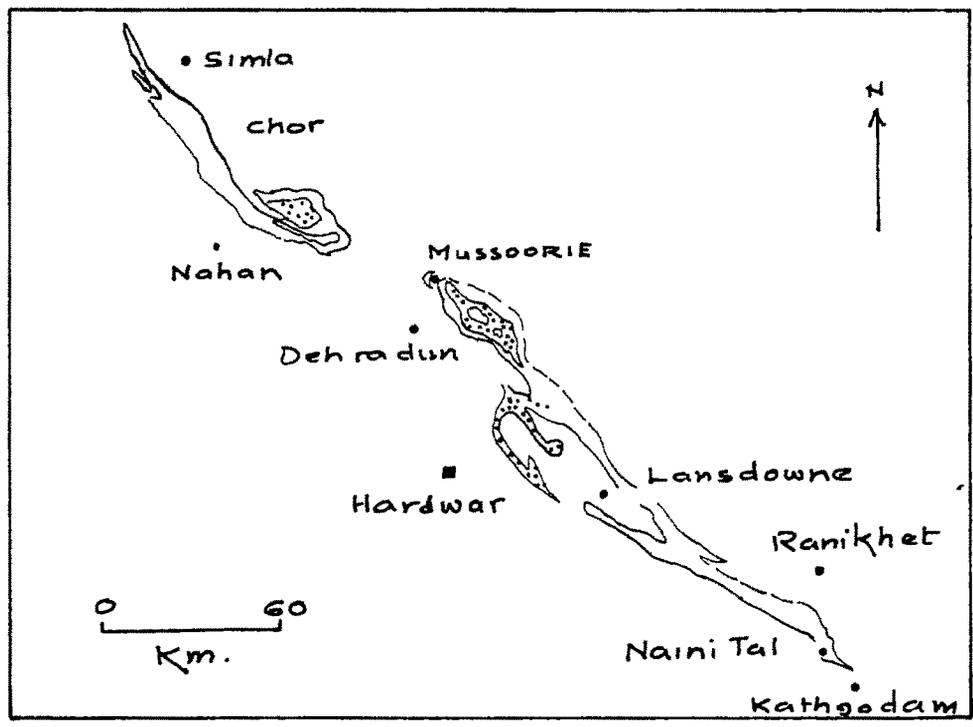


CHAPTER III
S T R A T I G R A P H Y

GENERAL

The Naini Tal area comprises the south eastern extremity of the Krol belt (Fig. 3.1), and its rocks compare fairly well with those of the type area which have been described ideally by Auden (1934). Though many workers investigated the geology of the Naini Tal in the past, none made any serious attempt to study these Krol belt rocks in as much detail as that done by Auden in the Simla-Chakrata area. In Naini Tal area and its neighbourhood, these rocks show excellent exposures and interesting lithology. Perhaps the

POSITION OF NAINITAL IN KROL BELT
(modified from Tewari & Ramesh)
(1968)



Tal formation



Blaini - Infra-Krol - Krol formations

structural complexity of this region prevented workers from going into the details of the lithology and stratigraphy. The author had the opportunity to collect considerable data including that on structure, and hence, he has been able to work out for the first time a fairly convincing stratigraphical picture of the Naini Tal area.

So far as the broad stratigraphic outline is concerned, he has relied mainly on the work of Auden and Heim and Gansser, but in matters of detailed interpretation, the author's conclusions are at some variance with the previous workers. One of the most important aspect of stratigraphy on which the author has differed from Heim and Gansser (1939) is that of the age of lower most quartzitic rocks of the area. According to these two workers, they are Nagthats while the author has considered them as equivalent to the Blainis. There are certainly no evidences to consider these quartzites as of Nagthat age, while on the other hand the various lithological criteria^a very conclusively put them as Blainis. The author has, at appropriate places discussed these evidences. Further, in working out the stratigraphy, the author has taken into account the two important structural considerations. Firstly, the area shows two

episodes of folding, the synclinal structure of Naini Tal belonging to the second fold episode. The first folds are represented by a pair of anticline and syncline, over which the Naini Tal syncline has been superimposed. The author has found that the Bhowali anticline in the east belongs^{to} this early fold episode. Secondly, the slaty cleavage developed during the first folding and it was affected by the second folds. These structural aspects were brought out by none in the past, and generally the Naini Tal syncline was taken to be a complimentary to the Bhowali anticline.

The author's mapping has further discounted the so called "large scale" slipping and sliding of rock masses, envisaged by Thomas (1952) and Gansser (1964). Of course, the area is considerably faulted, but not so much as to obscure its correct interpretation. In fact, the author has found that apart from some complexities imparted due to the inversion brought about by first folds and some vertical displacements along faults, there is nothing to suggest that the Naini Tal area is all broken up.

The various structural details of the area have been discussed later (Chapter IV) and in this chapter,

the author has confined himself exclusively to the stratigraphic and lithologic details of the various formations (Fig. 3.2).

The author's study and correlation of the stratigraphy of the area is based on the field observations and petrographic characters of the various rocks from all over the area. He has found that the various formations, typically represent an almost complete sequence Blaini - Infra-Krol - Krol which is pushed over Siwaliks along the Krol thrust. The different formations of this sedimentary sequence show variation within themselves, thus giving rise to a number of lithological types recognisable in the field. The formations comprise numerous calcareous, argillaceous and arenaceous units. These units show widespread occurrence of sedimentary structures; cross bedding and ripple marks are quite common in quartzites, Shales and slates show their primary laminations. Bedding is quite conspicuous in limestones. These sedimentary structures proved very useful in understanding the correct stratigraphic picture.

STRATIGRAPHIC SUCCESSION AND LITHOLOGY

The various rock formations of the area are as under:

- (4) Siwaliks
- (3) Krols
- (2) Infra-Krols
- (1) Blainis.

These are seen cut by a number of post-thrusting mafic igneous rock-bodies.

The generalised stratigraphic succession is as follows:

<u>Formation</u>		<u>Lithology</u>	<u>Thickness</u>
Siwalik		Sandstones and shales	?
	Upper	(iv) Oolitic (Siliceous) limestones	60-120 m
		(iii) Dolomitic limestones	200-300 m
Krol	Lower	(ii) Red shales (slates with thin bands of limestones)	60-120 m
		(i) Thinly bedded limestones with intercalated slates	120-250 m
		(iii) Pebbly quartzites and slates interbedded	60-120 m
Infra-Krol		(ii) Slates silty slates and quartzites interbedded	120-200 m
		(i) Purple and carbonaceous slates	30-60 m
Blainis		(ii) Purple and red slates with limestone	10-30 m
		(i) Pebbly quartzites and sub-greywackes	120-200 m

----- Unconformity -----

Blainis are resting over the foliated traps.

Blaini Formation

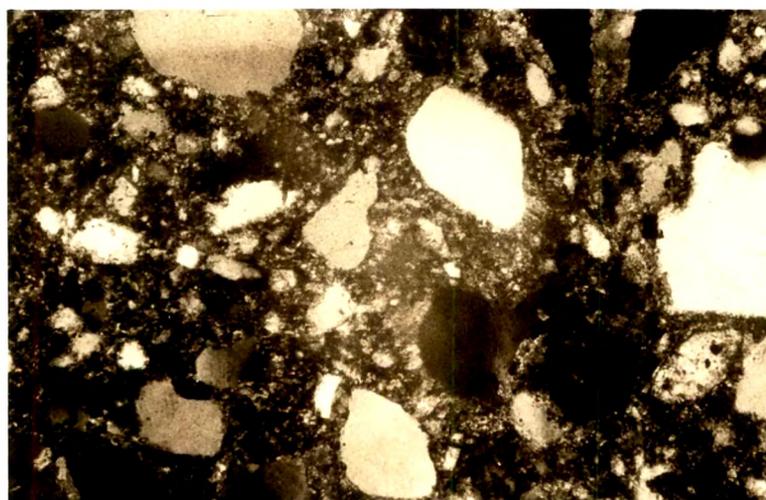
The pebbly quartzites, intercalated with slates and lenses of limestones, that occur in the NE, have been considered as equivalent to the Blainis. Heim and Gansser (1939) thought that these were Nagthats, but the author is not inclined to accept the above correlation, because these rocks show a lithology that compares very well with the typical Blaini formation. Moreover, the slates of this formation grade imperceptibly without any break, into the overlying Infra-Krols.

This formation is represented by its two upper members. The lowermost boundary beds, lie outside the limit of the study area, and have been reported by C.P. Shah (personal communication) from the Garampani-Khairna bridge area in the NE.

Of the upper two, the lower member is dominantly of pebbly quartzites with thin layers of grey slates. These quartzites contain sub-angular to sub-rounded large fragments (1 cm to 6 cm) of greenish quartzite, quartz, red shales etc embedded in a gritty variable matrix (Plate 3.1). A few samples contain fragments of the underlying foliated trap also (Plate 3.3). In thin section (Plate 3.2), the matrix itself shows considerable

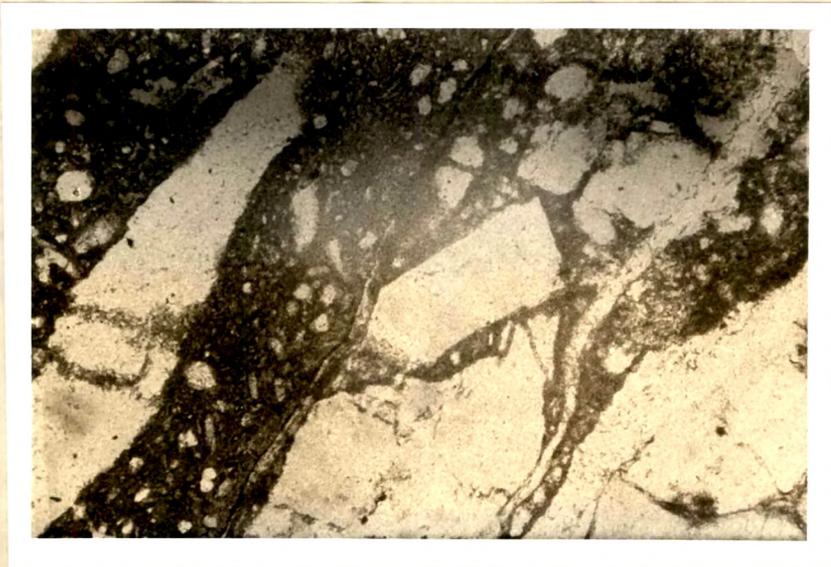
PLATE 3.1

Pebbly and gritty quartzite - Blaini
(Loc. 4 km NE of Naini Tal)

PLATE 3.2

Heterogeneous immature matrix of
pebbly quartzite (Photomicrograph:
cross nicols, X45)

PLATE 3.3



Trap fragments in pebbly quartzites
(Photomicrograph: cross nicols, X45)

heterogeneity and is seen to be made up of small fragments of quartz, quartzite, slate, jasper, agate and feldspars cemented by argillaceous and calcareous material. Due to some recrystallisation, the cement is now seen to consist partly of mica and calcite crystals. On the whole, the rocks betray immaturity, their sorting being very poor. From the lithology point of view, many of these rocks could better be called a "sub-greywacke".

The upper part of the Blainis consists of purple and red slates with a limestone horizon at the top. The slates are continuously exposed, while the limestone within them is seen to be^a discontinuous lensoid. The limestone has been found to be dolomitic and its thickness never exceeds 30 metres any where in the area. The association of dolomitic limestone and red slates is yet another evidence to suggest that this formation is similar to the Blainis of other areas in Himalayas.

The Blainis pass upward into Infra-Krol formation without any break or discordance, and in the field, it is rather difficult to separate them. However, an arbitrary line of separation above the limestone keeping in mind the type area has been put by the author.

The Blainis form a prominent belt in the north-eastern part extending roughly NNW-SSE with westerly dips.

Infra-Krol Formation

The purple and red slates that overlie the Blaini limestone, belong to the Infra-Krols. In the study area, this Infra-Kro formation, on the basis of field occurrences can be divided into following three horizons (members):

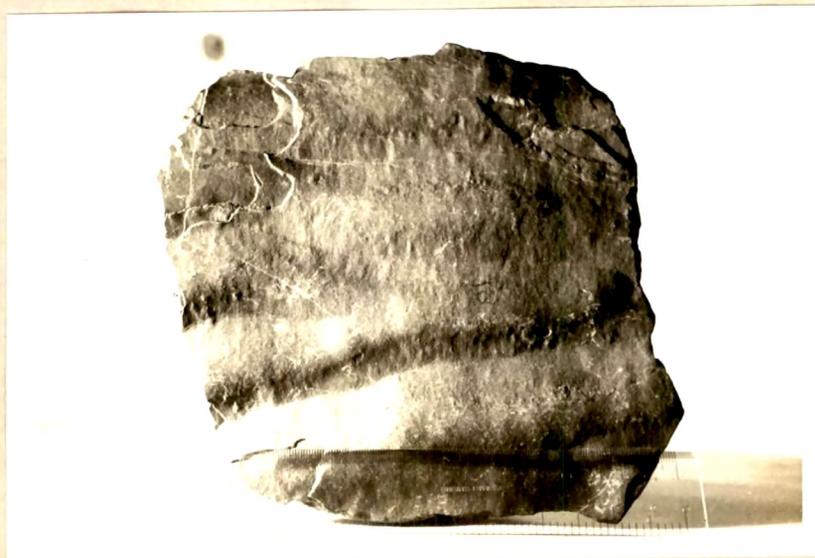
- (iii) Pebbly quartzites and slates,
- (ii) Carbonaceous slates, silty slates and quartzites,
- (i) Purpole and carbonaceous slates.

The lowermost member of the Infra-Krol consists of purple and carbonaceous slates which conformably overlie the limestone (lenses) of Blaini. In fact, these slates are in no way different from those of the underlying Blaini slates, and wherever the limestone has pinched out, the demarcation cannot be made. These slates are very well cleaved and do not show any sedimentary bedding. The total thickness of this slaty horizon varies from 30 to 60 metres. The slates are well exposed around Dunikhal and Pangot villages in the N and NW. The lower part of the horizon is dominantly purplish, while the upper is carbonaceous. The carbon content tends to increase upward, and in the uppermost part, these slates soil the fingers. Yellowish limonitic encrustations are commonly observed on the surfaces of these slates.

The carbonaceous slates of the middle (member) horizon are grey and sheeny and alternate with quartzite layers. Various layers of intermediate lithology can best be described as silty slates. The layers of slates of carbonaceous and silty slates are easily recognised by their hardness and colour variation in shades of grey. The quartzites tend to be brownish. This interbanding is ideally seen in the hills of Dunikhal and Ghungua and on the NE slopes of Lariakanta peak. Quartzites show good bedding and possess sedimentary structures like ripple marks and current bedding (Plate 3.4, 3.5 & 3.6). The carbonaceous slates on weathering give rise to yellow concentric rings of limonite, the parent mineral of which must have been pyrite. Thin sections of carbonaceous slates reveal very little except the carbonaceous dust with other faint argillaceous matter showing a slaty texture. The siltstones show a somewhat coarser texture and tiny granules of quartz are identified. The carbon content is seen to gradually decrease upward. Thin sections of the quartzites show considerable variation in the grain shape and size. The outlines of the grains are generally smooth and only occasionally sutured. The rock does show some recrystallisation but the original size and shapes of the

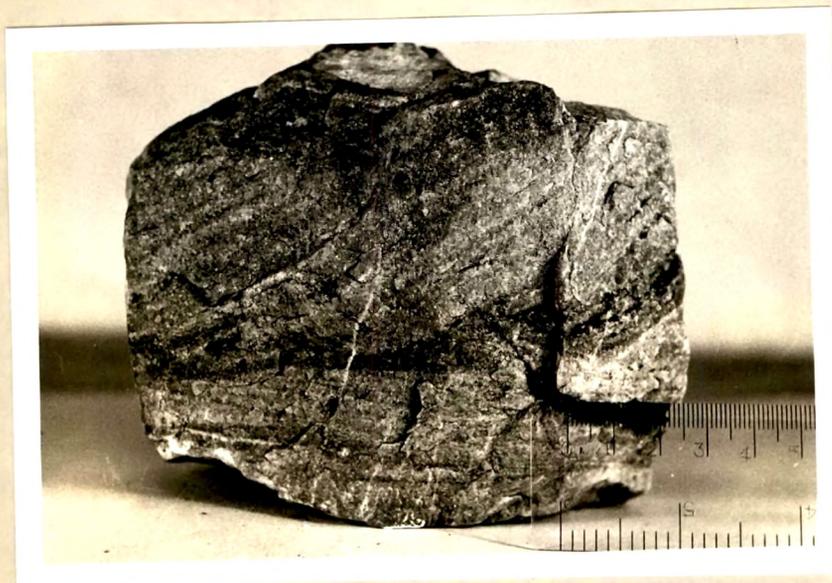
PLATE 3.4

Infra-Krol quartzite showing well marked sedimentary bedding (Loc. Pines, 3 km E of Naini Tal)

PLATE 3.5

Infra-Krol quartzite showing ripple marks. (Loc. Gainthia, 2 km E of Naini Tal)

PLATE 3.6



Infra-Krol quartzite showing current bedding
(Loc. Gainthia, 2 km E of Naini Tal)

quartz grains are not totally obliterated. The cementing matrix is fine chlorite. Occasionally, bigger fragments of slates are also seen embedded in these quartzites. Grains of zircon, tourmaline and hematite comprise the heavy minerals.

The uppermost member of Infra-Krol consists of quartzites with layers of purple slates. These are well exposed in the Lariakanta and Chorsa ridges. The quartzites are pebbly. This horizon shows a total thickness 60-120 metres being maximum at the Chorsa village. These Infra Krol rocks occupy a synclinal core and as such show unusual thickness. Slaty beds are quite frequent, but the total quartzite-slate ratio never exceeds 60:40. The slates and quartzites show considerable interfingering. The individual quartzites beds, are 10 to 15 cm thick, have preserved good sedimentary structures, and tend to taper off laterally in slates, while the same is true for slates within the quartzites.

The thin sections of the matrix of the pebbly quartzites show sandy to argillaceous material. When sandy, it is seen to consist of an aggregate of quartz grains of variable size, cemented by silica. Wherever

the matrix is semi-pelitic, the recrystallisation has given rise to slender flakes of chlorite and sericite which occurs around and in interstices of quartz grains. The bigger grains are usually of quartz, but quite often those of slates and jasper too are recorded (Plate 3.7, 3.8). Occasional tiny grains of zircon and tourmaline are also met with.

Krol formation

The Krol formation of the Naini Tal area has been divided into two parts - Lower and Upper. The Lower Krols are dominantly argillaceous limestones while the upper are massive dolomitic and oolitic limestones.

The Krol formation in the study area comprises four members:-

	⊖	(iv) Oolite limestone
Upper Krol	⊖	(iii) Dolomitic limestone
	⊖	(ii) Red shales (slates)
Lower Krol	⊖	(i) Thinly bedded limestone
	⊖	with intercalated slates

Lower Krols: Lower Krol rocks overly the Infra-Krols rather conformably and are represented by slates and thinly bedded shaly limestones (Plate 3.9).

PLATE 3.7

Infra-Krol pebbly quartzite showing pebbles of quartz and slates (Loc. Gainthia, 2 km E of Naini Tal)

PLATE 3.8

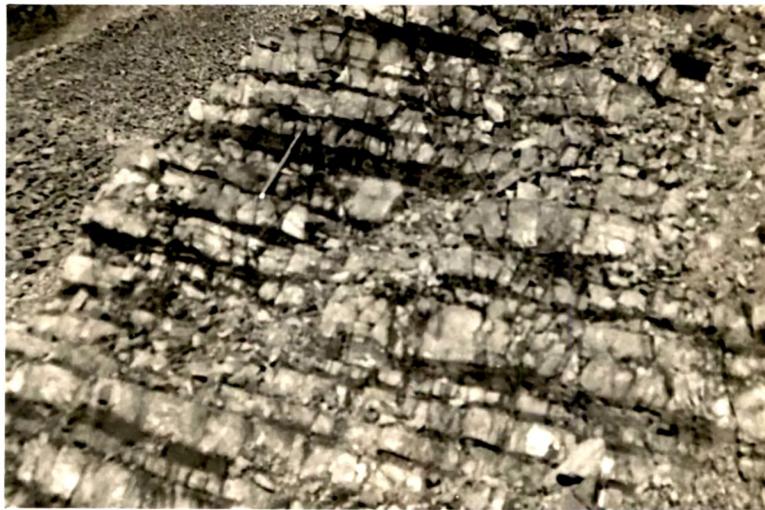
Infra-Krol pebbly quartzite showing rounded to sub-rounded quartz pebbles. (Loc. Gainthia, 2 km E of Naini Tal).

The rocks of the member (i) i.e. Thinly bedded limestone with intercalated slates show extensive outcrops all around the Naini Tal lake except in the south. This member consists of alternating layers of limestones and slates. The individual beds never exceed 10 cm in thickness (Plate 3.10). The limestone is of greyish blue colour though on weathered surfaces, it shows greenish tint. Development of a strong fracture cleavage, oblique to the bedding is a very characteristic feature of the limestone beds (Plate 3.11). The limestone is frequently traversed by calcite veins. Variegated slates of many hues—purple, green, grey and brown, rapidly alternate with the limestone beds. These slaty layers vary in thickness from 5 to 15 cm. In addition to a strong slaty cleavage, these argillaceous rocks abundantly show sedimentary laminations, the latter often making a wide angle with the cleavage (Plate 3.12).

The variation in colour in the slates is so rapid and frequent that sometimes a single specimen may possess all the colours. The various hues are clearly due to (i) the variation in the calcareous content and (ii) different degrees of oxidation of iron. These slates are ideally exposed along the slopes of the Sherka Danda ridge (i.e. the NE side of the Naini Tal Lake).

PLATE 3.9

Thinly bedded limestone of Lower Krol
(Loc. Northern slope of China peak)

PLATE 3.10

Limestones and slates interbedded.
(Loc. South of Ayarpatha ridge)

PLATE 3.11



Fracture cleavage in Lower Krol limestone.
(Loc. 1 km NW of Naini Tal)

PLATE 3.12



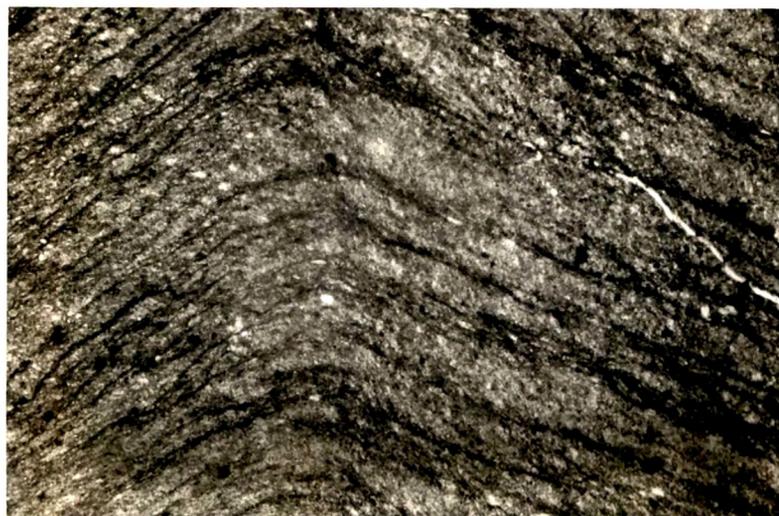
Argillaceous limestone showing sedimentary
lamination and well developed cleavage.
(Loc. Northern slope of China peak)

An important structural feature of these slates is their extensive puckering and microfolding. Quite often, a crenulation cleavage characterising the axial plane of the microfolds is recorded (Plate 3.13).

The upper member of Lower Krols (i.e., Red shales) is characterised by soft, thinly laminated slaty rocks. The author has preferred to call this member as 'Red Shales', following the name given by Oldham (1888) and Auden (1934) to these rocks in the type area. In fact, this member of the Krol sequence is almost continuously encountered all over the Krol belt and has been used by all as a marker horizon. The dominant rock is a red coloured slate with small lensoid, blotches and thin layers of green colour. The red colour also show variation in its tint from light to deep.

This horizon is well exposed along the southern slopes of Sherka Danda, China Peak and on the southern face of the Ayarpatha ridge. The upper part of this member contains thin bands of limestone, ~~which occur as small~~ ^{lenses} limestone, which occur as small lenses, a few cm thick and never extending beyond 50 metres, wedging laterally.

The slates show good lamination and slaty cleavage, the two quite often being oblique to each other.

PLATE 3.13

Microfold in Lower Krofs slate.
(Photomicrograph: cross nicols, X45)

In thin sections these rocks show a parallel arrangement of tiny micaceous flakes in an argillaceous matrix. The parallel arrangement of micaceous flakes mark the slaty cleavage (Plate 3.14).

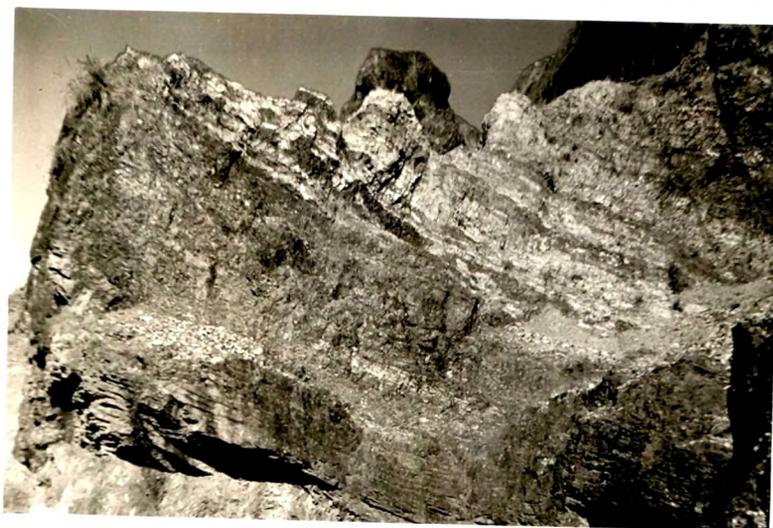
At the south face of the Ayarpatha, because of the steep bare scarp, these slates are ideally seen underlying the upper Krol limestones. This massive limestone rests over cleaved slates gives an erroneous impression of discordance (Plate 3.15). Actually the contact is a normal lithological one.

Upper Krols: These comprise the uppermost horizons of the study area, and are almost totally made up of limestones.

The Dolomitic Limestones (member iii) thickly bedded massive (Plate 3.16) resting conformably over the Red Shales of Lower Krols. The contact seen along the south face of Ayarpatha ridge, has been described as a thrust plane by Thomas (1952) and Gansser (1964), but the author found that it is not so. The massive and hard nature of the limestones has given rise to a scarp, and the underlying Lower Krol slates show a slaty cleavage which makes some angle with the bedding, and these two factors give an impression of tectonically disturbed contact.

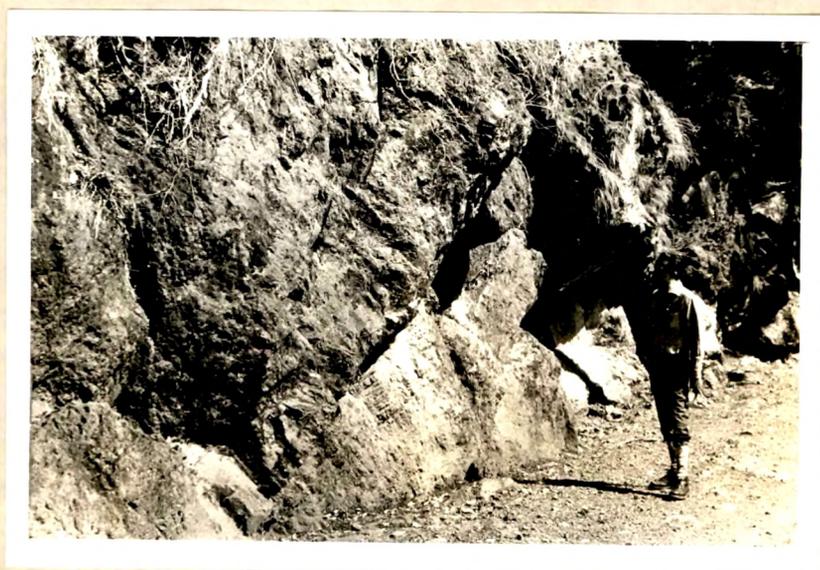
PLATE 3.14

Texture of Lower Krol slate
(Photomicrograph: cross nicols, X45)

PLATE 3.15

Upper Krol limestones giving an impression
of discordance with the underlying slates.
(Loc. South of Ayarpatha ridge)

PLATE 3.16



Massive limestones of Upper Krol.
(Loc. Ayarpatha ridge)

These limestones are of bluish grey colour, with a pitchy lustre. Generally they are medium to fine grained. Bedding is preserved but is not very conspicuous. The individual beds are of 2 to 3 metres thickness and between two beds occur thin slaty layers of 5 to 10 cm thickness (Plate 3.17). The slates are easily recognised by their cleavage and greyish colour.

These limestones do not give effervescence with acid. Gypsum pockets and calcite veins are frequent in these limestones. Staining with Alizarin red S, has indicated that the carbonates are both calcite and dolomite.

In thin sections, these rocks show a finegrained crystalline equigranular mass of calcite and dolomite. The grains are too small to show any twinning etc.; staining has revealed their true nature, quartz grains are present in grey patches (Plate 3.18).

The dolomitic limestones when followed upward become more siliceous and oolitic (member iv). Of course, this distinction could not be observed in the field, and the oolitic nature of this uppermost part of the Krol formation, was established with the help of thin sections. The

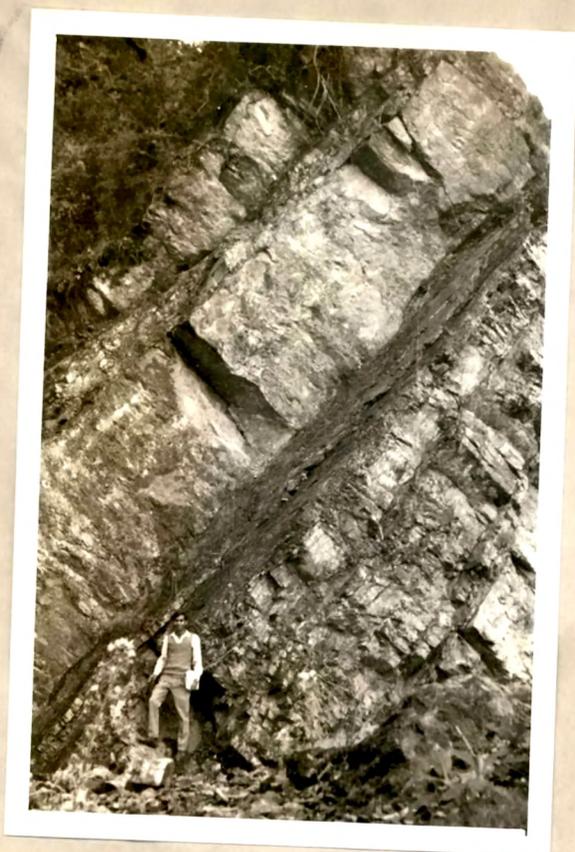
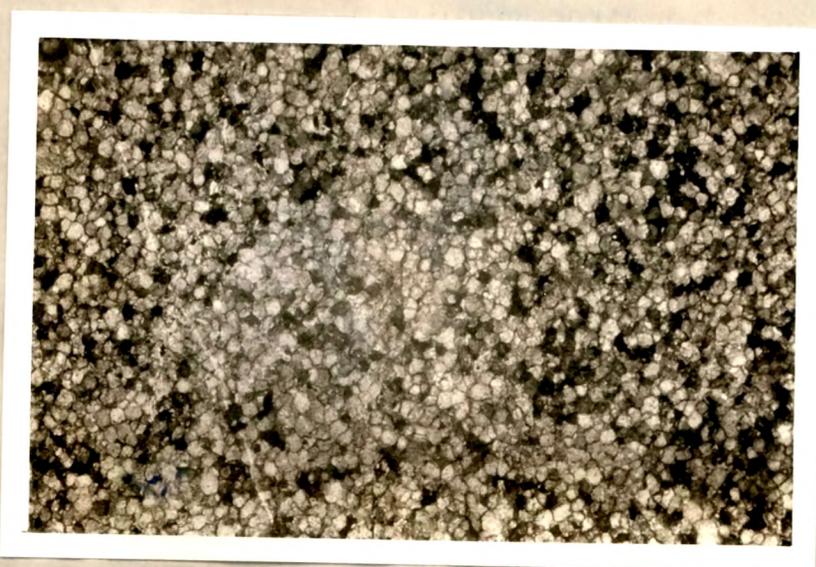


PLATE 3.17

Upper Krol limestone with
thin slaty layers.
(Loc. Ayarpatha ridge)

PLATE 3.18

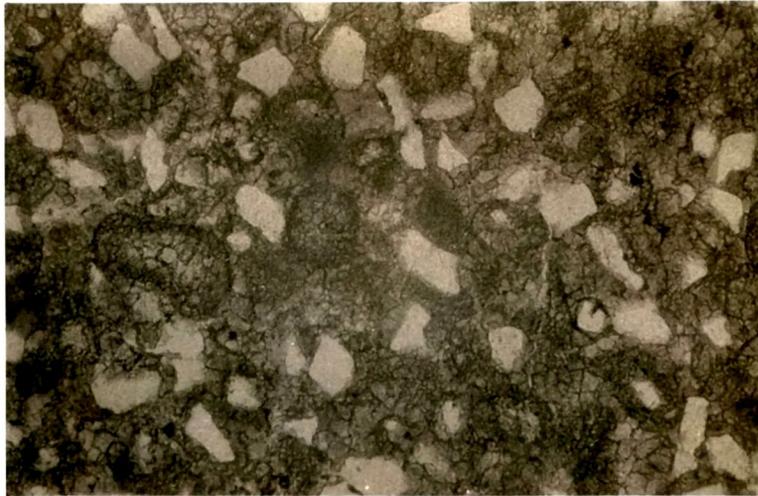


Fine grained equigranular texture of Upper
Krol dolomitic limestone. (Photomicrograph:
cross nicols, X45)

limestones of this member are greyish in colour, bedding being not very prominent. In thin section, these limestones show typical oolitic structure and are seen to consist almost entirely of oolites. Within the oolitic mass are seen interspersed sub angular grains of quartz. The quartz content is quite variable. The oolites are sub-spherical to oval in shape, 0.5 to 1.0 millimeter in diameter, fairly uniform in shape and size. The oolites are concentric and show that they have grown outward from a centre, this growth having taken place around nuclei of detrital quartz sand grains. The boundaries of oolites are sometimes vague. The cement is of calcite (Plate 3.19 & 3.20)

The author has observed that even within this member occasionally the oolitic structure is absent and in such non-oolitic limestones quartz content considerably increases (~~Plate 3.20~~).

This oolitic member is indicative of very shallow depositional condition, and it is likely that in the Naini Tal area, no deposition took place after this oolitic upper Krol member. Perhaps this explains the absence of Tal formation in this area.

PLATE 3.19

Oolitic structure in Upper Krol limestone.
(Photomicrograph: polarised light, X45)

PLATE 3.20

Oolitic structure in Upper Krol limestone.
(Photomicrograph: polarised light, X45)

Siwalik formation

[The Siwalik rocks occur across the Krol thrust in the southern part of the area and constitute the autochthonous zone.]

[The Siwalik system represents a depositional sequence of Middle Miocene to Lower Pleistocene, having originated in the long narrow depression formed in front of the rising Himalaya.] Most of the sediments were derived from the denudation of the newly risen mountains to the north. The system thus is made up of sandstones, grits, conglomerates, clays and silts having characters of fluvial deposits of torrential streams and floods in shallow fresh-water basins. Siwaliks typically represent a 'molasse' formation, over 5000 m thick. This system is noted for its rich vertebrate mammalian fauna. On lithological and faunal grounds the Siwalik system has been sub-divided into three main groups, Lower, Middle and Upper Siwaliks. This three fold division of the sub-Himalayan section is recognised in most of the sub-Himalayan sections, a rather surprising fact considering their fluvial nature of the deposits.

The age given to the Siwaliks depends so far entirely on their prolific vertebrate faunas (mainly mammalian) and the correlation of these faunas with dated sections elsewhere.

Their age is given below:

	Upper	Upper Pliocene to Lower Pleistocene
Siwaliks	Middle	Upper Miocene to Middle Pliocene
	Lower	Middle to Upper Miocene

[Taking into account the lithology of the Siwalik rocks of the study area, they have been considered equivalent to the Lower Siwaliks. The prevalent rocks are medium to coarse grained, friable, micaceous sandstones of greenish grey colour. There are ^unumerous intercalations of shales of red and violet colour. While the sandstone beds vary in thickness from 1 to 5 metres, the slaty layers are hardly 30 cm thick at the maximum.]

[In thin section, the sandstones show a coarse texture, and consist mainly of quartz grains. Biotite, muscovite and chlorite are the main micas. Stray grains of garnet, zircon and tourmaline are also common. Other accessory minerals are epidote, apatite, rutile and sphene. The quartz grains do not show any strain shadows, nor ^{do} they show any recrystallisation.]

[These rocks are well exposed nearly all along the road from Baldiyakhan to Jeolikot. Sandstones and shales can be well seen at Phagania Khet Malla, Kulaithi and Patwadungar.] The sandstones show well preserved sedimentary bedding. Sometimes cross bedding is also seen.]

Mafic Intrusions

These mafic bodies have been recorded from the Krol nappe only. Most of them occur in the form of sills but some cut across the bedding and the cleavage to form dykes. In the field, they are recognised easily by their appearance and mode of occurrence.

A prominent 60 metres wide sill of epidiorite is seen to occur in the Upper Krol limestones trending E-W nearly. This is exposed at 5 places, viz, Timalpani; Adhaura, Gahari Khet, Chorkhat (these 4 places lie at the Deopatha hill) and near Lend's end at Ayarpatha hill. The author has named it as Adhaura sill. In the field, this is nearly parallel to the bedding of upper Krol limestones and is not much weathered. It is greyish green in colour. Its total length is nearly 4 km. Another prominent body, a dyke of epidiorite is seen intruding the Lower Krol limestones at Snowview, Lalpani, in the Kilbury Nainital road section and near Pali village. It is 20-50 metre thick and cuts across the bedding. It extends E-W for about

3 km. This doleritic dyke has been referred to as Palidyke. One more relatively thicker, doleritic dyke occurs at Jaultimli hill. It intrudes the Infra-Krol slates and forms a small hillock. The thickness is nearly 80 metres but it does not extend beyond the two nalas on either side. The author has named it as Jaultimli dyke.

A very small sill of only about a metre thickness is met with on the road to Government house at Ayarpatha ridge. It is a very fine grained basaltic rock, and exposed in a road cutting. It does not extend beyond a few metres, it has been referred to as Tiffin Top sill.

A thick sill of 80 metres is also seen at Patli village. This is named as Patli sill. It extends NNW-SSE for 200 metres.

The author could make only a very preliminary study of mafic rocks, as detailed and exclusive attention to these intrusives was beyond the scope of the present study. He has therefore given below in outline, the petrography of the mafic rocks.

These intrusives are seen as greenish grey to dark grey, compact rocks medium to fine grained. Under the

microscope, they have been identified as coarse to fine grained dolerites, showing ophitic to sub-ophitic texture. In coarser varieties tabular laths of partly altered plagioclase are seen enclosed wholly or partly within the pyroxene. Fine grained variety tends to show a basaltic texture comprising needles and slender laths of plagioclase embedded in a groundmass dominantly of pyroxenes.

Plagioclase is labradorite (An_{35-45}), forms prismatic and tabular subhedral laths, which show a combination of carlsbad and albite twinning. The feldspar shows much alteration to either saussurite or sericite. The degree of alteration is not uniform. Augite occurs as subhedral plates, partly or wholly enclosing the plagioclase laths. It is light pink in colour, non-pleochroic and shows typical two sets of cleavage. It is also considerably altered. Hematite and magnetite are the other primary minerals which occur as stray patches and grains. The remaining minerals epidote, chlorite, sericite, uralite, apatite and calcite are the secondary minerals derived from the alteration of the pyroxenes and feldspars (Plates 3.21 & 3.22).

These rocks show considerable hydrothermal alteration, but no effect of deformation is seen on them anywhere. This

PLATE 3.21

Doleritic texture of mafic rock
(Photomicrograph: cross nicols, X45)

PLATE 3.22

Coarse basaltic texture of mafic rock
(Photomicrograph: cross nicols, X45)

clearly points to their intrusion at a date later than all the tectonic events.

DEPOSITIONAL HISTORY OF KROL GROUP

The various rock formations, it is seen, right from Blaini to Krol, comprise an almost unbroken depositional sequence. No where the formation boundaries could be convincingly placed. Obviously, the entire sequence forms a single lithostratigraphic group. Bhattacharya and Niyogi (1971) have rightly included Blainis, Infra-Krols and Krols of the type area into one single lithostratigraphic unit - the Krol Group. They have found (1971, p.182) that the entire succession, starting with Blaini and ending with Krol D formation, shows close stratigraphic association, absence of marked unconformities, somewhat related environments of deposition and continuity of depositional history. Bhargava (1972, p.58) describing the Krol belt rocks has written "The Blaini formation undoubtedly marks a major unconformity in this part of the Himalaya. The Blaini formation passes without break into the Infra-Krol formation in the Krol belt region."

The Krol belt rocks of Naini Tal area too show almost identical depositional history. The oldest formation, viz. the Blaini, mainly comprises pebbly quartzites and sub-greywackes. This lithological association typically represents a shallow-water marine environment of deposition, ranging between littoral and infra-littoral zones under tectonically unstable conditions (Krumbein and Sloss, 1963, p.510-11). The presence of various sedimentary structures including cross-bedding and ripple marks indicate the influence of current or wave action which further supports the shallowness of the water (Pettijohn, 1957, p.313). Blainis here do not appear to be glacial or fluvioglacial. Though, within the limits of the study area, no boulder beds occur, a little outside the area, in the north, around Garampani-Khairna Bridge, the lowermost Blainis are exposed and these are highly bouldery. These pebbly and bouldery rocks appear to represent slump deposits involving shallow water sediments. The angularity of pebbles and lack of sorting, do not represent glacial origin, but they indicate frequent submarine slides when portions of partly consolidated Blaini sediments together with a few extraneous pebbles contributed towards the formation of the pebbly mudstones. Bhargava (1969, 1972) has however maintained that the Blainis are glacio-marine deposit.

The presence of limestones lenses also goes against the glacial origin as carbonate beds indicate warm shallow waters. Bhattacharya and Niyogi (op. cit. p.117) have, for the Blainis of Simla area, visualised "a shallow delta-front environment near the shore line where in local secluded clear-water pools, the carbonate lenses were formed." Rupke (1968) and Valdiya (1970) have also considered Blainis as shallow water turbidites.

The Blaini limestone is overlain by the purple and carbonaceous slates which have been included under Infra-Krol Formation. The slates in the upper part of the Blainis being quite identical with those that come over the limestone, it is rather difficult to distinguish between Infra-Krol and Blaini in those areas where the limestone does not exist. In fact, Blainis imperceptibly grade into Infra-Krols. It was on the basis of similar observations in the type area that Bhattacharya and Niyogi (op.cit., p.188-189) have questioned the justification of separating Infra-Krols from Blainis.

According to Bhargava (1969) the end of Nagthat period coincided with movement which brought about the Talchir glaciation in the Peninsula. These glaciers

towards north descended in the Krol basins to form the Blaini Boulder Beds. After the deposition of the Blaini, basins shrank in size and became euxinic in which the Infra-Krol was deposited.

The slate sequence in the lower part of the Infra-Krols, suggests a comparative deepening of the basin during this period. On the other hand, the upper part of the Infra-Krols, which shows increasing number of intercalated quartzites, tending to be pebbly, indicate shallowing of the basin again. This upper part of the Infra-Krol formation is also marked by cross-bedding and ripple marks. Perhaps due to the upliftment of the underlying sequence in the north provided the provenance for the upper Infra-Krol. Bhattacharya and Niyogi (1971, p.192) have suggested that the Infra-Krol of Simla area, were deposited in a transitional deltaic environment.

The basin again shows gradual deepening during the deposition of Lower Krols which is marked by presence of slates and thin bedded limestone alternations. The environment of deposition of the Krol members is indicated to be of stable tectonic set up - an environment of mixed clastic and carbonate deposition. The calcareous slates

and argillaceous limestone sequence of Lower Krols suggests a period of fine clastic and carbonate sedimentation in shallow marine conditions. Oxidising conditions prevailed during the deposition of Red Shale member, though the marine condition continued. The upper two members represent a regime of carbonate sedimentation in shallow marine conditions. Occasional layers of red shales, suggest periodic prevalence of oxidising conditions. The oolitic nature of the uppermost Krol member speaks of a shallow near-shore environment. Oolites indicate extreme shallowness of basin, nearness of shore-line and wave- and current-agitated environment. It is obvious that the basin became very shallow, sub-aerially exposed during late Krol deposition, and perhaps the area became positive soon after. It is ~~due to~~ this non-deposition in this area that explains the absence of Tal formation in Naini Tal area.

The next period of deposition was that of Siwaliks. In the study area, only the Lower Siwaliks are represented. These indicate deposition in a transitional shallow water marine to non marine environment. The Lower Siwaliks comprise typical molasse sediments, made up of sub-greywackes and red shales.

CORRELATION

The sedimentary sequence of the Krol group in the study area, starting with the pebbly quartzites in the north-east and ending upward with the oolitic limestones in the west resembles in many ways the Blaini-Infra-Krol - Krol sequence of the Simla - the Krol belt type area of Auden (1934). The similarity between the rocks of Naini Tal and those of the Krol hills of Simla, were observed long back by Middlemiss (1890), who suggested that the Ayarpatha limestone belonged to the Krol series. A couple of years earlier Oldham (1888), had investigated the limestones and associated shaly rocks of the Solan area, near Simla and designated them as Krol series. He divided the Krol limestones into three sub-stages:

- (iii) Upper Krol limestone
- (ii) Red shales
- (i) Lower Krol limestone.

Auden (1934) in his classic work on the Krol belt, preferred to divide the 'Upper Krol limestone' into three sub-stages, so that in all, Krols comprised five sub-stages as under:

		Krol E
(iii) Upper Krol limestones		Krol D
		Krol C
(ii) Red shales		Krol B
(i) Lower Krol limestone		Krol A

He has clearly mentioned that the Naini Tal rocks form the south-eastern limit of the Krol belt. Heim and Gansser (1939, p.26) too correlated the limestones of Deopatha and Ayarpatha ridges with the Krols of Simla area. According to them, the slaty formations of the northern slopes of the China peak, are Infra-Krols. Thomas (1952) also believed that the massive dolomitic limestones were of Krol age.

The author too finds the above correlation quite valid so far as the Krol and part of the Infra-Krol formations are concerned, but as regards the pebbly quartzites and carbonaceous slates of Lariakanta, they are not Nagthats as shown by Heim and Gansser. These two workers have included the entire succession from Lariakanta eastward upto Bhowali within Nagthat. They write that they searched for Blainis in vain and got them no where (op.cit., p.27). The author however tends to differ from this correlation. He has found that the

so called Nagthats of Heim and Gansser, partly comprise the Infra-Krols and partly the Blainis. The author fails to understand how these two eminent geologists could not observe the so obvious Blaini succession in this part. The bouldery and pebbly quartzites with intercalated slates and a lensoid limestone horizon near the top, clearly show a sequence which tallies well with a number of typical occurrences of Blaini formation. As in the type area, here too, the Blaini slates grade interceptably into the Infra-Krol quartzite-slate sequence. The Lariakanta ridge, is in fact a prominent quartzite band near the top of the Infra-Krols.

So far as the limestones above the Infra-Krols are concerned, they are no doubt of Krol formation, and are definitely similar to those of the type area. What is so striking about them is the great lithological similarity that they show with their extreme a north-western counterparts. It appears that Gansser (1964, p.91) had some reservations about this correlation, because he wrote, "The Naini Tal region, south of the large Dudatoli-Almora crystalline thrust is 270 km south-east of the Simla area with its classic Krol sections of Auden. Evidently, over such a distance, considerable changes in facies could be expected, and correlation of the various formations is

open to some doubt." The author on the other hand is inclined to state that though the two areas are separated by a vast distance, yet their Krol rocks show remarkable lithological similarity, of course allowing for minor variations in lithological facies.

In the Naini Tal area, the Krol formation is almost fully developed except the top most member (Krol E of Auden). Also the Krol sandstone is not present. But this member, even in other areas of Krol formation, is not always encountered. The author believes that either it has not developed in Naini Tal area, or it is quite likely that it is represented by the Lariakanta quartzite band. If the latter is true, then it would be worthwhile to reinvestigate the occurrences of Krol sandstones elsewhere to ascertain whether they are in fact a part of Infra-Krol formation, Krols and Infra-Krols represent quite different depositional conditions and considering the fact that Krols are almost entirely devoid of sandy layers, the possibility suggested by the author is worth investigating.

The various other members of the Krol sequence of the study area are fully comparable with those of the type area. Thus the upper and lower members viz (i) and (ii) of the Lower Krols are comparable- to the Krol A and

Krol B of Auden. Similarly, the two members - (iii) and (iv), of the Upper Krols are equivalent to the Krol C and Krol D.

The member (iv) (= Krol D) which is represented by an oolitic (siliceous) limestone marks the youngest horizon of the Krol Group, after which no deposition of either other Krol member or of Tal Formation took place.

The accompanying table (Table No. 3.1) shows the correlation of the Naini Tal rocks with those of the Simla area.

PROBLEM OF AGE

The stratigraphic age of the Blaini- Infra-Krol- Krol- Tal sequence of the Krol belt has always been a subject of controversy, and ever since Oldham (1888) assigned it an Upper Palaeozoic age, the problem has been much debated. In the absence of adequate direct fossil evidences, it has been found rather difficult to assign proper age to this important stratal sequence. The fixation of the age of this rock group has been attempted by a number of workers during the past 80 years, and mainly the following two criteria have been taken into consideration in this respect:

(i) The contention that the Blaini boulder beds are glacial and equivalent to the Talchirs of south India.

(ii) The discovery of fossil remains in Infra-Krols, Krols and Tals.

Oldham (1888) was the first worker to correlate the Blainis with Talchirs. On the other hand, Holland (1908) correlated these rocks of the Lesser Himalayas with rocks of the Peninsula including Vindhyan, and considered them of Pre-Cambrian or Cambrian age. He suggested that the Blaini Boulder bed marked an unconformity between Pre-Cambrians and Cambrians. Practically at the same time, Hayden (1907-8) correlated Blainis with Spiti Beds, and contended that the Spiti shales were non-glacial and much younger than the Talchir Boulder Bed considered to be of Upper Carboniferous age.

Dasgupta and Vredenburg (1918) noted the occurrence of Upper Palaeozoic brachiopod Chonetes from the Krols of Solon area near Simla. Dasgupta (1929) therefore suggested an Upper Palaeozoic age to the entire Krol group. Subsequent work by Hayden (1919) and Auden (1932) regarding this fossil find, revealed that the rocks under question

were in fact Lower Tertiary marine formations, and Auden opined that the reference to Chonetes was erroneous, and a case of misidentification of a Subathu Oyster.

The large limestone inliers of Jammu, have often been referred to as of Permo-carboniferous age (Medlicott, 1876; Wadia, 1928, 1937). Fermor (1931) established that the Infra-Trias Sirban limestones of Hazara were identical to those of the Krol series. A close resemblance between the Krol limestone, Permo-carboniferous limestone of Jammu and that of Hazara, has been observed.

Pilgrim and West (1928) considered that the Krol Group could be of Upper Palaeozoic to Mesozoic ~~in~~ age. They did not think that the sequence was Pre-cambrian as suggested earlier by Holland. Auden (1932) was not very certain but thought the Krols to be Permian to Mesozoic, on the basis of the Blaini Boulder Beds being of Uralian (Upper Carboniferous) age. In his subsequent paper on the Krol belt, Auden (1934) suggested Blainis and Infra-Krols to be of Upper Carboniferous while the Krols and Tals were equated with Permo-Carboniferous, and Jurassic and Cretaceous respectively.

Boileau (1954) on the other hand included Krol formation with the Shali and Dharmakot limestones and

correlated them with the upper part of Vindhya. Thus, he doubtfully, suggested an Ordovician to Devonian age to the Krol series.

In the course of last 20 years, numerous workers have succeeded in obtaining microfossil evidences from Tal, Krol and Infra-Krol formations, and their findings have thrown much light on this complex problem of age. Sitholey et al. (1954) and Lakhanpal et al. (1968) have reported the occurrence of plant microfossils from the Infra-Krol carbonaceous slates of Naini Tal area, and according to these workers, the assemblage indicates affinity to the microfossil fauna from the Permo-Carboniferous Gondwana rocks. Ghosh and Srivastava (1962) on the basis of the occurrence of certain fossil spores in the Infra-Krols, Krols and Tals near Mussorie in Garhwal, have assigned a Triassic age to Krol formation.

Bhargava and Srikantia (1967) have also suggested that the Krols must be of Mesozoic age. They have arrived at this conclusion on the basis of a precise and detailed mapping.

More recently, Shah et al. (1968) have published another paper on the palynological assemblage from the

Infra-Krol carbonaceous slates of the Naini Tal area. These have reiterated the earlier views of Sitholey et al. (1954) and Lakhanpal et al. (1968), and suggested that the dominance of non-striate bisaccate pollen in these rocks, points to the lowermost part of the Triassic. In the same year, Tewari and Ramesh (1968) reported bryozoan and foraminiferal fossils from the Upper Tals of Garhwal. On the basis of these fossils, they suggested a Lower Cretaceous age to the Tal formation, and accordingly considered the Krols underlying "with the intervening small unconformity" to be as young as Jurassic.

Bhattacharya and Niyogi (1971) have more or less accepted the Upper Palaeozoic to Jurassic age for the Blaini-Krol sequence originally suggested by Auden (1934). They have written (op.cit., p.200), "The Krols because of their normal sedimentary occurrence over the supposedly U. Carboniferous Blainis, were thought to represent the Permian and the Triassic by earlier workers. Though the glacial origin of the Blaini boulder beds and their consequent correlation with the Talchirs can be challenged, a probable U. Palaeozoic to Jurassic age for the Blaini-Krol sequence is still suggested by recent finds of animal fossils and spores in the south-east extension of this belt."

In the most recent work on the Krol belt, Bhargava (1972) has also maintained that the Krol group is Permo-Carboniferous to Lower Cretaceous. He has considered the Blaini formation to be of glacio-marine origin, having been deposited at the time of the Talchir glaciation. He has assigned Blaini an Upper Carboniferous age. Taking into account the views of previous workers on microfossils, Bhargava has suggested the following ages for the various formations of the Krol Group:-

Ages	Formations
Lower Cretaceous to Jurassic	Tal
Triassic	Krol A,B,C,D and E
Permian	Infra-Krol
Permo-Carboniferous	Blaini

The Krol group rocks of the study area which have been quite satisfactorily correlated with the other areas, could also be considered as representing an almost unbroken depositional sequence that started in the Permo-Carboniferous (or Upper Carboniferous) period and came to a close either in Triassic or Jurassic.