SEDIMENTOLOGY OF THE ROCKS OF DEOBAN BASIN, DHURAPHAT AREA, SARYU VALLEY, EASTERN KUMAON LESSER HIMALAYA

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ABSTRACT

The Riphean sedimentary rocks of the Deoban Basin (Garhwal Group) represent a linear autochthonous belt known as 'Deoban-Tejam belt' in inner part of the Kumaon Lesser Himalaya. Three major facies of the Deoban Basin namely, lower areno-argillaceous (Rautgara Formation), middle carbonate (Deoban/Gangolihat Formation and upper arenaceous (Bearinag Formation) are well exposed in the Dhuraphat area, Saryu Valley, eastern Kumaon, Lesser Himalaya.

Sedimentological investigations were carried out in all three facies of the Deoban Basin. Detailed petrography, geochemical investigations (major and trace element geochemistry), insoluble residue analysis, differential thermal analysis (DTA) and X-Ray diffraction study (XRD) of Deoban (Gangolihat) carbonates has been done and analytical data interpreted. All these studies indicate an overall dolomitic composition for Gangolihat Carbonates and reveal that the Gangolihat carbonates were deposited in shallow marine environment (carbonate tidal flats of a shallow sea where evaporitic conditions also prevailed). The magnesite is inferred to have formed under evaporitic conditions in restricted shallow basin.

The palaeocurrent pattern of the Rautgara, Gangolihat and Berinag Formations show bimodal to polymodal distribution of current patterns and is indicative of reversals of the palaeoflow (tidal flat environment). The main current direction was northerly during the deposition of sediments of the Deoban Basin. The facies analysis, petrography and the distribution of primary sedimentary structures in the vertical sequences of the Rautgara, Gangolihat and the Berinag Formations suggest a subtidal, intertidal to supratidal depositional environment for Rautgara, protected intertidal flat to subtidal (based on stromatolites) and supratidal flat for Gangolihat and sandy tidal flat, coastal beach comlex depositional environment for Berinag Formation. The pebbly quartzite beds in the Berinag Formation indicate fluvial channel deposits.

The deposition of Rautgara, Gangolihat and Berinag Formations represent a single cycle of tidal flat sedimentation in the Deoban Basin during Riphean period. The marked vertical and lateral facies changes suggest that there were

profound changes in the conditions of deposition and also the basinal subsidence was responsible for the sedimentation of huge thickness in a single sedimentary basin. It appears that subsidence of the Deoban Basin kept pace with sedimentation to accumulate the enormously thick pile of sediments.

The withdrawl of the Deoban sea is attributed to some tectonic event which uplifted the basin and regressed sea from the inner Lesser Himalaya and the sedimentation was restricted to the south in the Krol Basin. The Deoban basin (Deoban-Tejam belt) is interpreted to have terminated due to Baikalian Orogeny which separated the Riphean carbonate terrigenous complex (Damta- Deoban-Jaunsar/Rautgara-Gangolihat-Berinag) from that of the Neoproterozoic or Vendian (Blaini Formation). The Blaini-Krol-Tal sequence (Vendian to Lower Cambrian) represent second cycle of sedimentation in Krol Basin and Jaunsar (Nagthat Quartzite) formed the foundation for the Krol Basin.

The shallow tidal sea of Krol Basin regressed from the Lesser Himalaya during Lower Cambrian times. The termination of sedimentation in the Krol Basin is attributed to another important orogenic event (aroud 550-500 Ma) at this time generally referred to as *"Caledonian"* or *"Pan-African"* orogenies.

INTRODUCTION

The rocks of the Dhuraphat area, under study lies SSE of Bageshwar and NE of Almora in Sarju Valley, Kumaon Lesser Himalaya (Fig. 1 and 2a). These rocks belong to two lithotectonic units. The metasediments lying north of the North Almora Thrust (NAT) belong to the autochthonous sedimentary (Deoban-Tajam) belt [illegible]esignated as 'Zone of Badolisera' (Garhwal Grou[illegible] in the Sarju Valley and occupy most of the area under investigation in the northern part. In the southern part, the metamorphic rocks of the thrust sheet lies south of the North Almora Thrust and belong to 'Crystalline Zone of Almora'. The rocks of Ga[illegible] are [illegible]eparated by Crystalline Zone of Almora by North Alm[illegible] [illegible]hrust (NAT).

In each lithotectonic units the rocks are lithostratigraphically subdivided into different formations and members. Attempts have been made to follow the established old names of the lithounits in adjoining areas by earlier workers. However, new names were given wherever necessary. The work of Heim and Gansser (1939), Valdiya (1962, 1964, 1968, 1979, 1980, 1986), Gansser (1964), Misra and Kumar (1968), Misra and Banerjee (1968) has been followed with slight modifications. The idea of regional inversion of the rocks of Garhwal Group proposed by earlier workers in Pithoragarh, Badolisera, Bageshwar and Kakot area (Misra and Valdiya, 1962, 1964, Misra and Banerjee, 1968, Misra and Kumar; 1968, Misra and Bhattacharya, 1972, 1973), has been modified. The normal stratigraphy established in the adjoining areas of eastern Kumaon Himalayas by Mehdi *et al.* (1972), Kumar and Agarwal (1975), Ahmad (1975), Banerjee and Bisaria (1975), Kumar (1976), Ramji (1976), Merh (1977), Bhattacharya (1979), Ahmad (1980), Agarwal and Kumar (198[illegible]), [illegible]war (1980) and Tewari (1986) has been followed in the present stratigraphy. The stratigraphic sequence in the area is given in the Table 1a.

STRATIGRAPHIC SET UP

CRYSTALLINE ZONE OF ALMORA

In the SW of the present area, Heim and Gansser (1939) designated a great thickness of crystalline rocks and associated granites as Crystalline Zone of Almora. The rocks of the Crystalline Zone are well exposed in the southern part of the area (Fig. 2a). These are represented by chlorite schist, biotite schist, porphyries, garnetiferous biotite gneisses, augen gneisses and quartzite. The good exposures are seen on Takula-Almora road section. The northern limite of the crystallines is marked by North Almora Thrust.

These crystalline rocks show upward increasing mesograde of metamorphism i.e. at the base Crystalline Zone in the present area, near Kangar, Chlorite schists are exposed which grade into biotite schist and garnetiferous biotite schists towards Takula and Basoli (Central part of the Almora Syncline). The mylonite gneisses, migmatites and granites occupy the core portion of the Almora Syncline. The inversion of metamorphism is attributed to thrusting and common in the Himalayan thrust sheets (Le Fort, 1975). The inverted metamorphism has also been observed in the crystalline rocks of adjoining areas like Askot, Lohaghat and Baijnath (Heim and Gansser 1939; Gansser 1964; Valdiya, 1965, 1980; Misra and Kumar, 1968; Misra and Banerjee, 1968 and Merh, 1977). These crystallines have been put under a huge nappe known as Almora Nappe and the root of this nappe is considered in the high grade Central crystallines (Vaikrita Group of Valdiya, 1979) constituting the base of Higher Himalaya. The Almora crystallines are also taken as south-westernly extension of the Jutogh Nappe of Himachal Pradesh (Valdiya, 1979; Misra and Tewari 1988).

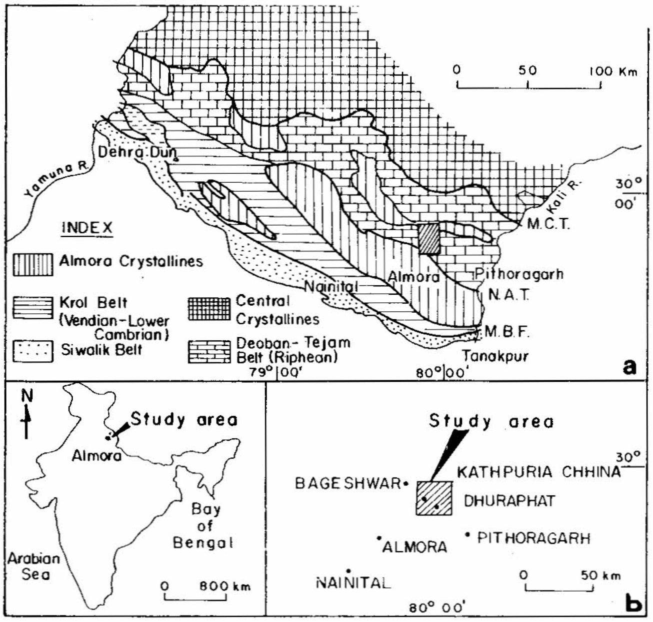

FIG. I

(a) Simplified Geological Map of Kumaon Lesser Himalaya

(b) Location of Study Area

LITHOSTRATIGRAPHY OF THE ZONE OF BADOLISERA (GARHWAL GROUP)

The name 'Zone of Badolisera' was introduced by Heim and Gansser (1939) to the metasedimentary rocks exposed northeast of the North Almora Thrust (NAT) around Badolisera (70°53′ 33′′ : 29°42′ 25′′) in Pithoragarh district, Kumaon Lesser Himalaya.

According to Heim and Gansser (1939) the rocks of the 'Zone of Badolisera' include enormously thick sequence of carbonates, variegated slates and quartzites. Sills and amphibolites are intercalated in the slates and quartzites. The area is tectonically complicated but the stratigraphic order of these metasedimentaries were taken in normal order. Misra and Valdiya (1961) and Valdiya (1962) subdivided this zone into two groups, the thick sequence of orthoquartzite and amphibolite as older Berinag Quartzite and the younger limestone, slate and quartzite sequence as Calc. Zone of Pithoragarh. Misra and Valdiya (1961) and Valdiya (1962, 1965) suggested that this sedimentary zone is inverted based on the convexity of the stromatolite laminae.

However, the concept of the inversion of sedimentary rocks of Kumaon Lesser Himalaya was completely changed in the early seventees. Mehdi *et al.* (1972) have established a normal stratigraphic sequence in the entire Kumaon Himalaya. Ahmad (1975) and Banerjee and Bisaria (1975) did not find any inverted succession of metasedimentaries between Bageshwar and Kapkot north of the present area. The work of Kumar and Agarwal (1975) in

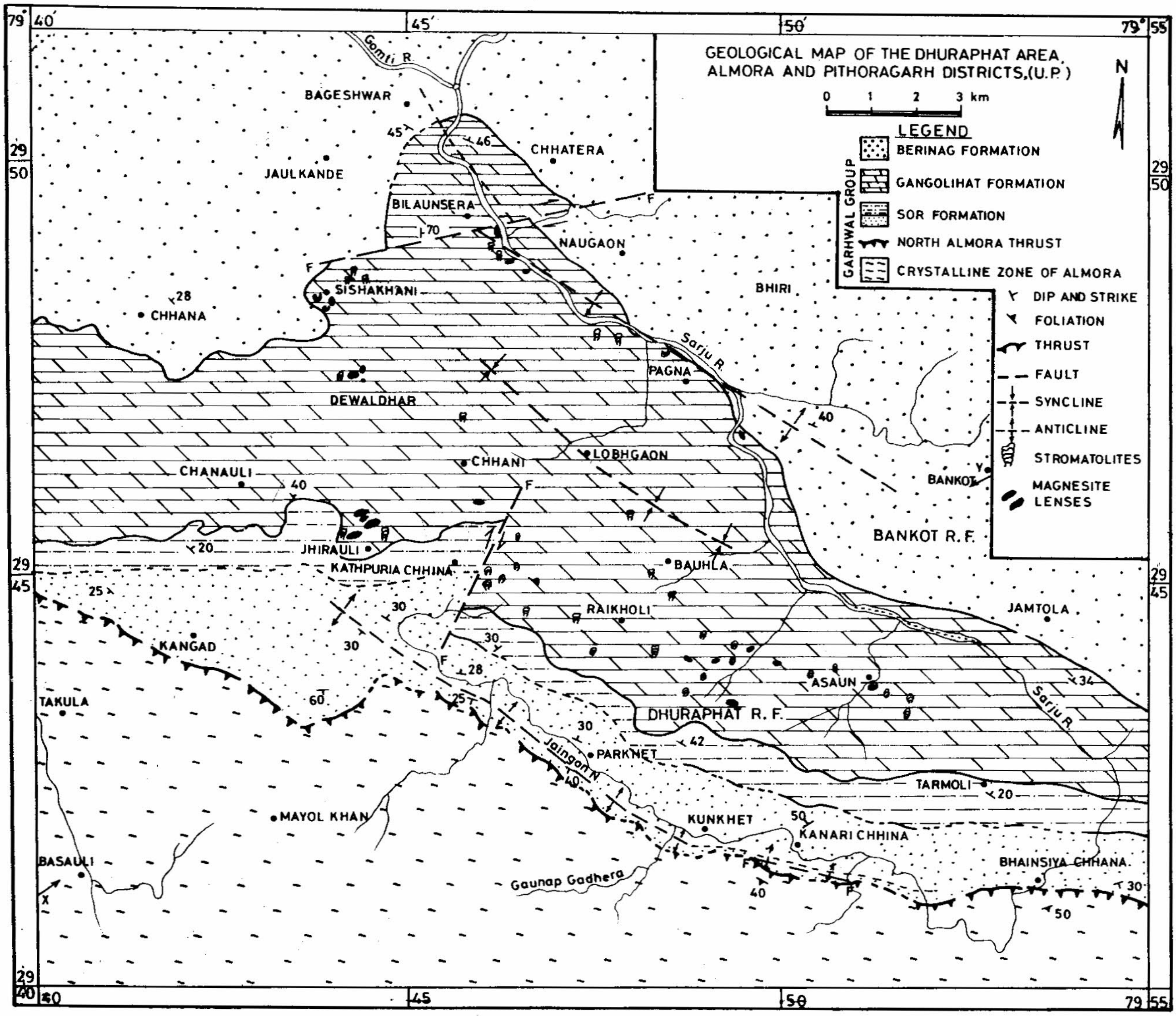

Fig. 2a. Geological map of the Dhuraphat area, Almora and Pithoragarh districts Uttar Pradesh.

Alaknanda valley, Kumar *et al.* (1976) in Tejam area, Ramji (1976) in Almora and Pithragarh areas, Dungrakoti *et al.* (1976) in Mandakini valley, Merh (1977) in Chaukhutia area, Kumar and Tewari (1977, 1978a, b, 1979) and Tewari (1985) in the Kathpuria Chhina area, Bhattacharya (1979) in Bageshwar-Kapkot area, Kumar (1979) in Ganai-Gangolihat area and Power (1980) in Chaukhutia- Someshwar area has demonstrated a normal stratigraphic succession in adjoining areas as well as in entire Kumaon Lesser Himalaya. Valdiya (1980) in his monograph on "Geology of Kumaon Lesser Himalaya" has also partially revised the stratigraphy of the Calc Zone of Pithoragarh. However, the inversions of local nature and development of local faults at places near contact between different formations have been observed.

In the recent years, many local names have been assigned to this metasedimentary autochthonous linear belt between Main Central Thrust (Heim and Gansser, 1939) and North Almora Thrust.

In most of the above mentioned recent work the term 'Garhwal Group' has been used by many workers for the sedimentaries occurring between the Munsiari Thrust of Valdiya (1980) or Main Central

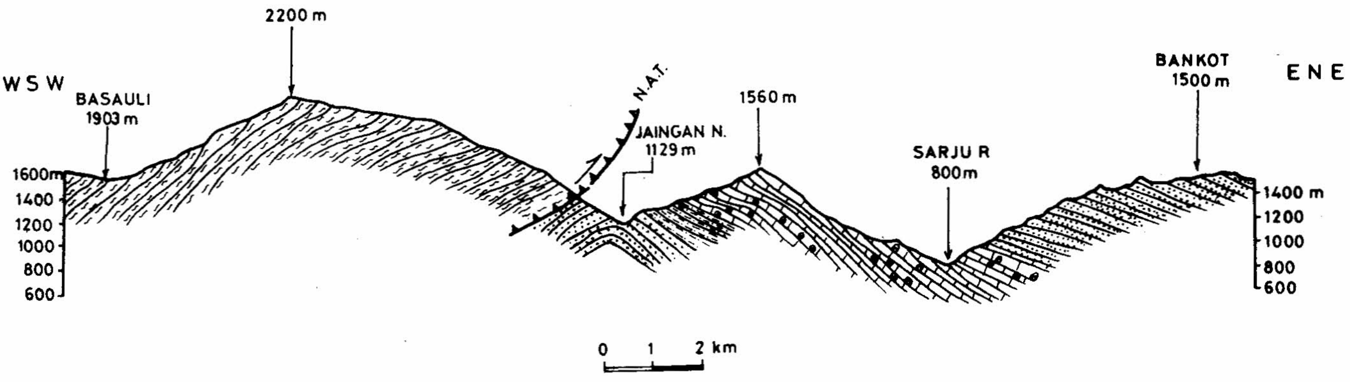

Fig. 2b. Representative geological cross section across the regional strike along X-Y line (legend is same as in geological map).

Thrust (MCT of Heim and Gansser, 1939) and North Almora Thrust. Agarwal and Kumar (1980) have suggested a unified scheme for the nomenclature of Garhwal Group to minimise the multiplicity of names, which is followed in the present work. In the prese. ι nomenclature of the sedimentary rocks the term 'Garhwal Group' has been retained as it is deeply entrenched in the modern geological literature of Kumaon Lesser Himalaya. The name 'Garhwal Group' has been used for the metasedimentaries of the 'Zone of Badolisera' in the present area of investigation.

In the present area, only three formations of the Garhwal Group namely areno-argillaceous Rautgara Formation, Calcareous Gangolihat Formation and purely arenaceous Berinag Formation is well exposed. The North Almora Thrust (NAT) directly comes in contact with Rautgara Formation in the southern part of the area and marks the boundary between the Crystalline Zone of Almora and Garhwal Group (Fig. 2a and b).

The various lithological characters of the Rautgara Formation, Gangolihat Formation and the Berinag Formation, Their limits, nature of contact and geographical distribution is given below. Lithostratigraphic correlation of the formations of the Dhuraphat area, Kumaon Himalaya is summarised in Table 1b.

RAUTGARA FORMATION

Table 1a gives the detailed lithostratigraphic classification of the Rautgara Formation which attains a thickness of ca. 1150 m. The Rautgara Formation has been subdivided into two lithologic member in the present area (Table 1a). The predominantly arenaceous member is named as Kafligair Quartzite Member and predominantly argillaceous member, around Kathpuria Chhina as Kathpuria Chhina Slate Member. The litholog of the Rautgara Formation is given in Fig. 3a.

GANGOLIHAT FORMATION

The Deoban (Gangolihat) Formation of Valdiya (1962, 1980) is represented by varied assemblages of dolomite, dolomitic limestone, stromatolitic dolomite and magnesite, talcose phyllites, calcareous quartzite and slates in the present area. The huge thickness of the Gangolihat Formation is well exposed in Sarju valley between Seraghat in the SSE and Bageshwar in the NNW (Fig. 2). The Dhuraphat region shows excellent outcrops of the rocks of the Gangolihat Formation. The entire sequence of the Gangolihat Formation is exposed along the road between Kathpuria Chhina and Bageshwar. The detailed composite litholog of the Gangolihat Formation

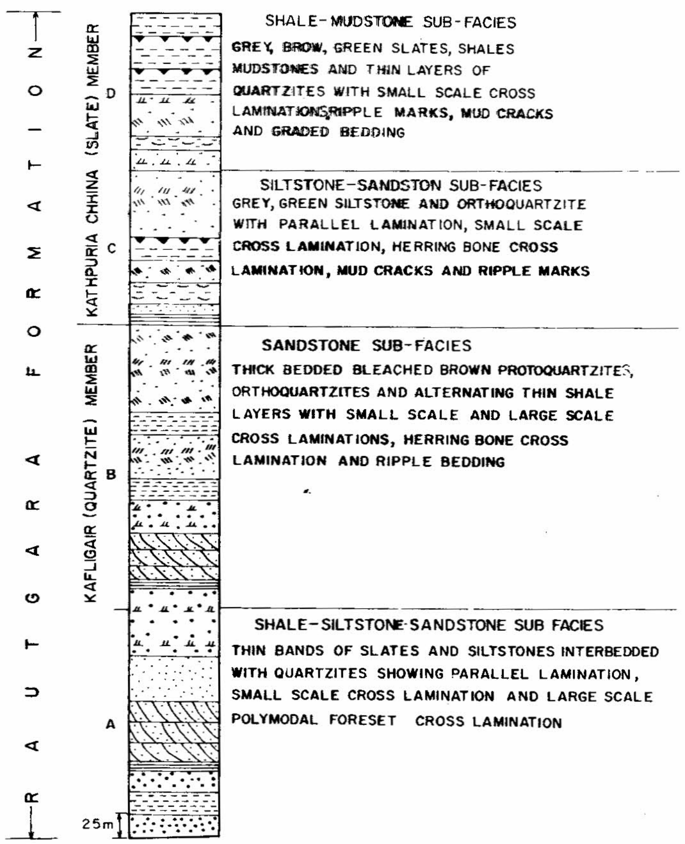

FIG. 3a COMPOSITE LITHOLOG OF RAUTGARA FORMATION, KAFLIGAIR–KATHPURIA CHHINA AREA

between Kathpuria Chhina and Bageshwar is shown in Fig. 3b.

The contact between the Rautgara Formation and the Gangolihat Formation is gradation in the Dhuraphat area and can be seen in S ra nat-Tar-moli-Siya section in Jaingan Valley and fur er north-west in Jhiroli-Chhauna section.

The contact between the Rautgar ormation and the Gangolihat Formation is gr nal in the Dhuraphat area and can be seen in eraghat-Tar-moli-Siya section on Jaingan valley and further north-west in Jhiroli-Chhauna section.

The contact between the Gangolihat Formation and the overlying Berinag Formation has been sub-divided into six informal lithostratigraphic members as A, B, C, D, E and F (Fig. 3b). No formal names have been assigned to them. Each lithounit is characterised by association of specific rock types and show subfacies changes within major calcareous facies.

BERINAG FORMATION

The thick sequence of purely terrigenous clastics exposed in the northern and eastern parts of the area, is the strike contnuation of the thick succession of arenaceous rocks designated as the Quartzite Series by Heim and Gansser (1939) in Berinag-Thal section, overlying the Calc Zone of Badolisera (the Garhwal Group). Misra and Valdiya (1961) and Valdiya (1962b) referred to these rocks as Quartzite Zone of Berinag and latter as Berinag Quartzite and gave the status of a group.

Regaining of the rank of a Group, in the eastern continuation of the area, Misra and Kumar (1968 b) have subdivided the Berinag Group into three formations viz. the Salia Formation, the Ganai Formation and the Simal Formation. Misra and Banerjee (1968 a, b) and Misra and Bhattacharya (1972) also described the arenaceous rocks occurring around Bageshwar in Sarju Valley and Kapkot- Loharkhet area as Berinag Quartzite and maintained the status of group. Ahmad (1975) reduced the status of the Berinag Quartzite from group to formation level and designated the quartzites between Bageshwar and Kapkot and Bageshwar Formation. Banerjee and Bissaria (1975) and Bhattacharya (1979) revised their earlier views regarding the inversion and status of the Berinag Quartzite in Bageshwar-Kapkot-Loharkhet area. The rank of the Berinag Group was brought down to formation level. Kumar *et al.* (1976) and Agarwal and Kumar (1980) referred to these rocks as Berinag Formation in Berinag-Munsiari section which is the youngest formation of the Garhwal Group conformably overlying the Tejam Formation. Powar (1980) designated these Berinag Quartzites as Bhankot Formation in Chaukhutia-Someshwar area which is western continuation of the present area. Valdiya

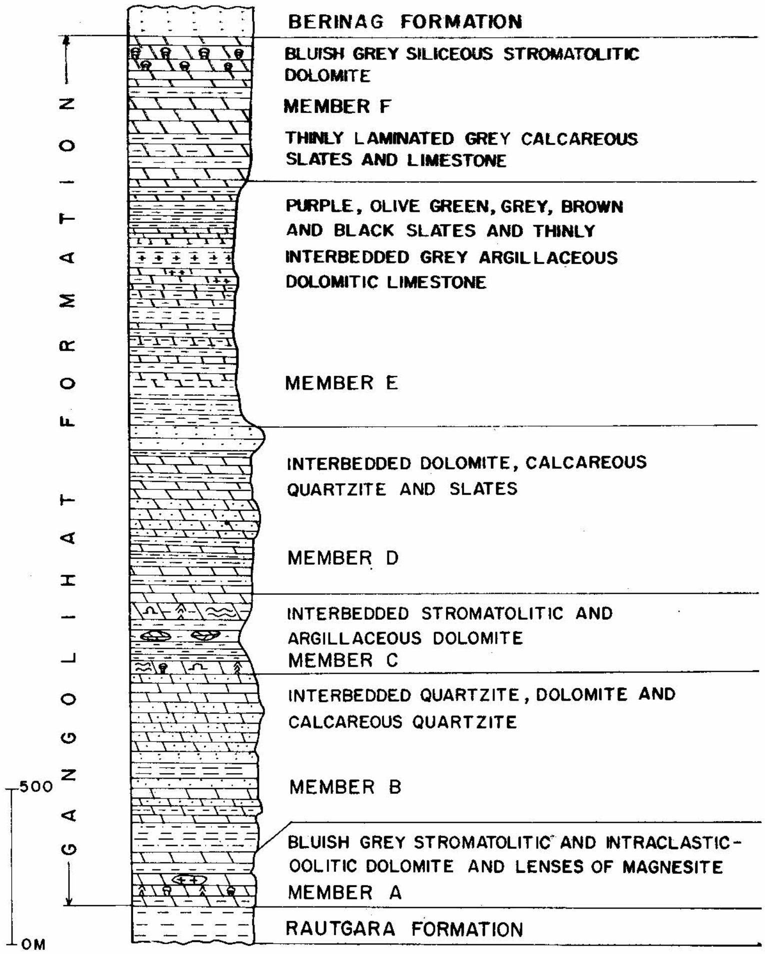

FIG.3b COMPOSITE LITHOLOG OF GANGOLIHAT FORMATION BETWEEN KATHPURIA CHHINA AND BAGESHWAR

(1980 a, b) and Valdiya and Pant (1981) have used the term Berinag Formation in the eastern extenstion of the area but they put thrust contact between the Berinag Quartzite and the underlying Deoban (Gangolihat Dolomite) and consider the Berinag Formation to represent a separate nappe.

In the present work, the entire pile of arenaceous rocks overlying the Gangolihat Formation has been designated as the Berinag Formation. Since the name Berinag Formation is now used for Berinag Quartzite in entire Kumaun Lesser Himalaya and deeply intrenched in the literature, has been retained in the present nomenclature.

The Berinag Formation is the direct lateral continuation of the arenaceous rocks exposed at Berinag in the eastern part of the area. This formation is made up of white to tawn coloured massive to bedded quartzite and interbedded chlorite schists, phyllite, amphibolite and boulder beds.

The lithostratigraphic units of the Berinag Formation as establised in the present area are given in Fig. 3c. The orthoquartzite units of this formation show good preservation of sedimentary structures like parallel lamination, small scale cross lamination, large scale cross lamination, herringbone cross lamination and ripple marks etc., which indicate normal stratigraphy of the Berinag Formation.

The rocks of the Berinag Formation are well exposed between Bageshwar in the NW and Jamtola in the SE of the present area (Fig. 2a). Good exposures are seen around Bageshwar, along the mule path from Bageshwar to Jaulkande and Sishakhani. The thick sequence of orthoquartzite conformably overlies the member F of the Gangolihat Formation in Sarju valley. The contact between the calcareous Gangolihat Formation and arenaceous Berinag Formation is gradational and marked by the development of phyllitic rocks in Berinag-Pithoragarh area (Ahmad, 1975). Misra and Bhattacharya (1972) have also noticed such transitional phyllitic facies in Kapkot area further north of the present area. This facies is developed in the southern part of the area. These phyllites gradually grades into the orthoquartzite. Good exposure can be seen in Sarju Valley along Bankot-Naugaon mule path.

The various lithounits of the Berinag Formation in Bageshwar, Shisakhani, Naugaon and Bankot areas were measured and detailed lithologs prepared. The composite litholog of the Berinag Formation around Bageshwar is shown in Fig. 3c.

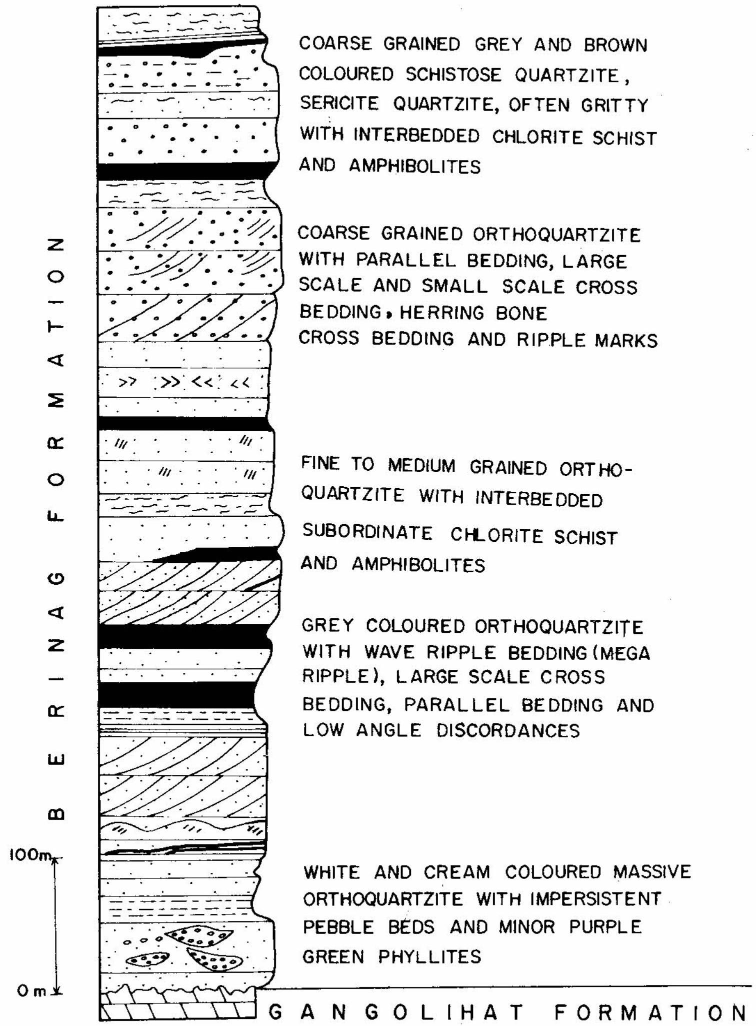

FIG. 3c COMPOSITE LITHOLOG OF BERINAG FORMATION, BAGESHWAR AREA

GEOCHEMICAL INVESTIGATIONS OF THE DEOBAN (GANGOLIHAT) CARBONATE

Chemical analysis of a few representative samples of limestones, dolomites and magnesites of the Gangolihat (Dolomite) Formation have been carried out in order to know their chemical composition. The chemical analysis includes quantitative determination of the major oxides and trace elements. In order to understand the distribution pattern of these oxides at various stratigraphic levels, samples were collected from the rocks exposed between Kathpuria Chhina and Raikholi (Dhuraphat area, sample No. 329, 333, 335, 337, 338, 340, 344, 345, 346, 347). These samples were colleected from the base to the top of these three sections of the Gangolihat Formation.

The major and trace element data of limestone and dolomite are represented in Table II a, b and the data on the magnesite is shown in Table III. Further, no definite relationship exists betweeen any two chemical varients of the Ghangolihat Formation. The CaO, MgO and SiO_2 (+ insolubles) and CaO, MgO, SiO_2 plot for the Gangolihat Formation indicate an overall dolomitic composition for these carbonates as shown in Fig. 4a.

The detailed geochemical data was not available from the Gangolihat carbonates. However, Israili and Khan (1980) have done some trace element geochemical studies in the Gangolihat Dolomites of the Pithoragarh area.

INTERPRETATION OF DATA

Major elements (Limestone and Dolomite)

Silica

This distribution of SiO_2 varies from 0 to 64.8% an increase in Si is related to the silicification or the presence of quartz (Sample No. R 2, SiO_2 is 80.17%). The silica shows an antipathetic relationship with Ca and Mg and no definite relationship is observed between Si and Fe.

Calcium

The CaO content varies from 2.24% to 38.13% in the carbonate rocks. The CaO varies from 29.7% to 38.13% in micrite and 2.24% to 31.4% in dolomicrite, dolosparites, oodolosparite and intrasparite.

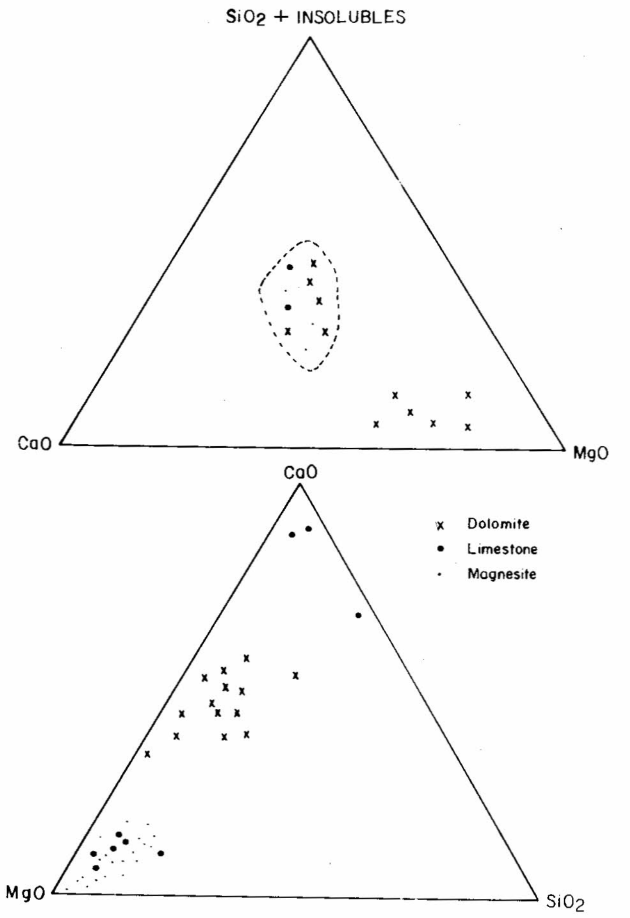

FIG.4a PLOT OF CaO-MgO-SiO2+ INSOLUBLES AND CaO-MgO-SiO2 OF DOLOMITE AND MAGNESITE OF THE GANGOLIHAT FORMATION

Magnesium

The MgO content varies from 1.0 to 22. 98% in different samples of the gangolihat carbonates, The MgO varies from 1.0 to 1.2% in micrite and in other facies it varies from 3.42 to 22.98% It shows a antipathetic relationship with Si and insoluble reside.

CaO/MgO

The CaO and MgO are important constitutents of carbonate rocks. CaO/MgO ratio reveals that no significant relationship exist between them in these rocks.

Iron

Fe_2O_3 varies from 0.32% to 4.91%. There is much fluctuation in Fe_2O_3 values in the carbonates of the Gangolihat Formation.

Manganese

MnO varies from 0.0088 to 2.234% but most of the samples show average value of 0.050. There is general paucity of Mn in carbonates of the Gangolihat Formation. However, Manganese mineralization has been reported from the dark reddish brown ferruginous slates in the form of lenses in the Gangolihat Dolomite near Jhiroli (Tewari, 1983 c). The chemical analysis of ore bearing samples show presence of 30 to 50% MnO and 6% FeO. The manganiferous shales dominantly contain pyrolusite mineral.

Petrographic studies reveals that stromatolitic laminations are found associated with iron and manganese minerals. The association of iron and manganese with stromatolitic laminae suggest that algae must have played some role in deposition of manganese in the Gangolihat Formation.

Sodium

Na_2O content varies from 0.35 to 1.8%. It has sympathetic variation relationship with K_2O in the Gangolihat Formation.

Potassium

The range of K_2O alkali in the Gangolihat Formation varies from 0.2 to 4.95%. The low content of K_2O is observed in micrites but no significant relationship is observed for other carbonate facies.

Aluminium

The Al_2O_3 content of the carbonate rocks of the Gangolihat Formation varies from 0 to 17.2% but the average value varies from 0.34 to 0.75%. The Alu-

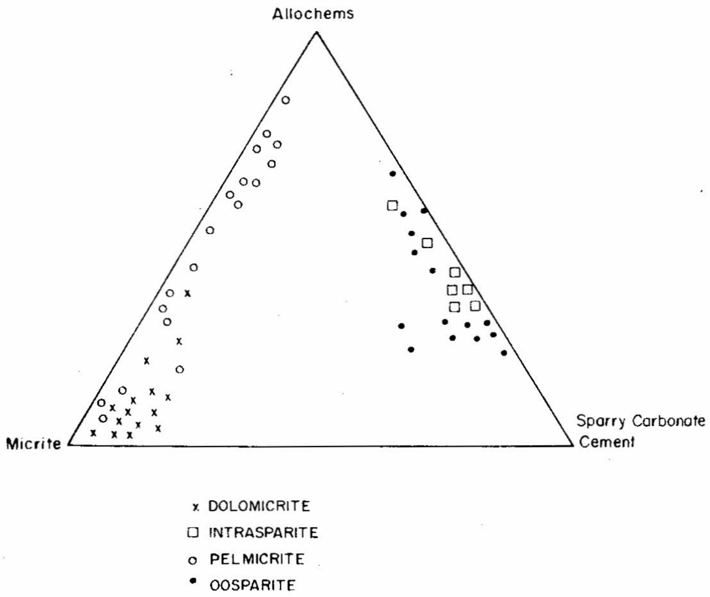

FIG 4b TRIANGULAR PLOT SHOWING VARIATION IN COMPOSITION OF THE DIFFERENT MICROFACIES OF THE GANGOLIHAT FORMATION

minium has the tendency to increase and decrease in few samples. It has a positive relationship with silica and insoluble residue.

Titanium

TiO_2 varies from 0.12 to 0.88% in the carbonate rocks of the Gangolihat Formation. It also has a positive relationship with silica.

TRACE ELEMENTS

Strontium

The concentration of Sr ranges from 6 to 86 ppm in the carbonates of the Gangolihat Formation which is less than the average value of the Sr reported from the carbonate rocks. Weber (1964) reported a concentration of 174 ppm Sr in dolostones. Veizer and Demovic (1969) found Sr variability from 33 to 274 ppm in dolomites and 148 to 1000 ppm in limestones. However, Land *et al.* (1975) suggested that a low concentration of Sr is due to equilibrium with fresh water during diagenesis. In the present case, the Sr does not show any sympathetic relationship with other major or trace elements of the Gangolihat Formation.

Barium

Ba varies from 0 to 12 ppm in the Gangolihat Formation. It is very close to the average value reported by Turekian and Wedephol (1961) for carbonates (10 ppm). Weber (1964) reported a value of 85.8 ppm of Ba in primary dolomites. The variability of Ba concentration is between 0 to 132 ppm in limestones and 0 to 235 ppm in dolomites (Veizer and Demovic, 1969).

Zinc

Zn varies from 46 to 143 ppm. This value is slightly higher than the average value of 20 ppm reported by Turekian and Wedepohl (1961). However, Weber (1964) has reported 1100 ppm Zn in the primary dolostones. Iron shows the positive relationship with the Zn in the Gangolihat carbonates.

Lead

Pb varies from 19 ppm to 44 ppm and is higher than the average value of 9 ppm reported by Turekian and Wedepohl (1961). Weber (1964) reported an average concentration of 68.2 ppm in the primary dolostone. In the Gangolihat Dolomites, the average value of Pb is 35 ppm and there is not much fluctuation in the concentration of Pb. Srivastava and Gaur (1979) while studying the genesis of sulphide mineralization in Sisakhani-Chhanapani areas reported that there is a sharp anomaly in the concentration of Pb and Zn along with fair enrichment in other elements is found exactly in the mineralized veins. The host rock dolostone (Gangolihat Dolomite) shows a fairly rich and widespread concentration in Zn. Ni, Sr, Cr, Cu and Co contents.

Copper

Cu varies from 7 ppm to 46 ppm, in the carbonate rocks of the present area. This value is higher than the average value of 4 ppm for carbonates reported by Turekian and Wedepohl (1961).

Nickel

It varies from 8 ppm to 70 ppm but the average value recorded is 20 ppm. Turekian and Wedepohl (1961) reported an average value of 20 ppm and Weber (1964) recorded 126 ppm value for primary dolostones. The present value of Ni from the Gangolihat Dolomites is in agreement with those given by Turekian and Wedephol (1961).

Lithium

Li varies from 0 to 65 ppm. The lithium content in the present case does not show any sympathetic relationship with other trace elements.

Cobalt

Co varies from 4 ppm to 28 ppm. The Co does not show any positive relationship with other trace elements.

ELEMENTAL DISTRIBUTION IN MAGNESITE

The distribution of major (in Wt.%) and trace elements (in ppm) in the magnesites of the Dhuraphat (Bauri) area is given in Table III.

MgO varies between 39.1 to 44.15% in the magnesites of the Dhuraphat area. CaO ranges from 1.96% to 7.01% in these magnesites and may be due to the presence of dolomite and calcite as impurity. SiO_2 varies from 1.55% to 3.01% and may have derived from quartz or talc. SiO_2 does not show any definite relationship with CaO and MgO. The CaO-MgO-SiO_2 plot for magnesite is shown in Fig. 4a. The SiO_2 content of carbonates below the magnesite deposits are very high. Fe_2O_3 content ranges from 1.1 to 4% and this value is higher than the surrounding dolomites.

Fe_2O_3 in most samples increases with the percentage of MgO. This indicates that iron has a preference to Mg and tends to fill up the imperfections of a magnesite crystal lattice. In country rock it is related with ferron dolomite, whereas in magnesite it is incorporated in the crystal lattic.

Al_2O_3 content (0.3 to 0.6%) in the magnesite samples is low and does not show much variation and it seems to be derived from clay minerals originally present in the host rock. The Al_2O_3 is generally higher than Fe_2O_3 in limestones and dolomites, however, the ratio is reversed in magnesite which suggests a concentration of the same at the time of ore genesis. Rarely high MgO value were noted along with high silica such as with a high silica such as with a high proportion of talc, MgO values may be as high as 44.15%. However, if silica is low, CaO is high suggesting the presence of unreplaced dolomite.

The range of the alkalies (Sodium and Potassium) in magnesites varies from 0.06% to 0.7% (Na_2O) and 0 to 1.01% (K_2O). The concentration of MnO varies from 0.08 to 0.14 in magnesites, TiO_2 is generally absent and does not has any significant role.

Trace elements data reveals that Co, Ni, Zn, Sr are having good concentration in the magnesite samples, and Pb and Cu also show fair enrichment, however, the concentration of these elements is high in limestones and dolomites of surrounding area. Sr varies from 2 ppm to 12 ppm, Co varies from 12 ppm to 27 ppm, Ni varies from 9 ppm to 22 ppm and Zn varies from 26 ppm to 63 ppm. The dolomite and ferron dolomite are generally encountered as impurities in magnesites and thus the higher amount of these elements is incorporated in the lattice of these impurities. It seems that these elements must have been trapped into new lattice during the process of replacement of dolomite by magnesite. Pb content varies from 2 ppm to 50 ppm and Cu ranges between 6 ppm to 37 ppm. These trace elements do not show positive relationship with any other element.

STUDY OF INSOLUBLE RESIDUE

The quantitative determination of insoluble residue (non carbonate component) of 14 samples collected along Kathpuria Chhina-Bageshwar road section were carried out.

The insoluble residue study of the Gangolihat carbonates reveals the presence of quartz and chert as chief constituents, along with clay minerals and the carbonaceous matter. Pyrite, small amount of hematite, limonite and leucoxene are also present. The relative distribution of the insoluble residue is given in Table IV.

RELATIONSHIP BETWEEN INSOLUBLE RESIDUES AND MgO CONTENT

Considerable attention has been paid to the relationship between the insoluble residues and MgO content (Fairbridge, 1957; Dunbar and Rodgers, 1961).

The present study of insoluble residue of the Gangolihat (Dolomite) Formation indicates that no definite relationship exist between the insoluble residue content and MgO in the Gangolihat Formation. The data on chemical analysis and insoluble residue from Calc Zone of Pithoragarh (Gangolihat Dolomite) by Valdiya (1965), Kumar (MS), Misra and Banerjee (1968 a) indicate that the Gangolihat Dolomite contains 0.5 to 42% insoluble residue and 0.5 to 45% MgO. Jain (1975) has indicated that the Dichli Dolomite exhibits high insoluble, high magnesium relationship and the Khattukhal Limestone and Upper Uttarkashi Limestone of Uttarkashi region (Garhwal Group) indicate low MgO- high clayey content and high clayey content low insluble residue magnesium relationship in the Calc Zone of Pithoragarh (Garhwal Group) broadly resembles with the pattern obtained from the carbonate rocks of Uttarkashi region. It is noteworthy that insolubel residue content of the present area resembles with the insoluble residue of the Dichli Dolomite of Uttarkashi area.

These carbonate rocks can be correlated on the basis of insoluble residue, chemical properties and the insoluble residue-magnesium relationship. From the above studies of insoluble residue the Middle Riphean Gangolihat (Deoban) Formation of Garhwal Group can be correlated with the Dichli Dolomite of Uttarkashi region.

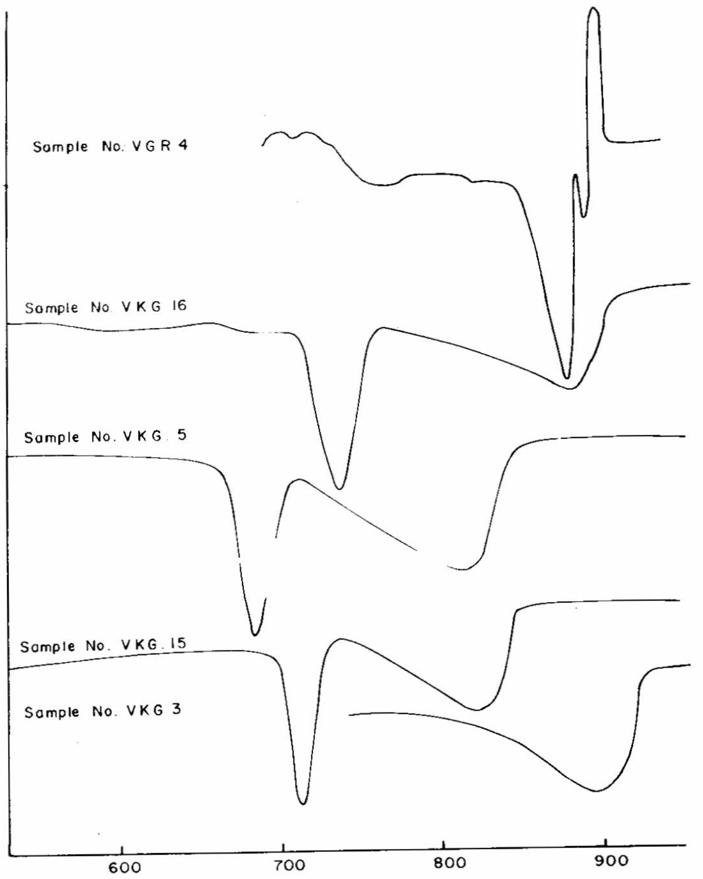

FIG.5a D. T. A. CURVES OF CALCITE AND DOLOMITE SAMPLES OF THE GANGOLIHAT FORMATION

THE DIFFERENTIAL THERMAL ANALYSIS (D.T.A.)

The differential Thermal Analysis of the carbonates of the Gangolihat (Dolomite) Formation were carried out. The D.T.A. was done in air atmosphere using Hall DTA 02 Unit. The rate of heating was kept at 10°C per minute and the carbonate samples were crushed in a diamond steel mortar to 150 mesh (ASTM).

The DTA curves obtained for calcite, dolomite and magnesite are shown in Figs. 5a and 5b.

In all twelve representative samples were chosen for differential thermal analysis. The samples of limestone/dolomite were systematically collected from the road sections near Kathpuria Chhina, Kathpuria Chhina-Bageshwar road and Kathpuria Chhina- Raikholi (Dhuraphat) forest road. The magnesite samples were collected from Bauri, Girthal, Asaun and Baiter in Dhuraphat area. The location and megascopic characters of these samples are given in Table V. The endothermic and exothermic peaks obtained on DTA thermograms of these carbonate samples have been given in the Figs. 5a and 5b respectively. These thermograms of dolomite, calcite and magnesite are being discussed separately.

Dolomite

Six samples of microcrystalline dolomite (dolomicrite) were taken for DTA, of these, three samples were collected near the contact of Gangolihat (Dolomite) Formation and Rautgara (Kathpuria Chhina Slate Member) Formation (sample Nos. VKG 1, VKG 2 and VGR 1). The third sample VGR 1 is of oolitic-stromatolitic dolomite (oodolomicrite microfacies).

Three samples (VKG 5, VKG 15, VKG 16) are from Kathpuria Chhina-Bageshwar motor road section, one (VKG 5) near the contact of the magnesite body at Bugari and the other two VKG 15 and VKG 16) from Khankar area. The DTA curves of these samples are given in Fig. 5a. All the six curves show two endothermic peaks characteristic of the mineral dolomite. The first peak in these analysis occurs between 683°C-825°C (mean value 750°V) and the second one between 888°C-910°C (mean value 899°C). The DTA curves show a slow downward base line drift within the temperature range 100°C-680°C followed by the two successive endothermic peaks of dolomite. All the six samples are essentially composed of the mineral dolomite. However, the endothermic peaks at 688°C and 812°C and 812°C respectively of stromatolitic-intraclastic- oolitic dolomite (Fig. 5a) were slightly lower than those in other cases. Coarsely crystalline dolomite of brownish grey colour (No. VKG 5) occur in association with magnesite near Bugari which on staining with potassium ferricyanide solution (Friedman, 1959), takes a blue colour, thereby indicating the presence of ferron dolomite which is also confirmed by its chemical

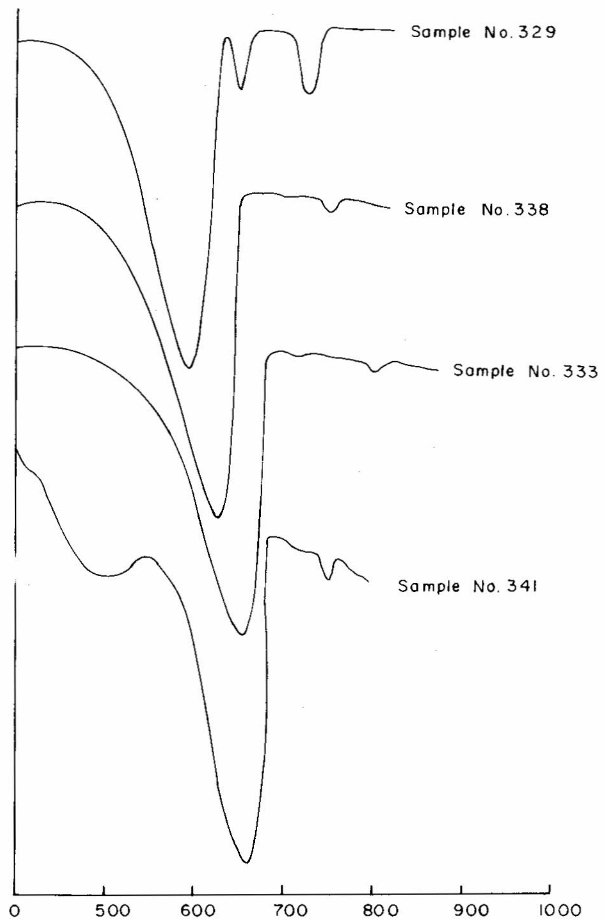

FIG.5b D. T. A. CURVES OF MAGNESITE SAMPLES OF THE GANGOLIHAT FORMATION

analysis. The thermogram for this sample shows two endothermic peaks at 687°C and 825°C. The variation in the nature and temperature of the two endothermic reactions in case of the dolomite samples may be attributed to the impurities.

Calcite

The thermograms for the two samples (VKG 3 and VGR 4 of bluish brown limestone show only the endothermic peak at 880°C and 900°C (Fig. 5a). According to Beck (1950) in case of calcite endothermic decomposition begins at 850°C, reaches a peak at 990°C and ends repidly at 1000°C. In the present case, however, it seems that the decomposition started in the neighbourhood of 700°C. This may perhaps be due to the presence of some impurities and the other peaks obtained on the thermogram of the sample VGR 4 also represent the same.

Magnesite

Four magnesite samples (Nos. 329, 333, 338 and 341) from Bauri (Girthal) deposit were subjected to the differential thermal analysis. The DTA curves of all the samples are asymmetric and show a sharp rise after attaining the maxima. The thermograms of all the four samples are given in Fig. 5b. The endothermic peaks were recorded at 645°C to 660°C (Nos. 333, 338 and 341) which confirms the presence of essentially magnesite with minor presence of impurities.

The samples No. 329 is a light grey coloured magnesite which contains appreciable amount of dolomite also. The DTA curve of this sample which shows three successive endothermic peaks. The first peak at 620°C represents magnesite, while the other two at 680°C and 750°C are due to the breaking of dolomite structure. In this case however, these endothermic peaks for dolomite indicate that the endothermic reactions have taken place much ahead of the lowest temperatures on which these reactions generally take place. Perhaps the predominance of the magnesite over dolomite and its earlier decomposition at 620°C must have lowered appreciably the temperatures of break down of dolomite structure. Another factor that might have affected the lowering of these temperatures is the presence of iron. The small exothermic and endothermic reactions in siderite must have affected the decomposition on account of partly overlapping of the two phenomenon, the oxidation of FeO and the breaking of dolomite structure.

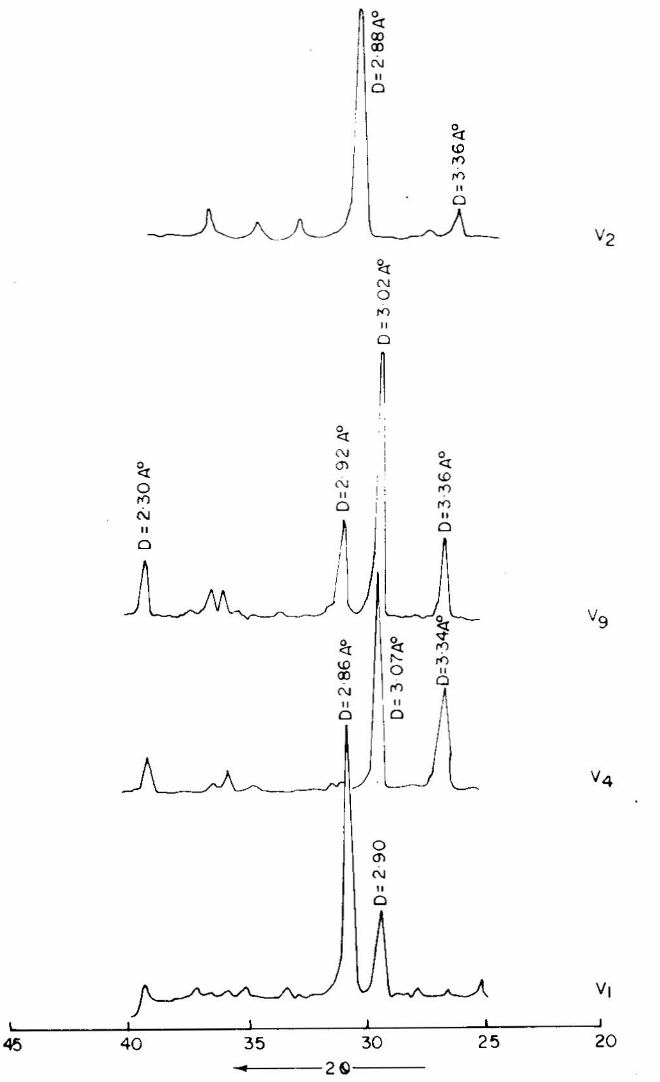

FIG.6a X-RAY DIFFRACTOGRAMS OF CALCITE AND DOLOMITE SAMPLES OF THE GANGOLIHAT FORMATION

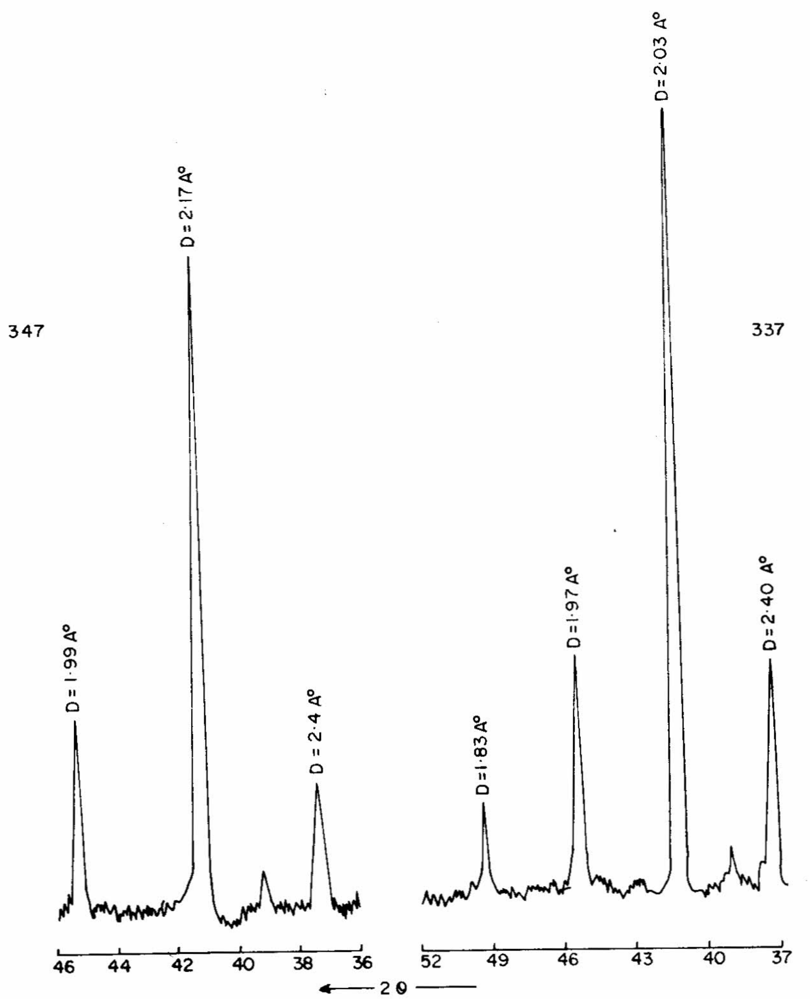

FIG. 6b X- RAY DIFFRACTOGRAMS OF MAGNESITE SAMPLES OF THE GANGOLIHAT FORMATION

X-RAY DIFFRACTION (XRD) STUDY OF CARBONATES

X-ray diffraction studies of the carbonate samples of the Gangolihat (Dolomite) Formation have been carried out by Philips X-ray diffraction unit, using nickel filtered Cu Kd radiation. The 2 range is 20^0 to 60^0.

These representative samples were collected from the Gangolihat Formation exposed between Kathpuia Chhina and Bageshwar. The magnesite samples were collected from Girthal, Bauri and Bugari deposits in Dhuraphat area.

The samples Nos. V1, V2, V3, V4, V5, V6, V7, V8, V9 and V10 containing calcite and dolomite as principal constituents have been collected from measured section along Kathpuria Chhina- Bageshwar motor road. The samples of magnesite Nos. 329, 333, 337, 338 and 347 have been collected from Bauri (Girthal) deposit. The sample No. 382 has been collected near Baiter which shows the replacement of stromatolitic dolomite by magnesite. The X-ray diffraction data of these samples is given in Table VI a and Table VIb.

X-ray diffractograms of different samples are given in Figs. 6a and 6b. Fig. 6a indicates the presence of calcite ($3.07A^0$, $3.02A^0$), dolomite ($2.92A^0$, $2.92A^0$, $2.88A^0$) and quartz ($3.34A^0$, $3.36A^0$). The diffractograms for magnesites have been shown in Fig. 6b ($2.03A^0$, $1.97A^0$, $2.17A^0$). No other significant peaks for other minerals are observed in the diffraction pattern except a few minor peaks of quartz, talc and siderite as impurites.

The X-ray diffraction patterns of the Gangolihat carbonates show characteristic peaks of dolomite, calcite and magnesite. The over all mineralogical composition suggest that dolomite is the chief mineral in the carbonate rocks. The dolomitic nature of these rocks has been corroborated by the chemical analysis, staining and DTA studies of the Gangolihat (Dolomite) Formation. The magnesite deposits of the area (Bauri, Dhuraphat) chiefly constituted of magnesite mineral in which dolomite, calcite, quartz and negligible amount of talc and siderite occur as impurities. The comparative visual estimation of the X-ray diffractograms of dolomite and magnesite indicates that the peaks of dolomite are sharp and distinct. On the contrary, the peaks of magnesite are slightly less sharp, this suggest good crystalinity of the mineral.

PALAEOCURRENT PATTERN, DEPOSITIONAL ENVIRONMENT AND SEDIMENTOLOGICAL EVOLUTION OF THE BASIN

PALAEOCURRENT PATTERN

Palaeocurrent analysis of Rautraga Formation, Gangolihat Formation and Berinag Formation has been done. Though any sedimentary structure having directional significance can be used for palaeocurrent study, however, in the present work only small scale and large scale cross bedding have been considered as these are well preserved and extensively developed throughout the succession in respect to any other sedimentary structures having directional significance. The stromatolites are also used for palaeocurrent determination of the Gangolihat Formation. The palaeocurrent pattern and statistical parameters computed for each formation is given below. On the basis of palaeocurrent pattern the dominant current directions and environment of deposition of all the three formations have been interpreted.

METHODOLOGY AND STATISTICAL PARAMETERS USED

The data has been classified into groups with 30^0 class interval and plotted in the form of rose diagrams (Fig. 7). Mean vector azimuth (Q) magnitude of the resultant mean vector (r), vector strength in percentage (L), variance and standard deviation were calculated for each formation by the formula suggested by Potter and Pettijohn (1963).

Table

The statistical parameters for the palaeocurrent analysis

1. Mean Vector Azimuth (0) =

$$\frac{\tan^{-1} N1 \sin\theta}{n^1 \cos 0}$$

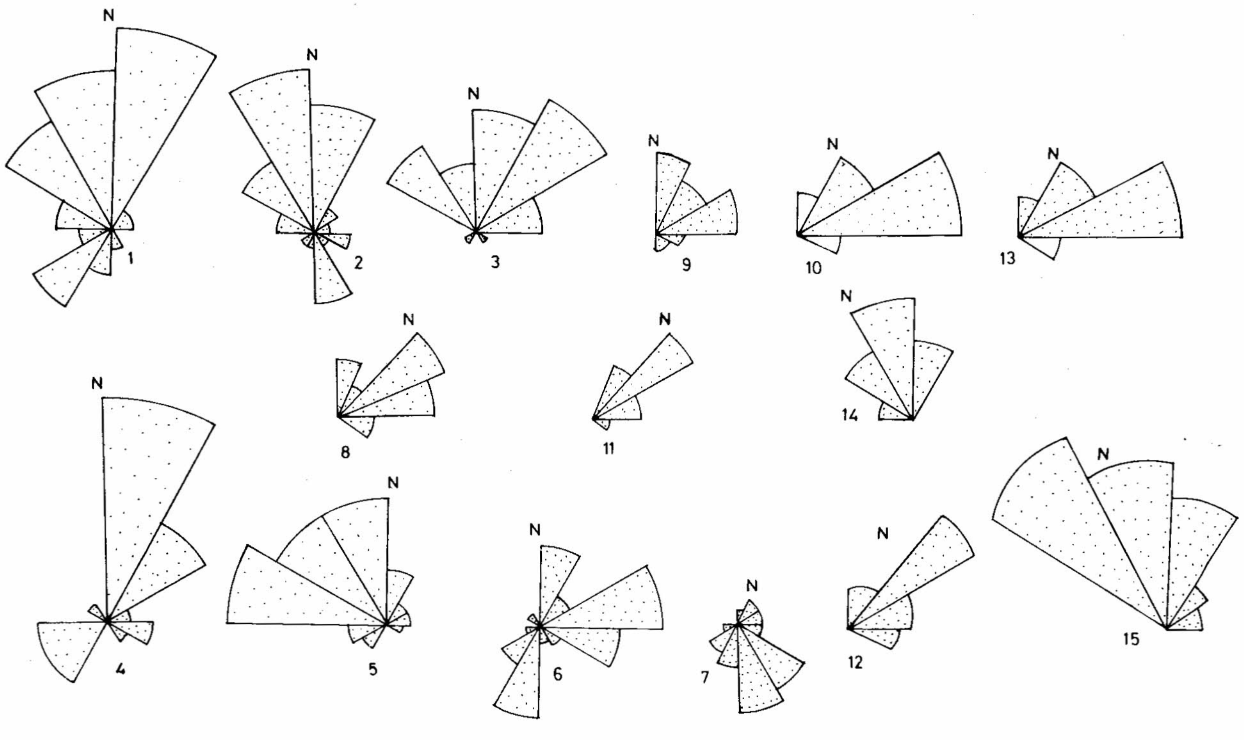

FIG.7 PALAEO CURRENT ROSE DIAGRAMS FOR RAUTGARA FORMATION (1 to 7), GANGOLIHAT FORMATION (8 to 13) AND BERINAG FORMATION (14 to 15)

2. Magnitude of resultant or Mean vector (r) =

$$\sqrt{\frac{(n1 \sin \theta)^2}{(n1 \cos \theta)^2}}$$

3. Vector magnitude in percent (L) =

$$\frac{r}{N} \times 100$$

4. Variance (S^2) =

$$fo\frac{(\theta m - \theta v)^2}{n-1}$$

5. Standard Deviation (S) =

$$\sqrt{fo\frac{(\theta m - \theta v)^2}{n-1}}$$

Where sin θ and Cos θ = East-West and North-South components or vectors

n^1 = Number of observations in each class

N = Sum of observation

θ = Mean Vector Azimuth

Fo = Observed frequency

θm = Midpoint of class interval

θv = Vector mean

n = Number of observation

PALAEOCURRENT DIRECTION

Rautgara Formation

In all 329 cross bedding azimuthal directions have been systematically taken from seven sectors (Fig. 7/1-7) along Almora-Kathpuria Chhina motor road between Kafligair and Kathpuria China. The Kafligair (Quartzite) Member and Kathpuria Chhina (Slate) Member of Rautgara Formation show good preservation of sedimentary structures (Plate 1, Figs c, e, f).

The general dip of the bed is NNE The azimuths of the cross bedding thus recorded have been reoriented in NNE direction over the stereographic net to calculate the original direction of current bedding.

The rose diagrams are shown in Fig. 7. All the rose diagrams are bimodal to polymodal with currents in all the directions. The rose diagrams in Fig. 7/1 and Fig. 7/4 show dominant current in NNE direction while it is NNW and NE in Fig. 7/2 and Fig. 7/3 respectively.

In Fig. 7/5 the main current direction is westerly while in Fig. 7/6 it is easterly. In Fig. 7/7 the main current direction is southerly. Thus considering the entire sequence of Rautgara Formation it is evident that there is a wide scatter and no definite current pattern obtained. However, the dominant current direction is generally northerly with respect to WNW-ESE trending coast line as the regional dip of the beds is taken as NNE. The linear ripples predominantly show NW-SE palaeocurrent direction and probably parallel to the WNW-ESE coast line. The statistical parameters calculated are given in Table VII.

Gangolihat Formation

Small scale and large scale cross beddings are meagerly developed in Gangolihat Formation about 1 km SE of Bageshwar, Chhani and near the contact with Rautgara Formation at Kathpuria Chhina where the oolites and intraclasts are also cross bedded. In all only forty three cross bedding azimuthal directions have been taken. The general dip of the beds is NNE and the original current bedding directions have been calculated as described earlier for Rautgara Formation. The statistical parameters have been calculated and interpreted. The rose diagrams are shown in Fig. 7 (8 to 13). The rose diagrams show dominant current in NE direction. There is a narrow scatter of vector azimuth and the dominant current direction is northerly with respect to WNW-ESE trending coast line. At places the stromatolites are also seen oriented in a NE direction. The *Plicatina antiqua* (Plate 2, Fig. b) domal biostrome in Baitar-Assun mule track is well developed (Tewari, 1983 a, b) and the columns lies at right angles to the direction of the dip. The columns are about one meter high and they show a general trend in N30°E direction.

The domal and inclined columnar stromatolites are generally good indicators of palaeocurrents (Hoffman, 1987). The columnar stromatolites when subjected to the strong current/wave get aligned along the direction of force.

This may be due to the fact that algae prefer to grow on the protected side of the structure. The pitch of the axes of the domal stromatolite columns were measured in different sections. After tilt correction, they were plotted on rose diagrams to indicate the palaeocurrent directions (Fig. 7/8 to 13). From the palaeocurrent pattern, it appears that the strong northeasterly currents prominently marked by the rose diagrams were transverse to the WNW/NW-ESE-SE trending coast line while the northwest southeast modrate currents were parallel to the shoreline. These indicate a general north northwest-south-southeast trend of coast line with a north-easternly palaeoslope for the Gangolihat Formation.

Berinag Formation

Thirty readings of cross bedding forests were recorded from the Berinag Quartzite, SE of Bageshwar on either side of the Sarju river. The rose diagrams show a narrow scatter of vector azimuth with principal direction in northerly quadrant. The dominant current direction is in NW direction (Fig. 7/14 and 15). The statistical parameters calculated are given in Table VII. It is difficult to interpret the palaeoslope in a wave current dominated tidal flat deposits in which the palaeoslope is generally disturbed by storms etc. The limited data of palaeocurrent pattern of Berinag Formation indicates that strong north and northwesterly currents were parallel to the coast line trending WNW/ESE.

The palaeocurrent pattern obtained from the above studies from Rautgara Formation, Gangolihat Formation and Berinag Formation, show bimodal to polymodal distribution of current patterns. Thus, considerring the entire sequence, the main current direction was northerly during the deposition of the Rautgara Formation, Gangolihat Formation and Berinag Formation. The bimodal to polymodal distribution of current patterns is indicative of reversals of the palaeoflow also very wide scatter of the current direction and suggest the tidal flat environment of deposition for Rautgara, Gangolihat and Berinag Formations of the present area.

The palaeocurrent direction may not correspond with the palaeoslope in a tide dominated shallow marine environment and the current pattern is rather complex (Reineck and Singh, 1980, Kumar *et al.* 1977). In this environment both current and wave are variable in both direction and intensity due to the morphology of the area, wind direction, strom etc. and thus not much can be interpreted about the palaeoslope during the deposition of the Rautgara Formation, Gangolihat Formation and Berinag Formation with respect to WNW-ESE trending coast line.

DEPOSITIONAL ENVIRONMENT AND SEDIMENTOLOGICAL EVOLUTION OF THE BASIN

Rautgara Formation

The facies analysis and the sedimentary structures (Plate 1; c, e, f) (Fig. 3a) of the Rautgara Formation in the present area suggest a tidal flat environment of deposition for Rautgara Formation (arenoargillaceous facies). Studies on modern tidal flats have suggested that large scale cross laminations, lenticular bedding, small scale cross laminations in sands and alternation of sand shale units are characteristic of subtidal zone (Humbolt, 1968; Reineck, 1975, Reineck and Singh, 1980). The herringbone cross laminations, channeling, bipolar cross laminations are indicative of subtidal-intertidal zone (Reineck and Singh, 1980, Reineck, 1975). Dominance of wave ripples is characteristic of restricted environemnt in the modern tidal flats (Reineck and Singh, 1980). Bipolar orientation of cross laminations is indicative of tidal sand bar environment (Klein, 1970).

In the present subfacies analysis the supermature lithology of the rocks, distribution of characteristic sedimentary structures in a sequence fining upward grain size, reversals of the palaeoflow suggest that tidal processes were operative at the time of deposition of Rautgara Formation. The shale-siltstone- sandstone subfacies and sandstone subfacies represent intertidal flat of medium energy.

The siltstone-sandstone subfacies is also a product of subtidal- intertidal flat depositional environment. The sand must have been brought in the depositional site from the coastal region. The linear and asymmetrical ripples in this facies are indicative of a combined wave current process or formed by landward and seaward orbital velocities near shore zone. These ripples were parallel to the shore line. The association of sedimentary structures in shale mudstone subfacies are indicative of a protected intertidal restricted circulation (lagoonal ?) environment. Desiccation (mud) cracks (Plate 1, Fig. f) are suggestive of a period of dryness and supratidal conditions. The protected intertidal or partly lagoonal conditions were prevailing only in the uppermost part of the basin in the present area. Petrographically the rock is composed of more than 95% quartz grains which are rounded to subrounded and sub angular (Plate 6, Fig. e, f). Sorting is moderate to poor.

The subtidal-intertidal depositional model for different members of Rautgara Formation has also been suggested by Kumar (1979) and Mukherjee *et al.* (1979) from the adjoining areas Valdiya (1965, 1980) suggested a shallow water flyschoidal depositional environment for Rautagara Formation.

The Rautgara Formation is conformably overlain by a mixed carbonate facies of bluish grey dolomite, intraclastic oolitic dolomite and stromatolitic dolomite (Gangolihat Formation). All these suggest an intertidal zone of a carbonate tidal flat. This facies is indicative of a change in depositional conditions from restricted intertidal/lagoonal Rautgara Formation (Kathpuria Chhina Slate Member) to carbonate tidal flat (intertidal zone) of Gangolihat Formation.

Gangolihat Formation

In the begining, the basin was marked by the development and flourishment of stromatolitic algal colonies in the Gangolihat Formation of the present area (Fig. 3b Member A). Their development controlled the deposition of limestones by way of their distribution in restricted to warm waters of intertidal to subtidal and shallow littoral zone. In recent years, the stromatolites and their bathymetric significance have been studied in great detail (Walter, 1976, Flugel, 1977). Modern stromatolite forms grow mostly in supratidal to intertidal environment and have provided the key to understanding such structures in ancient sediments. Logan (1961), working in the Shark Bay, W. Australia, has suggested that they are confined to the intertidal zones of the bay beads, where conditions are hypersaline with a salinity range of 5.6% to 6.5%. The stromatolites use CO_2 of the sea water for photosynthesis is believed to have a direct control over the Ph value of the environment, which is an important factor in carbonate sedimentation. Thus, deposition of lower part of the Gangolihat Formation took place under the biochemical realm (algal biolithite facies, Folk, 1959 a). Six algal biolithite facies were recognised in the Gangolihat Formation.

It is suggested that algal biolithite facies I to VI of the Gangolihat Formation (from bottom to top) are indicative of protected intertidal flat to subtidal and supratidal flat depositional environment. The energy conditions, turbulence and probable environment of each biolithite facies is given in Fig. 8. The columnar and conical forms (*Colonnella* sp., Plate 2, Fig. a) *Conophyton garganicus* and *Kussiella* sp. (Plate 3, Figs. a, b) suggest prolonged calm water conditions protected from strong waves and currents in intertidal zone. The laterally linked *Conophyton* (*Conophyton misrai*) and domal forms (*Plicatina antiqua*) were formed in shallow subtidal to intertidal zone of carbonate tidal flat. The stratified stromatolites (*Stratifera* msp. and *Gongylina* msp.) (Plate 4, Fig. f) indicate a low energy supratidal and intertidal zone as probable environment for the growth of these structures. The smooth and crenulated algal mat and *Cryptophyton* msp. structures are commonly observed in all the algal biolithite facies of Gangolihat Formation and suggestive of low energy inner intertidal-supratidal depositional environment.

A substantial part of the carbonate sequence of Gangolihat Formation includes micrites/dolomites (Plate 4, Fig. e). They are the product of direct and relatively rapid chemical precipitation (Folk, 1959, a), thus the first cycle or autochthonous limestones. The physiochemical processes were mainly responsible for their deposition excepting the stromatolitic lime-

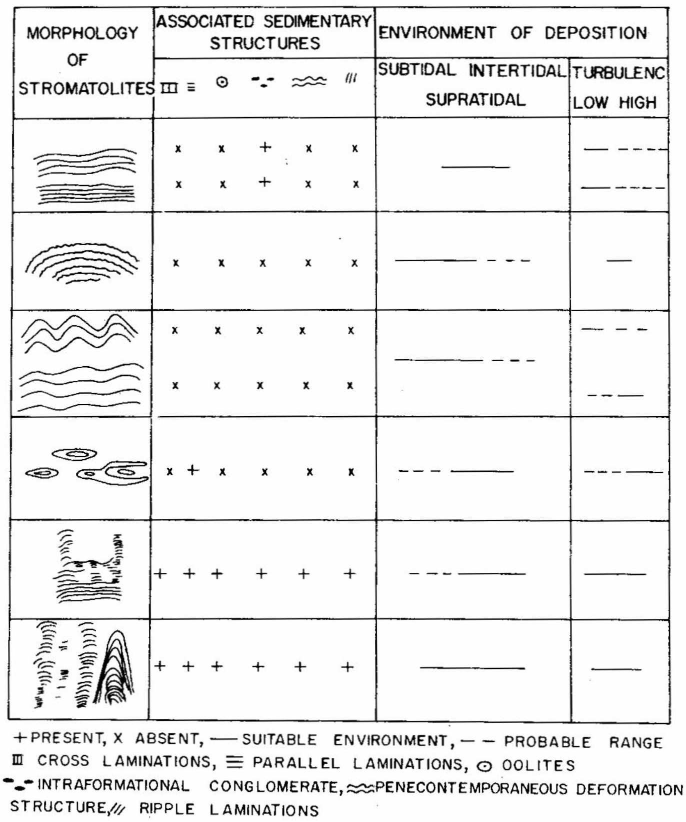

FIG. 8 RELATIONSHIP OBSERVED BETWEEN STROMATOLITE MORPHOLOGY WITH SEDIMENTARY STRUCTURES AND ENVIRONMENT OF DEPOSITION IN THE GANGOLIHAT FORMATION

Throughout the depositional history of the oolitic intraclasitc and pelletic rock the matrix content of these almost remained constant. In other words, they developed uniformly in their number, with respect to time. A decreased carbonate concentration with a sympathetic decrease in the silica content made the environment favourable for the formation of these textural components. The silica content of these rocks has a low value and this may be due to the fact that throughout the depositional history, the rate of silica precipitition was almost constant. However, the posibility of some of the silica being introduced during the process of diagenesis (Silicification) cannot be ruled out. Two stages of silicification i.e. early and late silicification has been recognized in the Gangolihat Dolomites (Tewari, 1984a, 1985).

The intrasparite microfacies of intraclastic oolitic dolomite facies comprises intraclasts formed by the contemporaneous breakdown of generally weakly consolidated carbonate sediments. A high proportion of sparry dolomite cement and abundance of the intraclasts in the intrasparites suggest that these rocks developed in the zone where the depositional interface remained within the wave and current action of the Deoban sea. A general low content of the micrites in these rocks suggest winnowing action of the currents.

stone which were deposited by the biochemical processes (Plate 4d, e).

The oolitic and pelletic rocks bear a negligible amount of micrite. It appears that the bulk of the micrite had been converted to dolomicrite as a result of dolomitisation that affected the entire Gangolihat Formation on the regional scale (Kumar and Tewari, 1978b, Tewari, 1984a). The carbonate concentration of the medium (i.e. the oceanic water) remained almost the same during sedimentation of intraclastic oolitic dolomite facies. The diagram (Fig. 4b) between the textural components and the carbonate content reveals an inverse relationship between them, i.e. the process of formation of the oolites, intraclasts and pellets is an inverse function of the carbonate concentration of the medium of deposition in this facies. Geochemical data of intraclastic oolitic dolomite facies reveals that the silica and carbonate content bear a direct relationship between them.

The pelsparite and pelmicrite microfacies differ from sparry allochemical rocks in having dolomite ooze in high proportion and at the same time with dolomicrites in containing large proportion of microscopic allochemical sparites and pellets and occasional sparry dolomite grains. The finely laminated pelsparites and pelmicrites with intervening algal mats are suggestive of periodic flooding of the tidal and mud flats.

It is envisaged that the earlier cycle intraclastic and oolitic rocks of Gangolihat Formation were deposited in a comparatively low energy environment as evidenced by the presence of microcrystalline cementing material in them (dolomicrite). The massive dolomicrites imply both a rapid rate of precipitation as well as lack of persistent strong currents or wave action. Such rocks according to Folk (1962) mostly form in very low energy environments like shallow sheltered legoonal areas or on broad sea marginal shelves of little of moderate depth were wave action is cut off by the very width of the shelf.

The second cycle of formation of this intraclastic rock possibly indicates increase in the energy level either due to the lowering of sea level or alternatively upheaval of the basin or both so as to rework the earlier formed low energy intraclastic and oolitic rocks and the adjoining fine carbonate sediments are redeposited in a new high energy environment.

Intraclasts of Gangolihat Formation (Member A) are made up of fragments of the intraclastic rock of earlier cycles, and composite oolites derived from the earlier formed oolitic rock (Plate 5, Figs. a, b, c, d) indicate the unstability of the depositional basin and changes in the palaeo-environmental conditions. Well rounded to sub-rounded intraclasts clearly indicate their prolonged abrasion by the waves and currents before their final deposition. The fragments of the first cycle intraclastic and oolitic rocks clearly show their strong cementation and lithification, such that they resisted disintegration after a prolonged aggradation by wave and current action. The sparry dolomite cement of these rocks typically suggests that they have been deposited in a sufficiently high energy environment to remove the fine carbonate matrix. Most composite oolites and some broken oolites are derived from older or contemporaneous oolitic rocks (Plate 5, Fig. c). Kumar and Tewari (1978b) and Tewari (1984) have studied the oolites and diagenesis in detail.

The dolomite lithofacies with magnesite in the Gangolihat Formation is indicative of a change in depositional environment from open sea carbonate tidal flat to a restricted tidal flat or shallow hypersaline lagoon during the formation of magnesite. During the genesis of magnesite this coastal lagoon was connected with open sea and highly variable conditions like increased salinity (evaporitic) conditions were prevailing in the barred basin. The algae was thriving in this basin and the algal stromatolites were mainly responsible for the formation of magnesite. The crystalline magnesite is (Plate 4, Fig. a, b, c) inferred to have formed under evaporitic conditions in restricted shallow basin. The deposition of carbonates on a shallow shelf often experience supratidal and intertidal environment where such evaporitic conditions may develope.

Although, sedimentation took place mainly under chemical conditions in Gangolihat Formation but mechanial action of waves and currents has much to do in transporting the sediments. Occurrence of faintly preserved ripple marks, current bedding, etc. in Gangolihat Formation (Member B and Member D) bear testimoney sedimentation, gave rise to calcarenites and calcirudites in calcarenaceous facies and calc-areno-argillaceous facies of Gangolihat Formation. The basin became relatively shallow during the deposition of Gangolihat C Member (stromatolitic dolomite argillaceous facies). Sedimentation took place predominatly under chemical environment during which, periods of carbonate sedimentation were interrupted from time to time by primary silica (chert) precipitation and also by non chemical sedimentation of argillaceous materials. A few periods of localised channel deposits, also intervened in the Gangolihat Formation (Member D).

Calcareno-argillaceous and argillo-calcareous facies predominates in the middle hrizones of Gangolihat Formation (D and E Members).

Periods of calm water, predominantly under the chemical regime were succeeded by calm water periods of non chemical sedimentation. Clay/shale partings and shale/silt-mud laminations within same limestones record periods of intermittent supply of detrital material or mud during periods of chemical sedimentations. This is indicative of a muddy channel in intertidal zone. Red, purple, brown, grey and green slates (Calcargillaceous facies) suggest their deposition under mildly oxidising to reducing conditions. Occassional occurrence of pyrite is some black shales and slates indicates mildly reducing condition. The black shales which belong to local euxinic facies, within the basin, record anaerobic reducing conditions. All the above mentioned environmental conditions were more or less repeated cyclically throughout the sedimentational history of the middle part of the Gangolihat Formation.

Petrographic study also reveal that sometimes the low energy micrites are interbedded with high energy calcarenite (sandy micrite microfacies), the latter showing evidences of current action (Gangolihat D Member). In such cases the micrites might be of shallow water origin, and the alternation might represent a fluctuation between lagoon and barrier bar (Folk, 1959a). The calcareno-argillaceous facies (Member D) and Calc-argillaceous facies (Member E) were deposited in an environment fluctuating between lagoon, barrier bar and protected intertidal zone.

After the deposition of Gangolihat E Member, the basin became relatively shallow during which a thick pile of dolomitic- limestone/dolomite of the Gangolihat F Member was deposited. The development of columnar stromatolites in this calcareous facies is indicative of intertidal zone of carbonate tidal flat.

Berinag Formation

After the deposition of calcareous facies (Gangolihat Formation) the environment changed over from carbonate tidal flat to coastal sand-beach complex influenced by tidal waves/currents and coastal rivers, suitable for the deposition of terrigenous/siliciclastic sediments of Berinag (Quartzite) Formation (Arenaceous facies). At places the transitional facies contains characters and suite of rocks which resembles in certain aspects to the underlying carbonate rocks of calcareous facies (Gangolihat Formation) and to some extent resembles with overlying arenaceous facies (Berinag Formation) has been observed.

A gradual change in lithofacies from phyllites and slates interbedded with limestone bands to pink fine grained quartzite has been observed in Bankot-Naugaon section. This transitional facies is restricted to some parts of the area which separates the purely calcareous facies (Gangolihat Formation) below from the purely arenaceous facies (Berinag Formation) above it. This facies was also deposited in shallow marine environment (Carbonate tidal flat to sandy beach).

About 765 m thick sequence of Berinag Formation is a product of a very shallow coastal environment and slightly modified by tidal, wind and fluvial agencies. There was no change in depositional environment during the deposition of this huge thickness of quartzites which suggests that the deposition of Berinag Formation took place in tectonically stable shelf and continued shifting and abrasion of slowly depositing sediments keeping pace with the equally slow rate of subsidence.

Orthoquartzites (quartzarenite, Plate 6, Figs. a, b) constitutes the bulk lithology of the Berinag Formation along with some interbedded argillaceous beds and basic rocks. These orthoquartzites show high degree of textural and mineralogical maturity.

Petrographic studies reveal that the sediments have suffered much transportation (Plate 6, Fig. a). During their transport within the basin, they have been temporarily deposited and washed many times before finally coming to rest, as is indicated by the marked separation (absence) of mud and silt, which has finally caused the deposition of pure and clear orthoquartzite.

Presence of low angle discordances, parallel bedding (Plate), Fig. d) large scale and small scale cross bedding, herringbone cross bedding (Plate 1, Fig. a, b) and ripple marks, suggest a shallow water (sandy intertidal flat-coastal beach) conditions of deposition. All the sublithofacies of Berinag Formation (Fig. 3c) show characteristic sedimentary structures of sandy tidal flat, coastal/beach complex depositional environment for Berinag Formation. The lower pebbly quartzite phyllite facies indicate a sandy intertidal flat, coastal beach and channel deposits influenced by fluvial agencies. Herringbone cross bedding, wave ripple bedding, ripple marks and parallel bedding are the dominant bedding types suggest a depositional environment dominanted by tides. The middle gritty quartzite metabasic facies show mainly parallel bedding, large scale cross bedding and low angle discordances suggestive of beach/coastal sand bar environment. The very large scale cross bedding (bar type) are produced by migration of mega ripples. The upper schistose quartzite metabasic facies also show low angle discordance, parallel bedding and large scale cross bedding as dominant bedding types. These structures suggest the development of shales and migrating sandbars in shallow sea which produced logshore bars and mega ripples and made large scale cross bedding. All these sedimentary structures suggest a medium to high energy coastal sand bar, sandy intertidal flat and beach/shoal complex depositional environment for Berinag Formation. The boulder/pebble beds are the product of fluvial processes deposited by fast moving currents of coastal rivers. Since, the sands above sea level, were exposed to wind activity and fluvial agencies which resulted in the modification of sands into river channel deposits. Reineck and Singh (1980) have suggested that in case of the prograding coasts, the major part of the sand has to be brought in by the rivers.

Thus, the enormously thick terrigenous clastic sequence of Berinag Formation represents coastal sand deposits (beach coastal sand shoal complex) which was influenced by tidal waves and coastal rivers. Petrological attributes of the rocks of the Berinag Formation points to their deposition in the sublittoral to littoral (beach) zones under tectonically stable conditions.

However, according to Folk (1968) the orthoquartzites derived from the reworked sediments require no period of stability and can be formed under any tectonic framework.

Possibly penecontemporaneous with the sedimentation, there were a few periods of submarine/near the coast volcanic activity, as a result of which basic magma was ejected on the oceanic floor. It appears that the basic rocks, most of which have now converted to chlorite schists, have originated in this manner.

Petrographic studies reveal that some of the orthoquartzites show the phenomenon of neomorphism which has been described by Folk (1959b) as "textural inversion". In such rocks the poorly sorted grains are well rounded, while on the other hand, the well sorted grains are angular. According to him, this indicates the mixing up of the products of two energy levels, or rocks transported from two different sources. These petrographic characters are well displayed by the gritty or pebbly conglomeratic orthoquartzites. Folk (1959b) further believes that the latter type of rocks are formed due to occasional turbulance created by hurricane and stroms in the shelf area.

The impersistent boulder beds, which include boulders of vein quartz in quartzitic matrix, appear to be fluvial channel deposits of local extent. The boulder beds, might have been deposited by fast moving currents of coastal rivers. A low relief for the source regions of this formation is also suggested because it is now believed that, low relief leads to complete destructions of the feldspars with the consequent formation of high quartzose sandstones (orthoquartzites). High relief, on the other hands, is responsible for the deposition of incompletely weathered materials. So that the resulting rocks are feldspathic and other immature sands like argillaceous conglomerates and sandstones, arkoses, graywacks, etc. A general absence of the latter type of rocks within the Berinag Formation, thus indicate a low relief for the provenace. The study of heavy minerals suggest that the Berinag Quartzarenite (orthoquartzites) are highly matured and only ultrastable minrals like tourmaline and zircon etc (Plate 6, Fig. c,d) could survive the prolonged transportation and abrasion. A complex varied provenance is suggested for Berinag Formation.

Valdiya (1965) has suggested a littoral or beach instable shelf environment as depositional model for Berinag Quartzite in Pithoragarh area mainly based on the petrographic evidence. Kumar (1967) also suggested a tectonically stable shelf condition near beach or littoral zone as possible depositional environment of Berinag Quartzite in Badolisera-Ganai area. Kumar (1978) again proposed a coastal beach sand dune complex depositional environment for Berinag Quartzite in Ganai-Gangolihat area based on detailed study of primary sedimentary structures.

CONCLUSIONS

The depositon of Rautgara, Gangolihat and Berinag Formation represent a single cycle of tidal flat sedimentation in the Deoban Basin during Meso-proterozoic (Riphean) Period. The marked vertical and lateral facies changes suggest profound changes in the conditions of deposition. The basinal subsidence was also responsible for the sedimentation of huge thickness in a single sedimentary basin. It appears that subsidence of the Deoban Basin kept pace with sedimentation to accumulate the enormously thick pile of sediments.

The withdrawl of the Deoban sea is attributed to some tectonic event which uplifted the basin and regressed the sea from the inner Lesser Himalaya and the sedimentation was restricted to the south in the Krol Basin. The Deoban Basin (Deoban-Tejam belt) is interpreted to have terminated due to Baikaliam Orogeny which separated the Riphean carbonate-terrigenous complex (Damta-Deoban-Jaunsar/ Rautgara-Gangolihat-Berinag) from that of the Vendian (Blaini Formation). The Blaini-Krol Tal sequence (Vendian to Lowerr Cambrian) represent second cycle of sedimentation in Krol Basin and Jaunsar (Nagthat Quartzite) formed the foundation for the Krol Basin.

The shallow tidal sea of Krol Basin regressed from the Lesser Himalaya during Lower Cambrian times (around 500 Ma). The termination of sedimentation in the Krol Basin is attributed to another important orogenic event at this time generally referred to as *"Caledonian"* or *"Pan-African"* orogenies.

ACKNOWLEDGEMENTS

This paper was synthsized while I was on a Professorship assignment at the University of Kumaon (Nainital) in the Year 1991-93. I am thankful to Prof. S. Kumar of Lucknow University for discussions and suggestions for revision of the earlier draft of the paper. Director Wadia Institute of Himalayan Geology, Dehra Dun is thanked for permission to publish the paper. Shri Shiv Singh Negi ably typed final manuscript.

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Table-1a

GENERALISED LITHOSTRATIGRAPHY OF THE AREA

(Major Units) Group	(Minor Units) Formation	Lithology	Sedimentary structures	Age	Remarks
	Berinag Formation	Coarse grained grey and brown schistose quartzite and sericite quartzite often gritty with interbedded chlorite schist White to pinkish white and cream coloured massive orthoquartzite with impersistent pebble beds and minor purple green phyllites.	Large scale cross bedding, small scale cross bedding, parallel bedding, ripple marks, flaser and lenticular bedding, wave ripple bedding, herringbone cross bedding, graded bedding.	Upper Riphean	
	Gangolihat Formation	Bluish grey, grey dolomite limestone, stromatolitic dolomite, siliceous limestone with chert bands, intraclastic. Oolitic dolomite, slates and lenses of magnesite.	Parallel bedding, small scale cross bedding, large scale cross bedding, ripple marks, rhythmites, stylolites, pinch and swell structure, convolute bedding.	Lower to Middle Riphean	
	Rautgara Formation	**Kathpuria Chhina Slate Member** Grey, brown, green shales and slates with interbedded mudstone and quartzitic sandstone. **Kaflifair Quartzite Member** Thick bedded protoquartzite and orthoquartzite with subordinate slates and shales.	Tidal bedding (Rhythmites), flaser and lenticular bedding, mud cracks, convolute bedding, graded bedding, ball and pillow structure, tool marks. Large scale cross bedding, small scale cross bedding, herringbone structure, trough cross bedding, parallel bedding, ripple marks, wave ripple bedding.	Lower Riphean	
---------- NORTH ALMORA THRUST ----------					
CRYSTALLINE ZONE OF ALMORA		Biotite chlorite schist, feldspar porphyry, gneisses and mylonites.			

Table-1b: LITHOSTRATIGRAPHIC CORRELATION OF THE FORMATIONS OF THE DHURAPHAT AREA, KUMAON HIMALAYA

PRESENT WORK (Dhuraphat area)	ALMORA DISTRICT (Bageshwar-Kapkot Tejam area)	PITHORAGARH DISTRICT (Badolisera-Gangolihat-Pithoragarh area)	CHAMOLI AND PAURI DISTRICT (Rudraprayag-Pipalkoti area)	UTTARKASHI AND TEHRI DISTRICT (Deoban-Gamri-Pratap Nagar area)
BERINAG FORMATION Coarse grained grey and brown and schistose quartzite and sericite quartzite often gritty with interbedded chlorite schist and amphibolites. White to pinkish white and cream coloured massive orthoquartzite with impersistant pebble beeds and minor purple green phyllites.	Berinag Formation (Misra and Banerjee, 1968) Loharkhet Quartzite (Misra, and Bhattacharya, 1972) Bageshwar Formation (Ahmed, 1975) berinag Formation (Banerjee and Bisaria, 1975; Ramji, 1976; Bhattacharya, 1979) Berinag Group (Agarwal and Kumar, 1980) Bhatkot Formation (Powar, 1980) Berinag (Nagthat) Formation (Valdiya, 1980a)	Berinag Quartzite (Valdiya, 1963) Salia Quartzite and Ganai amphibolites (Misra and Kumar, 1968) Ladhiya Formation (Valdiya, 1963)	Mainthana Quartzite (Kumar *et al.*, 1974) Pauri phyllite (Marchula Quartzite) Kumar *et al.*, 1974 Nagthat Quartzite (Auden 1935) Chamoli Quartszite (Mehdi *et al.*, 1972) Patroli Formation (Kumar and Agarwal, 1975) Gulabkoti and Chinka Formation (Gaur *et al.*, 1977)	Nagthat stage (Auden, 1934) Jaunsar Series (Auden, 1935) Bawar series (Oldham, 1883) Gamri Quartzite (Jain, 1971) Pratapnagar Quartzite (Saklani, 1971) Sandra Formation (Sharma, 1972; Rupke, 1974), Nagnithank Formation (Agarwal and Kumar, 1973) Berinag (Nagthat) Formation (Valdiya, 1980a)
GANGOLIHAT FORMATION F. Bedded and massive grey dolomite with columnar stromatolites and thinly laminated grey and green colour slates. E. Thinly bedded blue and cream colur dolomite with small lenses of magnesite and interbedded greyish brown, green and black slates with minor phyllites and lenses of quartzite. D. White and grey bedded quartzite calcareous at places with thin bands of grey dolomite and interbedded with slates, talcose phyllites and quartzite. C. Bluish grey dolomite with columnar, stratified and domal stromatolites and brown, green, grey and black slates. B. Grey calcareous quartzite with purple phyllites, talcose quartzite and minor bluish grey dolomite. A. Grey colour dolomite with thinly laminated dark grey slates. Bluish grey dolomite with columnar stratified and laterally linked stromatolites and lenticular bodies of magnesite. Grey and brown colour dolomite with greenish grey slates.	Badolisara Zone (Heim and Gansser, 1939) Gangolihat Dolomite (Misra and Banerjee, 1968) Kapkot Formation (Misra and Bhattacharya, 1972) Jhatakwali Formation (Ahmed, 1975) Tejam Dolomite and Patet Formation (Kumar *et al.*, 1976) Kapkot Bolomite (Ramji, 1976) Kapkot Formation (Bhattacharya, 1979) Kapkot Formation (Bhattacharya, 1979) Deoban Formation (Valdiya, 1980a) Chaukhutia Formation (Powar, 1980).	Gransitional Limestone (Mc Lelland, 1934) Gangolihat Dolomite (Valdiya, 1962; Misra and Kumar, 1968) Gangolihat Dolomite (Ramji, 1976) Deoban Formation (Valdiya, 1980a)	Pipalkoti Limestone and Slate (Heim and Gansser, 1939; Gaur *et al.*, 1977) Lameri-Gwanagarh Formation (Mehdi *et al.*, 1972), Kumar and Agarwal, 1978) Dasoli Dolomite (Gaur *et al.*, 1977) Deoban Formation (Valdiya, 1980a)	Lower Deoban (Rupke, 1974) Barnigad-Sauli Formation (Pachauri, 1972) Dichli-Kattukhal-Shylana and Uttarkashi Limestone (Jain, 1971; Jain *et al.*, 1971) Shyalna Formation (Agarwal and Kumar, 1973 Bhelunta Limestone (Saklani, 1971) (Valdiya, 1980a)

SOR FORMATION **Kathouria Chhina Slate Member** The Upper part of Kathpuria Chhina Member is comprising of grey, brown, green shales mudstone and interbedded minor green and brown quartzitic sandstone. The lower part is made up of grey, green slates, sandy shale, mudstone and quartzitic sandstone. **Kafligair Quartzite Member** The Upper part of Kafligair Quartzite is made up of thick bedded protoquartzite and orthoquartzite. The lower part is made up of slates, shales and quartzite. Thin bands of shale inter-bedded with grey brown quartzite.	Upper Tejam Zone (Heim and Gansser, 1939) Pungar Valley Slates (Misra and Banerjee, 1968) Saling Slates (Misra and Bhattacharya, 1972) Sor Slate (Banerjee and Misara, 1975) Hatsila Formation (Ahmad, 1975; Bhattacharya, 1979) Naulara Phyllite (Kumar *et al.*, 1976) Mandhali Formation (Valdiya, 1980a)	Sirdang Zone (Heim and Gansser, 1939) Sor Slates (Valdiya, 1962) Ghughtia-Salan Satbe Formations (Misar and Kumar, 1968) Sor, A, B, C, D, E, F (Kumar, 1979) Sor Slate (Ramji, 1976) Mandhali Formation (Valdiya, 1980a)	Lameri Slate (Agarwal, 1974) Pipalkoti Formation (Gaur *et al.*, 1977)	Chail Series (West, 1931) Morar Chakrata Beds (Auden, 1934) Bhankoli Formation (Pachauri, 1972) Tikri Slates (Sharma, 1972) Damta Group (Rupke, 1974) Chakrata Formation (Valdiya, 1980a) Mandhali Formation (Valdiya, 1980a)
---------- Thrust ----------	---------- Thrust ----------	---------- Thrust ----------	--------------------	---------- Thrust ----------
CRYSTALLINE ZONE OF ALMORA	CRYSTALLINES OF BAIJNATH	CRYSTALLINES OF ASKOT, DHARAMGARH	DUDATOLI-ALMORA CRYSTALLINES	

Table-IIa

SHOWING DISTRIBUTION OF MAJOR (IN%) AND MINOR (IN ppm) ELEMENTS IN THE GANGOLIHAT FORMATION, KATHPURIA CHHINA - BAGESHWAR SECTION

Sample No.	CaO%	MgO%	Na_2O%	K_2O%	Fe_2O_3%	MnO%	TiO_2%	SiO_2%	Al_2O_3%	Pb	Li	Sr	Ba	Co	Ni	Zn	Cu
V1	29.7	18.95	1.4	0.2	2.234	2.234	0.078	Nil	Nil	33	8	86	Nil	26	12	135	1
V2	31.12	19.95	0.4	0.3	0.704	0.1063	0.024	0.8	Nil	33	Nil	34	Nil	18	19	69	46
V3	30.08	18.97	0.13	0.7	0.98	0.0261	Nil	4.3	Nil	26	Nil	31	Nil	25	13	118	46
V4	28.1	19.35	0.4	0.2	0.704	0.0718	0.06	5.2	0.75	35	5	30	1	18	45	95	36
V6	17.9	22.98	1.8	0.4	0.384	0.0093	0.054	Nil	Nil	30	30	52	1	18	10	81	7
V7	2.24	18.14	1.4	1.6	4.9142	0.0088	0.8893	53.3	16.21	24	65	8	12	18	8	109	11
V8	24.25	17.53	1.25	0.25	0.512	0.0268	0.012	16.8	0.69	33	3	36	1	16	9	58	13
V9	14.05	8.06	0.35	4.95	2.304	0.0444	0.5116	Nil	Nil	25	12	62	2	28	46	143	46
V10	24.0	16.32	0.5	0.45	0.960	0.0367	0.078	19.5	0.75	35	5	28	Nil	18	70	77	18
V11	23.79	19.7	0.45	0.2	0.576	0.0308	0.042	10.27	1.035	38	Nil	16	Nil	16	12	67	27
V15	28.8	20.76	0.4	0.2	0.896	0.274	0.048	1.6	0.6	35	3	26	1	16	30	71	20
V16	21.3	14.31	0.5	0.65	0.64	0.0308	0.03	Nil	Nil	35	3	24	Nil	12	18	77	18
V18	8.25	3.42	0.5	4.25	4.3165	0.0928	0.6152	64.1	13.42	30	18	14	2	18	30	95	36
V20	37.9	1.0	1.0	2.0	1.536	0.0246	0.2315	20.8	3.75	33	8	48	1	28	11	80	23
V21	34.7	1.2	0.4	2.85	1.92	0.0342	0.3046	24.17	4.48	27	8	22	1	24	31	91	44
V22	23.55	16.12	1.35	0.45	0.448	0.0198	0.66	20.41	0.69	25	Nil	40	Nil	20	15	106	10
V23	25.2	17.74	1.35	0.45	0.64	0.0291	0.006	14.2	Nil	33	3	26	1	16	9	58	13
V24	31.4	20.56	1.7	0.2	0.96	0.1513	0.012	0.8	0.34	44	Nil	64	Nil	24	12	97	12

Table-IIb

SHOWING DISTRIBUTION OF MAJOR (IN%) AND MINOR (IN ppm) ELEMENTS IN THE GANGOLIHAT FORMATION KATHPURIA CHHINA - RAIKHOLI SECTION.

Sample No.	CaO%	MgO%	Na_2O%	K_2O%	Fe_2O_3%	MnO%	TiO_2%	SiO_2%	Al_2O_3%	Pb	Li	Sr	Ba	Co	Ni	Zn	Cu
R1	31.1	20.36	1.2	0.4	0.576	0.1289	Nil	Nil	Nil	27	3	32	Nil	20	9	48	13
R2	9	7.25	0.75	0.25	0.576	0.2497	0.042	80.17	0.34	19	Nil	6	Nil	4	8	56	7
R3	21.85	10.95	1.2	0.45	0.448	0.015	0.26	13.62	0.34	27	36	34	Nil	20	11	46	15
R4	38.15	1.2	0.85	0.3	0.32	0.0105	0.018	26.52	0.34	33	Nil	56	Nil	20	9	51	12
R5	30.84	3.6	0.5	0.2	0.576	0.0127	0.018	35.2	0.35	35	Nil	62	Nil	16	20	115	31
R7	30.8	21.0	1.2	0.4	0.384	0.0461	0.018	0.8	0.34	27	3	26	Nil	18	8	58	10
R9	2.24	2.41	0.95	8.00	3.136	0.024	0.8162	64.8	17.2	33	18	26	3	26	11	115	15

Table-III

SHOWING DISTRIBUTION OF MAJOR (IN%) AND MINOR (IN ppm) ELEMENTS IN THE MAGNESITE SAMPLES, DHURAPHAT AREA

Sample No.	CaO%	MgO%	Na_2O%	K_2O%	Fe_2O_3%	MnO%	TiO_2%	SiO_2%	Al_2O_3%	Pb	Sr	Co	Ni	Zn	Cu
329	4.6	40.6	0.7	0.7	2.32	0.1053	Nil	2.01	0.6	2	9	21	15	63	13
333	1.96	44.15	0.09	0.2	1.52	0.0885	Nil	3.01	0.3	3	2	15	21	31	8
335	3.64	41.93	0.108	1.0	1.584	0.0924	Nil	2.15	0.3	4	4	18	22	38	37
337	4.08	41.12	0.12	Nil	3.6	0.1242	Nil	2.15	0.3	3	3	21	9	26	13
338	2.52	42.7	0.135	0.1	4.0	0.142	Nil	2.08	0.3	4	2	18	21	36	8
340	2.52	42.3	0.13	0.8	3.74	0.1302	Nil	1.55	0.6	50	3	27	13	27	10
345	7.01	39.1	0.06	1.0	1.24	0.0798	0.004	2.15	0.3	3	10	15	15	32	10
346	4.48	41.12	0.1	0.6	1.18	0.0798	Nil	3.01	0.3	20	7	15	16	40	24
344	6.01	40.12	0.12	0.2	1.31	0.081	Nil	2.08	0.6	4	12	12	19	54	11
347	3.08	41.93	0.1	0.9	1.45	0.1014	Nil	2.15	0.6	15	2	18	15	43	14

Table-IV

RELATIVE DISTRIBUTION OF THE INSOLUBLE RESIDUE IN THE GANGOLIHAT (DOLOMITE) FORMATION

Si. No.	Sample	Weight of insoluble residue	Weight			Percentage		
			Sand	Silt	Clay	Sand	Silt	Clay
1.	VKG 1	64.1130	33.7370	30.2360	0.1400	52.6	47.1	0.23
2.	VKG 3	72.6710	32.0480	39.1030	1.5200	44.08	53.80	2.09
3.	VKG 4	19.7560	9.1090	8.8870	1.7600	41.01	44.90	8.90
4.	VKG 5	36.9690	27.0260	0.7630	8.1800	73.10	2.08	22.28
5.	VKG 6	19.6315	15.3120	3.9595	0.3600	77.94	20.16	1.82
6.	VKG 7	24.9560	10.2620	10.7340	2.9600	45.27	43.85	10.86
7.	VKG 10 (2)	36.4380	14.8080	21.5500	0.080	40.66	59.33	0.005
8.	VKG 11	29.9840	17.9550	11.5090	0.5200	59.87	38.35	1.73
9.	VKG 15	1.5730	0.1545	1.2385	0.0800	9.55	78.34	5.09
10.	VKG 16	34.0020	18.7190	15.1230	0.1600	55.02	44.47	0.47
11.	VKG 18	19.4350	10.0710	7.764	1.600	51.82	39.93	8.23
12.	VKG 20	31.5590	22.9910	7.9680	0.600	72.55	24.24	1.90
13.	VKG 23	5.6855	0.7960	4.1395	0.4600	12.13	72.56	15.30
14.	VKG 24	1.4920	0.2535	1.0785	0.1600	16.60	71.81	11.49

Table-V : Showing the details of the carbonate minerals of the Gangolihat Formation For D.T.A.

Sample No.	Carbonate mineral	Texture and characters	Sample location
1. VKG 1	Dolomite	Light brownish grey (Dolomicrite)	Near the contact with Routgara Formation Kathpuria Chhina
2. VKG 2	Dolomite	— do —	— do —
3. VGR 1	Dolomite	Bluish grey intraclastic oolitic stromatolitic dolomite (oodolomicrite, intrasparite and biolithite)	Kathpuria Chhina-Raikholi Forest Jeep road just near the contact
4. VKG 5	Dolomite	Brownish blue crystalline dolomite	Near the contact with magnesite at Bugari
5. VKG 15	Dolomite	Bluish dolomite (olomicrite)	Near Khankar, Kathpuria Chhina-Bageshwar road
6. VKG 16	Dolomite	— do —	— do —
7. VKG 3	Calcite	Bluish brown calcitic limestone (micrite)	Kathpuria Chhina-Bageshwar road near the contact
8. VGR 4	Calcite	Light grey calcitic limestone	Kathpuria Chhina. Raikholi Forest jeep road
9. 329	Magnesite	Light grey colour magnesite near the contact with dolomite	Bauri (Dhuraphat) area
10. 333	Magnesite	Light yellow colour crystalline magnesite	Girthal near Bauri (Dhuraphat)
11. 338	Magnesite	— do —	— do —
12. 341	Magnesite	— do —	— do —

Table-VIa : X-Ray diffraction data of representative carbonate samples (Calcite And Dolomite) of the Gangolihat Formation

(2 θ in degrees, d in A°)

Sl. No.	Sample No.	2 θ Reflection angle	d	Mineral
1.	V 1	29.8	2.90	Ferron dolomite
		31.2	2.86	Dolomite
2.	V 2	31.0	2.88	Dolomite
		26.5	3.36	Quartz
3.	V 3	29.7	3.00	Magnesian calcite
		26.8	3.32	Quartz
4.	V 4	29.0	3.07	Calcite
		26.6	3.34	Quartz
5.	V 5	30.9	2.89	Dolomite
6.	V 6	31.0	2.88	Dolomite
7.	V 7	30.5	2.92	Dolomite
		26.5	3.36	Quartz
8.	V 8	29.8	2.90	Ferron dolomite
		26.7	3.33	Quartz
9.	V 9	30.5	2.92	Dolomite
		29.5	3.02	Calcite
		26.5	3.36	Quartz
10.	V 10	31.0	2.88	Dolomite

Table-VIb : X-Ray diffraction data of representative magnesite samples of the Gangolihat Formation

Sl. No.	Sample No.	Reflection angle (2θ)	d	Mineral
1.	329	37.5	2.39	Magnesite
		39.0	2.30	
		45.5	1.95	
2.	333	36.3	2.47	Magnesite
		41.5	2.17	
		45.8	1.97	
3.	337	37.4	2.40	Magnesite
		41.4	2.03	
		46.0	1.97	
4.	338	37.5	2.39	Magnesite
		41.6	2.17	
		45.5	1.99	
5.	347	37.5	2.4	Magnesite
		41.5	2.17	
		45.5	1.99	
6.	382	33.5	2.67	Magnesite
		35.5	2.52	
		39.0	2.30	
		40.6	2.22	

Table-VII : STATISTICAL PARAMETERS OF RAUTGARA FORMATION, GANGOLIHAT FORMATION AND BERINAG FORMATION

Sl. No.	Stratigraphic Horizon	Locality	Number of Reading (N)	Mean Vector Azimuth (Q)	Mangitude of Mean Vector (r)	Vector strength (L)	Variance (S^2)	Standard Deviation (S)
1.	Berinag Formation	Bageshwar	30	28	9.712	32.37	61937	248
2.	Gangolihat Formation	Kathpuria Chhina	15	55	6.5	82.4	11484	166
3.	— do —	S.E. of Bageshwar	18	64	12.50	85.5	5288	72
4.	— do —	Asaun	10	40	7.22	90.25	89857	184
5.	Rautgara Formation	Kafligair	30	115	19.50	65.01	4396	66
6.	— do —	— do —	45	125	19.1	42.4	6095	78
7.	— do —	— do —	51	308	31.4	61.71	15251	123
8.	— do —	Kathpuria Chhina	26	19	8.4	34.4	18446	135
9.	— do —	— do —	48	13	33.5	69.9	32649	180
10.	— do —	— do —	80	294	24.69	30.8	16643	129
11.	— do —	— do —	49	341	33.5	68.3	9206	95

EXPLANATION OF PLATE-1

Fig. a: Herringbone (bipolar) cross lamination in the Berinag Formation.

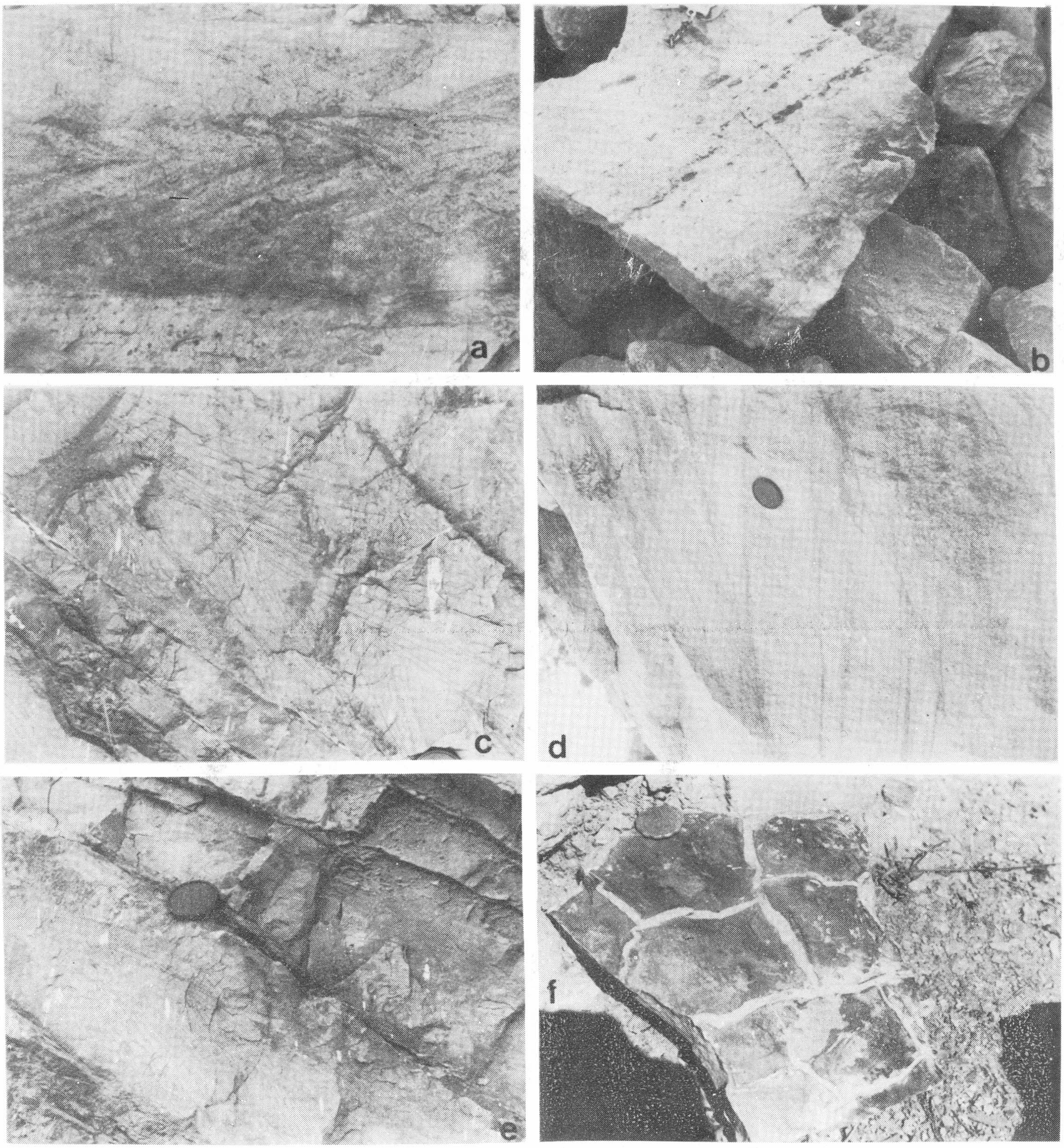
Fig. b: Coarse grained quartzarenite of Berinag Formation.

Fig. c: Large scale cross laminations (herring-bone structure) in sandy units of the Rautgara Formation, Kathpuria Chhina-Kafligair road section.

Fig. d: Large scale cross laminations and low angle discordances in Berinag Quartzite, Bageshwar area.

Fig. e: Small scale cross laminations in the Rautgara Formation.

Fig. f: Polygonal mud cracks in shaly units of Rautgara Formation.

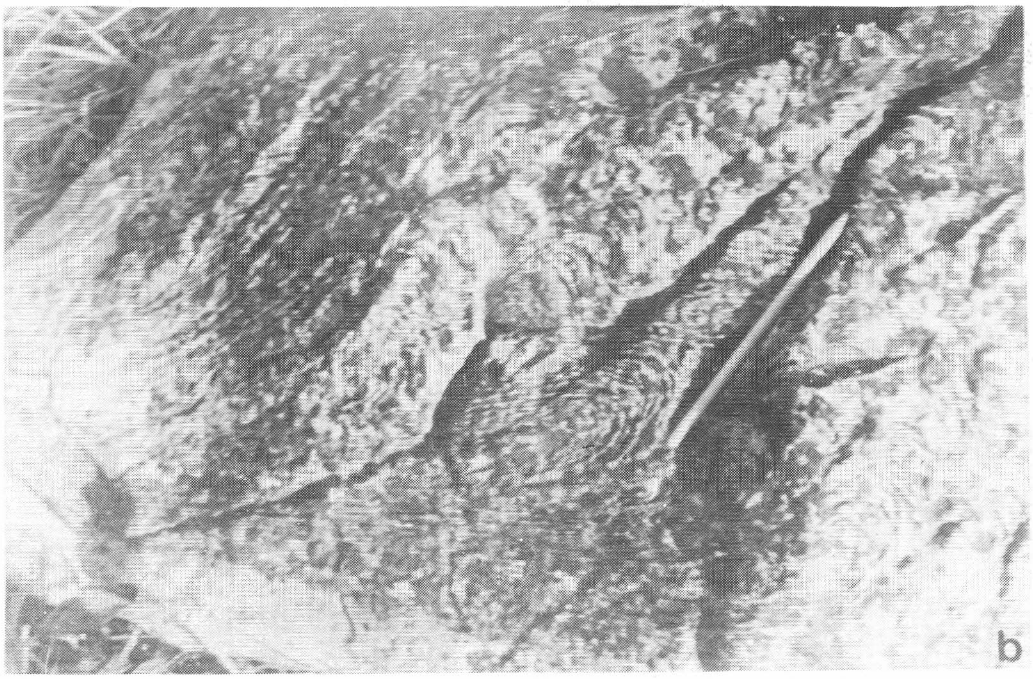

a
b
c
d
e
f

EXPLANATION OF PLATE-2

Fig. a: *Colonnella columnaris* biostrome, Gangolihat Dolomite, Congolihat area showing laminae and columns.

Fig. b: Biostrome of domal stromatolite (*Plicatina antiqua*), Gangolihat Dolomite, Dhuraphat area.

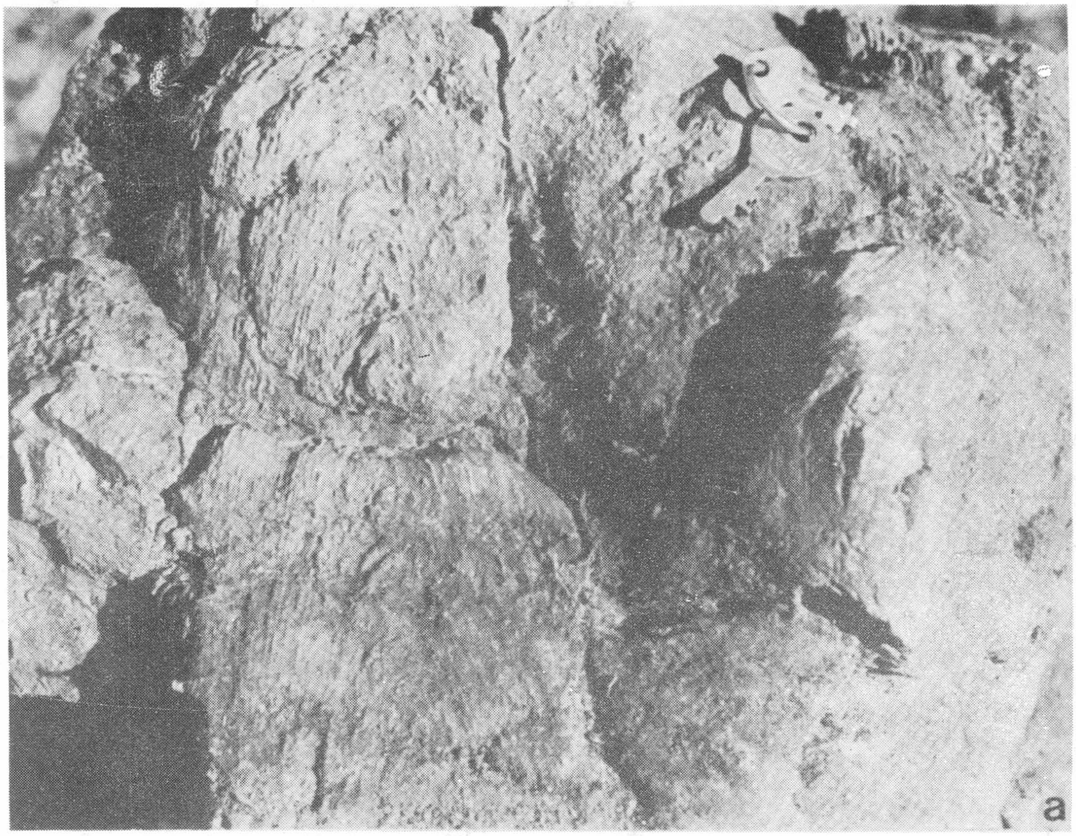

a

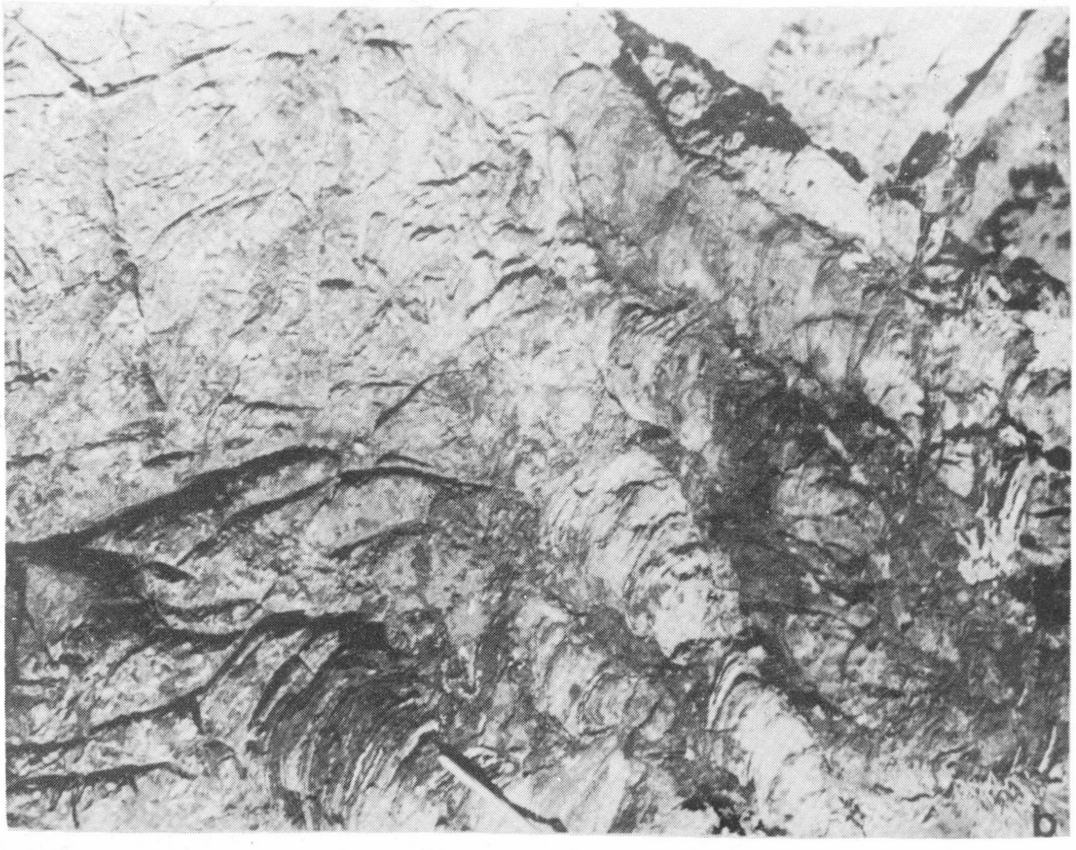

b

EXPLANATION OF PLATE-3

Fig. a: Longitudinal section of *Conophyton garganicus* showing conical laminae, Gangolihat Dolomite, Kathpuria Chhina area.

Fig. b: *Kussiella krylov* biostrome showing columns and nature of laminae Gangolihat Dolomite, SE of Bageshwar.





EXPLANATION OF PLATE-4

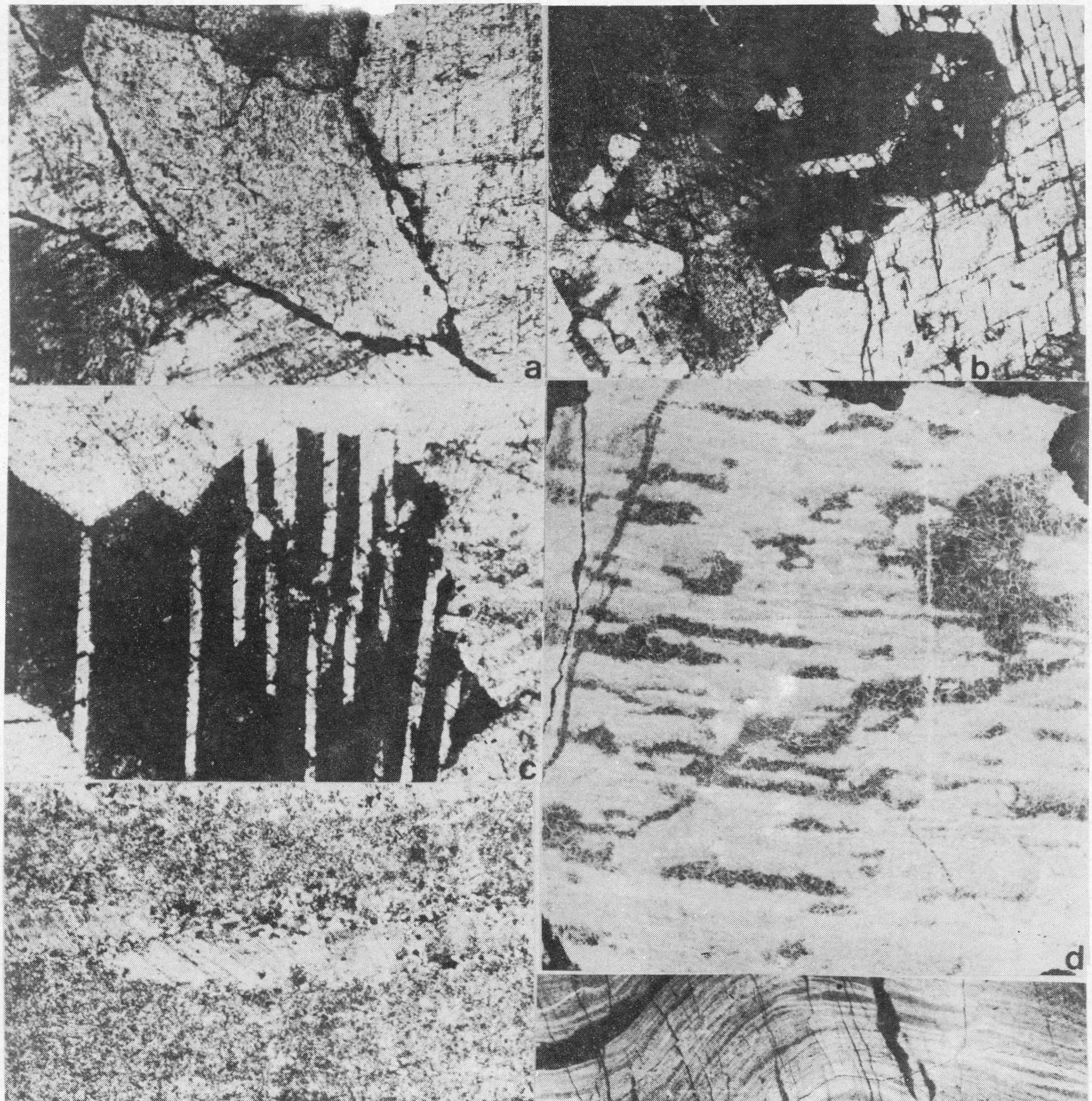
Fig. a: The large coarse grained rhomb of magnesite showing granoblastic texture (crossed nicol, x 63), the Gangolihat Dolomite Formation, Bauri area.

Fig. b: The large grains of magnesite showing inclusions of fine grained dolomite. The Gangolihat (Dolomite) Formation, Guiurthal area.

Fig. c: Magnesite crystals showing honey comb structure (crossed nicol x 63), the Gangolihat (Dolomite Formation, Bugari area.

Fig. d: Microstructure of *Conophyton garganicus* showing inorganic (carbonate laminae) and organic (dark) lamine, Gangolihat Dolomite.

Fig. e: Photomicrograph of the calcilutite showing micritic texture in the Gangolihat (Dolomite) Formation (crossed nicol, x 63), Chhani area.


a
b
c
d
e

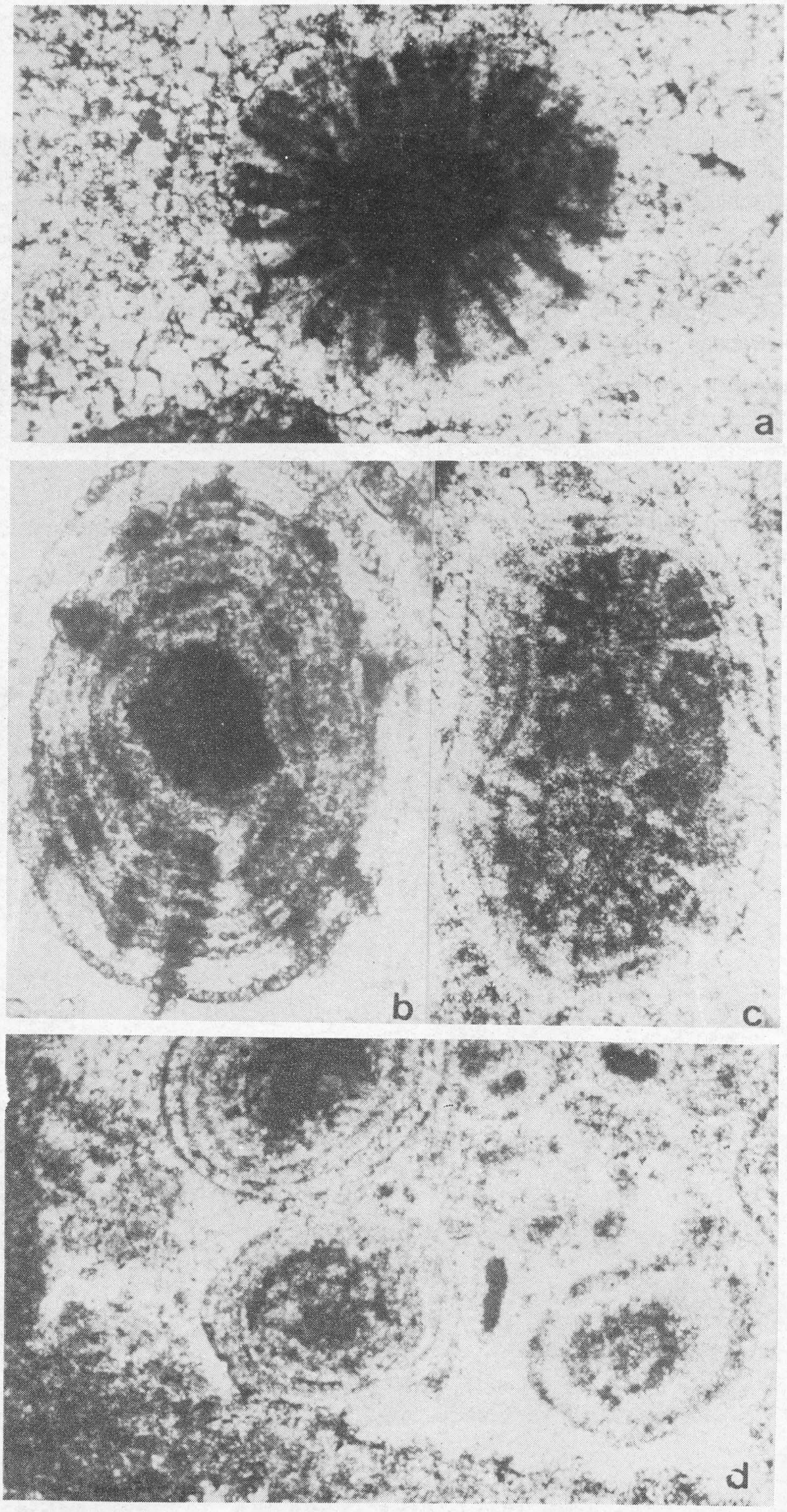
EXPLANATION OF PLATE-5

Fig. a: Photomicrograph of concentric cum radial oolite showing radial fibrous fabric and dolomitization in outer margins (crossed nicol x 64), intraclastic oolitic dolomite, Gangolihat Formation.

Fig. b: Concentric cum radial oolite superimposed over concentric rings and encroaching on the matrix (ordinary light, x 64).

Fig. c: Composite oolite showing two concentric cum radial oolites enveloped by a single rim (ordinary light x 64).

Fig. d: Photomicrograph of concentric oolite embedded in sparry dolomite cement (ordinary light x 32), intraclastic oolitic dolomite, Gangolihat Formation.


a
b
c
d

EXPLANATION OF PLATE-6

Fig. a: Moderate to poorly sorted quartz grains in quartzitic and sericitic matrix showing intergranular recrystallization, the Berinag Formation (crossed nicol x 63).

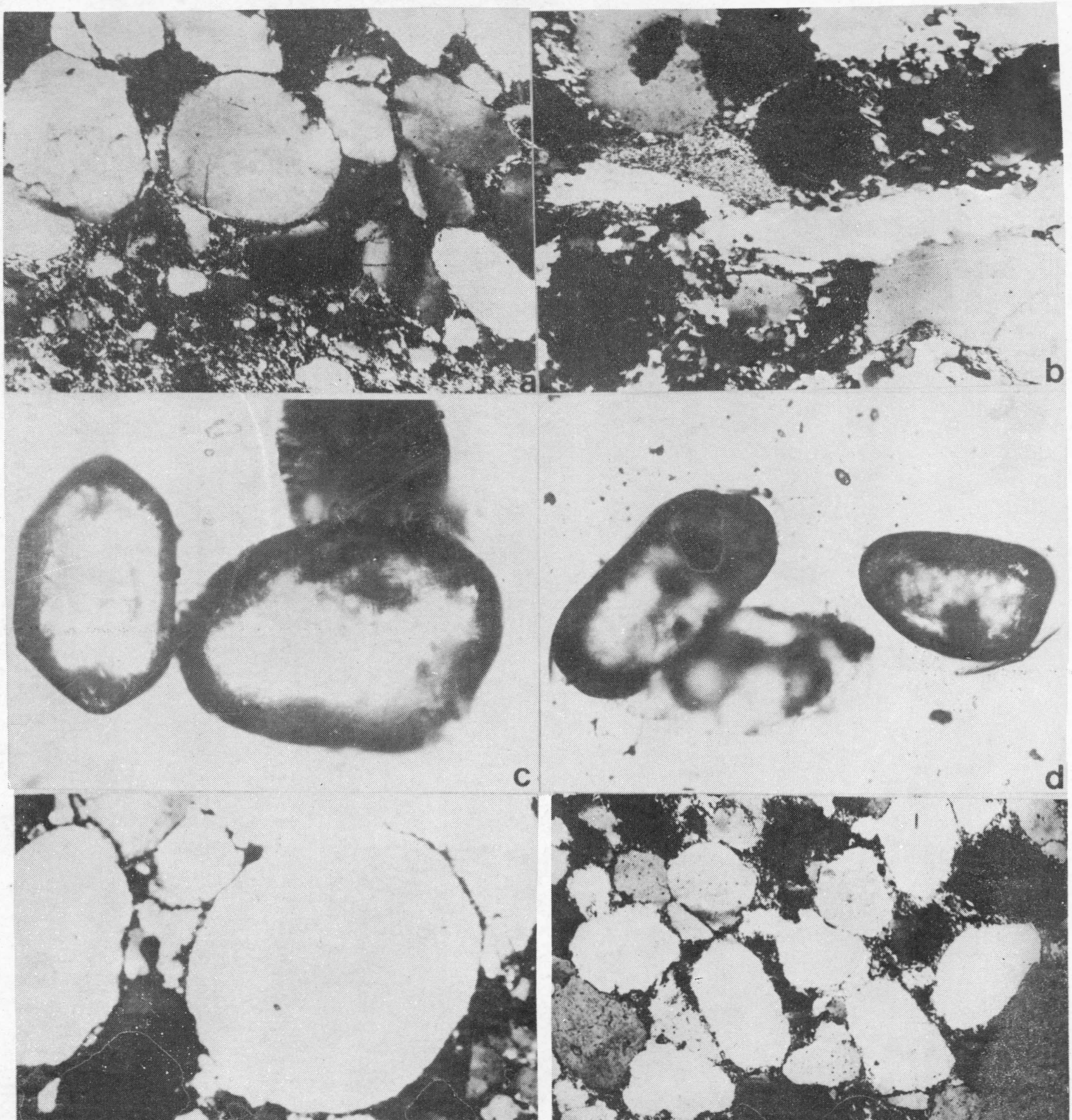
Fig. b: Sericite quartzite showing foliated character and highly stretched quartz grain. The Berinag Formation (crossed x 63).

Fig. c: Photomicrograph showing prismatic and rounded grains of Zircon in quartzaranite of the Berinag Formation (Polarised light x 63) SE of Bageshwar.

Fig. d: Photomicrograph showing subrounded and rounded grains of tourmatline in quartzaremite of the Berinag Formation (polarised light x 63) Naugaon area.

Fig. e: Photomicrograph of well rounded to subrounded moderately sorted quartz grains in the ortho quartzite of the Rautgara Formation (crossed Nicol x 125) Kafligair area.

Fig. f: Subangular to subrounded, well sorted quartz grains in the siltstone of the Rautgara Formation (crossed nicol x 125) Kafligair-Kathpuria Chhina road.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