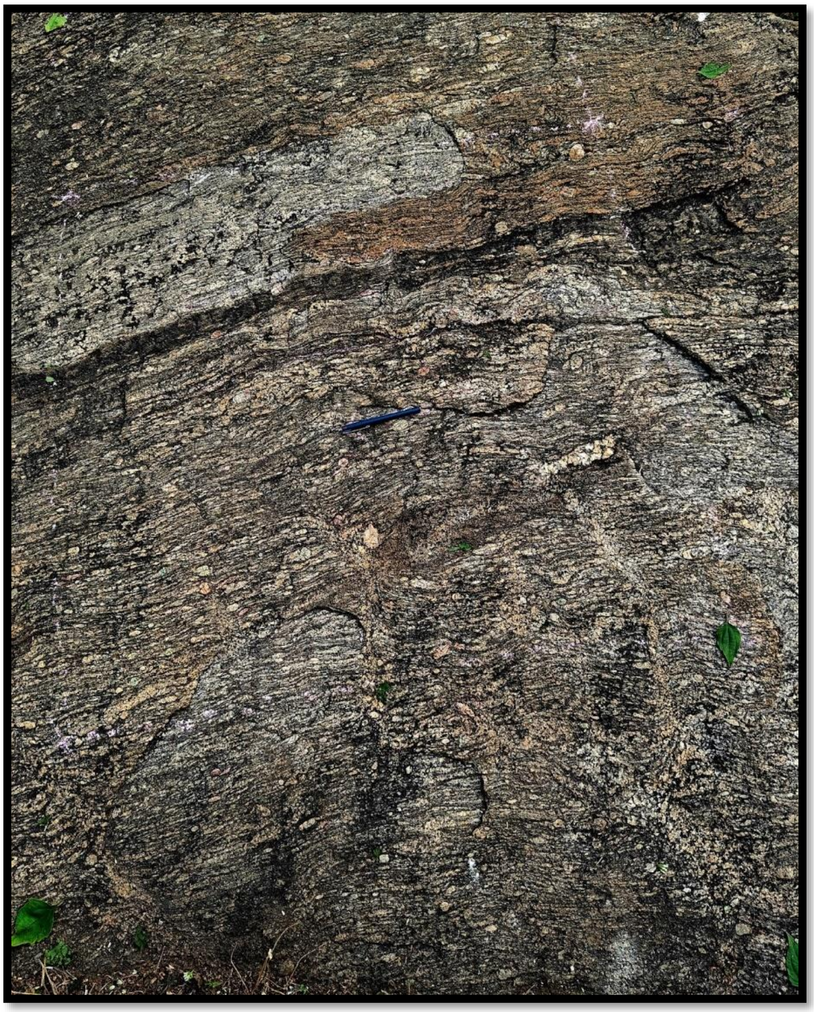


Fig. 44 Outcrop on which strain analysis was performed.

Data collected from field:

Serial No.	Long axis (a)	Short axis (b)	Aspect ratio(RF)	Phi (Φ)	Porphyroclast type	Sense of Shear
1	3.8	2.5	1.52	50	**θ**	Dextral
2	2.8	1.6	1.75	0	σ	Dextral
3	2	1.8	1.111111	0	δ	Dextral
4	1.4	0.8	1.75	58	σ	Dextral
5	1.8	1.1	1.636364	0	Φ	Dextral

6	1.5	0.6	2.5	4	δ	Dextral
7	1.7	1	1.7	-30	δ	Dextral
8	3.5	0.6	5.833333	-10	Φ	Dextral
9	1.8	0.5	3.6	0	Φ	Dextral
10	1	0.6	1.666667	-8	Φ	Dextral
11	2	1	2	-20	σ	Dextral
12	1	0.6	1.666667	-2	Φ	Dextral
13	1.4	1	1.4	10	δ	Sinistral
14	2.3	1.5	1.533333	10	Φ	Dextral
15	1	0.5	2	5	σ	Dextral
16	1.4	0.9	1.555556	-13	σ	Dextral
17	1.2	0.5	2.4	13	Φ	Dextral
18	2.6	1.5	1.733333	-20	Φ	Dextral
19	2.7	1.7	1.588235	25	σ	Dextral
20	1.3	0.5	2.6	4	σ	Dextral
21	1.1	0.9	1.222222	0	Φ	Dextral
22	5	1.2	4.166667	-2	Φ	Dextral
23	1.8	0.9	2	-26	σ	Dextral
24	2.5	1	2.5	-15	Φ	Dextral
25	3	0.8	3.75	8	σ	Dextral
26	2.5	1	2.5	15	σ	Dextral

27	1.4	0.7	2	-5	σ	Dextral
28	5.5	1.9	2.894737	10	Φ	Dextral
29	5.5	1.9	2.894737	-30	δ	Dextral
30	1.2	0.4	3	-5	Φ	Dextral
31	1.7	0.9	1.888889	-18	Φ	Dextral
32	2	1	2	6	Φ	Dextral
33	2.5	1.3	1.923077	4	Φ	Dextral
34	2	1	2	25	σ	Dextral
35	1.8	0.8	2.25	10	Φ	Dextral
36	0.9	0.5	1.8	-24	σ	Dextral
37	3	1.7	1.764706	10	σ	Dextral
38	1.4	0.7	2	-11	Φ	Dextral
39	0.7	0.4	1.75	10	Φ	Dextral
40	0.7	0.5	1.4	11	Φ	Dextral
41	1	0.3	3.333333	17	σ	Dextral
42	1.5	0.5	3	12	Φ	Sinistral
43	1.8	1	1.8	19	δ	Dextral
44	1	0.3	3.333333	2	σ	Dextral
45	0.9	0.4	2.25	17	Φ	Dextral
46	1.5	1	1.5	8	δ	Dextral
47	2	0.8	2.5	-15	Φ	Dextral

48	1.5	0.6	2.5	5	σ	Dextral
49	1.5	0.6	2.5	-18	Φ	Dextral
50	1.4	0.5	2.8	5	Φ	Dextral
51	2.4	1.4	1.714286	12	Φ	Dextral
52	2.5	1.5	1.666667	14	Φ	Dextral
53	2	1	2	-42	Φ	Dextral
54	3	1.7	1.764706	10	Φ	Dextral
55	2.2	1.9	1.157895	20	δ	Sinistral
56	2	1.7	1.176471	15	Φ	Dextral
57	1.6	1	1.6	65	δ	Sinistral
58	2	1.7	1.176471	50		Sinistral
59	1.5	1	1.5	50	Φ	Dextral
60	1.7	0.6	2.833333	27	Φ	Dextral
61	1	0.4	2.5	45	Φ	Dextral
62	1.5	1.2	1.25	-20	δ	Dextral
63	1.7	1.5	1.133333	30	σ	Dextral
64	2.2	1.5	1.466667	-70	δ	Dextral
65	1.5	1	1.5	-40	Φ	Dextral
66	3.2	1.3	2.461538	-41	δ	Dextral
67	1.6	1.6	1	25	σ	Dextral
68	2.3	0.6	3.833333	0	Φ	Dextral

69	3.2	1	3.2	16	σ	Dextral
70	3	2	1.5	20	Φ	Dextral
71	4.2	2.2	1.909091	10	δ	Dextral
72	3	1.5	2	26	σ	Dextral
73	1.1	0.8	1.375	48	Φ	Dextral
74	2.2	1	2.2	47	σ	Dextral
75	2	1.5	1.333333	25	σ	Dextral
76	1.7	0.5	3.4	15	Φ	Dextral
77	1.8	1	1.8	28	σ	Dextral
78	2.7	1.2	2.25	30	Φ	Dextral
79	3.4	1.1	3.090909	22	Φ	Dextral
80	3	1.4	2.142857	27	Φ	Dextral
81	4	1.5	2.666667	24	Φ	Dextral
82	1.2	0.3	4	33	σ	Dextral
83	1.3	0.5	2.6	45	σ	Dextral
84	1.2	0.6	2	60	δ	Dextral
85	1.8	1	1.8	24	δ	Dextral
86	1.5	0.8	1.875	4	Φ	Dextral
87	2	1.4	1.428571	21	Φ	Dextral
88	2.3	1	2.3	14	Φ	Dextral
89	1	0.5	2	4	Φ	Dextral

90	1.5	1	1.5	-40	Φ	Dextral
91	1.1	0.5	2.2	17	σ	Dextral
92	2.3	1	2.3	37	Φ	Dextral
93	2.7	2	1.35	38	σ	Dextral
94	1.2	1.2	1	35	Φ	Dextral
95	1.2	0.5	2.4	33	σ	Dextral
96	1.2	0.6	2	-35	Φ	Dextral
97	1.5	0.7	2.142857	-6	Φ	Dextral
98	2	0.5	4	-6	Φ	Dextral
99	1.5	0.7	2.142857	-10	Φ	Dextral
100	2.5	0.7	3.571429	-29	Φ	Dextral
101	1.1	0.7	1.571429	10	Φ	Dextral
102	1	0.5	2	-23	Φ	Dextral

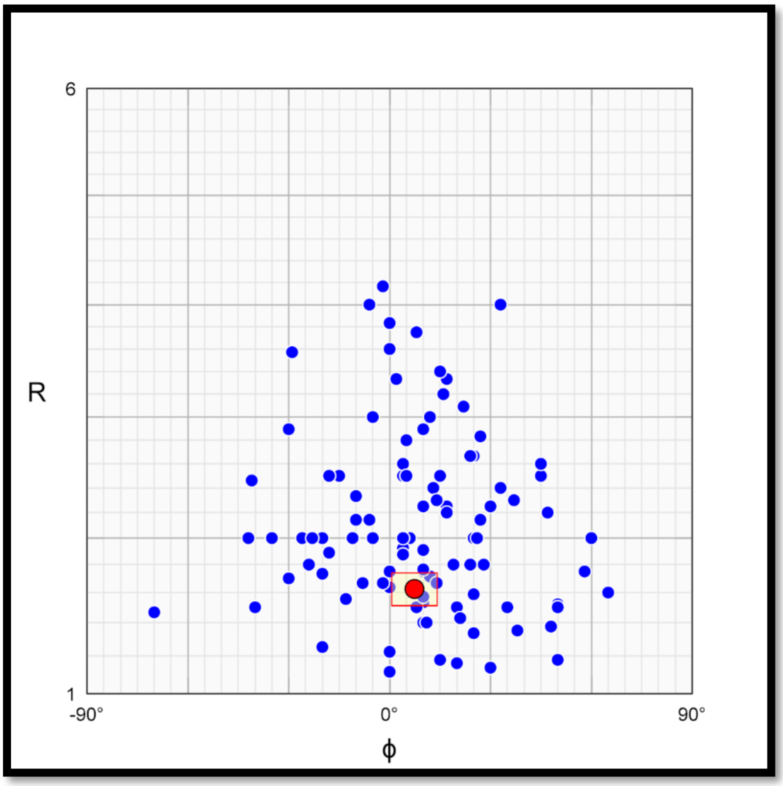


Fig. 45 Rf/Φ plot made using ellipsefit software.

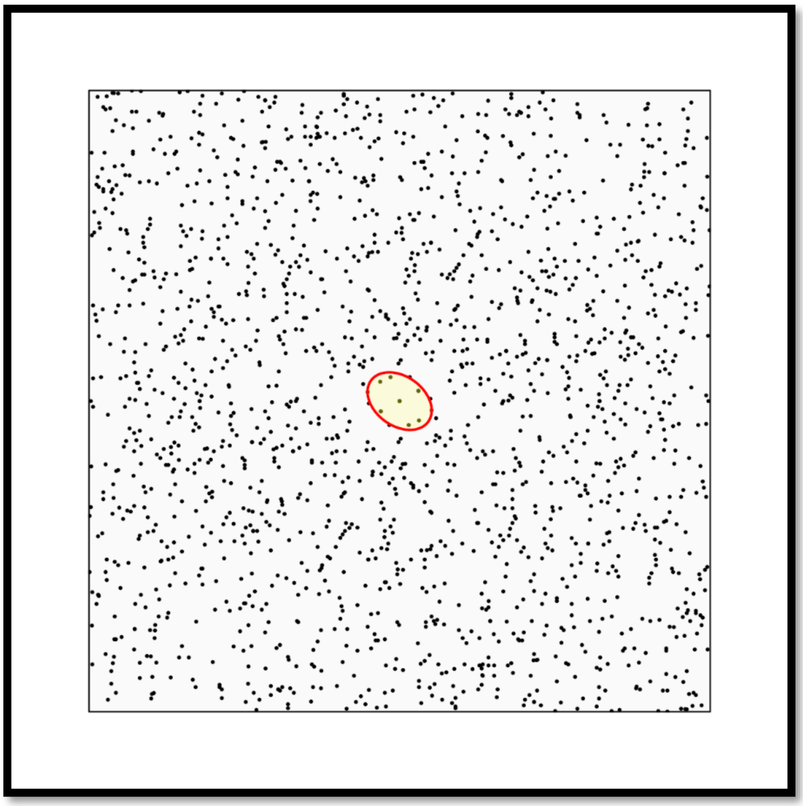


Fig. 46 Fry plot made using Geofry software.

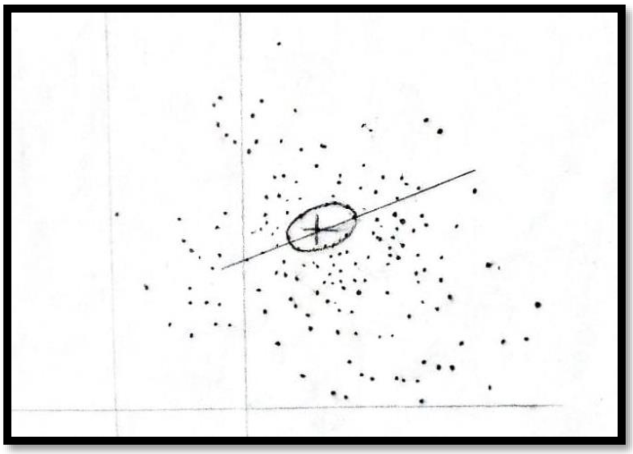


Fig. 47 Manual Fry plot.

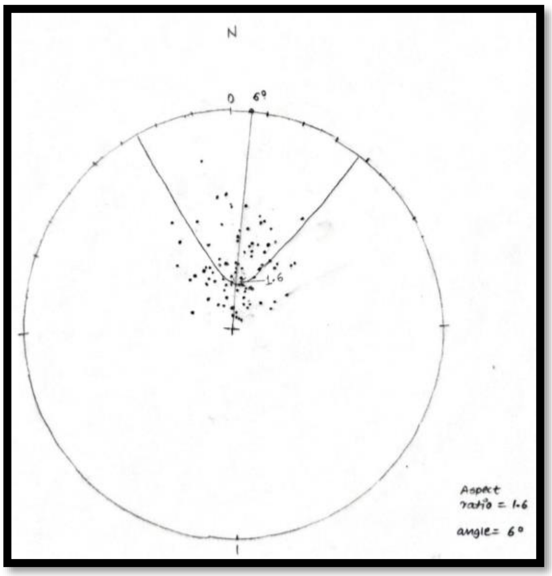


Fig. 48 De-Paor's net.

Results:

- Using Ellipse-fit software: R=1.62; Angle= N354
- Using Fry Plot: R=1.606; Angle = N6ºW
- Using De Paor's net: R=1.6; Angle = 6º
- $R_s = 2.14$
- $R_i = 1.93$
- $R_s > R_i$

Fig. 49 Sudent performing strain analysis.

Chapter 6: Rengali Province and Kaniha

Location: Rengali Dam

Coordinates: 21.2763142372°N, 85.03508203°E

The Rengali Dam is situated in the northern part of Talcher in Rengali province, located within the shear zone separating the Eastern Ghat Mobile Belt and Singhbhum.

Lithology

The lithology of the Rengali region primarily consists of granulite facies rocks with peak metamorphic conditions reaching temperatures of approximately 900°C and pressures around 8 kbar. These rocks date back to approximately 1 Ga. Two dolerite dykes intrude this lithology and have undergone metamorphism to form amphibolite. The region also features Charnockite, characterized by orthopyroxene, feldspar, and quartz mineralogy.

Structures

Observed Features

- **Foliation Planes:**
  The foliation planes of the main lithology exhibit an NW-SE orientation and dip southerly.
- **Dyke Orientation:**
  The amphibolite dykes trend predominantly in the N-S direction but cross-cut the NW-SE trending foliations.
- **Isoclinal Folds:**
  Small-scale isoclinal folds are observed, indicating significant deformation.
- **Faulting and Shearing:**
  Evidence of dextral shearing is visible in some foliation planes. Faults and thinning in dykes indicate high strain in the shear zone.
- **Kinematic Indicators:**
  - Asymmetric folds in amphibolite sills.
  - E-W trending shear zones displacing amphibolite dykes.

- Boudinaged quartz veins indicating intense deformation.

Deformation Sequence

The region has undergone multiple deformation events (D2 to D5):

D2 Event:

- **Processes:**
  - Formation of isoclinal folds and shearing.
  - Development of S2 foliation plane, trending E-W.
- **Significance:**
  This deformation phase played a crucial role in shaping the overall lithological structure.

D3 Event:

- **Processes:**
  - Intrusion of mafic dykes during extensional deformation.
  - Creation of an N-S trending basalt or gabbro dyke, later metamorphosed into amphibolite.

D4 Event:

- **Processes:**
  - Non-penetrative dextral shearing accompanied by granite and pegmatite intrusions.
  - Folding events converted earlier folds into sheath folds.
- **Significance:**
  This event caused significant thinning of dykes towards the east, indicating the presence of a highly strained shear zone.

D5 Event:

- **Processes:**
  - A final deformation cycle obliterated much of the evidence from earlier events.

- Limited to areas near Angul, this event represents a distinct tectonic cycle.

Kinematic Analysis

Indicators:

- **S-C Fabrics:**
  Present in E-W trending shear zones, showing a dextral sense of shear.

- **Foliation Planes:**
  The merging of foliations into shear zones further supports the presence of shearing episodes.

- **Amphibolite Dyke Displacement:**
  Displaced along the E-W trending shear zones, highlighting the intensity of deformation.

Fig. 50 Amphibolite dyke displaced (camera oriented N17)

Fig. 51 Displacement in amphibolite dyke.

Fig. 52 Ductile displacement in amphibolite dyke (Camera oriented N14).

Inference:

The presence of E-W trending foliations, dextral shear zones, and kinematic indicators like S-C fabrics and boudinaged veins suggests a complex deformational history. The observed structures and lithological patterns are consistent with multiple deformation episodes, culminating in a highly strained shear zone. This deformation history reflects the tectonic evolution associated with the Eastern Ghat Mobile Belt and its interaction with the Singhbhum Craton. The Rengali Dam's geological significance lies in its location within this shear zone, providing insights into the region's tectonic and metamorphic history.

No.	Strike	Dip amount	Dip direction
0	180	75	W
1	85	70	S
2	85	75	S
3	100	60	S
4	110	60	S

5	100	65	S
6	110	55	S
7	105	65	S
8	90	50	S
9	100	50	S
10	80	50	S
11	90	50	S
12	100	50	S
13	85	50	S
14	75	60	S
15	90	58	S
16	100	60	S
17	95	60	S
18	100	60	S
19	104	60	S
20	83	60	S
21	76	60	S
22	86	60	S
23	0	0	E
24	358	79	W
25	324	24	S

26	216	68	S
27	260	41	S
28	280	49	S
29	270	43	S
30	292	66	S
31	270	56	S
32	286	76	S
33	290	52	S
34	260	74	S
35	260	49	S
36	75	60	S
37	58	79	S
38	272	80	S
39	260	78	S
40	105	58	S
41	260	72	S

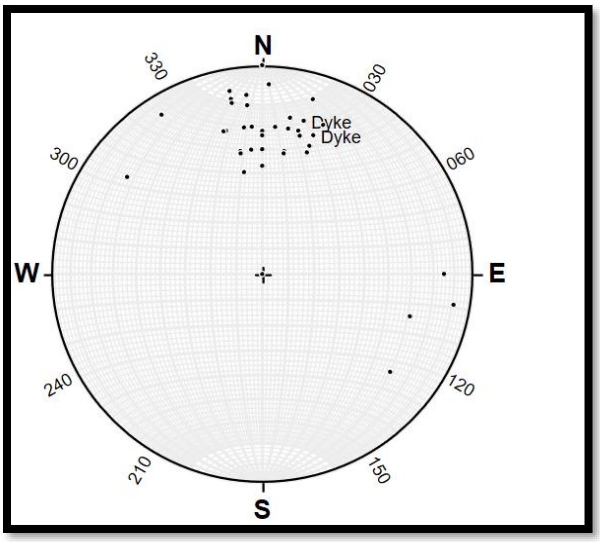


Fig. 53 Stereoplots for the dykes.

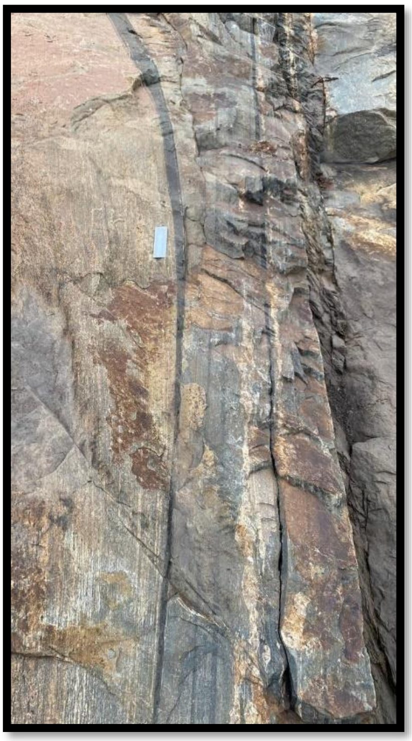


Fig. 54 Thinning of the dyke as it moves closer to the shear zone or a high strain localization area.

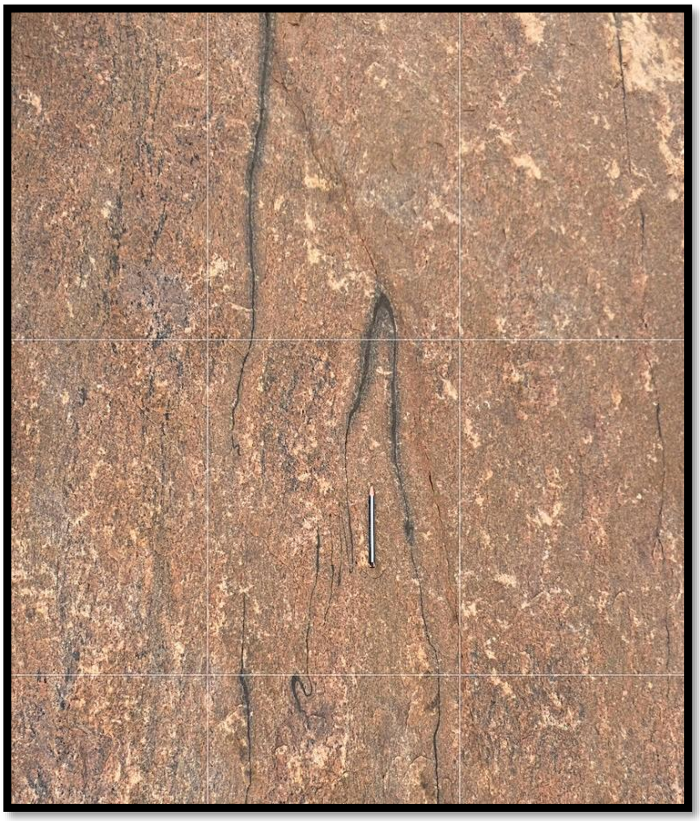


Fig. 55 Refolded amphibolite dyke.

Fig. 56 Folded dyke.

Location: Kaniha

Co-ordinate: 21^{0}07’19”N   85^{0}02’17”E

Lithology: Micaceous Quartzite

Mineralogy: Quartz, mica (muscovite) as an accessory phase

Textures and Structures:

The Kaniha Shear zone is located between the Talchir formation and the Rengali province. It is situated in the northern part of Talchir. Quartzite forms a contact Gondwana rocks (horizontal) and this suite rocks vertical dip.

Band goes up to 100 km till sambal pur Here the lithology, structures, and metamorphic events show a distinct pattern than Eastern Ghat Mobile Belt. The lithology of this area is comprised of quartzite. This area has evidences of both Amphibolite facies metamorphism and greenschist facies metamorphism that it had undergone during different deformation events. There were no evidence of suture which could indicate binding of two lithospheric plates that indicates there were no convergent plate tectonics but the two continental masses were juxtaposed. The only reason that could explain this juxtaposition is Intracontinental Strike slip tectonism. Thus, any suture here (if present) would be Strike slip suture. Dextral shearing evidences support this logic. The area consists of pre-existing non plunging isoclinal upright and recumbent folds which had undergone refolding during subsequent metamorphism and deformation events.

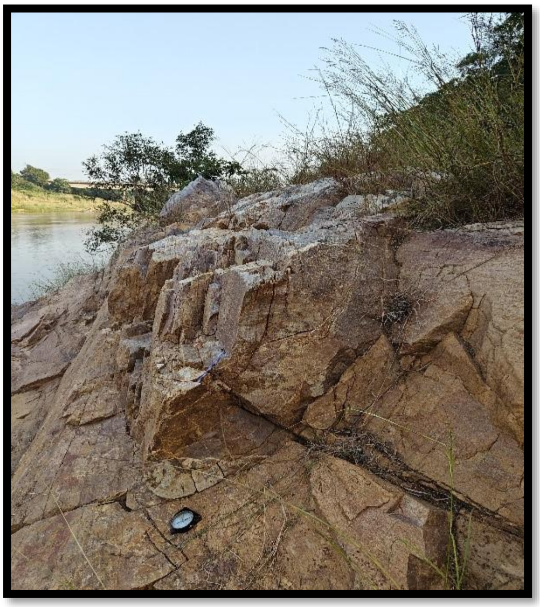
Variation in color of quartzite helps in identifying the bedding planes. The bedding plane itself shows evidences of folding. On the bedding surface, lineations were visible parallel to hinge of the fold indicating these lineations to be fold axis lineations (S_o^S_1 intersections).

The trend of those lineations were measured to be 2° towards 99^0 suggesting the fold axis to be horizontal inferring the fold to be non-plunging. When plotted on a stereonet the fold axis of the refolded fold is found to be parallel to Fold axis of the earlier isoclinal folds indicating Type-3 interference pattern during superposed deformation.

Deformation History:

The area records evidence of majorly three deformation events.

The 1st deformation D1 involves thrusting and folding of So bedding plane which led to the development of the S1 foliation i.e non plunging recumbent fold and S2 foliation as its axial plane.



The 2nd deformation D2 involves refolding of S2 foliation i.e axial plane of the later fold which was observed to be nearly vertical inferring development of an non plunging upright fold. The folds were cylindrical.

The 3rd deformation D3 involves dextral shearing during strike slip tectonics which led to rotation of the preexisting upright folds. Moreover, the dextral shearing has transported this continental fragment further west, displacement in order of 1000s of Kms.

During this dextral shearing, the limbs of the pre-existing fold got folded about a vertical axis and the hinge became doubly plunging. This led to development of steeper lineations away from the limb region of the fold towards the hinge region. The trend did not vary much but the plunge amount varied a lot. This variation in lineation can be explained by looking at the behaviour of S0 and S1 during various deformation events. S1 remains more or less constant and S0 keeps on changing which leads to variation of the intersection lineations.

This dextral shearing can be related to the dextral shearing event that was observed in EGMB by looking at their orientation. Thus, dextral shearing can be related at places. There was no significant vertical movement. Moreover, the difference in geothermal gradient in between EGMB and the Rengali Province can also explain thrusting and extension in this region.

Chapter 7: Independent Mapping & Synthesis.

The area that was assigned lied to the north of the railway track of Angul railway station.

In the regional mapping, there are two ways to map the area:

• Band tracing, in which traverse was conducted along the strike of the outcrop (foliation plane or bedding).

• Band traversing, in which traverse was conducted across the strike of outcrop or along the dip of the foliation or bedding plane.

LOCATION 1: North of Railway Track on the railway cutting section

Orientation: 20º51'51" 85º6'43"

Lithology: Quartzofelspathic gneiss

Observations: In the location the following observations are seen:

- The gneissic body shows various generations of foliations forming isoclinal folds, foliation boudinages and pinch and swell structures.
- The exposure shows that the region has experienced atleast four generations of deformation
- The first deformation D1 resulted in segregation of mafic and felsic bands which formed the gneissic layering i.e S1 in the rock
- The second deformation D2 resulted in the isoclinal folding of the S1 foliation i.e the S2 foliation.
- The third deformation D3 resulted in the development of the most prominent foliation i.e S3 trending N-S throughout the outcrop.
- The 4th deformation D4 has occurred in the area which led to the development of E-W trending crenulations named S4 due to melting at very high temperatures.
- This deformation has also resulted in sinistral shearing of S3 foliation which is concordant with S4 foliation.
- This melting event has formed leucocratic layers which cross cut the foliations and shows complex folding.
- All the existing foliations are sheared sinistrally by the D4 event.

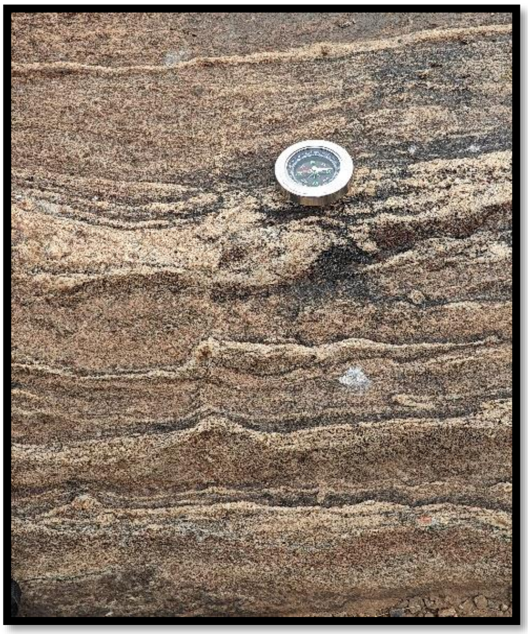


Fig. 57 S3 and S4 foliation.

Fig. 58 Melt showing complex folds and distortion.

Fig. 60 Foliation Boudinage.

Fig. 59 Pinch and swell structure.

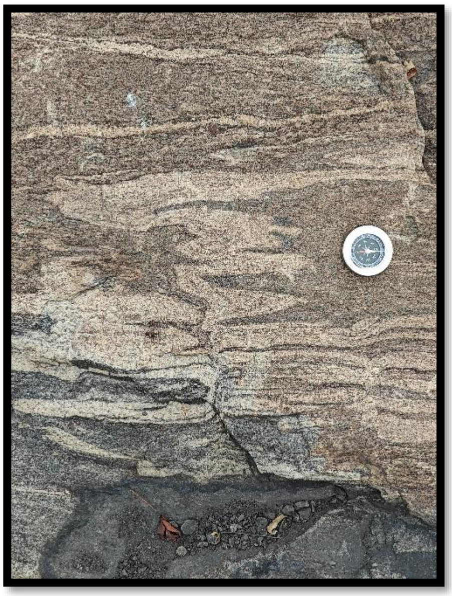


Fig. 61 Refolded S3 Foliation.

Orientations of foliations (S3):

Serial no.	Strike	Dip amount	Dip Direction
1	000-180	56	W
2	355-175	60	WSW
3	350-170	85	WSW
4	355-175	74	WSW

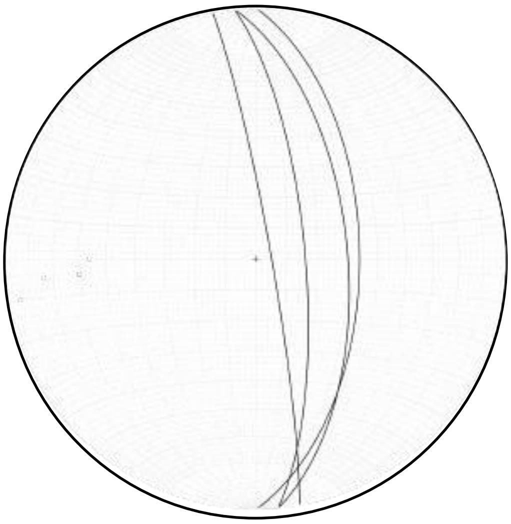


Fig. 62 S3 foliation stereoplot.

- The orientation of S4:

Serial No.	Strike	Dip Amount	Dip Direction
1	84-264	75	SSE
2	82-262	80	SSE

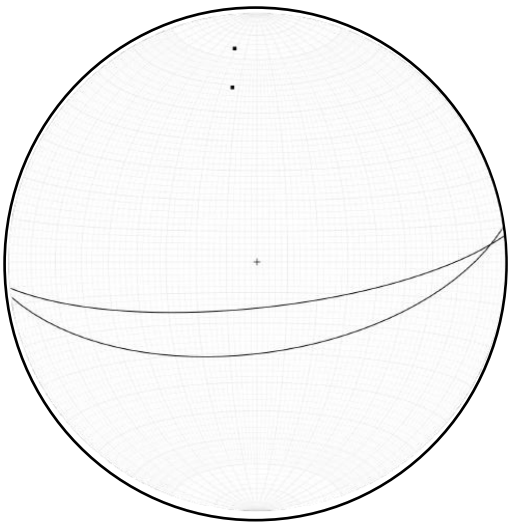


Fig. 63 S4 foliation.

On moving along strike of location 1, location 2,3,4,5,6,7,8,9 having same lithology and orientation same as location 1 were encountered.

Location 2:
Orientation: N20º51'52" E85º6'43"

Location 3:
Orientation: N20º51'54" E85º6'41"

Location 4:
Orientation: N20º51'54" E85º6'44"

Fig. 64 S3 Foliation trending E-W.

Location 5:
Orientation: N20º51'57" E85º6'43"

Location 6:
Orientation: N20º51'59" E85º6'42"

Location 7:
Orientation: N20º51'59" E85º6'41"

Location 8:
Orientation: N20º52'02" E85º6'42"

Location 9:
Orientation: N20º52'04" E85º6'42"

Moving further, different lithologies indicating contacts and hinge regions of folds.

Location 10: [South of nala]

Orientation: N20º52'04" E85º6'40"

Lithology: Quartzofelspathic gneiss

Observations: The orientation of most dominant S3 foliation observed here showed a E-W trend which was previously seen as a N-S trending foliation in former locations.

This observation infers that this location is a part of the hinge of a regional scale fold.

Fig. 65 Crenulation showing N-S trend.

Orientation of S3 foliation is:

Serial No.	Strike	Dip amount	Dip Direction
1	110-290	45	SSW
2	100-280	40	SSW
3	115-295	43	SSW
4	110-290	48	SSW

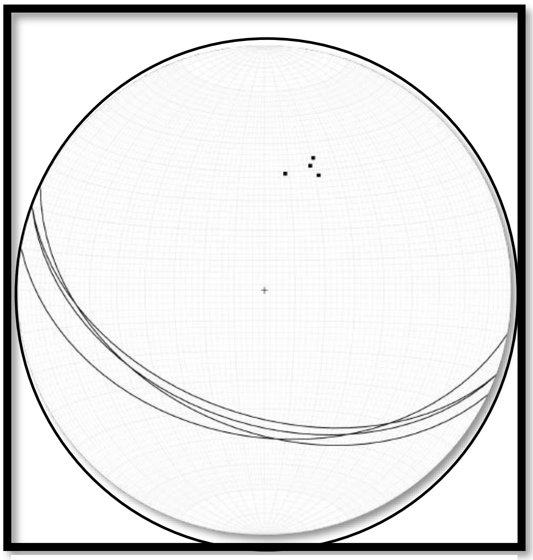


Fig. 66 S3 Foliation stereoplot.

The melt layer distorted both S1 and S2 foliations which indicates that the melting event must have occurred post D2 deformation but is pre D3 and the trend observed here was E-W compared to its N-S trend formerly

Fig. 67 Melt layer distorting Both S1 and S2 foliations.

Location 11: South of Nala

Orientation: N20°52'06" E85°6'43"

Lithology: Quartzofelspathic gneiss and augen gneiss

Observations: In this location, the following things are observed:

A contact between Augen gneiss and quartzofelspathic gneiss was seen.

Folds were seen with layering of Augen gneiss (inner) and quartzofelspathic gneiss (Outer)

A refolded fold was observed with orientation nearly E-W and dipping towards South.

Beside that, there was a fold showing the similar orientation as that observed on the regional scale.

Fig. 68 Refolded fold.

Serial No.	Strike	Dip amount	Dip Direction
1	310-130	60	SW
2	100-280	56	SSW
3	60-240	70	SE

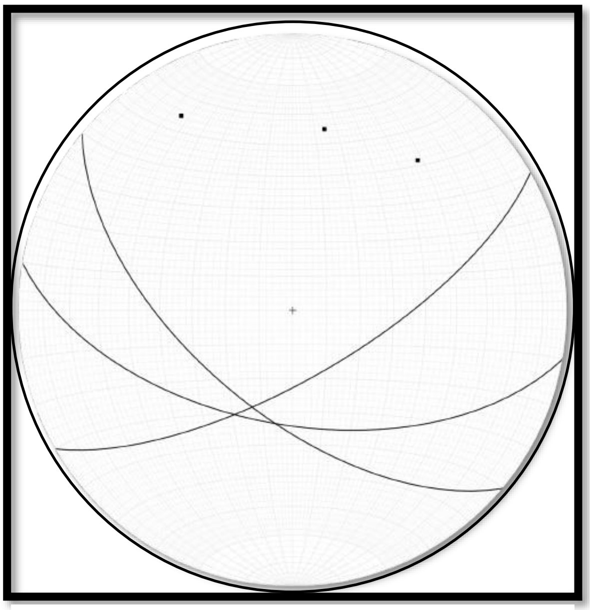


Fig. 69 Stereoplot of foliations.

After observing the different orientations of same foliation at different places, this region can be inferred to be a part of the hinge of the fold at regional scale. D3 deformation forming S3 foliation is prominent.

Strain analysis :

Fig. 71 Outcrop on which strain analysis was conducted.

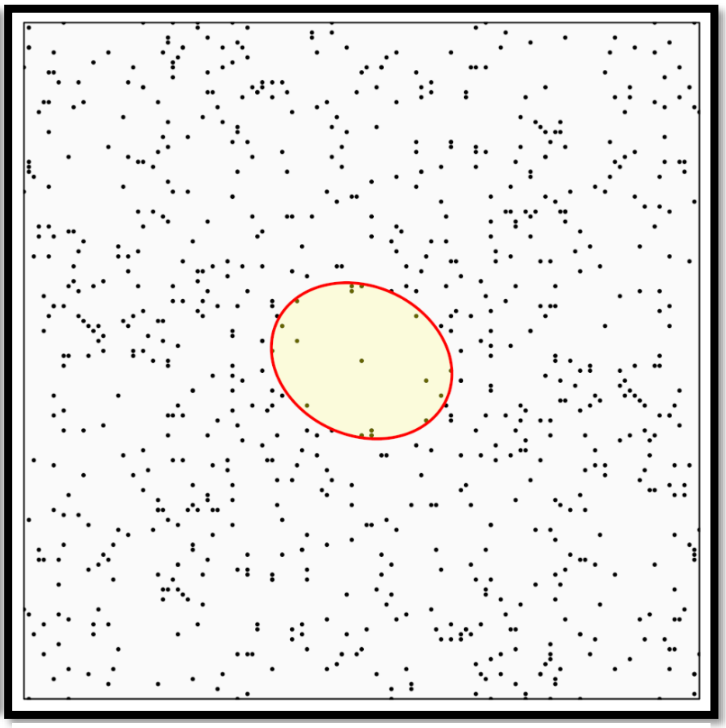


Fig. 70 Fry plot using Geofry software.

R = 1.382

Fig. 73 Fold (camera facing south west).

Fig. 72 Fold (camera facing north east).

Location 12: **South of Nala**

Orientation: N20°52'08" E85°6'44"

Lithology: Quartzofelspathic gneiss and augen gneiss

Observation: An intrusive contact between both the rock types was observed. Similar observations of the orientations as former.
D3 deformation forming S3 foliation is prominent.

Fig. 74 Augen gneiss.

Orientation of Augen gneiss:

Serial No.	Strike	Dip Amount	Dip Direction
1	300-120	75	SW
2	305-125	77	SW

Orientation of Quartzofelspathic gneiss: 320/52 SW

Location 13: North of Nala

Orientation: 20°52'08" N, 85°06'41" E

Lithology: Augen gneiss and Quartzofelspathic gneiss.

Observations: In the location the following observations are observed:

• A contact between the QF gneiss and Augen gneiss can be inferred.

• The rock has suffered the most dominant D3 deformation forming the S3 foliation planes and very little to no trace of S4.

• The orientation of the S3 foliation is around 145/46 SW

Mafic granulite was also observed here.

Fig. 75 Contact between augen gneiss and quartzofeldspathic gneiss.

Location 14: North of Nala

Orientation: 20°52'06" N, 85°06'36" E

Lithology: Augen gneiss

Observations: In the location the following observations are observed:

• The Augen gneiss has large porphyroclasts of feldspars which shows shearing, as can be obtained by the tails of the porphyroclasts of the feldspars.

• The rock has suffered the most dominant D3 deformation forming the S3 foliation planes and very little to no trace of S4.

• The orientation of the S3 foliation is around 145/46 SW

Band Traversing: On moving perpendicular to the strike of the location 1 towards West, the observations are as following:

Location 15: [Near Railway Cutting]

Orientation: 20°51’51” N, 85°06’36” E

Lithology: Quartzofelpathic gneiss and augen gneiss

Observations: Both the rock types were observed here with an intrusive contact defining the maximum extent of Quartzofelspathic gneiss demarcating the thickness of the limb. If we band traverse further towards west, we will encounter augen gneiss. The dominant deformation is D3 forming the S3 foliation.

The orientation of the foliation measured is 355/75W

Fig. 76 Aygen gneiss.

Fig. 77 Quartzo-feldspathic gneiss.

Location 16: **Moving along strike of location 15 towards north**

Orientation: 20°51'55" N, 85°06'36" E

Lithology: Quartzofelspathic gneiss and augen gneiss

Observations: The orientation of the major foliation S3 was 335/75SW. It can be inferred to be a part of the Eastern limb of the regional fold.

Fig. 79 Augen gneiss.

Fig. 78 Augen gneiss.

Location 17: **Moving further towards North**

Orientation: 20°52'00" N, 85°06'38" E

Lithology: Quartzofelpathic gneiss and augen gneiss

Observations: A contact between both the lithologies was observed. Orientation of S3 foliation was 310/60SSW.
Type 3 superposed patterns can be seen within the melt layers which developed in subsequent deformation events after D3. Both these observations infer that this can be a part of the hinge of the regional scale fold.

Fig. 80 Contact between Quartzo-feldspathic gneiss and Augen gneiss.

Location 18: **Near Sai Baba Mandir**
Orientation: 20°51’20” N, 85°05’38” E

Lithology: Garnet bearing Quartzo-feldspathic gneiss

Observation: Two foliations were visible. Out of them the later foliation was more prominent and remnants of the earlier foliations were there due to its obliteration by the later foliation. The earlier foliation was coarse whereas the later foliation was fine.

Orientation of earlier foliation was 80/34S and later foliation was 358/80E

Fig. 81 Garnet bearing Quartzo-feldspathic gneiss.

Fig. 83 Quartzo-feldspathic gneiss showing traces of older foliations.

Fig. 82 Coarser older foliations in Augen gneiss.

Location 19: [Near Loco-shade]
Orientation: 20°51'44" N, 85°05'43" E

Lithology: Augen gneiss

Observations: Here the following observations can be drawn:

The most dominant deformation event was D3 forming the S3 foliation.

Moreover, S3 foliation was seen to be dextrally sheared.

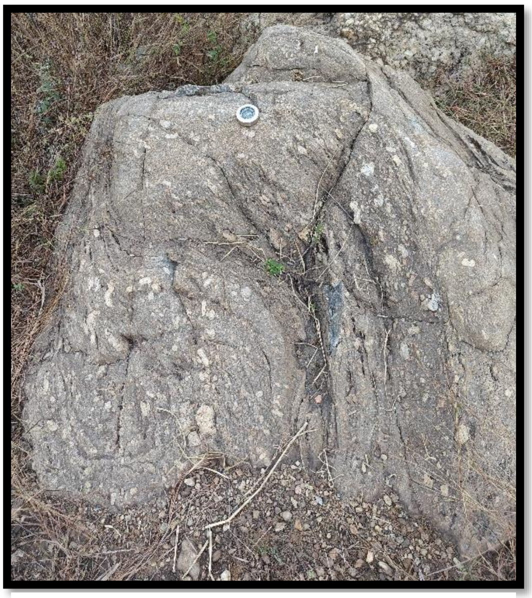


Fig. 84 Augen gneiss outcrop near loco-shade.

Orientation of S3 foliation:

Serial No.	Strike	Dip Amount	Dip Direction
1	52-232	84	SE
2	49-229	78	SE
3	74-254	56	SE
4	62-242	65	SE

Location 20: [On moving East from location19]

Orientation: 20°51'55" N, 85°06'05" E

Lithology: Khondalite

Observations: In the location, the observations were :

The outcrop has khondalite with various interlayering of melts.

Moreover, Isoclinal folds were present on the outcrop.

The dominant foliation here was S3 formed due to Deformation D3.

Orientation of S3 foliation was observed to be

30/60 SE.

Fig. 85 Khondalite near Siddheshwara temple.

Location 21: [On moving further East]

Orientation: 20°51'56" N, 85°06'07" E

Lithology: Khondalite and augen gneiss and qfg

Observations: In the location, the observations were:

Here three rock types were present, namely khondalite ,augen gneiss and quartzofelspathic gneiss.

The dominant foliation visible in both augen gneiss and quartzofelspathic gneiss, here was S3 formed due to D3 deformation.

Trend of S3 foliation was observed to be E-W.

Fig. 86 Khondalite outcrop.

Fig. 87 Folds in Khondalite outcrop.

Fig. 88 Foliation in Augen gneiss.

Moreover, Superposed deformation were visible in the khondalite outcrop present there.

Location 22: [Near Temple (Jaggannath)]

Orientation: 20°51'53" N, 85°06'15" E

Lithology: Khondalite

Observations: Orientation of the dominant foliation there was 60/54SE

Lineation oreientation was 39^{O} towards 203^{O}

Fig. 89 Khondalite showing lineations.

Location 23: [Near Railway cutting]

Orientation: 20°51’49” N, 85°06’34” E

Lithology: Augen gneiss

Observations: The orientation of the dominant S3 foliation there was found to be 10/70 W

Fig. 90 Augen Gneiss showing S3 foliation.

SYNTHESIS:

In the above listed regions of study , the rock types, the dominant foliations and the melting events evidences suggest that the region has suffered at least 3 deformations which has led to the development of the regional scale fold in the area.

Thus, fold can be traced using the orientation data of the above listed locations.

Major rock types here were quartzofelspathic gneisses, augen gneisses and khondalite.

The contact between these rock types infers the overall thickness of the hinge and the limbs of the fold.

Moreover, based on these observations the EGMB terrain can be inferred to be highly folded, sheared, refolded and distorted by subsequent melting events. This suggests the whole Angul district to have suffered at least 5 deformation events which has shaped the present EGMB pattern.

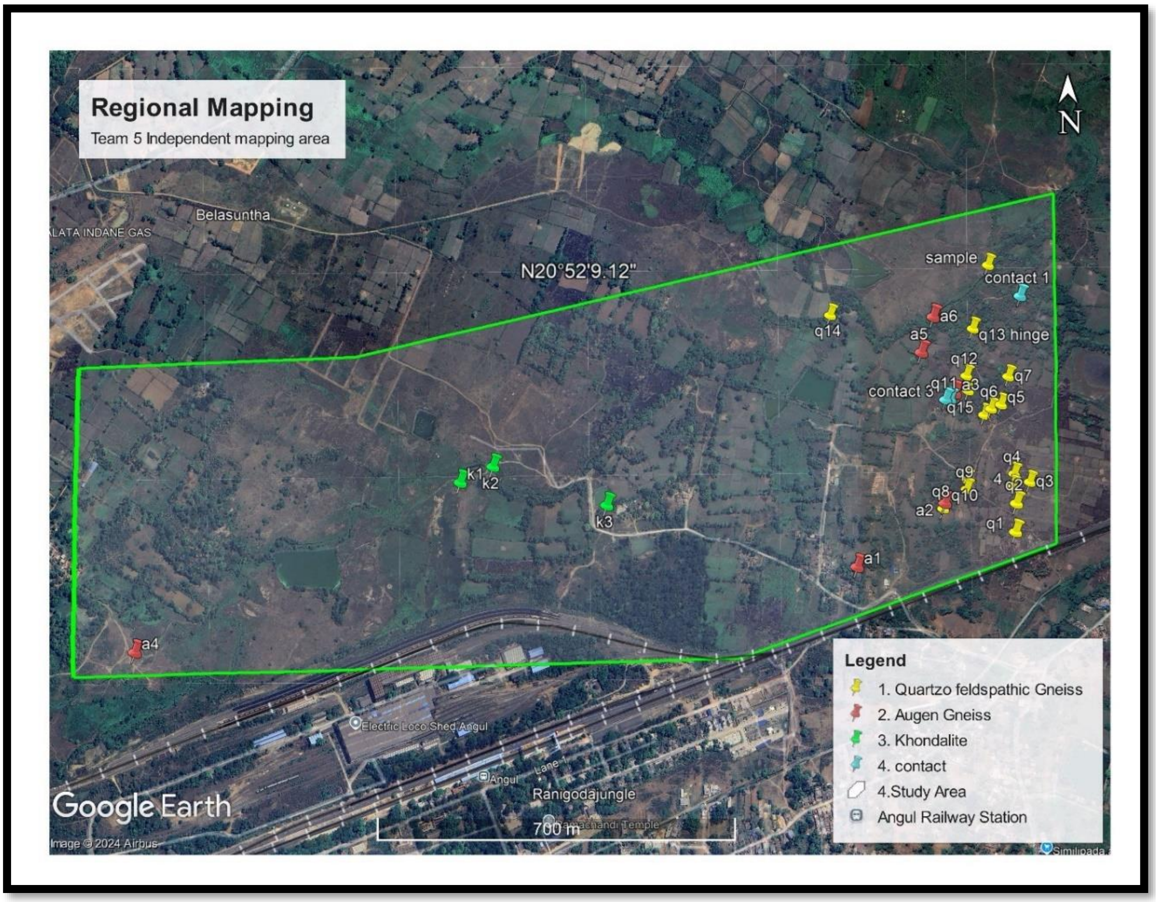


Fig. 91 Area considered for regional mapping.

THE REGIONAL SCALE MAP OF THE ABOVE LISTED LOCATION IS AS FOLLOWS:

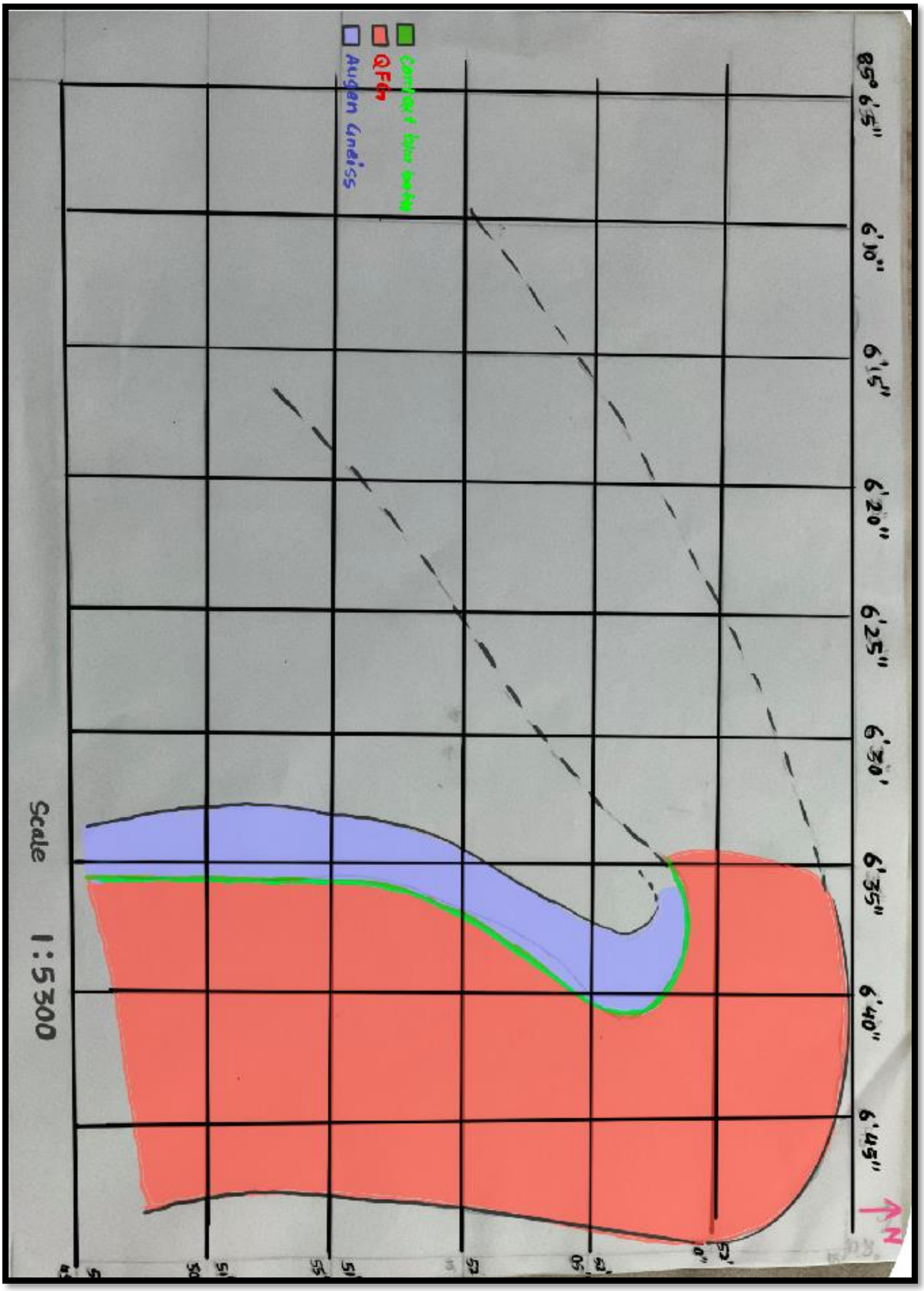


Fig. 92 Outcome of Regional Mapping exercise.

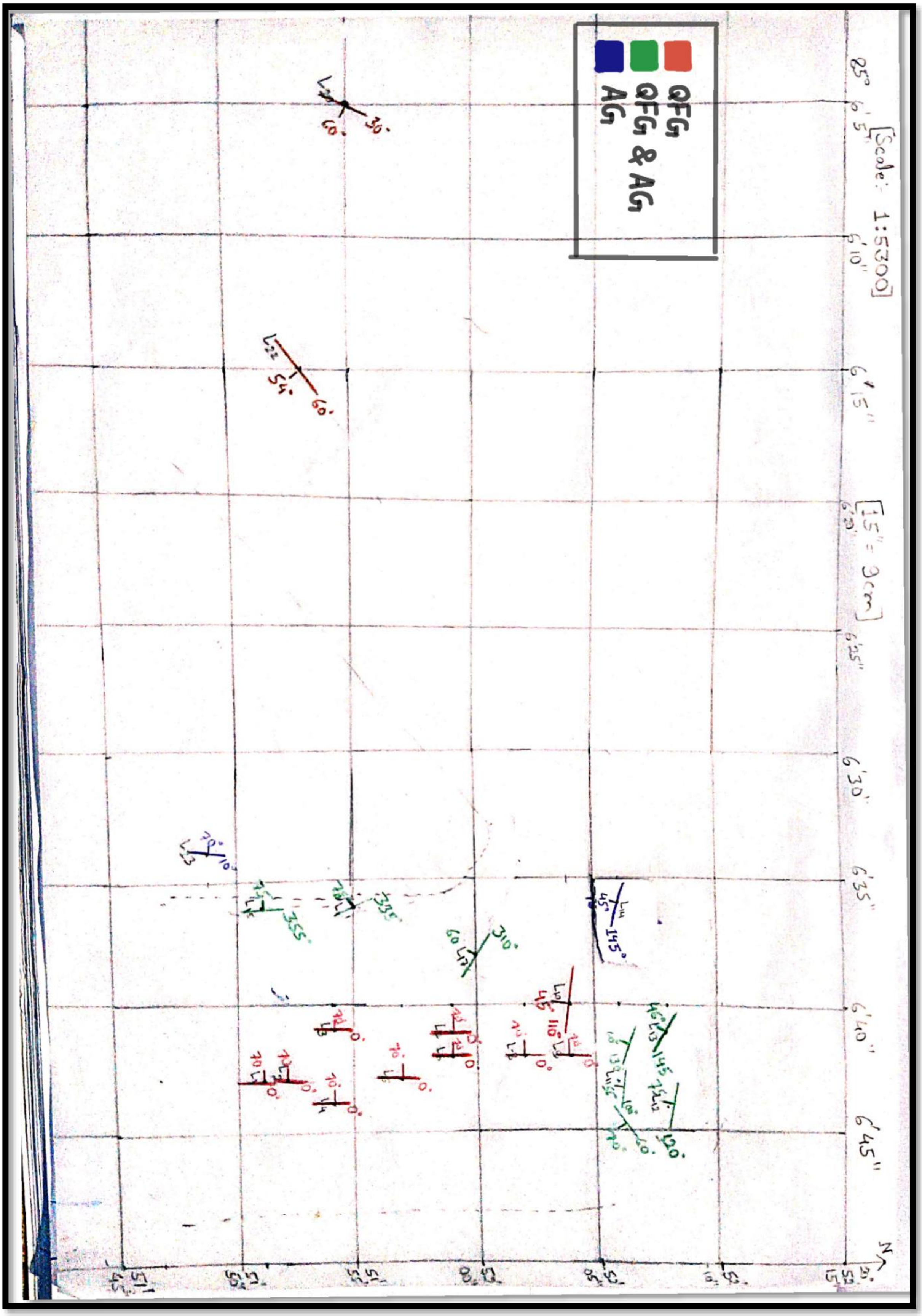


Fig. 93 Attitudes of the beds mapped.

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