GEOLGY
GEOLOGICAL OVERVIEW

Mountain belts created by continent-continent collision represent the most dominant geologic features of the surface of the Earth. The Rockies and the Appalachian belt in North America, the Andes in the South America, the Ural mountains in central Eurasia, the Alps of Europe and the Himalayas are some of the best examples, each extending for thousands of kilometres along strike. A great deal of attention has been paid to the evolution of these mountain belts since the advent of plate tectonics. The youngest and perhaps the most impressing of all the continent-continent collisional belts on the Earth is the Himalayan orogen; its evolution has been the subject of many discussions (Gansser, 1964; Spencer, 1974; Molnar and Tapponnier, 1975; Bhat, 1987; Treloar and Searle, 1993). The Himalayan mountain building is the product of collision between the India and the Eurasian plate that began during the Eocene epoch and is considered to be one of the major tectonic events in the Cenozoic era and a live example of collision mountain belt as the process of mountain building is still active, forming the highest range and plateau in the world (Brookfield, 1993).

3.1. Tectonostratigraphic Subdivisions of the Himalaya

The Himalayan mountain belt extends over 2,500 Km from northwest to northeast with a variable width of 230 to 330 Km and terminates at both east and west ends with syntaxial bends. Based on the works of Burrard and Hayden (1932), Wadia (1953), Bordet (1961), Gansser (1964, 1974), Le Fort (1975), Windley (1985), Hodges (2000), DiPietro and Isachsen (2001), Steck (2003), DePietro and Pouge (2004) the Himalayan terrain (Fig.3.1) from south to north has been conventionally divided into subparallel tectonostratigraphic subdivisions as under:

- Sub-Himalaya or Outer Himalaya
- Lower Himalaya or Lesser Himalaya
- Higher Himalaya or Greater Himalaya
- Trans Himalaya or Tibetan Himalaya

The dividing planes between these subdivisions are the thrusts of regional dimension and varying tectonic activity (Gansser 1964, 1974;
Valdiya, 2002) and each subdivision has a characteristic stratigraphy which is not easily correlatable with adjacent zones (DiPietro and Pogue 2004). From south to north, the classic bounding faults are: The Main Frontal Thrust (MFT) between the Indo-Gangetic alluvial plain in south to the Outer Himalaya in north, the Main Boundary Thrust (MBT) between the Outer Himalayas and the Lesser Himalayan sedimentary zone (LHSZ), the Main Central Thrust (MCT) between the Lesser Himalayas and the Higher (or Greater) Himalayan Crystallines (HHC), the South Tibetan detachment system (STD) between the Higher Himalayas and the Tethys Himalaya, and finally the Indus-Tsangpo suture zone, which marks the northern limit of exposed Indian plate rocks. Along each of these thrusts, tens to hundreds of kilometres of the displacement between India and Asia have been accommodated (Powell and Conaghan, 1973; Gansser, 1981; Seeber and Armbruster, 1981; Schelling, 1992; Treloar et al. 1992; Srivastava and Mitra, 1994). All three zones exert a major influence on landsliding and many of the larger and most catastrophic landslides are associated with movements along these thrusts (Nakata, 1982).

Sub-Himalaya or Outer Himalaya: The southern hilly terrain of Himalayas, comprising late Tertiary Siwalik ranges, constitutes the Outer Himalaya. These ranges are composed of thick pile of sediments, which are folded and thrusted. These sediments are Palaeocene to Late Pleistocene in age (Gansser, 1964). In the south the MFT expresses as a prominent topographic break of the Outer Himalaya against the alluvial

Fig 3.1. Himalayas showing the main tectonic units (Windley 1985).
plains. The Tertiary sediments comprise Siwalik, Murree and Sabathu groups, which overlay the buried peneplains of the northern fringe of the Indian shield (Prakash et al., 1980). Lithologically the Siwaliks and Murree Groups constitute consolidated and semi-consolidated sandstones, shales, conglomerates, siltstone and claystone while as the Sabathu Group constitutes carbonaceous shale, coal seams, quartzarenite and limestone.

**Lesser Himalayas:** The Lesser Himalaya comprise mainly low to high grade metamorphic rocks of Precambrian age, besides rocks of Early Eocene age (Wadia, 1975). Although the lithostratigraphy and major structural units of the zone have been established, a lack of fossil control has given rise to divergent opinions about the age and stratigraphic positions of various lithostratigraphic units (Thakur, 1981). The Lesser Himalayan zone narrows towards the northwest from Simla hills to the Jammu area of Kashmir (Thakur, 1981).
Jammu area of Kashmir (Fig 3.2). The Lesser Himalayan terrain has undergone alternate phases of stability and upliftment during the Quaternary period along the MBT (Valdiya, 1992).

Greater Himalaya: The Greater Himalaya represents the highest mountains physiographically, and comprises low to high grade metamorphic rocks like schists and gneisses and complete sequence of para-orthometamorphites with igneous intrusions of Proterozoic and younger age (Thakur, 1987). Treloar and Searle (1993) ascribed crustal thickening and subduction two main reasons for the metamorphism of Greater Himalayan rocks.

Trans-Himalaya: The Trans-Himalaya to the north consists of northward thrusted mass of Cretaceous flysc with basic and ultrabasic exotics, which rest on Palaeogene molasse (Steck, 2003). In the northwestern Himalaya, the northern margin of the Tethys Himalayas is sharply defined by the Indus-Tsangpo thrust in the Ladakh and southern Tibet, and the Main Mantle Thrust in Kohistan, against which lie the rocks associated with the Indus-Tsangpo, or the trans-Himalaya (DiPietro and Pogue, 2004). Ophiolites and the flysch and molasse sediments of the Kailash range, the Yarlung-Tsangpo belt and Lahsa block of southern Tibet represent the eastern continuation of the Trans-Himalaya in the northwest (Thakur, 1987).

Whereas the age and extent of thrusting on the Indus-Tsangpo Suture and MCT have received considerable research attention, the history of the MBT is not much known owing to poorer exposure and fewer radiometric dates associated with it (Meigs et al., 1995). As this thrust (MBT) along with the Panjal Thrust traverses the area of the present study and influences the rock slopes to a great extent and exerts a major control on the evolution of geomorphology, it is described below in some detail.

The Main Boundary Thrust: The MBT was introduced by Medlicott (1864) to define the faulted contact between the Siwalik and the Older Murree (Miocene: Wadia 1975)/Dharamshala (Oligocene to early Miocene: Kumar, 1988) beds in the Himalayas of Jammu-Himachal Pradesh. The MBT is represented in the northwestern sector from Kashmir to Chamba by the Murree Thrust (Wadia, 1934, p. 130), in the Kangra-Mandi belt in southwestern Himachal Pradesh by the Drang or Shali Thrust (Shrikanta and Sharma, 1972), in long belt stretching from south central Himachal Pradesh to south central Nepal by Krol Thrust.
(Auden, 1934; Bhargava, 1972; Valdiya, 1980a,b). east of the Gandak Valley up to the Kosi Valley in south eastern Nepal by Mahabarta Thrust (Stocklin, 1980), and east of the Kosi by the Garu Thrust (Jain et al., 1974).

The MBT is suggested to have formed sometime around 25–20 Ma (Hodges et al., 1988; Macfarlane, 1993), although an older middle Paleocene age has also been suggested (Srivastava and Mitra, 1994). However, Meigs et al. (1995) argues that subsidence, lithostratigraphy and geocronological data independently suggest that the MBT formed before 10 Ma. The oldest well-dated evidence for displacement along this thrust is 4.5 Ma, which comes from Pakistan and northwestern India (Burbank and Reynolds, 1988). Nakata (1989) concludes that the geomorphology of the Himalayan front suggests that the MBT could have been active until recently.

The disposition of the Murree Thrust (MT) in the present study area around Baglihar Project is shown in Fig.3.3. Here it is also known as Riasi Thrust. Across the study area the MBT closely parallels with the Panjal Thrust. Some workers (e.g., Fuchs, 1975; Shah, 1980; Gansser, 1981; Rautela and Thakur, 1992; Fuchs and Linner, 1995; Misra, 1999) treat Panjal Thust as an equivalent to MCT, while as Frank et al. (1995), Thakur (1998), place the Panjal Thrust below the MCT, there by showing them as two different geological entities. However, from Banihal to Budil sector both these thrusts occur so close to each other that at places they are just a few tens of meters apart from each other. However, the rock slopes in the study area are strongly influenced by the MT, which passes in close vicinity of the project area (about 800m SW of Head Race Tunnel). The inclination of the thrust varies from place to place, dipping (75°-85°) near the surface.

The MT can be traced from Netra-Blaut Khad area south of Ramban towards Khairi in Ravi valley. On Srinagar-Jammu Highway section, the MT can be located on a road cut near Peera (Fig. 3.4) displaying severely shattered rocks. However, it has been observed in Ramban-Blaut Khad Peerah-Chakwa Nalla section that the Panjal Traps and the associated quartzites carbonaceous shale-slate and limestone, which in rest of the area form the upthrust block and rest tectonically over the Murrees, are seen below the Murrees, thereby suggesting an unconformable relationship instead of thrust one.
Fig. 3.3. Disposition of the Murree (Riasi) Thrust (MBT) in the study area around Baglihar Hydro-electric Project Ramban J&K.

Fig. 3.4. Murree Thrust demarcated by (line AB) the limit of red clays on the left side (towards Jammu) near Peera nala and overthrusted Salkhalas are seen in the photograph.
In the study area the MBT trends N330°W and represents a high angle reverse fault, dipping at more than 80° at the contact between the Murrees and the Salkhalas. For instance, in the Nashri Nalla section Salkhalas lie almost vertically over the Murrees. The MT is covered with rock debris and scarce vegetation in a few sections around study area, from Kathyala Nala in the NE to Botote Kishtwar road in the SW. The juxtaposition of Slakhalas over Murrees over a narrow zone is so intense that the rocks display weak strength reflected by uncompressive strength (UCS) $\leq 100$ Mpa, joint volume of $>30$, and weathering grade of $W_3-W_4$.

3.2. Regional Geology

William (1861) is credited with the first detailed account of the topography of Kashmir Himalaya, followed by Lydekker (1876) who made the first systematic attempt to work out the stratigraphy of the Kashmir Himalaya. A detailed account of the stratigraphy of southeastern portion of the Kashmir Himalayas (including study area) was published by Middlemiss (1910b) and Reed (1910).

Lydekker (1883) gave an account of the geology of the Pir Panjal range and according to him the region is covered by (1) Sirmur rocks comprising Subathu, Dagshai and Kasauli; (2) Triassic, and (3) Crystalline schists. A similar study by McMohan (1885) in the adjoining area of Basohli-Bani-Bhaderwah area brought out the existence of the Bhaderwah slate of Silurian age resting unconformably on the Central Gneisses (Kaplus granite) succeeded by conglomerate of Upper Silurian age. Wadia (1928, 1931) mapped the northern part of the Jammu Himalaya extending from Jhelum Valley in the northwest and Ramban-Banihal area in the southeast. He suggested an intimate association of the Salkhala rocks with granites and gneisses. The granatoid gneiss intruding the Salkhala has been designated by Stoliczka (1866), McMohan (1877) and Middlemiss (1896) as the Central (Greater) Himalayan Gneiss. Gansser (1964), Gupta (1978), Ramesh and Kailash (1978), Sharma et al. (1978) and Srikantia and Bhargava (1974) depicted the Ramban and Doda area as covered by the Salkhala and the Dogra Slates with a thin band of Panjal Trap, Blaini and Rajputra Formations. Srikantia and Bhargava (1974) worked out relations between the Salkhalas of Kashmir and Jutogh Slates of Himachal Himalaya. According to these authors, the Dogra Slate on the sub-thrust
side of the Salkhalas is equivalent to Simla Group of rocks. Wakhloo and Dhar (1968a, 1969, 1970, and 1971) and Wakhloo et al. (1968b) worked on the geochemistry and metamorphism of different rock types of the Doda region.

Vohra (1966) mapped the Ramsu-Manjmi-Kaukut area and according to him the Salkhalas are unconformably overlain by a sequence comprising pebbly phyllites and limestone with some gypsum beds to which he gave the name Ramsu Formation, which he considered to be younger than the underlying Salkhalas upon which it rests with an unconformity of a considerable magnitude. He thus considered that the Ramsu Formation is probably of Paleozoic age and is not a part of the Salkhala series of Archean age as suggested by Wadia (1928).

Fuchs and Gupta (1971) consider that the area under discussion forms a part of Wadia’s Kashmir Nappe (Wadia, 1931), which has come to rest over the rocks of the autochthonous folded belt along the Panjal Thrust (Fig. 3.5). The authors believe that the erosion of the Nappe by the Chenab river near Kishtwar has exposed the epimetamorphic rocks of the Chail Formation ranging in age from Precambrian to the Triassics. They considered these rocks to be the westward strike continuation from Himachal Himalaya via Kashmir basin and are separated from the latter by the deep cut made by the Chenab that created the Kishtawar window. Raina et al. (1971) reported for the first time the occurrence of Permo-Triassic fossiliferous sequence of Bhallesh area of Bhaderwah Tehsil.

Sharma (1973a, 1974) studied stratigraphy, structure and tectonics of Doda-Bhaderwah-Chamba and suggested that the region in fact forms southeastern strike extension of Kashmir basin.
Stratigraphy: The stratigraphic sequence of the rocks from Banihal-Ramban-Budil region has been established on the basis of the works of Wadia (1928,1934,1975), Bhatia and Bhatia (1973), Sharma (1973b) and Shah (1980). Stratigraphic classification of the rock units into various formations, their salient lithological characters, probable age and their position in the standadrd stratigraphic column from north to south have been shown in the (Table 2.1)

Ramsu Formation: The name Ramsu Formation was given by Vohra (1966) after the village of Ramsu where this formation is typically developed. In the area under study, the formation rests unconformably over the Salkhalas and nowhere its contact with Chamalwas or Ramban Formations is seen. Vohra (1967) ascribed it Paleozoic age. The Formation is about 300 m thick and is composed mostly of slates, phyllites and limestones, and at base is conglomeratic in nature. Higher up in the succession, the phyllites alternate with limestone and are mostly carbonaceous and calcareous in composition (Bhatia and Bhatia, 1973). Sole markings and graded bedding are characteristic features of the Ramsu Formation.

Chamalwas Formation: This formation is exposed in the northern side of the study area around the village of Chamalwas. It is composed of slates and sandstone but unlike Ramban Formation, there is no regular alteration of sandstones and shale beds. The slates of the Chamalwas and Ramban, however, are astonishingly similar in their petrographic character (Bhatia and Bhatia, 1973). The Chamalwas Formation is overlain by Salkhalas and underlain by the Ramsu Formation. Obviously, the two formations were deposited in the same basin under different tectonic settings and domain of sedimentation (Bhatia and Bhatia, 1973).

Salkhala Formation: These rocks have been variously named by different workers; thus we find terms as Salkhala Series (Wadia, 1928; 1931; Gupta, 1982), Salkahala Formation (Srikantia and Bhargava, 1974; Greco and Spencer, 1993; DiPietro and Pogue, 2004), and Salkhala Group (Guha, 1985; Thakur, 1987; Sharma, 1973). This clearly reflects low level of information on these rocks. Here I restrict to the usage of first worker who later (Wadia, 1934) described these rocks as Salkahala Formation, for no particular technical reason, though. The Salkhala Formation has been named after a little hamlet situated on the left bank of Kishanganga river Wadia (1934) described the Salkhala Formation as less metamorphosed, less varied, easily identifiable assem-
<table>
<thead>
<tr>
<th>Group/Formation/ Series</th>
<th>Lithology</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramsu Formation</td>
<td>Predominantly phyllites of various colours and composition interstratified with limestone, conglomerate phyllite at the base.</td>
<td>Palaeozoic</td>
</tr>
<tr>
<td>Chamalwas Formation</td>
<td>Slate interbedded with thin bands of quartzite dark grey to grey greenish</td>
<td>Precambrian (may be homotaxially equivalent of Ramban)</td>
</tr>
<tr>
<td>Salkhala Formation</td>
<td>Various types of phyllites, schists, gneiss and quartzites, crystalline limestone, gypsum lenses with granitoid intrusives.</td>
<td>Precambrian</td>
</tr>
<tr>
<td>Rajpura (Subathu)</td>
<td>Limestone, shale, patches of calc shale over Sauni volcanics</td>
<td>Palaeocene-Eocene</td>
</tr>
<tr>
<td>Dogra Formation</td>
<td>Alternating sequence of black slates phyllitic slate and quartzites of varying thickness</td>
<td>Precambrian</td>
</tr>
<tr>
<td>Sincha Formation</td>
<td>Quartzite, dolomite, limestone, phyllite, slate,</td>
<td>Proterozoic</td>
</tr>
<tr>
<td>Murree Formation</td>
<td>Red, brown and grey sandstone, claystone, shale, with inliers of limestone</td>
<td>Early Miocene to Oligocene</td>
</tr>
<tr>
<td>Siwalik Group</td>
<td>Sandstone, conglomerate, mudstone</td>
<td>Miocene to Pliocene</td>
</tr>
</tbody>
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blege of ordinary phyllites and slates with characteristic rock type of deep black graphitic slates, black crystalline limestone, or snow white marbles and flaggy quartzite. Salkhala belt of Kashmir Himalaya has a wide areal distribution; it covers entire Lesser Himalayan zone. Contrary to its Archaean age assignment (Wadia, 1928; Sharma, 1973), DiPietro and Isachsen (2001) on the basis of lithology and stratigraphic position suggest a Lower Proterozoic age for Salkhalas. The metasedimentary rocks of Doda region belong to Salkhala Formation of Jammu segment of Lesser Himalayas, and display evidence of multiple deformation and regional metamorphism, suggested by the development of biotite-garnet-, staurolite-, kyanite and sillimanite zones (Guha, 1985).

Subathu (Rajpur) Formation: The Sabathu Formation is composed of thick greenish grey limestone interbedded with thin shale, which has been dated as Late Palaeocene-Eocene (Mathur, 1978). Verma et al. (1983) considered these rocks as tectonic outliers resting upon Dogra slates in the Ramban area traversed by local thrust (Digdaul Thrust). In the study area the Sabathu limestone is named as Chenab limestone. The limestone as well as shale beds are criss-crossed by calcite veins.

Sincha Formation: The Dogra (Ramban) Formation is underlain unconformably by a zone of highly tectonised (sheared, heavily fractured and shattered) dolomite and limestone assemblage of rocks known as Sincha Formation. The contact between the two formations is demarcated by a local Balaut Fault. This formation is well exposed around Scincha village north of Ramban where it is flanked by the Panjal Thrust. The Formation was earlier grouped under the Dogra Slates (Precambrian); however, Jangpangi et al. (1986) assigned it a Proterozoic age.

Dogra Formation: The Dogra Slates are typically exposed in the vicinity of Ramban along the national Highway and are found up to Digdoul where it is overthrust by Salkhalas. The individual thickness of greywackes varies from a few centimeters to about a metre. Along the Highway section the Formation is composed of sandstone, grey to dark grey shales/slates with bands of grey quartzites, bluish grey phyllitic slate/calcareous phyllites and occasional pebbly slates. Load casts, flute casts and ripple marks are observed in the basal parts of the Formation.

Murree Formation: The Murree Formation has been named after a village in Pakistan. The epicontinental shallow marine facies of Sabathu
grade estuarine and lacustrine deposits of the Murrees (Upper Eocene to Lower Miocene) constitute most part of the Murree Hills (Bagati, 1991). The Murree Formation is predominantly composed of sandstone and shales with ripple marks and pseudo-conglomeratic structure. This Formation forms the inner part of the foreland thrust belt (Tertiary belt of Jammu & Kashmir) extending from Poonch to Basoli and lateraly up to Pakistan in the west (Karunakar and Ranga Roa, 1979). The Murree Formation has been divided into Lower and Upper Murree formations, which are in conformable contact.

**Siwalik Group**: These rocks of Middle Miocene-Middle Pleistocene age represent about 6 km thick sedimentary strata deposited in the Himalayan foreland basin (Bagati 1991). Classically Siwalik Group is divided into Lower, Middle and Upper Subgroups. The Siwalik Group is dominated by the multi storeyed sandstone, which is interbedded with minor mudstone units at different stratigraphic levels. Swalik Group is conformably overlain by Murree Formation.

### 3.3. Geology around the Study Area

The geological formations exposed in and around the study area from south to north in a narrow zone are in strike continuity to those found to the east in Doda and to the west in Budil (Fig. 3.6). This narrow zone starts from Uri in the Jhelum valley, extending through Mandi and Bafiaiaz, both in (Poonch district), crossing the Jammu–Srinagar National Highway (NH-1A) near Peera and further extending eastwards up to Basholi across Ravi river (Wadia, 1931; Sharma 1973; Shah, 1978; Frank et al., 1995).

The rocks exposed are the Salkhala Formation consisting of deep and light grey quartzites (interbedded on the centimeter scale with slates), phyllitic quartzites, slates and thin lenses of schists, all intruded by quartz veins. The rocks underlie the Dogra slates with a gradational contact that it is difficult to demarcate. The general trend of the rocks is N 30°-40°W with dips of 60°–68° due ENE.

The project area is situated between the M1 (Murree Thrust) and the Panjal Thrust. The rocks are strongly influenced by the M1, which cuts across in close vicinity of project area (about 800 m SW of HR1). The rocks are folded into a broad plunging syncline, with a relatively tight complimentary anticline to the NE. The plunge of the folds is about 25° due N. Two sympathetic N-S trending reverse faults/thrusts, dipping by 40°–55° due westerly (opposite to the general dip of the formations).
cut across the project near the intake (T₁) and at the mid length of HRT (T₂), respectively. The upward throw/displacement ranges between 0.5 and 1.50 m. The rocks manifest four major sets of joints and 2 random sets and shear seams, which are moderately to highly weathered (W₃ - W₄). The low angle joints with clay gouge material/shear seam are frequent feature in the area and greatly influence the stability of rock mass.

3.4. **Geology of the study area (around Baglihar dam site and powerhouse)**

As is the case with surrounding area, the dam site is occupied predominantly by (i) quartzite with thin slate partings, (ii) phyllitic quartzite with slate bands, and (iii) slate with thin quartzite lenses (Fig. 3.7). The general trend of the rocks varies between N10° W - S10° E to N10° W - S40°E with dips of 60 - 68° towards N 80° E to N 50° E. The dam site slopes rise from an elevation of 700 m at river bed to an elevation of over 1150 m on the abutments. The right abutment is steeper (70°) than the left abutment (45°). The abutments are occupied by quartzite with slate partings. The rock mass is slightly weathered to unweathered (W₀ - W₁). The exploratory drifts expose some low angle
Fig. 3.7. Geological Map of the Baglihar Hydroelectric Project
shear seams dipping mostly into the abutment, except one such seam that dips towards the valley. As in the surrounding areas, rocks here too manifest four major sets of joints plus 2 random sets and shear seams. The higher reaches of the left abutment of the dam forms a part of the larger landslides. About 800 m upstream of the dam site, the right abutment has thick deposit of over burden/slide and debris/terrace deposits within the reservoir limits that could be potential sites for sliding during reservoir filling. The power house site is mainly occupied by the slates which are dark grey, relatively soft having occasional competent ribs of fine grained sandstone/quartzite and shear seams with profound weathering (W₃ – W₄). These are thinly foliated and jointed with foliation and shear joints, and break mostly along perfect foliation joints rendering them to very small blocks like sugar cubes. The hill slope shows destressing cracks/ gapping joints, which day lights the slope face. The unit also displays squeezed ground conditions. These slates are marked with profound rill erosion.

3.5. Recent Deposits: These deposits of varying thickness, but not exceeding 1-2 m, consist mainly of silt and clay and form small fields on fluvial terraces on which some important villages like Baglihar on the left bank of river Chenab, Dhalwas, Dharmund, Peera, etc. are situated. The heterogeneous, unsorted nature and dumped forms of these deposits attest to their fluvioglacial origin. The angular and sub angular rock fragments especially of quartzite, phyllites, and slates are frequently met within them.