CHAPTER II

BACKGROUND INFORMATION

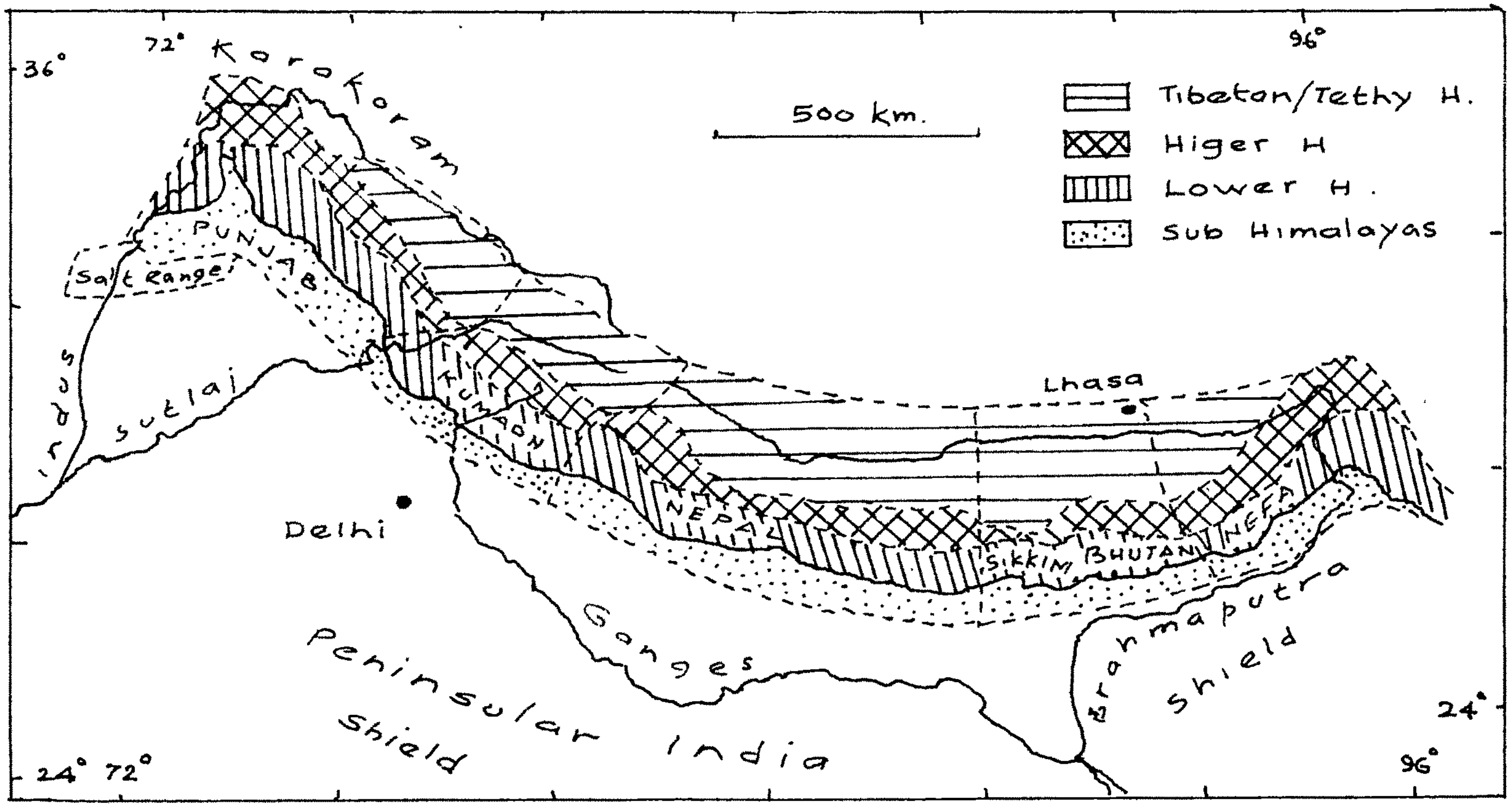
HIMALAYA IN GENERAL

Gansser (1964) has divided the Himalayan mountain chain into the following regional and geographical units (Fig. 2.1).

1. Punjab Himalaya: This 550 km long section of true Himalayan chain is bordered in the west by the Indus river and in the east by the Sutlej river. It includes Kashmir and Spiti region, geologically the best known region of the Himalaya.

2. Kumaon Himalaya: From the Sutlej eastwards this section stretches for 320 km right upto the Kali river

fig 2.1.



The general subdivisions in the Himalayas on the western boundary of Nepal. It includes the Himalayan ranges of Garhwal, Kumaon and parts of southern Tibet.

3. Nepal Himalaya: From the Kali river in the west to the Tista river in the east, it extends along the whole 800 km length of Nepal.

4. Sikkim/Bhutan Himalaya: This part of the Himalayan range is occupied by autonomous states of Sikkim and Bhutan, and measures about 400 km.

5. NEFA Himalaya (former Assam Himalaya): This eastern part of the range (400 km long) leads from the eastern boundary of Bhutan to the cross gorges of the Tsangpo-Brahmputra rivers. Lying in the somewhat politically unsettled North Eastern Frontier Agency (NEFA) now known as Arunachal Himalaya it is geologically the least known part of the whole mountain system.

Each of the above sections, is usually divided into following four longitudinal zones from the south to the North:-

(i) the foot-hills of the Siwaliks (also called the Sub-Himalaya or the outer Himalaya),

(ii) the Lesser Himalaya of unfossiliferous sediments and thrust sheets (also called the Middle Himalaya),

(iii) the Central Himalaya of the batholithic granite intrusions and root-zones (also called the Great Himalaya or Inner Himalaya),

(iv) the Tethys Himalaya of fossiliferous sediments (also called the Tibetan Himalaya).

Beyond these four zones are the Ladakh and Kailash ranges followed by the Trans-Himalaya ranges.

The Himalaya is a youthful mountain system, contemporary of the Alps. It comprises a number of successive nappes and in tectonic design, bears some similarity with the latter. Although vastly greater in dimensions the Himalayan mountain chain is structurally far more simple than the Alps. In the words of Wadia (1938, p.117) "We cannot be so bold as to say that the Himalayas are built on the plan of the Alps, nor even that their architecture is individual. No doubt several tectonic features are common and the Alpine-Himalayan axis of earth-folding originated in one common and continuous impulse. But the proportions are so vastly different that the very magnitude of the earth-waves raised in the case of the Himalayas gave them a comparatively simpler tectonics, while the smaller convolutions at the other end of the axis may have more severely plicated the shallower surface folds;

the one may be like an ornately built, delicately chiselled chapel, the other a huge sun-altar of rough hewn blocks. Perhaps the old pioneers who worked before us recognised this fact and I hope those that follow will not entirely ignore this factor".

The Himalaya mountain chain arose out of two geosynclines parallel to and separated by the present crystalline axis. The northern geosyncline in the Tibetan Himalaya, where biogenetic conditions prevailed and permitted the preservation of a fully fossiliferous succession right from the Lower Palaeozoic to the early Tertiary, while in the southern or the Lesser Himalayan geosyncline, the environmental conditions were inimical to the existence of life upto the Mesozoic, although the sedimentation in the southern geosyncline may have taken place at the same time as that in the northern. However, certain fossiliferous occurrences in the Lesser Himalaya in Kashmir, Nepal, Sikkim and the eastern Himalaya indicate that some connections might have existed between the two major geosynclines. Wadia (1955, p.6) has designated the barrier separating the two major geosynclines, as the central Himalayan Geanticline in the embryonic Himalaya of the Eocene.

IMPORTANT PREVIOUS WORK

In the course of last 150 years, numerous geologists have investigated one or the other part of the Himalaya, and it is a synthesis of their painstaking work that provides a rather coherent and fairly clear picture of the stratigraphy and structure of this lofty mountain chain.

The most outstanding contribution to the geological studies of the Himalaya in the 19th century was that of Medlicott (1864). He gave the first connected account of the geology of the Lower Himalaya, of the portion between the river Ganges and Ravee. His work not only laid the foundations on which our present knowledge of the Himalayan structure has been built and firmly established, but also his correlation and nomenclature of the rocks of the Simla have undergone little alteration at the hands of the subsequent workers. He classified the Himalayan rocks of the area, into two series (1) Sub-Himalayan Series and (2) Himalayan Series.

These two Series, classified further into various sub-divisions, formed the following sequence:

1. Sub-Himalayan Series:

Upper	Siwaliks	
Middle	Nahan	Kasauli
Lower	Subathu	Dagshai

2. Himalayan Series:

A. Unmetamorphosed

Krol	-	Limestone
Infra Krol	-	Carbonaceous shale
Blaini	-	Conglomerate
Infra Blaini	-	Slates.

B. Metamorphics

Crystalline and sub-crystalline rocks.

The works of Middlemiss (1887, 1888, 1890) in the Lower Himalaya of Garhwal and Kumaon, mark another landmark. He established (1887) the following succession of the Garhwal rocks:

Sub-Himalaya	Siwaliks
Outer formation	Nummulite Tal Massive Limestones Purple slates Volcanic breccia
Inner formation	Schistose series with intrusive Gneissic granites

The first modern section of the thrust folding over the entire width of Himalaya, was presented by

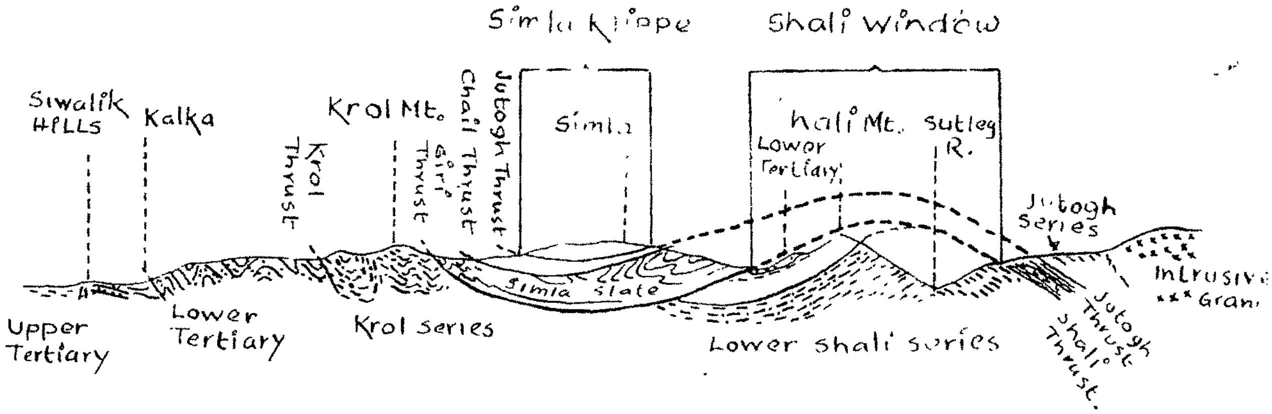
Professor Loczy (1907). His section of Kanchanjangha showing an enormous overfold with huge reversed series thrust for 150-200 km towards the Indian plains, has been more correct at least in principle.

An outstanding contribution towards the proper understanding of the complex structure and stratigraphy of the Himalaya came from Pilgrim and West (1928). These two officers of the Geological Survey of India, mapped the region around Simla, and found that the rocks of the Simla-Chakrata area lying to the north of Tertiary belt, are not in their normal position but they have undergone thrusting and inversion (Fig. 2.2). According to these two workers, the metamorphic rocks which are really a part of the belt of rocks forming the central axis of the Himalaya, have been forced southward for many miles along a nearly horizontal Jutogh Thrust plane so as to lie now on the top of unaltered rocks. These metamorphic rocks were named as Jutogh Series on which the city of Simla is situated. They postulated existence of other thrusts also below the main Jutogh Thrust, of which the Chail Thrust was the most important. The sequence of events in Simal region as put forth by Pilgrim and West has been summarised as under:

Fig 2.2

SECTION THROUGH THE SIMLA HIMALAYA

(W. D. West.)



0 16 Km.

Horizontal scale

0 6060 mt.

Vertical Scale

(a) Deposition of Jutogh Series;

(b) Basic igneous intrusion as Sills and dykes;

(c) Recumbent folding and metamorphism;

(d) Intrusion of Chor granite at the close of folding and metamorphism.

They gave the following stratigraphical sequence of Simla Himalaya:

Daghsai Series	Lower Miocene
------------------Unconformity------------------	
Uppermost Subathu beds	Upper Oligocene
------------------Unconformity------------------	
Krol Series Infra-Krol beds Blaini beds	Lower Gondwana
------------------Unconformity------------------	
Shali Limestone and slate Simla Series (Infra Blaini)	?
------------------Unconformity------------------	
Jaunsar series	Purana
------------------Unconformity------------------	
Chail series	Purana
Jutogh series	Archaeans (?)

On account of large scale thrusting and inversion the above formations show the following structural sequence:

Jutogh Series

-----------------Jutogh Thrust--------------------

Chail Series

-----------------Chail Thrust---------------------

Jaunsar Series

-----------------Jaunsar Thrust-------------------

Simla Slates

-----------------Giri Thrust----------------------

Krol Series

-----------------Krol Thrust----------------------

Subathu Series

The classic work of Wadia (1931) in the Kashmir area of Punjab Himalaya constitutes another important milestone in the progress of the Himalaya's geological studies. He pointed out the most striking feature of the NW Himalaya - the way in which the strike of the mountains, after following an arcuate SE-NW direction from Assam to Kashmir, makes a great bend in Hazara, rapidly curving round through an E-W to N-S direction, and producing thereby a great re-entrant angle in the alignment of the mountains between Abbotabad on the SW and Kashmir valley on the NE. Wadia's (op. cit.) work in the south of this syntaxial area has shown that both from structural as well as from stratigraphical points of view, there is a complete geological continuity around this re-entrant. The structure and stratigraphy on the Hazara side of the syntaxis is the mirror image of the structure and stratigraphy of the Kashmir side. Wadia concluded that there had been a single Himalayan movement from the north which came up against some underground obstacle around which it has been forced to diverge. He suggested that a tongue of the ancient and stable Peninsular rocks extended upto the NW beneath a covering of Cenozoic rocks, and that this formed the obstacle to the folding movement coming from the north, so that the original north and south direction of movement was resolved into a NE-SW direction in Kashmir and NW-SE in Hazara.

Kumaon Himalaya has received maximum attention of Auden (1934, 1937) and his works, in fact provide the most lucid and convincing account of the Himalayan rocks of Simla, Garhwal and Kumaon. He studied in great detail the 270 km long sedimentary belt of Mesozoic rocks lying to the north of the thrust which has brought these rocks over the younger Subathus of Tertiary age, extending from

Solon in the NW to as far as Naini Tal in the SE. He called it as 'Krol Belt' and gave the name Krol Thrust to the dislocation that separated these rocks from the underlying younger Subathus. According to Auden (1934, p.364) his work was a continuation of the work started by Pilgrim and West. The sequence of formation in the Krol belt rocks of Simla-Chakrata area, as worked out by Auden, is given in Table 2.1.

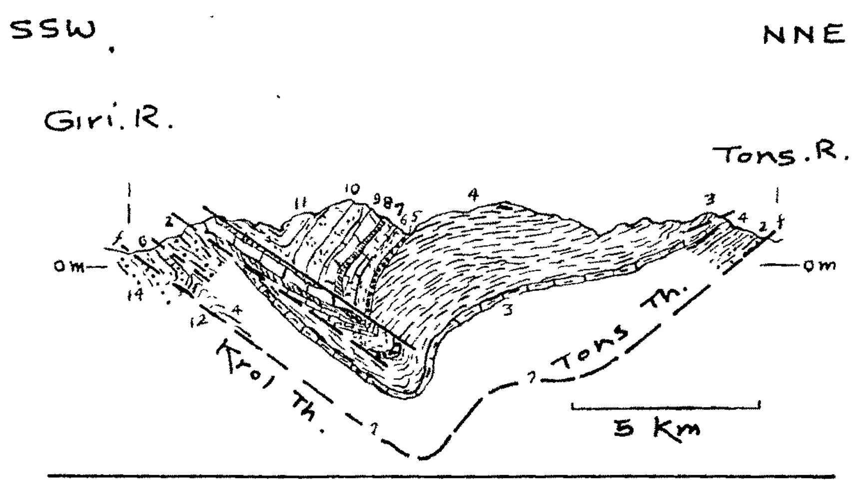
Auden visualised three main thrusts in the Krol belt: (i) the Krol thrust, bordering the Sub-Himalayas and corresponding to the so called "Main Boundary Fault"; (ii) the Giri thrust, paralleling the Krol thrust approximately 6-8 km north east of the former, and (iii) the Tons thrust in the eastern area south of Chakrata, approximately 15 km north of the Krol thrust. The Krol and Giri thrusts are directed to the south and south-west respectively while the Tons thrust rises to the north. According to Auden, the Krol thrust and the Tons thrust are the same and the great syncline of Jaunsar rocks with overlying Krols and Tals rests as a nappe on a folded thrust plane (Fig. 2.3).

TABLE 2.1

Auden's sequence of Formations in Simla-Chakrata Hills

Age	Solon neighbourhood	Tons river neighbourhood
Miocene	Nahans (only at Kalka)	Nahans
Lower Miocene	Kasauli Dagshai	Dagshai
Oligocene Eocene	Subathu (Nummulitic)	Subathu (Nummulitic) never in contact
? Cretaceous and Jurassic	Absent	Tal: Upper Tal / Lower Tal
? Permo-Carboniferous	Krol Series: Krol limestone (Krol E, Krol D, Krol C); Krol B (Red Shales); Krol A Krol sandstone	Krol Series: Krol limestone (Upper Krol limestone); Red Shales; Lower Krol limestone
	Infra-Krol	Infra-Krol
Upper Carboniferous	Blaini	Blaini
? Devonian and Silurian	Jaunsar with possible Mandhali	Nagthat stage Chandpur stage Mandhali stage (Jaunsar series)
? Lower Palaeozoic and pre-Cambrian	Simla slates with Kakarhatti limeston	Deoban limestone Simla slates (Morar-Chakrata beds)
Miocene (and older)	Dolerites	

Tig 2.3



1. Simla slates
2. Mandhali
3. Bansa limestone
4. Nagthat and chandpur
5. Blaini
6. Infra Krol
7. Krol A
8. red shales, Krol B.
9. upper Krol limestones
10. Lower Tal
11. upper Tal
12. subathu (Eocene)
13. Dagshai - Kasauli (Murrees)
14. Nahan (Lower Siwaliks)

SECTION THROUGH THE KROL BELT

(after: AUDEN)

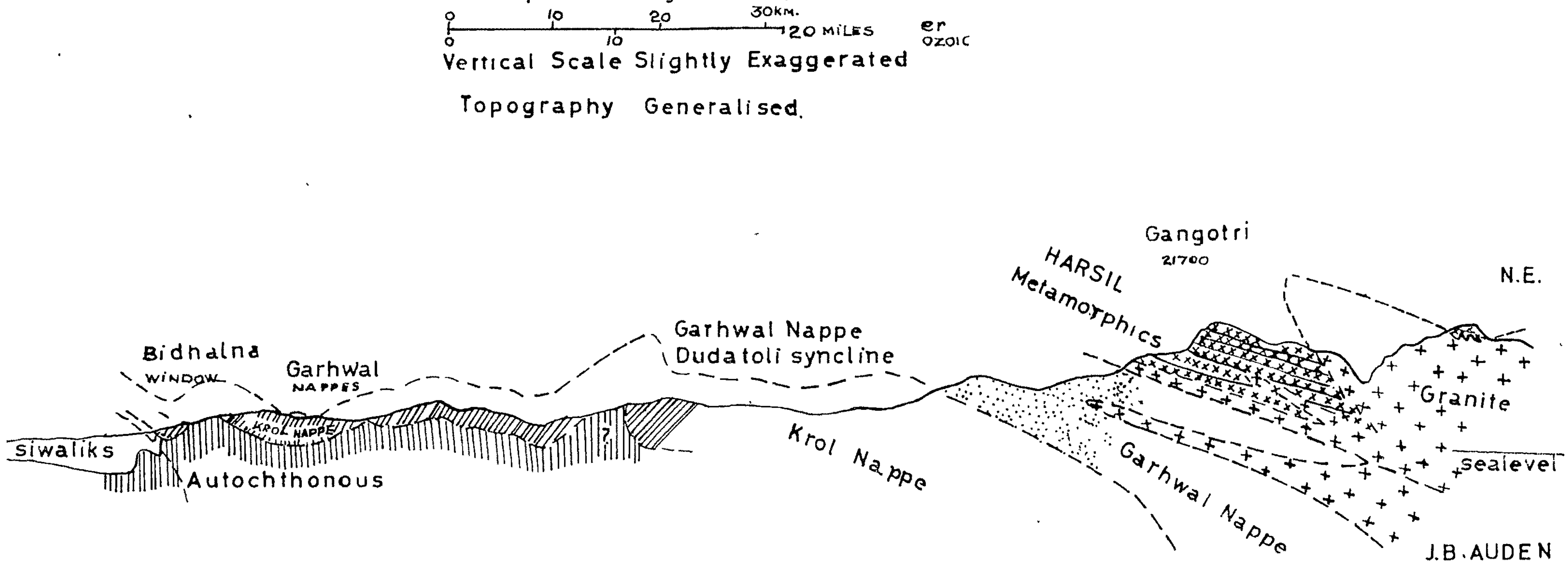
In a later work, Auden (1937) gave an excellent structural interpretation of the Garhwal Himalaya (Fig. 2.4). He worked out the following sequence of rocks in Garhwal:

Formation	Thickness	Probable age
Siwalik	16,000'	Upper Miocene to Pleistocene
Nummulitic	-	Eocene
Tal	6,500'	Upper Cretaceous
Krol	4,000'	Permian to Triassic
Blaini	2,000'	Talchir (Uralian)
Nagthat	3,000'	Devonian
Chandpur	4,000'	Lower Palaeozoic Pre-Cambrian

Fig. 2.4

TECTONIC SECTION ACROSS THE GARHWAL HIMALAYA

A preliminary attempt.



According to Auden (op. cit.), the abovementioned rocks are tectonically arranged to show the following structural succession:

Garhwal nappe

- Chandpur (metamorphosed)
- ------------Thrust------------
- Nagthat, Chandpur — Little metamorphosed
- Boulder beds, slates and limestones of uncertain stratigraphical horizon occur in one outlier below metamorphosed Chandpurs

------------------ Garhwal thrust ------------------

Krol nappe

- Nummulitic
- Tal
- Krol
- Blaini
- Nagthat, Chandpur — Metamorphosed and unmetamorphosed

------------------ Krol thrust ------------------

Autochthonous

Dagshai Nummulitic

Siwalik

Simla slates

He made a comparison of the structure of Garhwal with that of eastern Himalaya and according to him, in the eastern Himalaya there are two following main thrusts:

1. The thrust causing the Gondwana rocks to lie upon Siwaliks and
2. The thrust separating the Daling series from the underlying Gondwanas.

These two thrusts are analogous to Krol and Garhwal thrusts of the Garhwal Himalaya. In both the areas schistose rocks are thrust upon Gondwanas or their equivalents.

The pioneering work of Heim and Gansser (1939) forms another landmark. Their geological observations on the central Himalaya formed a part of the Swiss expedition to Himalaya. They have dealt with various geological aspects such as petrology, stratigraphy and tectonics of Kumaon, NW part of Nepal and Tibet Himalayas. They traversed the Siwalik border region of Kumaon, the great thrust fold region of Darjeeling, the Central high range of Nandadevi and Badrinath, the northern range of Tethyan Himalaya and the Tibet Himalaya. Their identification of rocks, regional correlation and tectonic interpretation are so perfect that their work will remain unique for many years to come.

West (1949) while summarising the work of Auden in Tehri and British Garhwal, mentioned that the structure of the Garhwal Himalaya is essentially the same as that of Kumaon Himalaya, and the two areas could be compared as below:

Garhwal Himalaya (Auden, 1939)	Kumaon Himalaya (Heim & Gansser,1939)
Thrust at the foot of main Himalayan range forming the NE boundary of the "Chamoli window"	Central thrust
Garhwal series in "Chamoli window"	Tejam Calc-zone, occurring in anticline below crystallines
Overthrust sheet of Dudatoli-Ranikhet-Almora	Crystalline Almora thrust zone

A few years later, Auden (1951) suggested an upper Miocene to Pleistocene age for the Krol and Garhwal thrusts.

In a more recent paper, Wadia and West (1964) have briefly discussed the structure of the Himalaya. They wrote that in Simla-Garhwal area the geological evidence suggests more than one period of orogeny. The earliest is pre-Eocene, as Subathu sediments are found resting unconformably on the strata of Palaeozoic and Mesozoic ages. A large-scale post-Subathu movement resulted into translation of sheets of rocks southward along low angle thrusts in a series of "nappes" possibly with granitic intrusion in root zone. This movement appears to have taken place at the beginning of lower Siwalik (Mid-Miocene) deposition, giving rise to a change in the deposition from arkoses to conglomerates containing Krol belt pebbles in the foot-hills, though the latter was affected by the final orogenic activity at the end of Siwalik (Lower Pleistocene) times. The "nappes" belt also moved further southwards at this time, coming to rest directly against the Siwalik sediments in places.

Valdiya (1964) ideally synthesised the work of many investigators in different parts of Himalaya, and has suggested a somewhat modified structural framework as given below:

1. The autochthonous Siwalik Zone comprising Jura-type simple open folds affected by steep reverse faulting which resembles the molasse zone of the Alpine border.

2. <u>The para-autochthonous Lesser Himalayan Zone</u> of early Tertiary formations beneath the overthrust Krol nappe.

3. <u>The Krol nappe system</u>, mostly unfossiliferous sediments comparable to the Helvetic nappes of the Alps.

4. <u>The Kashmir nappe system</u> which embraces the Kashmir, Jutogh, Garhwal and Kathmandu nappes, all built of Pre-Cambrian crystallines, and characterised by huge recumbent folds. These could be compared with Pennine nappes.

5. <u>The Tethys Himalaya</u>, consisting of Cambrian to Eocene fossiliferous sediments, comparable with the East-Alpine nappes.

PREVIOUS WORK ON BHIMTAL AND ITS NEIGHBOURHOOD

Bhowali and Bhimtal area has been visited by quite a few workers in the past. Especially, the trappean rocks of Bhimtal have attracted much attention. It is however suprising that though several geologists have recorded and described these metabasics, none has investigated these interesting rocks in detail.

The occurrence of basic rocks in this area was recorded for the first time about 100 years back by Ball (1878) when he traced these rocks from Bhowali to Bhimtal and Malwa Tal, and called them as "greenstones". Middlemiss (1890) while preparing the geological map of the Naini Tal area, came across the basic rocks at Bhowali and referred to them as "dolerite dykes and intrusive sills".

After a gap of about 50 years, Rode et al. (1941, 1942) published an account of their studies in Bhowali-Bhimtal area, and these workers for the first time gave brief but systematic details of the trappean rocks. They found that the traps were associated with granites and quartz porphyries. Describing the petrochemistry of the traps and their associated rocks they wrote that the igneous suite ranges from basic dolerites and basalts, through diorites to as acid as granites, granophyres and quartz porphyries, and that all these different types of eruptive rocks have originated from the same magma through crystallisation differentiation of a Circum-Pacific suite.

Heim and Gansser (1939) have made brief references to the Bhowali-Bhimtal area. These two eminent geologists, in the course of their expedition in the Kumaon Himalaya, took a traverse from Naini Tal to Almora and passed through Bhowali. They recognised the anticlinal structure of Bhowali and found that the traps formed the core of the anticline made by the overlying quartzites (Fig. 3.1). According to them (1939,p.220), "The quartzite of Bhowali, with diabase and limestone forms a peculiar anticline with vertical layers on the axis. Underneath an autochthonous anticline is supposed. The Bhowali zone is thrust by gneiss and schistose quartz porphyry (Ramgarh), upon which again follows the sedimentary series of uniform north-eastern dip". They correlated the quartzites with Nagthat. The traps of Bhowali have been described by them as "green amygdaloidal diabse with variety of epidote and calcite". The cleaved traps have been referred to as 'green schists' (op. cit.,p.27). The petrographic characters of the traps have been described by these two workers in the following words (op. cit.,p.52-53).

"The basic igneous rocks exposed along the road above Bhowali form large massive greenish rocks of reddish weathering colour. They show characteristic oval amygdaloid vesicles upto 1-2 centimeters in size, filled with intensely green epidote. Microscopically no other minerals are recognised in the fine-grained rocks. Even under the microscope the different minerals are small and partly decomposed by epidotization and uralitization".

"The basic zones of Bhowali are of the same type too, and mainly regarded as an epidotic diabase. The chief components are small lath-shaped stalks of andesine-labradorite. They are frequently epidotized. Small brownish augites are intercalated between the ophitic plagioclase. They are partly uralitized and chloritized. The uralite is easily recognizable by its intensely green pleochroism. The chlorite usually forms rather large patches which, however, are not transformed from augite, but are in connection with the amygdaloid epidote. This latter mineral is abundant in the following shapes: (a) as small pale to colourless grains, the result of secondary alteration, and (b) as rather large, intensely green (ferruginous) individuals filling the vesicles; (the rather large patches are often made of granular epidote with a rim of colourless epidote needles. The later mingle with chlorite individuals as the last formed amygdaloidal components."

"Finely spread leucoxenized titanite is found as an accessory mineral. The lack of ore is remarkable in contrast to the basic sill of Naini Tal. The interesting vesicles of epidote, sometimes mixed with rather large plagioclase, may originate from primary gas bubbles, filled with carbonate which was transformed to epidote". Gansser (1964) in his book on the Himalaya, has briefly referred to the rocks of Bhowali. He has written (p.92),

"In the Naini Tal region the oldest outcrops consist of tuffaceous greenstones, altered diabasic rocks followed by quartzites. Normal contacts between the basic rock sequence and the quartzites are not well exposed. The quartzites are thick bedded, yellowish to green, partly shaly and variegated. They can be over 500 m thick and have been correlated with the upper Jaunsars, the Nagthat quartzites".

Thomas (1952) in the course of his studies on the origin of Kumaon lakes, has briefly alluded to the rocks of Bhowali-Bhimtal. According to him, the rocks amongst which the Bhimtal group of lakes, are situated are the Nagthat quartzites, and greenstones and slate, which underlie them. While he has discussed the origin of Naini Tal lake in detail, he has not given any opinion on the Bhimtal group of lakes. Pande I.C. (1963) who has referred to the basic rocks of the study areas as Bhimtal traps, considering them to be intrusive into Nagthat quartzites. From his account, it is not clear as to when the intrusion took place but it appears that he has assigned a pre-Tertiary and post-Carboniferous age to these trappean rock. Pande P.C. (1964) has given some more details about the traps, and according to him, these comprise dolerite and flows of mugearite basalt.

Some information on the Bhimtal and its neighbourhood are available from the work of Mathur (1965) who has discussed the origin of Bhimtal group of lakes. This author has described, the basic rocks of the area as 'Traps' comprising basalts and dolerites. He has also referred to the overlying quartzites and slates, but nowhere in his paper, he has given the probable age of the rocks. Perhaps, he takes them to be intrusive into the Nagthats. As regards the origin of the lakes, he has written that "the Bhimtal, the Naukuchhiya Tal, the Sat Tal and Puna Tal are shown to be structural valleys enlarged by denudation of the valley bottoms and in case of Bhimtal also by the blocking up of the mouths of the valley. It is possible that some other minor factors played a part, but they acted only in reinforcing the main agencies. There is no direct evidence of any other major factor taking a hand. No evidence of glacial action can be seen".

Powar et al. (1968), while discussing the relationship between the volcanism, plutonism, regional metamorphism and tectonism in the part of Himalaya have concluded that the Bhimtal traps are the representatives of the late Mesozoic-Tertiary basic activity.

The two most recent papers that refer to the study area are those of Raina and Dungrakoti (1973) and Varadarajan (1973). The former have included the rocks of this area into Deoban group - a Palaeozoic sequence, comprising Bhimtal quartzites with associated Bhowali ophiolites and the limestone slates sequence of the Kosi valley. The Deoban group, according to these two authors, represents the autochthon or para-autochthon unit forming the basement over which sheets of Krol and Garhwal groups were thrust southwards during the Himalayan orogeny and was folded in an earlier orogeny (Hercynian?) and refolded in the Tertiary period.

Varadarajan (1973) has come out with the most detailed and systematic account of the basic rocks of Bhowali-Bhimtal area. He has made a very critical study of the rocks - referring them as metabasites. So far as the regional geology is concerned, Varadarajan has followed the earlier workers and has taken the overlying quartzites as of Nagthat age. His study mainly deals with the metamorphism and likely spilitization of the basic rocks. He has described (op. cit.,p.10-11) the basic rocks as under:

"Metabasites in the Bhimtal-Bhowali area, which form a part of the basic igneous activity in the Lesser Himalaya, occurring between Ramgarh Thrust in the north and Krol Thrust in south, is associated with marine shallow water metasediments of Nagthat (?) formation. They are mainly composed of contemporaneous basaltic lava flows with intercalated phyllitic bands in a few places. Later dyke phase is also present. They are metamorphosed to various degrees, corresponding with the development of incipient to well formed foliation with the main foliation in a NW-SE direction. Rocks vary from partly or completely altered ones, retaining the original texture but with voids filled with later formed minerals to those with completely reconstituted mineralogy and texture."

"Two distinct stages of metamorphism are indicated by metabasites. The first stage occurs in rocks which are partly or completely altered but with practically no incipient foliation. The second stage is exhibited by the rocks which are completely altered and are well foliated. The mineral assemblages of the first stage consist in addition to relict augite and labradorite (rarely) in some, of albite, chlorite, actinolite, pumpellyite, prehnite, epidote, calcite, hematite (magnetite), quartz and rarely zeolite. This represents the Prehnite-Pumpellyite-Greywacke (Quartz) and Zeolite Facies of metamorphism which are reported for the first time from the rocks of the Himalayan region. This is the result of load or burial metamorphism due to the increase in T and P and variation in H_2O and CO_2. This facies of the metamorphism is superposed by Greenschist Facies of metamorphism observed in the well-foliated rocks which consist of albite, chlorite, actinolite, quartz, magnetite ilmenite, stilpnomelane and also biotite and hydrogarnet in a few cases."

"During the load metamorphism, due to hydrolisation of glass and alteration of original minerals and metamorphic differentiation two distinct mineral assemblages developed. They are:

1. Albite + chlorite and/or actinolite + sphene (spilite) and

2. Chlorite + actinolite + pumpellyite + prehnite calcite + epidote + sphene + hematite with less albite (forming chlorite - rich or pumpellyite-rich or epidote rich regions).

The former assemblage constitutes the spilites, richer in Na_2O, CO_2, and H_2O and poorer in CaO and the second assemblage is richer in Ca silicates. There is no sharp line of demarcation between the spilitic zones and the non-spilitic zones formed due to metamorphic differentiation. The subsequent greenschist facies destroys this differentiation."