CHAPTER- II

GEOLOGICAL SETTING

2.1 Introduction

The ‘Bundelkhand massif’, the northern part of Indian Peninsula, occupies an area of about 26,000km². It lies between 24° 11' N to 27° 27' N latitude and 77° 30' E to 81° 24' E longitude and covers the southern parts of Uttar Pradesh and the northeastern parts of Madhya Pradesh. Bundelkhand massif comprises different types of crystalline rocks viz. igneous and metamorphic along with the quartz reefs, very low-grade metasedimentary and mafic dykes swarm (Basu 1986).

Geographically maximum area of Bundelkhand massif is covered by different variety of granites. This acid magmatism was very profound and has almost diminished the earlier geological records. Therefore it is very difficult to describe the geology of the fragile part of Archaean geology in general. On the basis of extensive acid magmatism the Bundelkhand massif has been classified into three events viz. Pre-Bundelkhand granitoids, Bundelkhand acid magmatic rocks, and Post-Bundelkhand granitoids in the present study.

Contrasting lithounits and polyphase deformational signatures depict a complex geological history of this massif. The relics of the signatures of Pre-Bundelkhand granitoids are occasionally preserved as a small to large lensoidal bodies within the Bundelkhand granitoids (Basu, 1986; Roday et al., 1995 and Prasad et al., 1999). Geochemical, petrological and structural studies (Basu, 1986, 2001, Mondal et al., 1995, 96, 97, Sarkar et al., 1995 and Sharma, 1998) reveal that there are some oldest crustal components in the Bundelkhand. The present investigated area has a unique place in the massif where Pre-Bundelkhand granitoid rocks are well exposed.

Lithologically, the study area comprises banded-magnetite-quartzite, quartzite, talc-mica schist, chlorite schist, and ferruginous quartzite, ultramafics and volcanosedimentary sequences. Granitoids are the most widely exposed rocks in the area and have an intrusive relation with above litho-units. Quartz reefs trending NE-SW are mainly associated with pink granitoids. Banded-magnetite-quartzite trending in E-W is present as isolated patches of hillock (Plate 8) that has been used as marker band in the present study. Beside this, tonalitic-gneisses occur in the form of rafts has been also used as marker band in the present study area. The mylonitised granites, granitoids and pegmatites are exposed at several places as enclave in the pink granite.
2.2 Regional Geology

Bouger gravity anomaly map prepared by Verma and Banerjee (1992), modified by Jain et al. (1995), a cross section along the Gwalior-Malanjkhand (Fig2 3) revealed that both Bundelkhand and Malanjkhand granite terrain (Baster craton) show low gravity, the northwestern part of the Bundelkhand shows gradual rise in gravity and maximum reached below the Sindh river section mainly covered by alluvium and large masses of basic rocks. Gravity over the Bijawar basin is considerably high, as the high gravity is slightly offset towards the northern margin of the basin. It is presumed that basic rocks invade the shoulder of the rift. Gravity below the Mahakoshal belt is remarkably high though a little offset to the south. It can be envisaged by the reverse North Narmada Fault dipping south / SSE (Basu 2001). There is a small high gravity in the central part of the Vindhyan basin. Mishra et al. (2000) recorded high Bouguer gravity anomaly of large wavelength over the Satpura Mountain, suggesting high-density material below the mountain.

The Bundelkhand craton consists mainly of granitoids, migmatites, gneisses, and low-grade metamorphics. The craton is delineated from Aravalli-Rajasthan craton by Great Boundary Fault (GBF) in the west (Agarwal et al., 1995, Basu 2001, Mondal et al., 2002) and is delineated from Bastar and Chhotanagpur craton by EW trending Son Narmada Lineament (SNL) in the south and southeast (Basu, 2001, Banerjee et al., 1987, Verma and Banerjee, 1992, Vaidya, 1982). The northern boundary of this massif is probably deep faulted but extends into the Indo-Gangetic plain and is covered by recent alluvium (Khan et al., 1996).

In this massif, the E-W trending low-grade and high-grade metamorphics viz. amphibolites, fuchsite quartzites, banded-magnetite-quartzite, schists, tremolite-chlorite schist, calc-silicates, garnet-sillimanite gneisses, tonalite-trondjhemitic-granodiorite (TTG) rocks have been recorded as sporadic bodies at the low land areas and are profusely intruded by less deformed granitoids (Prakash et al., 1975, Basu; 1986, Sharma 2000, Prasad et al., 1999). The major petrological episodes of late Archean to early Proterozoic is marked by the granite activities, which in fact has diminished all earlier lithounits. Due to subsequent tectonic activities continuous erosion caused the removal of upper part of early-formed crust, thus the geological signature in the massif is very limited. The recent geochronological data (Sarkar et al.1996, Mishra et al; 1998, and Mondal et al; 2002) and polyphase deformation and metamorphism pointed out that various phases of thermal activities have also taken place in North and South of Son-Narmada Lineament.
and affected the Bundelkhand craton as well as Baster craton (Fig 2.3). Only few patches of older relics are identified and mapped by the earlier workers.

Medicott (1859) gave the first geological accounts of Bundelkhand area. He described schist and banded iron formations at Barathna in the southwestern part of the massif and also recorded amphibolites and greenstone at Barathna and Girnar areas. Some gneisses and prominent quartz veins in the massif were reported by Mallet (1869) from the southern part of the massif. Chatterjee (1941-42), Mehata (1944-45), Krishnaswamy (1945-46), Chowdhury (1947-48) and Srivastava (1951-52) of Geological Survey of India carried out geological mapping and preliminary mineral investigations in several parts of the Bundelkhand massif, as mentioned by Basu (Basu 1986).

Mishra (1948) describes the petrological diversities of the granitic rocks of the massif. Mathur (1954) discussed the petrological evolution of the massif as products of granitisation of pre-existing intensively disturbed and metamorphosed sediments. Jhingran (1958) summarized the granite-gneisses of the various parts of the massif. He also described the numerous bodies of hornblende-chlorite-schist and quartz-amphibolite schist at Kuraicha. Saxena (1961) also described various schists including amphibolites, migmatites, coarse-grained pegmatitic granites, aplites, and quartz veins from Kabra's Prakash et al., (1975) studied the stratigraphy of the massif in southwestern part of the Bundelkhand massif. According to them, Archaean sedimentary-volcanic sequence (Rajaula Formation) is followed by the sediments (Berwar Formation), culminated by the emplacement of Bundelkhand granite block in the north, and the fracturing ultrabasic intrusion, Bajawar sedimentation, basic intrusions and lava flows in the granitic block of south.

Mishra and Sharma (1974) described the stratigraphy and structure of the north central part of the massif. They also described the petrochemistry of the Bundelkhand granites, and classified them into (i) Potassium poor and (ii) Potassium rich granites.

Sharma (1982) described the petrography and structure in various parts of the massif. According to him, Bundelkhand complex comprises metasediments, meta-acid volcanics, granites and basic rocks and also suggested that schist, amphibolites, quartzites and migmatites exposed in the Saprar river section (near Muanipur) are the oldest rocks in the Bundelkhand.

Prasad et al. (1999) described the met avocadoic and metasedimentary sequences viz. migmatitic orthogneisses, amphibolites, schists, metabasalts, BIF and felsic volcanic-plutonic rocks in the north central part of the massif. Shukla and Pati (1999) also observed some older enclaves viz. hornblende-biotite schist, diorite, amphibolite, hornblende...
tonalite, crystalline limestone, quartzite, biotite-gneiss, and migmatite-gneiss in the Bundelkhand massif from Bijoul (Jhansi) Pati and Mamgain (1996) reported orbicular granite around Banda for the first time.

Zainuddin et al (1992) carried out the detailed fundamental work on the Bundelkhand granitoids and identified five different phases of granites from the massif. According to them hornblende granite is the oldest phase followed by foliated biotite granite. Porphyritic biotite granite is intrusive into foliated biotite granite. Coarse-grained leucogranite has intruded into porphyritic biotite granite and the youngest fine-grained leucogranite is intrusive into all the older types of granites. On the other hand, three types of granitoids, viz. hornblende, biotite and leuco-granitoid have been identified within the massif on the basis of mineralogy (Mondal et al, 2002).

Bijawar outcrops occur sandwiched between Bundelkhand complex in the north and Vindhyan rocks to the south. The rocks of the Bijawar Group are exposed in the type area near Bijawar. In general Bijawars forms a monoclinal south dipping unit with flat, open WSW-plunging folds in the eastern part (Banerjee 1982). The Bijawar basin extends for about 80 km in ENE-WSW direction and the rocks are exposed in the form of a broad synclinorium over the basement of Bundelkhand granite-gneiss complex. In the south, Vindhyan Supergroup of rocks overlies Bijawar group of rocks. Kumar et al., (1990) revised the stratigraphy of Bijawar Group rocks proposed by the different earlier workers (Wilson, 1873-74, Mathur, 1960, Mani, 1969 and Haldar and Ghosh, 1981) According to them the Bijawar Group is divided into two subgroups- (i) the lower Moli Subgroup, which comprises sandstone, volcanic traps, chert, breccia, conglomerate and dolomite and (ii) the upper Gangu Subgroup which comprises ferruginous breccia, shale, sandstone, phosphont, sandstone and quartzite.

Towards northwest of Bundelkhand massif, the lower-Proterozoic Gwalior Group of sedimentary rocks are exposed. The main rock type around Gwalior city is made up of shales, sandstones, cherts, conglomerates and grits and has been considered equivalent to Bijawar Group.

The Vindhyan supergroup covers an area of 104,000 km² in central India, forming a vast semicircle and envelops about half of the outcrop of Bundelkhand complex. The Vindhyan Super-group of rocks overlies the Bundelkhand complex in SE, S and SW sides. The Vindhyan Super-group constitutes an unmetamorphosed column of calcareous, arenaceous and argillaceous sediments. The lower part of the supergroup is made up of calcareous and argillaceous sediments while the upper part on the other hand is made up of arenaceous rocks of estuarine or fluviatile origin.
All these rocks discussed above have left enough imprints of different episodes of magmatism, metamorphism, sedimentation and deformations. The Bundelkhand granitoids are nearly unmetamorphosed except the NE-SW trending quartz reefs and E-W trending shear zones. Therefore, it can be concluded that the metamorphic rocks present as lensoidal body within the granitoids received metamorphism and deformation before the granitic activities. Further Bijawar Group followed by Vindhyan Supergroup and Deccan volcanics, which exposed in the southern part of the massif overlay these rocks and are devoid from the NE-SW trending quartz reefs and also from NW-SE trending mafic dykes. This inference points that the Bundelkhand granitoid rocks have received atleast two phases of deformation prior to the deposition of Bijawar Group and Vindhyan Supergroup. But little attention has been given for the relationship of metamorphics of different grade as well as with deformations, and different thermal activities occurred so far. In the present work emphasis will be given in time relationship with metamorphism and crystallization of the different metamorphic rocks, which were deformed and metamorphosed before the great batholith of Bundelkhand granitoids.

The Regional geology of the Bundelkhand craton has been presented as follows.

**Table 2.1: Regional Geology of Bundelkhand Craton**

<table>
<thead>
<tr>
<th>Post-Bundelkhand rocks</th>
<th>Deccan Traps</th>
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<tr>
<td></td>
<td>Vindhyan Supergroup</td>
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<td></td>
<td>Bijawar and Gwalior Group</td>
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<td>Mafic Dykes and Swarms</td>
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<td></td>
<td>Quartz Reef</td>
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<td>Syn Bundelkhand granitoids</td>
<td>Fine-grained leuco granite</td>
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<tr>
<td>(Acidic Magmatism)</td>
<td>Coarse grain leucogranite</td>
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<td></td>
<td>Foliated biotite granite</td>
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<td>Biotite granite</td>
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<td></td>
<td>Hornblende granite</td>
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<tr>
<td>Pre- Bundelkhand granitoids</td>
<td>Metavolcanics of mafics and felsic</td>
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<tr>
<td>(Bundelkhand massif complex)</td>
<td>Banded Magnnetite Quartzite, Micaceous quartzites, commingtonite - grunente - garnet - magnetete schist</td>
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<td></td>
<td>Talc-chlorite schist, actinolite-tremolite- talc schist, hornblende-chlorite -epidote schist, garnet chlorite-actinolite schist</td>
</tr>
<tr>
<td></td>
<td>Biotite- gneiss, hornblende-biotite gneisses, sillimanite gneisses, amphibolite</td>
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<tr>
<td></td>
<td>Tonalite-trondhjemite gneisses, granite-gneisses, migmatite</td>
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**2.3 Bundelkhand Massif Complex (Pre-Bundelkhand Granitoids)**

A few years ago, the geology of Pre-Bundelkhand granitoids was mainly based on the small lensoidal xenoliths of gneisses, mafics-ultramafics, metasedimentaries, and metavolcanics (Mallet; 1869, Jhingaran, 1958, Basu, 1986, Saxena, 1961, Sharma; 1982), which occur in the granitoids. It is known that TTG constitutes a significant component of Archaean craton throughout the world. So nowadays geologists of all over the world are paying an attention to find out this early component of crust from different parts of the
shield blocks There are several localities in the Indian shield where the TTG have been reported (Sarkar et al, 1996) Sarkar et al (1996) reported this rock from the Bundelkhand craton for the first time and compared it with other TTG rocks reported from south Indian shield Besides this, the relics of other older crustal component were identified and reported from Bundelkhand massif These rocks are present as lensoidal body within the granitoids These xenoliths can be broadly classified into three categories

1. TTG and biotite gneisses
2. Metamorphics of mafics and ultramafics
3. Meta sedimentary

2.3.1 TTG and gneisses

Mid-Archaean (3500 Ma) crustal materials viz tonalite and trondhjemitic rocks were identified for first time from Bundelkhand massif by Sarkar et al (1996), and Sharma et al (1998) and is named after type area Baghora trondhjemitic gneisses and Lodapahar trondhjemitic gneisses respectively Subsequently Sharma and Rahman (1995) also reported the occurrences of large relict blocks of trondhjemitic gneisses from Kabrai and Rampura areas, on Mahoba-Charkhari road Rampura gneisses are highly deformed and closely associated with amphibolites, metasedimentary rocks and BIF These deformed gneisses have been intruded by an undeformed hornblende-granite Grey to pink and medium to fine-grained trondhjemitic gneisses is found intrusive into highly deformed basic host rocks (early crust) in Loda Pahar, Kabrai area TTG rocks of Bundelkhand are medium grained, leucocratic and comprise chiefly c’ gooclase quartz and biotite In general gneisses are well foliated with steep northerly dips and with an ESE-WNW strike and show evidence of polyphase folding (Plate2) Mesoscopic isoclinal folds are also common in gneissic rocks (Plate 3) Major NE-SW trending quartz reef of Post-Bundelkhand granite age bounded the gneissic raft along the western margin of the massif

Prakash et al (1975) marked the migmatites and gneisses, from various places of southern part of Bundelkhand massif Prasad et al (1999) reported the migmatitic gneisses at north of Simra from Tikamgarh District, Madhya Pradesh Grey, Pink, banded (stromatic) to streaky (schlieric) gneissic enclaves is also noticed from many places of the north of Simra area The trend of the gneissic banding varies from NW-SE to E-W. Mondal et al (2002) mentioned the five large lensoidal gneissic bodies in the massif (fig 2.2) Besides the gneisses the granulites were also reported from this massif Jhingran (1958) describes about granulites as inclusions in the Bundelkhand massif without giving any specific location Das (1959-60) describes a 30m x 30m exposure of garnetiferous granulites from 16 km north of Pandara
2.3.2 Metamorphics of mafic and ultramafic rocks

The older metamorphic enclaves of mafic and ultramafic rocks and metavolcanosedimentary are observed in lensoidal form at many places. Medlicot (1859) recorded amphibolite and greenstone rocks in associations with the Bundelkhand crystallines at Baraitha and Girar. The enclaves of hornblende-chlorite schists and amphibolites were also mentioned by Jhingran (1958).

Chlorite-biotite-schists and metabasalts, conformable with quartz-feldspar-biotite gneisses in the area around Madaura, are reported by Prakash et al (1975), Mishra and Sharma (1974) established the high-grade metasedimentary rocks as Kuraicha Formation, which formed the oldest crust in Bundelkhand, and the low-grade metamorphics as Palar Formation, which includes pelites, semipelites, volcanicogenic metasediments and meta-arkoses. They also considered hornblende schist and quartz-amphibolites schist as the main constituent of Kuraicha Formation and basic dykes transformed into talc-schist in the Kuraicha area.

In general metabasic and metaultrabasic enclaves occur as small-sized isolated bodies throughout the granitoids and are mostly foliated and devoid of any lineation. Magnetite-bearing gabbros occur to the south west of Kakarwaha village (Basu, 1986). Basu (1986) identified three principal metaultrabasic and metabasic rocks from Bundelkhand massif. Metaultrabasic rocks are represented by large bodies of talc-tremolite schist, which occur around Balwantgarh and tremolite-actinolite schist to the southeast of Kakarwaha. Grobboic rocks of metabasic rocks are observed towards south west of Kakarwao or east of Madaura.

Epidiorites (metabasic rocks) are the most widespread among metabasic rocks, occur in small patches within the granitic rocks. They can be seen on Haidarpur-Kakarwao track. A body of metadolerite has been reported by Srivastava (1970-71) in the north west of Baghara. This E-W trending thin body exhibits compressed filled vesicles, and it traverses the axial region of an E-W trending antiformal fold in the migmatites. Mani and Bhattacharya (1969-70) reported a large body of basic-ultrabasic rock to the north and northeast of Baraitha village.

2.3.3 Metasedimentaries

Medlicott (1859) reported metasedimentary enclaves, "ribboned (alternate thin layers) iron-oxide and quartz schist" from Barata (Baraitha) and adjoining Girar area. Jhingran (1958) reported quartzite, magnetite-quartzites, slate, carbonates and sandstone enclaves from Bundelkhand granites. Prakash et al (1975) postulated Archean sedimentation and volcanism, which was later on subjected to metamorphism and
described as Berwar Formation of 300 m thick metasedimentary exposed near Berwar village in southernmost part of the massif Basal lenticular quartz conglomerate, fuchsite-quartzite, grey to green chloritic shales and banded magnetite hematite-quartzites of Girar are the main rock types of Berwar Formation. The fuchsite quartzites described by Prakash et al (1975) are the same rocks mentioned by Wilson (1868-69, c.f. Basu 1986) and Mehta (1944-45, c.f. Basu 1986) as pyrophyllite schist.

Mishra and Sharma (1974) put the iron formation above at the top of Kuraicha Formation and describe red beds followed upwards by glauconitic quartzite to the north and northwest of Mauaranipur Railway Station. Prasad et al (1999) described three suits of volcanics and metasedimentary along with gneisses at Dhaura. These volcanic sedimentary and gneissic rocks occur in the form of a NW-SE to E-W trending belt and bordered by intrusive pink biotite granite towards north and south. They also noted inclusions of amphibolites, schists and BIF in the gneissic complex.

2.3.3.1 Banded iron formation

Banded Iron Formation has been recorded from many parts of the Bundelkhand massif- (i) at Baraitha and Girar by Medlicott (1859), (ii) between Babina and Papaoní, Wilson (1873-74), (iii) near Gora and Balyara, Das (1959-60), (iv) at Kamla Sagar Dam, Mishra and Saxena (1959), (v) west and north of Mauaranipur Railway Station, Srivastava (1970-71) and (vi) at Chanrro, Goyal and Jain (1972-73).

In general iron-formation consists mainly of banded quartz-magnetite rocks, banded magnetite amphibolite and amphibole-bearing Banded-magnetite-quartzites. The banded-magnetite-quartzites of Girar-Baraitha and Chanrro are hard and compact, while those of Babina, Papaoní, Gora-Balyara and NW of Mauaranipur are fragile. They are well banded with alternating gray and white bands of magnetite and quartz (Plate 13a). At places the magnetite and quartz bands show wavy boundary generally symmetrical, which indicates that these iron formation have suffered low-grade metamorphism. Not only this penicontemporaneous deformational sedimentary structure were also noted from BMQ at many places. Most of the iron formations in this massif have the general E-W strike and are tightly folded synclinal structures with axial planes dipping on the average 65° to the north.

Actinolite, cummingtonite, grunerite, garnet, hornblende, chlorite, epidote, biotite and hercynite, magnetite are the main silicates in these iron formations.

2.3.3.2 Carbonates

Jhingran (1958) recorded limestone as inclusions in Bundelkhand massif at Gairwar and Magur. Basu (1986) found some carbonate rocks about 0.6 km south of the
Berwar village Singh and Kumar (1970) reported lenticular calcite outcrops at Khajraha in Jhansi District. They considered these rocks as carbonatites. Mukherjee (1973-74) considers these as calcareous metasediments. Mishra and Sharma (1974) also considered these as carbonatites with magnetite and siderite bands.

### 2.3.3.3 Quartzites

Jhingran (1958) mentions small quartzites bands as inclusion in granites at several places but does not specify any locality. Das (1959-60) recorded biotite quartzite inclusions within the medium to coarse grained pink granite at west of Kuryankhirk and east of Gaiwara, about 0.8 km west of Laron, and to the NW of Pandra. Saxena (1961) mentions a number of bands of quartzite in the Kabrai area. Basu (1986) noted the quartzites from shear bands in granite. Mukherjee (1973-74) recorded lens of quartzites, in Rajpur and Jaswantpura, trending NE-SW and well foliated. Goyal and Jain (1972-73) records schistose and fine grained quartzite about 2.5 km east of Patha in the river Jamni. Mukherjee and Senthappan (1973-74) records quartzites, at Garhmau, Palar and Gaurani areas in the Jhansi district.

### 2.3.3.4 Phyllite and Schists

Jhingran (1958) describes inclusions of slaty rocks in Bundelkhand granites at NE of Nadgaon (in the Chhatarpur distt). Mishra and Sharma (1974) include black shales but they did not specify any locality of occurrence. Pascoe (1950) mentioned talcose schist, hornblende schist, chlorite schist, quartzose schist and "argillaceous schist" in areas around Mahroni in the southwestern part of Bundelkhand. Jhingran (1958) mentions quartz schists and feldspathic schists in the Sadhri nadi about 12 km WNW of Basatgawan Puri (in Basu, 1986) reported various schistose rocks including chlorite, hornblende, mica, talc-quartz and feldspathic schists in a narrow region between the granites and the Vindhyans near Marla.

Saxena (1961) described biotite-muscovite schists interbedded with flaggy micaceous quartzites and garnetiferrous muscovite schist at Kabrai. He also described greenish white quartzite and muscovite schist at the same place. Mishra and Sharma (1974) mention phyllites and low-grade schists in association with quartzites (quartz reefs) in the Palar formation. Srivastava (1970-71), Basu (1986) and Mukherjee (1973-74) located some stringers of schistose rocks with sillimanite occurring at 4Km milestone on Jhansi-Mauranipur Road from Jhansi. Jain and Goyal (1973-74) also found a band of sillimanite schist in the east of 7.6 km milestone from Jhansi on the Jhansi-Orchha Road.
2.4 Acid Magmatism (Bundelkhand Granitoids)

On the basis of mineral composition, texture, colour and location, the granites of the Bundelkhand have been classified into different types viz Jhansi granite, Matatila granite, Garhmau granite, pink granite, porphyritic granite, hornblende granite, foliated biotite granite etc Jhingran (1958) first time compiled the occurrences of Bundelkhand granitoids and classified ten types of granites in Bundelkhand Saxena (1961) grouped the granite into pink and gray and suggested that the granites of the massif are result of transformation of quartzites and other metasediments Prakash et al (1975) devided the granite into four categories and opined that the granites of north Lalitpur orginated as a result of regional granitisation of metasedimentary Basu (1986) recognized three main types of granites viz (i) the porphyritic coarse-grained granite, (ii) porphyritic medium grained granite, (iii) non-porphyritic to sparsely porphyritic medium to fine grained leucogranite and he further devided them into six types (Basu, 2001) Sharma (1982) devided the granites on the basis of the location- (i) Garhmau granite and (ii) Matatila granite and further classified into three phases.

The above said divisions of the granite were mainly based on texture, structure and location Due to similarity and overlapping characters, these classifications could not be satisfactorily functional for the purpose of geological study Therefore, Zainuddin et al, (1992) and Mondal et al, (1996) proposed genetical classification based on geochemical character, colour index and mineralogy beside the texture and structure of rocks They classified the granitoids batholith into five types- (i) hornblende granite, (ii) porphyritic-biotite granite, (iii) foliated-biotite granite, (iv) coarse-grain-leucogranite, and (v) fine-grain leucogranite

2.4.1 Hornblende granite/porphyritic coarse grained granite

The rock is commonly pinkish red to light pink in colour and is dark red on weathered surface The feldspar phenocrysts are tabular in form The hornblende is an essential mineral, which is usually associated with biotite High packing of feldspar phenocrysts is noted at many places Massive exposures around Jhansi, extending upto 14km stone on Jhansi-Lalitpur Road in the south, across the Jhansi-Lucknow Road on the east and upto the quartz reef north of the Jhansi Railway station, between the Betwa river at Jhararghat and upto 6km south of Talbehat It is also exposed around Mau ranipur, Mahoba, Khajuraho, and many other places. Sharma (1982) described this granite as Garhmau granite.
2.4.2 Biotite granite/porphyritic medium grained granite

Porphyritic medium grained granite recorded specially to north east of Karesra Kalan, 47km south of Jhansi on Jhansi-Lalitpur Road. This rock becomes coarser near the contact with Jhansi granite (Porphyritic Coarse Grained Granite). Compared to Jhansi granite, the rock is dull in colour with the smaller feldspar phenocrysts. At few places like Agon, the quartz grains are larger than the feldspar phenocrysts. In this granite microcline is dominant as phenocrysts. The biotite is one of an essential component. The hornblende may exist with this rock. This granite is more or less equivalent to porphyric medium grain granite proposed by Basu (1986).

2.4.3 Foliated biotite granite

The foliated biotite granite is commonly dark pink to light pink in colour and exhibits local foliation, and also shows coarse-grained porphyritic texture. The phenocrysts of feldspar are prismatic and are highly packed.

2.4.4 Coarse-grained leucogranite

Small veins and patches of syno-granite rocks are commonly seen in the Jhansi granite and to a lesser extent in the Karesra granite (Basu, 1986). Some lenses are recorded at Jhararghat on the Betwa River. These granite bodies exhibit a blocky habit. These are reddish pink to chocolate coloured rocks with phenocrysts of microcline orthoclase and perthite in a groundmass of albite, minor quartz and biotite. Basu (1970-71) first recorded this porphyry to the south of Jhansi on Jhansi-Lalitpur Road south of Ghuran Nala. A prominent zone can be seen from Khajraha Buzurg also be seen to the south east of Manpur Tal. The rock is of light fawn colour with tiny phenocrysts of white feldspar.

Granite porphyry dykes with coarse-grained feldspar phenocrysts are noticed in various parts of the massif. To the south of Talbehat, there are discontinuous parallel bodies up to 20m wide and 50m to 200m long. Many traceable bodies are recorded across the Jhansi-Lalitpur Road between 53km and 58km milestones from Jhansi. Several bodies of coarse porphyry are recorded from Birdha, southern bank of Dukwan Resevoir.

A light grey variety is commonly seen only in the coarse grained Jhansi granite occurring in the NE of Barora near 34.6km milestone on Jhansi-Lalitpur road, 3.6 km south of Jhararghat, 0 6 km north of Matatila Railway station and along the west bank of the Jamnī River to the east of Birdha.
A large outcrop of medium to fine coarse-grained non-porphyritic leucogranite occurs on the western flank of Chhikahra. It is a massive rock with a pegmatitic structure and is intruded by the Kabrai leucogranite.

Large composite bodies are also found in Jhansi town (Gwalior Road), in the Sonagir hills, to the west of Nathikhera, in the Kuraicha hill forming the east abutment of the Kamla Sagar Dam, on the Jamni Dam right canal and scores of other places. It is a grayish white to grayish pink rock with moderate proportion of dispersed ferromagnesian constituents. A number of prominent medium grained leucogranite bodies are seen at Kabrai (Basu, 1986).

2.4.5 Fine grained leucogranite

A small fine-grained leucogranite body was encountered on the southern flank of a hill to the west of Ratauli village. The younger fine-grained leucogranites have lower content of ferromagnesian minerals and they are conspicuously devoid of hornblende. Basu (1986) found out a body of fine-grained leucogranite from west of Nathikhera, trending in a NNW-SSE direction up to the Dukwan reservoir on the Betwa River for about 9 km. It is moderately dark with dominant fawn fine-grained groundmass and sparse small sized phenocrysts of cream-colored feldspars. Another 1.6 km extension of the body to the south was noticed by Mukherjee (1973-74) and describes as porphyryte. A similar body is noted across the Jhansi-Mauranipur Road at the Ghugwa Rest House 23 km from Jhansi. Fine-grained leucogranites are widely exposed in Lalitpur.

2.5 Post-Bundelkhand Rocks

2.5.1 Quartz reefs

Quartz Reefs are the characteristic features of parallel ridges of quartz, trending NE-SW in Bundelkhand massif. They rises about 175m above the surrounding land. Jhingran (1958) mentioned that sometimes quartz give out small offshoots and coalesce into one. He also mentioned that the cataclasites and the granulated nature of cherty reef rock together with the presence of schistose structures. It represent long narrow zones along which intense mylonitisation had taken place. According to Basu (1986) there are eleven major quartz reefs in Bundelkhand massif and spaced at 12 km to 19 km part, the average widths of reefs vary from 50 m to 60 m and lengths from 35 km to 40 km. The longest ridge passes through Nivan is traceable almost continuously for 100 km.

Quartz is the main mineral constituent in most of the reefs. The pyrophyllite and diaspore are mainly associated with quartz reefs. At places quartz reefs exhibit disseminated crystals of pyrite, secular hematite and rarely chalcopyrite. Grayish white
coloured quartz reefs are dominant in the massif. At many places reefs show pinkish white and milky white colour. Dark grey, rosy and black patches are also observed rarely. Maximum quartz reefs occur in the NW of Jhansi, SE of Chhatarpur and SE and SW of Tikamgarh. At many places the wall rocks bordering the quartz reef show signatures of crushing. Basu (1986) suggested that reefs do not relate with any sedimentary phase they are purely epigenetic manifestations and products of shearing and mylonitisation. Roday et al. (1995) pointed that quartz reefs were emplaced along brittle ductile shear zones, and their associated polymetallic sulphide and pyrophyllite-diaspore mineralisation, mark an end-stage of hydrothermal fluid activity after the crystallization of the granite plutons. They also mentioned that these events coincide with the stabilization of the Bundelkhand massif.

Roday et al. (1995) have developed a kinematic model attributed to the geometry of the quartz reefs and the mafic dykes in Bundelkhand massif. According to them mafic dykes and quartz reefs were emplaced along the fractures developed due to changes in maximum compressive stress from an initial NE-SW trend to a final NW-SE trend.

2.5.2 Mafic swarms and dykes

Mafic dykes, trending NW-SE, are more frequent near eastern and southwestern margins of the Bundelkhand massif. These dykes have a cross cut relation with the most prominent NE-SW trending quartz reefs. However, at places ENE-WSW and E-W trending dykes are also observed in the Bundelkhand massif. The maximum width of dyke (45m) is recorded near Kakarwao. In general the dykes are doleritic in nature. They are usually dark grayish green in colour. Basu (1986) recognized three generations of dykes. Coarse-grained variety is cut across by a medium grained variety, which in turn includes transverse bodies and lenticels of a very fine-grained aphanitic dolerite. Medium grained variety is more widespread and named after Mahoba as great dolerite dyke of Mahoba. This is about 11km long ENE-WSW and forms a prominent ridge. Coarse-grained variety has a gabbroic appearance and is recorded as Kakarwao Dolente. The fine-grained variety, which resembles the Malwa plateau basalts lying immediately to the southwest of the Bundelkhand massif, is designated as the Chhikahra dolerite.

2.5.3 Bijawar Group

Bijawar Group of rocks occur as low hills on the southern fringe of the Bundelkhand massif. Exposures of these rocks are in two sectors. The eastern one lies mainly in the Chattarpur and Sagar districts of Madhya Pradesh and Lalitpur district of Uttar Pradesh. Western part of Bijawar Group is seen after a gap of 250 km from eastern sector in Uttar Pradesh (Mirzapur Distt.). Another exposure is seen in the Harda inlier in
the Narmada Valley 275 km SW of the type area. The Harda and Mirzapur Bijawar are now known as Mahakoshal Group. Bijawar rocks lie above the Bundelkhand Massif and below the Vindhyan Supergroup of rocks. They are exposed along the south-southeastern edge of massif between Sonrai to Chitrakoot in the two-separate basins. Bijawar Group of rocks consists of pebble bed, quartz arenite, mafic trap, bedded chert and dolomite, chert Breccia, phosphatic shale, highly ferruginous shale and sandstone. Quartz veins, basic sills, stromatolite bands, are found.

2.5.4 Vindhyan Supergroup

Vindhyan rocks overlie the Bundelkhand massif on all sides except in northern part of it. The Vindhyan Supergroup forms a vast semicircle pattern extending in Rajasthan, Madhya Pradesh, UP and Bihar, and is delineated by Son-Narmada fault in south. The Yamuna-Ganga alluvium in the north conceals both the Bundelkhand massif and the Vindhyan. The basal conglomerates, limestone, porcellanite, shale, glauconite sandstone, quartzite and fawn sandstone etc. are the main rock types of the Vindhyan supergroup. Alternate layers of sandstone, shale, limestone and quartzite are the characteristic feature of Vindhyan Supergroup. The Vindhyan Supergroup is widely exposed in south of Bundelkhand massif (Fig 2.3) and has been lithologically divided into Semri, Kaimur, Rewa and Bhandar Groups. The carbonate facies dominates in Semri and Bhandar.

2.5.5 Deccan Traps

In Bundelkhand region Vindhyan rocks are directly overlain by Deccan Traps towards south south west of granitic massif. Deccan Traps covers an area of about 500,000 square kilometers in the northern and western parts of the Indian Peninsula. The lava flow some times reported at massif also. The extensive lava flows which give rise flat-topped mountains and plateau with step like terraces are believed that they have erupted sub-aerially through the fissures in the earth’s crust. Eastern and southern parts of the Deccan Plateau is composed of uniform horizontal tholeiitic flows representing the quiet type of eruptions and represents the lower unit. The upper unit exposed in the northern part of the Deccan Plateau, which having numerous inter-trapean beds is characterized by an explosive activity.

2.6 Regional Structure

Bundelkhand complex is ornamented by several regional structures like quartz reefs, dykes, folds, faults, shear zones etc. The different rock types of the complex have undergone several generations of deformation episodes. The contacts between Granitic terrain (massif), Bijawar Group and Vindhyan Supergroup in south, and Indo Gangatic
towards north are demarcated by faults or unconformity and are most important for the study of the structural evolution of terrain.

Major and Minor Structures viz. lineaments, folds, joints, schistosity and foliation, bedding plane structures are observed in the Bundelkhand Complex and has been discussed separately.

2.6.1 Structures in migmatite, gneiss and amphibolite

Gneissic structure exhibits well developed banding represented by melanosomes and leucosomes of variable thickness. The leucosomes are mainly of quartzo-feldspathic with minor biotite. The melanosomes are granodioritic to dioritic where biotite and minor amphibole are embedded. In the streaky gneisses, bands of biotite and rarely amphibole are interlayered with quartzo-feldspathic leucosomes. Basu (1986) described that the gneissosose structure exhibits a general WNW-ESE strike with moderate to steep (35 to 65°) dips in many parts of the complex.

Five phases of deformation were recorded from the migmatite gneisses and amphibolites (R P Sharma, 1982), which are represented by various types of foldings. The F1 folds are tight isoclinal, their hinge generally trend E-W. F2 folds are open to tight upright and coaxial to F1 folds and trending E-W. The F3 folds are subvertical and vertical, the fold axis is steeply plunging, F4 folds are upright to steeply incline and F5 folds are upright. Recently Prashad et al (1999) also reported five phases of deformation in the gneisses. They suggested that isoclinal to tight reclined and open folds (F1, 2, 3) were developed during first, second and third phase of deformations and in the fourth phase deformation sinistral shear zones were developed in NE-SW direction while in the fifth phase deformation dextral shear zones were developed in NW-SE direction.

Shukla and Pati (1999) also mentioned that migmatites, and gneisses show NW-SE strike trend, moderate to subvertical dip due north. They also noted that F2 folds plunging northwest are observed in migmatite gneiss.

2.6.2 Structures in meta-volcanic and meta-sedimentary rocks

In many parts of the Bundelkhand complex metabasalt/amphibolite, BMQ, gneisses and minor schists are found in association with granitoids. Metabasalts and schists exhibit well-defined schistosity. In many parts of the complex schistosity shows orientations of strike at NW-SE and NE-SW.

Prasad et al (1999) have described three phases of deformation in the volcanic and metasedimentary rocks exposed near Prithivipur. The first phase deformation resulted
in tight to isoclinal and reclined folds with schistosity. The axial surfaces of the first phase folds trend WNW-ESE to E-W with steep NW plunging fold axes (>50°). The second phase deformation produced reclined type folds (F2 folds) They are co-axial and co-planar with F1 folds. The third phase deformation produced tight to open folds (F3 folds) with axial surfaces at high angle to those of F1 and F2 folds. The axial surfaces of the third phase folds trend NW-SE to NE-SW and the fold axes plunge 25°-60°N. They also compared these three phases of folding in the volcanic and sedimentary rocks with orthogneisses. They also mentioned that an intense schistose fabric developed in metabasalts near the northern contact.

Slump structures and flowage of unconsolidated material resulting in podlike masses are common in Banded-magnetite-quartzite rocks of Chanrro and Girar areas (Basu, 1986). Similar slump structure and pencontemporaneous structure were reported by other workers (Shukla & Pati, 1999 and Sharma, 1998). Similar tight isoclinal folds are common in the banded iron formations of Bundelkhand complex, at places open folds are also observed. Generally fold axes are parallel to the strike of the iron bodies, i.e., east west and axial planes dip towards north.

The supracrustal rocks (metabasic and metaultrabasic rocks, meta-cherts, banded iron formations, fuchsite-bearing quartzites, quartzites) of southern part of Bundelkhand region are folded generally on E-W axes into tight to isoclinal folds overturned to the south (Prakash et al., 1975, Roday et al., 1995). These authors also mentioned that the F1 folds in these supracrustal rocks are generally variably oriented and coplanar folds and F2 fold structures lie at high angle to early structures and they appear to have been formed after the emplacement of granite.

### 2.6.3 Structures in granitic and other rocks

At many places, granitoids exhibit foliation, which is marked by the parallelism of tabular grains of feldspar phenocrysts in Bundelkhand Massif (Plate16). Basu (1986) mentioned that foliations in granites do not possess a regional control but are possibly the result of local stresses. The regional trend of foliation is WNW-ESE. Prakash et al. (1975) described that most of the ductile shear zone in the granitoids were developed towards the end phase of late kinematic diapirs and this is generally abound in contiguity with supracrustal rocks, or in proximity with adjoining diapirs. Two sets of shear zones in granitoids have been described by many workers (Basu; 1986, 2001, Sharma; 1988 and Roday et al.; 1995). Both the sets of shear zones are generally steeply dipping or vertical. The EW trending sinistral shear zones are more ubiquitous than their NW-SE trending dextral counterparts. Shear zones are generally located at the boundary of supracrustal rocks, sometimes they are also located at the boundaries of individual diapirs.
There is no doubt in saying that the Bundelkhand massif is traversed by two prominent sets of lineaments one having the general NE-SW trend and another trending NW-SE (Fig 2.4). The NE-SW one is observed as quartz veins and reefs, the NW-SE one as mafic dykes. Quartz reefs have slightly sigmoidal geometry, characteristic of the tensile veins, generated by a brittle - ductile inhomogeneous simple shear. They are at very definite periodicity and lie subperpendicular to ESE trending cleavage within the ductile shear zones.

Basu (1986) described three principal sets of lineaments based on the study of LANDSAT-I imageries. They are trending NE-SW, ENE-WSW, and NW-SE (Fig 2.4). The southwestern part of the massif has more density of lineaments than others. At palaces lineaments intersect each other and at places occur as curvilinear or parallel to each other. Basu also mentioned that low density of lineaments in the massif indicates absence of intense tectonism.

In general, granite exhibits three sets of joints in which two are trending NE-SW and NW-SE with steep dips and the third one horizontal. Commonly joints are observed in open forms. The gaps of the joints rarely exceed 10 cm in width and the length of the individual joints are also do not exceed 50 m. At places pegmatite veins have filled up some of the joints.

Bundelkhand massif is also well ornamented by fractures. The massif granite, rocks are extremely fractured at places and other dykes have followed particular sets of fractures. Granites show ENE-WSW trending fractures, pegmatites, and quartz reefs followed the NE-SW trend while dolerite has followed the NW-SE trending fractures. The fractures within massif are commonly observed as straight but at places zigzag fractures are also observed.

2.7 Regional Stratigraphy

The Bundelkhand massif mainly comprises granitoid rocks of different episodes, gneisses, migmatites, metabasics, schists, and volcano-sediments. Quartz reefs and mafic dykes are represented by NE-SW and NW-SE trending lineaments throughout the massif. Number of workers has been attempted to describe the geology and stratigraphy of the Bundelkhand massif (Table 2.3).

Medlicott (1859) described the occurrence of greenstone, dykes and quartz reefs for the first time on the maiden investigation in Bundelkhand craton. Fermor (1936) described the age of the gneisses as post Dharwar. Pascoe (1950) and Chatterjee (1971) attempted to set up a stratigraphic column of Bundelkhand. According to them, Mehroni Schist Belt is Archaean in age, and granite is considered as Pre Dharwar.
Jhingran (1958) mentioned that relicts of metasediments are equivalent to Dharwar Granites, quartz reefs and basic dykes respectively are of younger episodes. Saxena (1961) also attempted to describe the lithostratigraphy of the Bundelkhand. Saxena (1961) added an unconformity between granitoids & schist in the stratigraphic sequences proposed by Jhingran (1958).

Prakash et al. (1975) have classified the stratigraphic sequences of Bundelkhand massif as (i) Rajaula Formation, consisting of metamorphosed volcano-sedimentary, is unconformably overlain by (ii) Benwar formation consisting of ferroginous metasediments and mafic and ultramafics. They put these two formations under Mehroni Group. Above the Mehroni Group (after a gap of deposition) they put (iii) Bundelkhand Granite Formation which consists of variety of granites including migmatites and (iv) Madaura Formation on the top which consists dolerite dykes, quartz veins, pegmatite, gabbro, pillow lava etc.

Mishra and Sharma (1974) proposed a four fold classification of Bundelkhand Massif and suggested that (i) Kuraicha Formation, which is comparable to Rajaula Formation of Prakash et al. (1975), as the oldest formation of the region. It consists of migmatites, gneisses, schists, quartzites etc. Kuraicha Formation is unconformably overlain by (ii) Palar Formation, which consists of quartzites, phyllites, schists, diasporre, ferruginous quartzites etc., it is followed by (iii) Intrusive of Bundelkhand granitoids and (iv) Mafic dykes and Swarms.

Basu (1986) proposed a lithostratigraphic succession of this region after a long time field investigation in Bundelkhand region. According to him Banded Iron Formations and metabasites are the oldest rock types in the region and also opined that they are of Pre-Bundelkhand after a gap of deposition Bundelkhand Granitic Complex existed. Basu put the gneisses as oldest followed by various phases of granites of different episodes. He also considered quartz reefs and dolerites as the youngest lithounit.

Sharma (1982) also proposed the lithostratigraphy of the Bundelkhand complex. They placed the (i) Kuraicha Formation as the oldest unit which comprises migmatite, gneisses, amphibolites, chlorite - biotite schist, quartzites etc. Kuraicha Formation is unconformably overlain by Bundelkhand Group, which comprises six formations having different lithology. They are (i) Palar Formation, (ii) Paron Meta-acid volcanics, (iii) Garmau Granite, (iv) Matalila Granite, (v) Mahoba Dolente, and (vi) Madaura Ultrabasics. Sharma (1998) proposes the stratigraphy of Bundelkhand in terms of the tectonic events. They proposed the following stratigraphic sequences of Bundelkhand (i) Mahroni Formations of Archean is conformably overlain by Bundelkhand granitic complex.
(2600 Ma), (ii) Bijawar and Gwalior Groups (2400-2300Ma), (iii) the Vindhyan Supergroup (1500-550 Ma), and (iv) Malwa (Deccan) Traps (Cretaceous-Eocene)

On the basis of field observations, geochronological data available from literature and detailed structural review, the following stratigraphic sequences of Bundelkhand Complex is proposed (i) Tonalite-Trondhjemitic Gneisses (TTG) (>3100 Ma) suggested as older metamorphic group (OMG), is overlain by (ii) Newer Metamorphic Group (NMG), which comprises low-grade metamorphosed mafic and ultramafic suits followed by Banded Iron Formation. It is unconformably overlain by volcano-sedimentary rocks (iii) Bundelkhand granitoids were emplaced and deformed at late Archaean to early Proterozoic (2500-2300 Ma). The quartz reefs were emplaced at late stage (iv) Bijawar and Gwalior volcano meta-sedimentary were laid over Bundelkhand Granitoids after a prolong gap of depositions (v) Mafic and Ultramafic dykes and swarm (1600Ma) emplaced before the deposition and recrystallization of Bijawar Group of rocks. Vindhyan Supergroup is deposited after the recrystallization and deformation. Finally, Vindhyan Supergroup is unconformably overlain by Malwa Traps, which is the topmost/youngest lithounit of the Bundelkhand microcontinent.

2.8 Geochronology

The Bundelkhand Massif, lies in the central part of the Indian peninsula and is separated from the south by the Son-Narmada lineament, the Great Boundary Fault in the west of the Aravallis, and the Himalayas in the north. The Son-Narmada lineament has been considered as one of the oldest sources of thermal pool in Central Indian Craton since late Archaean times. Therefore, multiphases of tectonic and igneous activities have been taken place in and around this lineament. The signatures of these activities can be also recorded in the older crustal material in the form of reset date or disconchorded ages. The Satpura orogeny (1600 Ma) has been considered as the last strongest orogenic phase of Precambrian in Central Indian craton so far (Pandey et al, 1995).

The review of the geochronological data in Bundelkhand massif and Central part of Indian Peninsula (Fig 2.3) suggest that Bundelkhand and Baster Craton were the two oldest Archaean nucleus in the north and south of SONATA respectively. To update and understand the various geological events of Bundelkhand massif, several attempts have been made by different workers from time to time. The published geochronological data of different workers has been compiled and presented in table 2.4.

The oldest age 3500±99Ma has been obtained from the banded gneisses of tonalite-trondhjemitic affinity of Baghora area of Bundelkhand by Sarkar et al (1996). This age is comparable to the other tonalitic-trondhjemitic gneisses reported from the other part.

Age of Bundelkhand intrusive granite activity is supported by the Rb-Sr whole rock isochron age of 2560±106 Ma (Crawford, 1970) from the Jhansi, khajaraho granitoid of Bundelkhand and also radiometric date of Pb/Pb age 2518±6 Ma (Mondal, 1998), 2492 Ma (Mondal et al, 2002) These granites have been divided into three distinct intrusive phases (Sarkar et al, 1984, 89, 90 and 1995) viz (i) Gray granodiorites and granites (ca 2400 Ma) or Biotite granitoid (2521±6 Ma) (ii) Pink leucogranites (ca 2350 Ma) and (iii) Fine-grained leucogranites (ca 2270 Ma) or Hornblende-granitoids (2516±9 Ma), Leucogranite (2492±10 Ma), suggested by Mondal et al (2002) Xenolithic enclaves of deformed metasupracrustal rocks and silicic gneisses within undeformed granitic batholith (2521 Ma to 2492 Ma) thus, represent the presec of gneisses rocks before of the Pre-Bundelkhand granitoid (>2500 Ma)

The zircon ages of Kuraicha gneisses (3297±8 Ma) and Mahoba gneisses (3270±3 Ma) Lodhapahar, 3300 Ma (Sm/Nd) obtained by Mondal et al (2002), represent the minimum crystallization ages of the silicic protolith that were transformed into TTG gneisses during deformation and metamorphism after their emplacement They have also obtained different discordant dates for the gneisses viz 3100 Ma For Kuraicha and Mahoba gneisses, 2700 Ma for Babina gneisses and 2500Ma for Karera gneisses These radiometric data indicate the presence of multiple phases of thermal activities within the massif after the M1 metamorphism The oldest event of granitic magmatism in the region took place at 3297 Ma as indicated by the TTG gneisses cofolded with amphibolites and metasediments from Kuraicha and Mahoba The other discordant age viz 2700 Ma may be related to M2 metamorphism while 3200 Ma age may be correlated in mafic and ultramafic errupton for NMG The 2500Ma discordant date of gneisses may be correlated with emplacement of massive granitoids, which is intermingled with granite-gneisses during the M1 metamorphism

The younger gneisses dates of Karera and Panchwara (2500 Ma, Mondal et al, 2002) may be discordant age, which is either cooling or recrystallization age formed during reactivation of shears or may be related with large scale granitic magmatism in this region Three suits of granitoids, hornblende granitoid (2500 Ma), Biotite granitoid (2520 Ma) and Leucogranitoid (2490 Ma) suggest their emplacement in quick succession at 2500 Ma within a few tens of million years

Gray granodiorites and granites (Ca 2400 Ma), pink leucogranites (Ca 2350 Ma), and fine-grained (aplitic) leucogranites (Ca 2270 Ma) have been dated by Sarkar et al (1984, 1989,1990, 1996) These Rb/Sr dates point prolong acid magmatism in the Early-
Proterozoic time. They may be correlated with Bundelkhand continental growth and subsequent late stage pegmatitic and hydrothermal activities.

Crowford and Compston (1970) obtained the Rb-Sr isochron age of 1830±200 Ma for the mafic volcanic rocks associated with Gwalior Group of sedimentary. Pandey et al. (1995) reported Rb–Sr isochron age of 1691±180 Ma for the Kurrat volcanic rocks. Sarkar et al. (1997) reported Rb-Sr age of 1789±71 Ma for mafic rocks of the Dargawan sill of Bijawar basin. The clustering of these geochronological data around 1800 Ma points that last thermal activities perhaps took place due to release of tension & extensional tectonics in the massif.

On the basis of above discussion tectonothermal events and their relation with different metamorphic, magmatic and sedimentation along with deformational history have been proposed (table 2.5) for the first time for the evolution of Bundelkhand craton.

2.9 Geology of the Area

The study area Babina–Mauranipur transect covers about 1000sq km, of the central part of northern block of Bundelkhand massif. The area is consisting high grade metamorphics represented by TTG, biotite gneisses, migmatites and amphibolites, low-grade metamorphics represented by mafics and ultramafics, banded iron formation, and metavolcanics and mylonites, the massive exposures of different types of granitoids, quartz reef and mafic dykes. The study area has been mapped for detailed study of petrogenesis of different rocks and their structural relationship. The field investigations could be completed during several field sessions covering with a period of about two years. The geological map of study area is prepared after detailed fieldworks on the enlarge toposheet of the Survey of India and some lab works, and is presented in Fig. 2.6.

2.10 Topography and Drainage

The entire study area is characterized by more or less plateau type topography where E–W trending small-detached hillocks of banded iron formation and NE–SW trending quartz reef are exposed. Quartz reefs are generally raising about 100 m above the surrounding plain while small ridges of iron formation are raising about 60 m above the surrounding plain. Both the ridges are symmetrical and gentle slope and are occasionally characterized by dextral or sinistral displacement structure. The older metamorphic rocks are usually present at the low-level topography. At places granites terrain giving small hillocks of dome like structure. Geomorphologically, the study area has been divided into two parts.
- Plateaus with hillocks and ridges
- Plains with large valleys

Regional drainage system of the study area shows dendritic pattern. Betwa (Nadi) river is the only major perennial stream in the study area, which follows NW direction. Yamini, Sukhanai and Saprar are also important rivers flow from south to north in the study area.

2.11 Rock Types

2.11.1 TTG, migmatites, biotite gneisses and amphibolites

Good exposures of gneisses have been observed at Jaunpur, Ghisauli, Mankuan, Baghora, Dhoura, Gora and Mauanipur villages (Fig 2 6). They are characterized by leucocratic to melanocratic, medium to coarse grained with well-developed gneissose texture (Plate-2). Sometimes the bands of leucosome and melanosome varying in thickness (Plate-3) and sometimes the partial melting characters were observed. Feldspars, quartz, mica, sericite, apatite, zircon, opaque and epidote are the important mineral constituents of this rock unit. In general foliation in the gneisses are trending in NW–SE to WNW–ESE direction and steeply dip (> 75°) towards NE and NNE direction. Xenoliths of the gneisses have been found in the granites at many places, particularly at Jaunpur (Plate-2). A strip of small lensoidal, highly deformed migmatite-gneissic enclave is also observed at Kamalasagar Dam, Mauanipur in the medium to fine grained granite. In the study area majority of the gneisses are highly deformed (Plate-1 and 2). At Jaunpur area, streaky gneisses are also observed (Plate-4b). They are observed as gray in colour, medium grained hard and compact. In this area both the well-banded gneisses and streaky gneisses are exposed (Plate-3) and it seems that the banded gneisses are changing into gray granite due to partial melting and recrystallisation during the advance stage of metamorphism and deformations. Coarse-grained porphyritic leucogranite intrusion is observed at the contact of gneisses and mafic-ultramafics (Plate-8a). Gneisses are also observed directly at the contact of the iron formation and sometimes with mafics and ultramafics. At Dhoura area the waxing and winning patterns of gneissic bands are also observed. Augens of feldspars are observed in all the sections of the study area but south of Mauanipur and Jaunpur it is notable (Plate-6a, b & c). The size of feldspar varies from 3.5 cm X 2cm to 1.5cm X 0.8cm at these places.
2.11.2 Amphibolites and hornblende-biotite-gneisses

In the study area amphibolites are observed in all the sections but Dhaurra and Jaunpur (Babina) areas are the best examples. Amphibolite is hard and compact, massive, fine to medium grained and dark coloured. The constituent minerals are hornblende, biotite, plagioclase, quartz and chlorite. In Dhaurra section, hornblende and plagioclase minerals are dominant while in Jaunpur section, hornblende and biotites are dominant. Amphibolites are usually observed in the form of lenticular patches in gneisses. They have also undergone different deformational events. At Jaunpur a thick folded band of amphibolite is observed (Plate-1b,c). Sometimes the biotite-gneisses and amphibolites seem to be co-folded (Plate 2.2), which indicates that both the rocks were deformed and subjected to high-grade metamorphism during the same event.

2.11.3 Metamorphosed mafics and ultramafics

Mafic and ultramafic schist (hornblende–chlorite schist, talc–chlorite schist etc.) are mainly found at the contact of the BMQ and gneisses. Notable exposures are found at Babina, Dhaura, and Muraipur. They are medium to fine grained and gray to dark grayish green in colour. Foliation planes are generally in ENE–WSW, steeply dipping north word westerly (> 75°) (Plate 11b) and parallel to the banded iron formation. These mafics and ultramafics are generally observed as highly weathered form (Plate-11b). Talc, chlorite, amphibole are the main constituent minerals.

2.11.4 Banded magnetite quartzite

Banded magnetite quartzites are hard, compact and heavy, fine-grained brownish black in colour (Plate 10). The constituent minerals are magnetite, quartz, cummingtonite, garnet, magnetite and quartz (Plate 13a). Thick magnetite bands are also present in some sections.

Quartzites are observed generally in association with BMQ. Fuchsite bearing quartzite is observed at Muraipur near the railway crossing (Plate 17c). It is fragile in nature, and dull green in colour. The quartzites observed in Babina are dirty pinkish white in colour, fine-grained, massive and compact. The BMQ display a linear pattern trending ENE–WSW having steep dip (>60°) in NNW direction. This rock unit is also showing deformational events of the geological past. Two stages of folding in BMQ are observed at Muraipur section (Plate 14b). Tight to open folds are observed in Dhaurra section. Penicontemporaneous sedimentary structures were also recorded.

Near Pura Village BMQ display the NE–SW and E–W trending joints, which are parallel to the trend of quartz reef.
2.11.5 Metavolcanics

Very low grade metamorphosed mafic and felsic volcanic rocks (Plate 11b,c) are observed at Dhaurra and Babina in the study area. At Dhaurra mafic volcanics are observed in a narrow zone. Sometimes pillow type structures (Plate -11b) were found. Mafic rocks are dark gray in colour, very fine-grained, massive, very hard compact and at places, it is observed as pillow type structure (Plate-11b), at Dhaura (North of Simara) section Plagioclase feldspars, quartz, amphiboles are the main constituent minerals of this rock type.

Felsic rocks are light pink in colour, fine grained, massive, hard and compact. The best section can be severed at Dhaura. Rhyolitic flow structures are also observed (Plate-14a) at Dhaurra where K-feldspar stretched rotated phenocrysts and elongated. Quartz, biotite and magnetite epidote, sercite are the main minerals constituents observed in this rock types. Both, the basalts and rhyolites are showing the same trend i.e. NW–SE to E–W. It is worth to describe that these metavolcanics along with metasedimentary subjected to strong deformation and shearing (Plate-14a,17a,b,18) during low-grade metamorphism.

2.11.6 Hornblende granite / gray granite

Hornblende granite at Uprar (Plate 9a) and near Katera is dark gray in colour, medium grained hard and compact. Phenocrysts of feldspar are also observed (Plate 16). Hornblende granite has a contact with pink porphyritic granite without any deformation. This granite usually contains the xenoliths of metamorphites of different size and shape.

2.11.7 Foliated biotite granite

At Katera reserve forest (temple site) foliated biotite granite is observed. It is coarse to medium grained, pink in colour, hard and compact. Along the foliation plane feldspar phenocrysts are oriented in E–W direction and NE–SW fabric is clearly developed (Plate-12b), and also observed two stage deformation signatures.

2.11.8 Coarse grained leucogranite

Observed as pink in colour, coarse grained, hard and compact. Phenocrysts of K-feldspar are commonly observed (Plate-13c). Another very coarse-grained porphyritic granite, pink in colour is also observed. Quartz, feldspar and biotite crystals can be clearly identified by naked eye. Biotite is common in all leuco-granites but hornblende may be or may not be present. Very coarse variety is more common. It also occurs at the contact of iron formation and gneisses.
2.11.9 Fine grained leucogranite

It is fine-grained, light pink to pinkish white in colour, non-phorphyric hard and compact. This granite is observed mainly at Mauvaripur, SW of Kamla Sagar dam. The mineral constituents of fine-grained leucogranite are similar to that of coarse grained, but it is non porphyritic in general, hornblende is almost absent.

2.11.10 Quartz reefs

In the study area quartz reefs show different types of colour viz. grayish white, milky white, pinkish white, hard and compact. Quartz is the main constituent of reef minerals but feldspar, epidote, chlorite and opaque minerals are also observed. The reefs are generally trending in the NE–SW direction. However NNE–SSE and E–W trending reefs were also noticed. Seven major reefs trending in NE–SW direction have been mapped in the investigated area.

2.11.11 Dolerite

Dolerites are observed as dark green in colour, medium grained, very hard and compact. Pyroxenes, plagioclase, magnetites uralite, biotite, epidote, quartz and chlorites are the main mineral constituents observed in these rocks.

2.12 Structure

Large and small-scale structures observed in the investigated area are discussed in the following paragraphs. The detailed field study points out that the study area represents a long and narrow east-west trending major synform structure (Fig 27) where the highly deformed low grade metamorphics (NMG) occur in the core part and coarse to medium grained, folded gneisses (OMG) on the flanks. The monotonous northerly dips and small-scale structures reveal large synclinorium structure.

2.12.1 TTG, gneisses and migmatites

Migmatites and gneisses trending in WNW–ESE to NW–SE are characterized by vertical to moderate dips due NNE to NE. Different kind of complex structures have been observed in the gneisses. Tight to isoclinal folds (F1), axial plane NW–SE to E–W and plunging towards NW are observed from the biotite-gneisses (Plate 1 and 2). Tight to inclined fold (F2), sometimes coaxial and co-planar with F1 folds are also observed (Plate-1c). Open cross folds (F3) are also observed (Plate 1a), which postdate the gneissosity. The presence of sheeth fold (plate 5c) and S–C fabric (Plate 4a &b) in the gneisses
indicate a strong deformation event after the high-grade metamorphism. The rotation of fabrics, presence of sheeth and S–C fabrics in the gneisses suggest that the shearing and thrusting processes in Archean period cannot be ruled out. Moreover the rotation of porphyroblasts of feldspar in the gneiss (Plate 6 & 7) suggests sinistral shearing processes in shear zone. The structural studies revealed that these high-grade metamorphics have undergone at least two phases of deformation before the shearing and metamorphism and at least four phases of deformation after the metamorphism.

Most of the gneissic rocks of the study area preserve the deformational signatures of different phases. The rotation of feldspar phenocrysts (Plate 4, 6 b, 12c), S–C fabrics (Plate 2 a, b), sheath fold in E–W trending shear zones and mylonites point that a north-south directed stress, D4 deformation across the gneissosity was active after the crystallization of high grade metamorphites. The presence of mylonites and ultramylonites indicate ductile to brittle-ductile environment for the mylonitisation. It is also supported by shear zone mineralogy.

The fifth phase deformation structures are related with NE-SW trending shears (Plate 4a). This may be related to emplacement of quartz reef. In NE-SW direction is also observed in this rock unit as minor faults (Plate 1a). The last phase of deformation is recorded by dextral displacement of quartz reefs and NW-SE trending faults.

2.12.2 Mafic-ultramafic rocks and banded iron formation

Metamorphosed rocks of mafics, ultramafics and metasedimentaries (NMG) trending ENE-WSW overlies NW-SE trending high-grade metamorphics (OMG). The gneisses trending in NW-SE direction were found to swing in the E-W direction at the contact, which points that the rocks of these two groups have discordant relationship with each other and should have been formed at the two different events and then coarse to medium grained folded at one stage. They are present at Mauranipur and Dhaulra. The contact between these two metamorphic rocks at Babina, Dhaulra and Mauranipur is found to be mylonitised and sheared.

The tight to open folds, axial surface trending NW-SE, related to D3 deformation, plunging towards north is recorded. The ENE trending banded iron formation exposed in a linear pattern is used as a marker band (Plate 8) to find out the mafics and ultramafics and high-grade metamorphics in the study area. The structural study points that NMG rocks have subjected to at least three phases of deformation. These shears are nearly vertical and mostly confined to hornblende and biotite granitoids. The leucogranite found as intrusive in this unit is also involved in the shearing at many places. The fine-grained
granitoids of this phase are least affected In the shear zones, the rocks are highly mylonitised. The presence of epidote, chlorite, sericite etc points that they were developed in the brittle-ductile conditions.

A thick E-W trending shear zone is found in the north of NMG, exposed at Babina, Jhankari dhaura, Gora kalan (2.6) where felsic, mafic and volcanosedimentary were affected. These mylonites and ultra-mylonites of this zone are generally observed as medium to fine grained, and light pink to whitish green in colour. The ultramylonites observed at Jhankri Village (Mauranipur) comprise folded alternate bands of quartzofeldspathic and mafics rocks (plate 16 (a), (b) and 17 plate 18). The minerals constituents in this zone intensely folded bands of quartzofeldspathic materials are chlorite, amphibole, K-feldspar, quartz, and magnetic etc.

2.12.3 Granitoids

E-W trending dextral and sinistral shear zones have been observed at Babina, Katera, Dhaurka and Mauranipur areas. Thin to thick shear zones trending is E-W and NE-SW were observed at many places. The NNE-SSW trending shear was also noticed. S-C and S-C' fabrics are observed in granitoids (plate 12 (b)).

2.12.4 Quartz reefs

Emplacement of quartz reefs along NE-SE direction is undoubtedly related to major tectonic activity. The study point that they were emplaced after deformation received by the metamorphics and granitoids in the study area (plate 18). Sinistral displacement of older metamorphic group and newer metamorphic group in recorded at many places in the study area viz at Babina, at Orchha etc. At Babina the displacement is very distinct (Plate 8 b, c), even the contact observed at Mankua (plate 8(c)). The signatures of the emplacement due to the quartz reef in the older and newer metamorphic rocks, and the granitoids are marked by fault (plate 1(a) 11(c) and joints (plate 10(b)).

2.12.5 Dolerite dykes

The dolerite dykes emplaced is also observed in the study area at Babina and Dhaurra area (plate 15(c)). These NW-SE trending mafic dykes displaced the quartz reefs dextrally and sinistrally. Dextral displacement is observed at Nayakhera (Near Prithvipur) and sinistral displacement at Laron (South of Katera). So at present study this mafic dyke emplacement is considered as the last phase (6th phase) deformation phase.
2.13 Mylonites and shear zone structures

Mylonites can be defined as strongly deformed rocks in which the strains are localized into a relatively narrow planer zone. The zone in which mylonitization occur zone is called shear zone / mylonites zone. The grain size reduction usually occurred and recrystallization of crushed grains commonly observed in the form of foliation in the shear zone. Sense of shear can be easily deduced in the field when the displaced marker is present. It is possible to observe the variation in orientation of new foliation with respect to zone boundaries in the narrow shear zones.

In the study area, numerous thick to narrow shear zones of different types have been observed from all the litho-units. These shear zones are a few cm wide to 100m long marked by bands of mylonites (plate no.) The mylonites at places vitreous appearance where commonly sinistral and rarely dextral displacement of pre existing elements upto a meter have been observed. The border of shear zone with undeformed rock is quite sharp and at places wall rock granite react by fracturing and flattening of quartz grains. Some of the shear bands of the granite exhibit pink and gray laminations. It is unfortunate that many earlier workers have recognized the features as sedimentary origin. In the investigated area mainly three types of shear zones have been recognized. The E-W trending shear zone is very thick and exposed throughout the area. Its thickness varies from 100-200m it was cotemporaneous to E-W shear deformation. A NE-SW trending shears are mainly visible in the granite gneisses and are co-terminus with quartz reefs. Mylonites bands of this shear zone are few cm to few meter wide and 100m to 1 km long. The incipient lines of shears seem to have been occupied by the quartz veins. The third type sheared is NNE-SSW and has displaced all the earlier marked shear zones. These shears are less prominent are early hair type zone. This is few cm in width and 10-15 m in length.

2.13.1 E-W shear zone

These shear zone is marked in the gneisses, granite and volcanosedimentanes. The sense of shearing is marked by rotated porphyrobas of feldspar crystals (plate 6) in the gneisses and granite. Besides this, small-scale sense of shearing features are also observed such as S–C fabric near Sukuan (plate 4,5).

A thick zone of mylonites trending in E-W is observed at Jhankri (Mauranipur) in the low grade metamorphic (plate 17 and 18) where S–C fabrics are clearly demarked the rotation and displacement structures. Intense schistosity is observed within the bands. It indicates E-W trending sinistral shear zone. At Dhausra a thick mylonitised sheared zone is also observed in the felsic volcanic rocks of the NMG, where rotation of feldspar...
phenocrysts and quartz ribbons can be seen (plate 14a) Besides this at Dhaurra the banded iron formation follows a S-type structure due to E-W shearing (Fig 26)

At Katera reserve forest a narrow E-W trending mylonitised zone passing through the leucogranite is observed (plate 16)

2.13.2 NE-SW shear zone

Shear zones are observed at Mankua, and Bindrapura, east of the Sukuwan (Fig 26) Numerous NE-SW shear zones also observed at the north of Mauanipur railway station in the NMG. The NE-SW trending shear zones are mainly confined along the quartz reefs. They are 10-15 meter in thickness and 200-500 meters on length. Most of the shear zones are sinistral in nature and formed in the ductile to brittle - ductile in nature. The alteration and hydrous minerals are very frequent in these shear zones.

The structural study points that shear zone trending in E-W is the oldest mylonites which is followed by NE-SW trending shear. The NNE-SSW trending shears less prominent in the area and it has displaced the E-W and NE-SW trending shears.

2.14 Lineaments

The study area is characterized by three types of lineaments orientation (i) NE-SW (plate a) (ii) NW-SE and (iii) E-W (plate 8a). The first and the third are the predominant linear features observed in the area. Along NE-SW trending lineaments, mainly quartz reefs are observed and this lineament displaced the E-W trending lineament, which is represented by banded iron formation (plate 8b). The NW-SE lineament is represented by the most prominent mafic dyke swarms in the massif but in the present investigated area it is not so prominent like NE-SW and E-W lineaments. This NW-SE lineament has truncated the NE-SW trending quartz reefs. Therefore it is suggested that this NW-SE lineament, along which the mafic dykes were emplaced, is the youngest lineament observed in the study area, while E-W trending lineament represented by the Iron formation is the oldest lineament.

2.15 Faults

Faults of different trends are observed in many places of the study area and their mode of displacement are also different, but NW-SE faults are predominant (Fig 2.6). These faults are more or less parallel to the older lineaments as well as to the older shear zones. Different faults observed in the area have been demarcated in geological map (Fig 26). At Nayakhera the prominent quartz reef trending NE-SW is dextrally displaced by the NW-SE trending fault. In contrast near Laron toward southwest of the NE-SW trending
quartz reef in synistrally displaced by the NW-SE trending fault. In the northern side of Mauvaripur the E-W trending iron formation is faulted by parallel series of faults along NE-SW direction.

Tectonic, metamorphic and igneous activities of the study area in different lithounits are summarized in Table (26). On the basis of field relationships, structural data, geochronological information, macroscopic and petrological studies of the metamorphics and igneous rocks of the study area, a geochronostratigraphy of has been proposed for the first time and is presented in Table 27.
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<td>Basic dykes</td>
<td>NW-SW: trending mafic dykes, swarm displaced Palal formation</td>
<td>NW-SL dolerite dykes cutting across N-SW quartz veins</td>
<td>Phyllomictite structure and enclenh cv fractures observed</td>
<td>Dolerite dykes in the form of veins emplaced in the mafic is the evidence of extensional tectonics and last phase of thermal activity. General trend NW-SW and displaced the NE-SW trending quartz veins.</td>
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<td>POST BUNDALKHAND</td>
<td>North-South trending quartz veins observed</td>
<td>NE-SW quartz vein displaced granites &amp; BMQ</td>
<td>Cataclastic &amp; mylonitic nature, &amp; have sigmoidal characteristics of veins brittle-ductile shear displaced sinistrally the BIF</td>
<td>&amp;applied trigonometric shear zone</td>
<td>Emplaced in all rocks. Trend of quartz vein is NE-SW, in the mafic related to bimodal ductile in nature. Sigmoidal quartz veins developed within the main body in the late-stage deformation. Displaced older and minor metamorphic rocks sinistral. At places quartz vein displaced sinistrally by NW-SW trending faults. (D3, Deformation)</td>
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<td>Quarz/Reef</td>
<td>Two phases of deformation (D4&amp;D5) Upright to steeply inclined folds (F4) trending between W &amp; NW</td>
<td>Breccias in thin streaks observed. Inclination and long axes of feldspar in preferred foliation show shearing. At their border resembling gneissic structure observed</td>
<td>Two phases of deformed shear zones. Both steeply or vertical dip E-W sinistral shearing and N15° NE-SW dextral shearing slow brittle ductile nature. Minor sinistral and dextral strike slip faults observed</td>
<td>E-W trending dextral shear zones (D5) observed. Subhorizontal stretching limitation are also developed</td>
<td>The hornblende gneissoids and biotite garnet emplaced along E-W trending fracture zones. E-W trending dextral and sinistral shear zone are observed. S-C and S-C' fabrics developed in granite and felsic volcanics. L-W trending dextral &amp; sinistral shear zones indicates brittle ductile nature. Augen structure and subhorizontal lineation occurred in D4 &amp; D3 deformation. Shear zones are ductile to brittle ductile in nature. Three phases of deformation recorded.</td>
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<td>Granitoids</td>
<td>Two phases of deformation (D4&amp;D5) Upright to steeply inclined folds (F5) trending between W and NW. Alternate bands of magnetite and quartz observed. The schistosity in metamorphics.</td>
<td>Bedding in the form of alternate magnetite - Quartz layers. Trending E-W with steep dip (65°) due North. Tight similar fold, axes parallel to the foliation of the body. Plunging NE, joints are common. Quartz sericite - schist trending NW-SE &amp; NE-SW observed</td>
<td>Fold generally tight to isoclinal overturned to the southeast or North, F2 fold are variably oriented co-planer with F1 fold. F2 fold structure are smusoidal folds or single or conjugate rock bands.</td>
<td>E-N trending sinistral shear zones (D4), SC mylonite, ultramylonite developed. E-W trending dextral shear zone (D4) observed. Tight to isoclinal &amp; reclined F1 fold tight to open (F2) and tight to reclined (F2) folds observed</td>
<td>Development of S1 and S2 schistosity in the meta-sedimentary and meta-volcanics. E-W trending dextral shear (D4) zones observed. Sub-horizontal stretching lineations mylonites and ultra mylonites observed. Intensive schistosity at the contact between meta-sedimentary and meta-volcanics indicate sinistral shearing. Tight to open folds, axial surface trend NW-SE to NE-SW, folds axes plunging towards north. N 80° trending (BIF) beds steeply dip towards north. Four phases of deformed recorded.</td>
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<td>P/TandBundelkhand Granitoids</td>
<td>P/T and B Bundelkhand Granitoids, BMQ, Quartz, felsic volcanics.</td>
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<td>Rajgulla-Kharaha Formation, Metamorphics, Melanoraphes, Amphibolites, OMK</td>
<td>Five phases of deformation (D1, D2, D3, D4, and D5). F4 folds – Tight isoclinal, hinge trending E-W. F2 folds open to tight upright, coaxial to F1, hinge E-W trending. F1 folds sub-vertical and vertical steeply plunging. F4 folds upright steeply plunging.</td>
<td>Mafic minerals form the lentile, strike trend NE-SW dip North westerly and WNW-ESE strike steep dip south westerly</td>
<td>F1 fold observed initial developed in diorite to tonalitic rocks and developed sinistral shear zones.</td>
<td>Steep E-W trending shear zones gave sinistral sense (D4) and dextral (D5) sense D1, D2, D3 as folds NW-SE to EW trending axial surface (D1 &amp; D2) and NW-SE to NE-SW (D4) axial trend folds (F1, F2, F3) are isoclinal to tight reclined and open types.</td>
<td>Tight to isoclinal fold (F1), axial plane NW-SE to E-W trend and plunging towards NW are observed. F2, F3 folds – tight to reclined co-axial and co-planer with F1, tight to open fold (F4) axial plane trending NW-SE to NE-SW are plunging towards north. Sheath and quartz ribbons observed in the shear zone of gneissoids. Six phases of deformation recorded.</td>
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<td>Peridotites, pyroxenites (partially altered to serpentinites and talc-actionite dolerite-trap dykes)</td>
<td>Deccan Traps</td>
<td>Bundelkhand Group</td>
<td>Deccan Traps</td>
<td>(Post-Bundelkhand Granitoids)</td>
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<td>Pre-Dharwar, Bundelkhand granite Complex, with quartz reef, and with inclusions of Mahroni schist</td>
<td>Vindhyan Supergroup</td>
<td>Madura Group</td>
<td>Vindhyan Supergroup</td>
<td>Deccan Traps</td>
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<td>Bijawar and Gwaltor Group</td>
<td>Madura Formation: (Pre-to-post-Bijawar age)</td>
<td>Bijawar and Gwaltor Group</td>
<td>Vindhyan Supergroup</td>
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<td>a: dolerite dykes, granite member, quartz vein pegmatite, graphic granite, b: Gabbror member, coarse to medium grained gabbro, pillow lava, ultrabasic member, milky dense sheared veins quartz</td>
<td>Mahoba Doletire: Dolerite dyke keratophyres, lamprophyres, carbonatite</td>
<td>Dolerites</td>
<td>Bijawar and Gwaltor Group</td>
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<td>Bundelkhand, granite Formation: Dull pink, dense fine grained to porphyritic granite: coarsely crystalline pink un-foliated granites and migmatises</td>
<td>Matatila Granite: Pink granite coarse to fine, massive</td>
<td>Quartz reef (with pyrite, chalcopyrite, pyrophilite and diaspor)</td>
<td>Mafic Dykes and Swarms</td>
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<td>---- Unconformity ----</td>
<td>Garhorr granite: Grey, coarse to fine, massive, parphyroblastic gneisses</td>
<td>Aplite</td>
<td>Quartz Reef</td>
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<td>Paron meta-acid volcanics: Porphyroblastic, compact, sheet like granitic rocks</td>
<td>Esmeraldite</td>
<td>Bundelkhand Granitoids</td>
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<td>Palar Formation: Quartzite, phyllite, spotted phyllite, black shale, limestone, ferruginous quartzite with trace of chalcopyrite, galena, malachite, secondary</td>
<td>Porphryres</td>
<td>Fine grain leucogranite</td>
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<td>---- Unconformity ----</td>
<td>Pegmatite</td>
<td>Coarse grain leucogranite</td>
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<td>Kurachha Formation: Magnatites, gneisses, para-, ortho- and augen gneisses, amphibolite, chlorite and biotite schists, quartzites, meta-arkose, garnet-biotite gneisses</td>
<td>Leucocratic granites</td>
<td>Foliated biotite granite</td>
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<td>---- Unconformity ----</td>
<td>Migmatites &amp; Syenites</td>
<td>Biotite granite</td>
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<td>Rajaula Formation: Sedimentation-volcanism (amphibolites, biotite-feldspar foliated gneisses)</td>
<td>Medium grained porphyritic granites</td>
<td>Hornblende granite</td>
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<td>---- Unconformity ----</td>
<td>Coarse grained porphyritic granite</td>
<td>(Pre-Bundelkhand Granitoids)</td>
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<td>Rajaula Formation: Banded iron-formation</td>
<td>Coarse biotite granite</td>
<td>Newer Metamorphic Group</td>
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<td>Metasbates, gneisses, marble, schists, Metamorphosed mafics and amphibolite</td>
<td>Gneisses</td>
<td>Metavolcanics</td>
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<td>---- Unconformity ----</td>
<td>---- Unconformity ----</td>
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<td>Rajaula Formation: Banded iron-formation</td>
<td>Rajaula Formation:</td>
<td>Tale-chlorite schist, actinolite-tremolite-talc schist, hornblende-chlorite epidote schist, garnet chlorite-actinolite schist</td>
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<td>Metasbates, gneisses, marble, schists, Metamorphosed mafics and amphibolite</td>
<td>Coarse biotite granite</td>
<td>Older Metamorphic Group</td>
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<td>---- Unconformity ----</td>
<td>Gneisses</td>
<td>Biotite-gneiss, hornblende-biotite gneisses, sillimanite gneisses, amphibolite</td>
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<td>---- Unconformity ----</td>
<td>Tonalite-trondhjemite-gneisses, granite-gneisses, migmatises</td>
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<td>S No</td>
<td>Location &amp; Rock Type</td>
<td>Method</td>
<td>Age in M.a.</td>
<td>Reference</td>
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<td>1523</td>
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<td>Rb-Sr</td>
<td>1691±180</td>
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<td>Quartz Reef</td>
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<td>2000</td>
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<td>Bdera Gneissic migmatite</td>
<td>Rb-Sr</td>
<td>2130±102</td>
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<td>Coarse grain granites, granite porphyry and Aplit (Babina Talbeh)</td>
<td>Rb-Sr</td>
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<td>Sarkar et al., 1984</td>
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<td>Grey granodiorite near Jhansi</td>
<td>Rb-Sr</td>
<td>2359±53</td>
<td>Sarkar et al., 1984</td>
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<td>13.</td>
<td>Bansri Rhyolite</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>2517±7</td>
<td>Mondal et al, 2002</td>
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<td>14.</td>
<td>Lalitpur Biotite Granitoid</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>2521±6</td>
<td>Mondal et al, 1998</td>
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<td>15.</td>
<td>Bansri Rhyolite</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>2521±7</td>
<td>Mondal et al, 1998</td>
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<td>Karera Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>2563±6</td>
<td>Mondal et al, 2002</td>
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<td>18.</td>
<td>Pillow lava (near Bijawar)</td>
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<td>Crawford &amp; Compston, 1970</td>
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<td>Lalitpur Biotite Granitoid</td>
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<td>2521±6</td>
<td>Mondal et al, 1998</td>
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<td>Granites</td>
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<td>Karera Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
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<td>25.</td>
<td>Migmatitic Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>2696±3</td>
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<td>Panchwara Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>3189±5</td>
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<td>28.</td>
<td>Lodhaphar gneisses</td>
<td>Sm-Nd</td>
<td>3200</td>
<td>Sharma &amp; Rahman, 1995</td>
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<td>29.</td>
<td>Mahoba Amphibolites</td>
<td>Pb$^{207}$/Pb$^{206}$</td>
<td>3245±5</td>
<td>Mondal et al, 2002</td>
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<td>30.</td>
<td>Mahoba Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>3270±3</td>
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<td>31.</td>
<td>Kuraica Gneisses</td>
<td>Pb$^{206}$/Pb$^{207}$</td>
<td>3297±8</td>
<td>Mondal et al, 2002</td>
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<td><strong>POST BUNDELKHAND</strong></td>
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<tr>
<td>Quartz Reef</td>
<td>Emplacement quartz reefs in NW-SW trending direction in brittle and ductile deformational environment. Sigmodal veins developed at the late stage deformation. It displaced the older and newer metamorphics sinistrally.</td>
<td>The retrogression and alteration of feldspar and amphibole minerals observed. Hydrothermal and pegmatite activities were common. The prophyllite, disaporite, clay, epidote, kaolinite minerals developed along NNE-SSW trending reefs. The base metals, molybdenum and other ore fluid emplaced along fracture and shear zone.</td>
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<td><strong>SYN BUNDELKHAND</strong></td>
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<td>Granitoids</td>
<td>E-W trending dextral and sinistral shear zones are observed S-C and S-C' fabrics developed in granite gneisses, and volcano-sedimentary. Sheeth folds and quart ribbons developed. Shear zones are few meters to up to 1 km recorded thick and developed in ductile to brittle ductile environment. The new E-W trends fabrics in the gneisses</td>
<td>Local thermal metamorphism, specially in the mylonites zones, recorded. Mortar texture, recrystallization of chlorite, biotite, feldspar, hornblende developed in mylonites at the contact of hornblende/biotite granite. Crystallization of epidote, chlorite, sncite in the granite and gneisses are the indication of hydothermal activity and retrograde metamorphism at the late stage emplacement Bundelkhand granitoids. In the granitoids, NMG and OMG, E-W trending mylonites, blastomylonites, ultramylonites developed.</td>
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<td><strong>PRE BUNDELKHAND GRANITOID</strong></td>
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<td>Older Metamorphic Group</td>
<td>Tight to open folds, axial surface trending NW-SE to NE-SW folds axis plunging towards north recorded N 80° trending beds are steeply dip (&gt; 65) Alternate bands of magnetite and quartzite points two phases of deformation and metamorphism. Mafics, ultramafics, iron formation, ferroigneam quartzite, deposited in E-W trending epicontinental basin. The OMG metamorphics folded, rotation of strike from NW to EW.</td>
<td>Prograde M2 metamorphic minerals of green schist facies to lower amphibolite facies developed. Metamorphism (M2) recorded in the mafic ultramafic, ferruginous quartzites and volcanosedimentaries.</td>
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<td>Newer Metamorphic Group</td>
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<td>D4 (3200 Ma to 2600 Ma)</td>
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<tr>
<td>Older Metamorphic Group</td>
<td>F1 fold tight to isoclinal and reoriented, axial surface trending NW-SE to E-W, folds axis plunging NW. F2 fold - tight to reoriented, co-axial and co-planer with F1 folds.</td>
<td>3500 Ma old TTG were emplaced at 3200 Ma during the metamorphism (M2). Gneisses, migmatites and formations of upper amphibolite facies. M1 metamorphism recorded. Biotite granites, gray granites, streaky gneisses, Biotite hornblende gneisses, clac-silicate granulites, garnet - sillimanite gneisses were developed.</td>
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<td>Litho Unit</td>
<td>Deformation</td>
<td>Tectonics, metamorphism and magmatism</td>
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<td><strong>Basic Dykes</strong></td>
<td>$D_6$ (1800 Ma to 1600 Ma)</td>
<td>General trend of dyke is NW-SE, displaced sinistrally the quartz reefs trending NE-SW. Alteration along the shear zones, crystallised the minerals chlorite, muscovite, sericate, epidote, pyrite, pyrophyllite and diaspore. No metamorphism at the contact of basic dyke and country rock. Dolomite dykes in craton spread over the massif in the form of swarms is the evidence of extensional tectonic and last phase of magmatism in the region.</td>
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<td><strong>Quartz Reefs</strong></td>
<td>$D_5$ (2300 Ma to 2000 Ma)</td>
<td>NE-SW trending quartz reef, formed in the brittle - ductile deformational environment. Alteration of feldspars and amphibole minerals. Development of pyrophyllite, diaspore, kaolinite, epidote, chlorite, sercite are the indication of hydrothermal activity. Sigmoidal veins developed within the main body of reef at the late stage of deformation. Quartz reefs displaced the older rocks, marks the dextral shearing. Quartzite and Pegmatite emplaced in NE-SW direction.</td>
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<td><strong>Granitoids</strong></td>
<td>$D_4$ (2500 Ma to 2300 Ma)</td>
<td>Mortar texture, recrystallization of chlorite, biotite, feldspars, andalusites developed in E-W trending mylonites zones suggests thermal metamorphism on the local scale. Dextral and sinistral shearing, E-W trending shear zones in the brittle ductile environment, augen structures and sub-horizontal lineation were also occurred in gneisses, TTG rocks of OMG. E-W trending dextral shearing. Sub-horizontal stretching lineation, mylonites and ultra-mylonites developed along E-W in NMG. E-W trending shear zone with S-C and S-C' fabrics are observed in dextral and sinistral shears developed in granite OMG and NMG. Hbl, Granite, Biocr, Granite, deformed granite, Leucogranites observed.</td>
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<td><strong>Newer Metamorphic Group</strong></td>
<td>$D_3$ (2600 Ma to 2600 Ma)</td>
<td>The NW-SE trending fabrics in the gneisses rotated to E-W. Prograde ($M_3$) metamorphic rocks of green schist to lower amphibolites facies developed in NMG (mafic and ultra mafics with volcano-sedimentary rocks). Act-Tre-schist, micasceous, quartzite, BMS, Qtz schist, Com-Gru schist formed. Tight to open folds with axial surface trending NW-SE to NE-SW, plunging towards north recorded in NMG. M2 event of metamorphism recorded. Deposition of banded iron formation, ferruginous quartzite, mafics and ultramafics, volcanosedimentary rocks in epicontinental sea.</td>
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<td><strong>Older Metamorphic Group</strong></td>
<td>$D_1$ &amp; $D_2$ (3200 Ma to 3200 Ma)</td>
<td>Hook folds, tight to isoclinal fold $F_1$. $F_2$ folds coaxial with $F_1$, plunging towards NW, axial plane trending NW-SE to E-W. Tight to open fold $F_3$, plunging north, axial plane trending NW-SE to NE-SW, developed in $D_2$ deformation. $F_3$ fold post date the metamorphism $M_1$, formed during $D_2$ deformation. Gneisses, migmatites, granite-gneisses, streaky gneisses, biotite-hornblende gneisses, calc silicate granulites, garnet-sillimanite gneisses were formed ($M_1$, metamorphic event).</td>
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<td>Mafic Dykes (1800-1600Ma)</td>
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<td>Quartz Reefs (2300-2000Ma)</td>
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<td>Bundelkhand Granitoids (2500-2300Ma)</td>
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<td>Newer Metamorphic group (3200-2600Ma)</td>
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<td>Banded magnetite quartzites (BMQ), Quartzites, commingtonites-grunerite-magnetite quartzite micaceous quartzite, quartzite, mica schist, garnet mica schist etc</td>
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<td>Garnet-chlorite–actinolite schist, tremolite-talc-actinolite schist, talc-chlorite schist, hornblende-epidote chlorite schist, actinolite-chlorite schist</td>
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<td>Older Metamorphic Group (3500-3300Ma)</td>
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Fig 21 Location map of the study area. 1 Granite Massif, 2 Bjaawar, 3 Vindhyans, 4 Alluvium, 5 Study area inset locates the Bundelkhand Craton in the map of India.
Fig. 2.2 Regional Geology of Bundelkhand Massif (Modified after Mondal et. al. 2002, Basu 1986 and Prakash et.al. 1975).

The older Metamorphic Group (OMG) and Newer Metamorphic Group (NMG) of rocks are exposed in E-W direction and are mainly confined in central part of the massif. Blocks A, B, and C are based on topography. Inset locates in Bundelkhand craton in the map of India.
Regional tectonic set up and geological and geophysical map of the central India

(a) Geological map of Northern Part of Central India (after Basu 2001)
   1 Alluvium, 2 Deccan Volcanics, 3 Gondwana, 4 Vindhyan supergroup, 5 Gwalior group, 6 Bijawar Groups, 7 Mahakaushal Group, 8 Intrusive Granite, 9 Bundelkhand Granite, 10 Siddi Gneiss 11 Chhotanagpur Gneiss, 12 Madaura Group

(b) Proterozoic mobile belt in the Indian shield Map showing the boundary of Bundelkhand craton and granulite rocks of Eastern Ghats and its relation with other Indian provinces The abbreviation are BKC Bundelkhand Craton, AC Aravalli, Craton, SG Sothern Granulite Belt, EGB Eastern Ghats Belt, EDC Eastern Dharwar Craton BTC, Bastar Craton, DEC Deccan Basalt, D Delhi

(c) Geological Cross-section from Gwalior to Malanjkhand (for geological symbols an horizontal scale see figure (a) (after Basu 2001)

(d) Bouguer Anomaly Between Hirapur and Manda (after Ramakrishna, 1995)

(e) Crustal Depth Section from DSS along Hirapur-Jabalpur-Mandla (after Ramakrishna, 19995) 1 Refractor with velocity km/sec, 2 Reflector segments, 3 Reciprocal Reflection Segments, 4 Crystalline Basement 5 Moho segments, 6 Fault with direction of throw
Fig 2.4. Trend of (a) Quartz Reefs and (b) Mafic Dykes in Bundelkhand (after Sharma 2000)
Fig 2.5. Major River trend in Bundelkhand Region
Fig. 2.7 Geological cross-section along X-Y line of the Babina area, western part of the study area
Fig. 2.9 Geological cross section along P-Q line of the Dhaurra area, central part of the study area.
PLATE – 1

Fig. (A)  Hand specimen photograph of gneiss showing $F_1$ and $F_3$ folds
Sample collected from Gneisses exposure at Lakardevi, Babina

Fig. (B)  Hand specimen photograph of gneiss and amphibolite showing co-
folding ($F_1$ and $F_2$ folds) Sample collected from Jounpur, Babina

Fig. (C)  Hand specimen photograph of gneiss and amphibolite showing co-
folding and developed hook fold ($F_1$ and $F_2$ folds) Sample collected from Jounpur, Babina
PLATE – 2

Fig (A)  Field photograph shows the gneiss observed at Jounpur, Babina. It shows the alternate bands of leucocratic and melanocratic minerals. It also shows folding.

Fig. (B)  Field photograph of gneiss at Jaunpur showing folding and partial melting.

Fig. (C)  Field photograph showing intense folding ptygmatic fold in gneisses at Gora. The thickness of the bands is irregular.
Fig. (A)  Field photograph of gneiss at Jounpur, showing partial melting and recrystallization, and also showing development of augens of quartzfeldspathic masses.

Fig. (B)  Field photograph of gneisses at Gora showing recrystallization and development of augens of quartzfeldspathic masses. The thickness of the leucosomes decreases with increasing thickness of melanosomes. Augen structures are also showing the E-W shearing.

Fig. (C)  Field photograph of gneiss showing development of streaky gneiss converting to the gray granite.
Fig. (A) Field photograph showing minor faulting bands of gneiss along NE-SW direction near Babina iron formation

Fig. (B) Field photograph of streaky gneiss at Jounpur, Babina showing the development of gray granite and also showing the S-C fabric indicating E-W trend

Fig (C) Field photograph of seeth fold in gneiss near Babina iron formation shows the development of S-C fabric and indicating E-W shearing
Fig. (A) Field photograph showing S and C plane, indicating E-W shearing in gneiss at the road head of Babina Sukwa road near Babina iron formation

Fig. (B) Field photograph of gneiss at the road head of Babina – Sukwa road near Babina iron formation. Relict of S-C fabric is also observed.

Fig. (C) Field photograph of gneiss near Babina iron formation showing sheeth fold structure developed due to intense deformation.
Fig. (A) Field photograph of gneiss at the south of Mauanipur village showing the development of augens of quartzofeldspathic masses and also showing the reducing the melanosomes.

Fig. (B) Field photograph shows the augen structure in gneiss. The photograph also showing the E-W shearing at Mauanipur.

Fig. (C) Field photograph of gneiss at south of Mauanipur showing the development of augen structure and reducing of melanocratic and leucocratic bands.
Field photograph of gneiss at Dhaurra showing the S-C fabric and development of augens of quartzo-feldspathic masses.

Field photograph of mylonitised granite orientation of feldspar phenocrysts shows E-W shearing and NE-SW fracture developed due to deformation near Dhaurra.

Field photograph of porphyritic granite of Dhaurra showing E-W shearing by the rotation of feldspar phenocrysts and NE-SW trending fracture.
Fig. (A) Field photograph showing the panoramic view of the contact of ENE-NSW trending iron formation and older gneissic terrain at lower relief at Babina.

Fig. (B) The field photograph showing the panoramic view of iron formation which is synistrally, is displaced in NE direction.

Fig. (C) Field photograph showing the panoramic view of contact of ENE-NSW iron formation and the NE-SW trending quartz reef, which displaced the iron formation.
Fig. (A)  Field photograph showing the panoramic view of the contact between prominent NE-SW trending quartz reef and hornblende-biotite-gneiss at Bangra.

Fig. (B)  Field photograph showing the panoramic view of ENE-WSW trending quartz reef and NE-SW trending quartz reef at Bangra.

Fig. (C)  Field photograph showing the panoramic view of the contact junction of ENE-WSW and NE-SW quartz reef at Bangra.
Fig. (A)  Field photograph showing the northerly dipping fuchsite quartzite bed on the foot hill of BMQ at Muraunipur, near railway track

Fig. (B)  Field photograph showing the exposure of ENE-WSW trending mafics and BMQ at Kamla Sagar dam, Kuraicha. Photograph shows veins of later stage of late stage magmatism

Fig. (C)  Field photograph of iron formation at Muraunipur shows the banded magnetite quartzite dipping NNW
Fig. (A)  Field photograph showing the high angle dip in metamorphosed ultamafics, trending ENE-WSW at Dhaurra

Fig. (B)  Field photograph showing spheroidal weathering in metavolcanic to the north of Dhaurra iron formation

Fig. (C)  Field photograph showing the exposure of metavolcanic near Dhaurra
Fig. (A)  Field photograph shows the older gneiss enclave within medium grained leucogranite near Pura Village, Babīna

Fig. (B)  Field photograph showing an enclave of migmatite gneiss within fine grained pink granite at Kamla Sagar dam, Kuraicha

Fig. (C)  Field photograph showing the contact of older deformed (mylonitised) biotite granite and later phase undeformed pink granite at Katera reserve forest
**Fig. (A)** Field photograph showing the exposure of banded magnetite quartzite at Babina

**Fig. (B)** Field photograph showing the two sets of joints trending E-W and NE-SW, developed due to deformation received by the iron formation near Pura Village

**Fig. (C)** Field photograph felsic-volcano sedimentary (rhyolitic) rocks showing E-W and NE-SW trending fractures, which indicates deformation undergone by this rock unit
Fig. (A) Field photograph felsic volcano-sedimentary (rhyolitic) rocks showing E-W and NE-SW trending fractures, which indicates deformation this rock unit has undergone.

Fig. (B) Field photographs showing the folded quartz veins in iron formation at Kauricha (Kamla Sagar dam).

Fig. (C) Field photograph showing the NE-SW trending minor fault, which displaced the bands of gneiss, near Babina iron formation.
Fig. (A)  Field photograph showing the panoramic view of quartz vein within iron formation at Jhankari (Mauranipur)

Fig. (B)  Field photograph showing the deformed granite in which S-C fabric is clearly seen, indicating dextral shearing along E-W direction in the north of the investigated area

Fig. (C)  Field photograph of gneiss at the south of Mauranipur showing the crystals of feldspars in rotation
Fig. (A)   Field photograph showing E-W and NE-SW shearing developed due to deformations in granite at Katera reserve forest

Fig. (B)   Field photograph showing the S-C fabric developed in deformed granite and showing E-W trending shear at Katera reserve forest

Fig. (C)   Field photograph of porphyritic granite, shows feldspar phenocrysts at Katera reserve forest.
**Fig. (A)**  Field photograph of mylonites of Jhankri shows bands of quartzofeldpathic masses

**Fig. (B)**  Field photograph showing ptygmatice folds developed in mylonites at Jhankri (Mauranipur)

**Fig. (C)**  Field photograph showing the fuchsite quartzite vein within iron formation at Jhankri (Mauranipur)
Fig. (A)  Field photograph of mylonite showing dip towards north and high intensity of folding at Jhankri (Mauranipur)

Fig. (B)  Field photograph of mylonite showing shearing of folds at Jhankri (Mauranipur)

Fig. (C)  Field photograph showing lensoidal quartzo-feldspathic masses developed within the bands of mylonites indicating sense of shearing at Jhankri (Mauranipur)