1 INTRODUCTION

The proposed Tato-II Hydroelectric Project is one of the major hydroelectric projects identified by CEA in Siang basin in Arunachal Pradesh under Prime Minister's 50,000 MW initiatives. The project was conceived by CEA on the river Siyom, a major tributary of the river Siang, downstream of the powerhouse of the proposed Hirong Hydroelectric Project and upstream of the proposed Naying Hydroelectric Project near village Tato in West Siang district of Arunachal Pradesh. This scheme, as conceptualized by CEA at Pre Feasibility stage, envisaged construction of a diversion structure of a small height on the river Siyom at a site where river bed level attains +1120m elevation, about 5.5 km long headrace tunnel and a powerhouse with installed capacity of 360MW located on left bank of river. With a tailrace level of +840m, it was proposed to utilize a gross head of 280m to generate a firm power of 94 MW. The annual energy generation from the project in 90% and 50% dependable years was estimated to be 1795 GWh and 2010 GWh respectively. A line layout as proposed by CEA appended in **Annexure-I, Volume-VIB**. After identifying, the scheme was handed over to NHPC for preparation of PFR. Initially, the NHPC proposal, keeping in view the tail water level of upstream Hirong project, included construction of a 45m high diversion dam at a location where riverbed has elevation of +1080m. The length of HRT and TRT were kept same as conceptualised by CEA. Subsequently, after carrying out further studies, the project conceived at PFR stage envisaged construction of a diversion dam near the village Tato downstream of confluence of Shichu Nala with Siyom, an underground powerhouse with installed capacity of 700 MW about 14 km downstream of Tato village (as per road distance). As per this scheme a gross head of 187 m was proposed to be utilised to generate 3411 MU of energy 90% dependable year.

The project is located between latitude N 28º32'4.5" and N 28º31'25.18" and between longitudes E 94º23'57.2" and E 94º25'35.22". The project includes 155m high concrete gravity dam above the deepest foundation across the river Siyom about 1.1km downstream of its confluence with Shichu, a 10.4m diameter and 3.876km long headrace tunnel including 61m long conduit on the left bank of the river and an underground powerhouse with an installed capacity of 700MW located about 14km (road distance) downstream of Tato village. The project is being developed by Tato Hydropower Private Limited (THPPL), who engaged SNC-Lavalin Engineering India Pvt. Ltd. (SLEI) as an engineering consultant to prepare the Detailed Project Report (DPR).

The topography of the area is rugged and accessibility very poor, especially on the left bank of Siyom where most of the components of the project are located. The hill slopes in the area are steep to very steep and support very dense forests with luxuriant under growth. In addition, the facilities for crossing the river are very limited. Due to rugged topography and poor accessibility to the left bank of the river, the SLEI geology team that included the Canadian Geologists trained in rock climbing and mountaineering carried out geological mapping that was limited to the areas that could be accessed. The geological mapping was carried out in different phases during 2009 and 2010. Regional Geology, detailed geological setup of the project area as well as site specific geological assessment of the different project components are based on extensive literature consultations, surface and subsurface geological explorations carried out so far. Geological maps and sections appended with this document have been prepared based on the field studies and data obtained from surface and subsurface explorations carried out at the site.

2 REGIONAL GEOLOGY

2.1 Physiography

Physiographically, Arunachal Pradesh can be divided into four distinct units (**Figure-1**) and each unit has distinct geology setup and tectonic history. These are:

- Himalayan Ranges
- Mishmi Hills
- Naga- Patkoi Ranges and
- Brahmputra Plains

2.1.1 Himalayan Ranges

The Himalayan Ranges in Arunachal Pradesh are eastern most part of Himalaya and are known as Arunachal Himalaya. These extend from eastern border of Bhutan in the west to Dibang and Lohit valleys in the east where these abut against Mishmi Hills. This part of Himalaya like other parts has been divided into four parallel linear zones. These, from north to south are:

- Tethys or Tibetan Himalaya
- Higher Himalaya
- Lesser or Lower Himalaya and
- Sub- Himalaya

Tethys or Tibetan Himalaya in this part trends northeast- southwest and is located north of Higher Himalaya along its border with Tibet. The relief in this zone as compared to that in Higher Himalaya is low and slopes are gentle. The altitude in general varies between 3000m and 6000m above mean sea level. However a few peaks rise up to altitude exceeding 7000m. Almost all the rivers draining Arunachal Pradesh originate in this zone. The important passes such as Bum La, Tulung La (Tawang district), Mygyitun La, Tunga Pass (Upper Subansiri) and Tunga & Lemdo (West Siang) are located in this zone.

Higher Himalaya, a northeast - southwest trending zone is located between Tethys Himalaya in the north and Lesser Himalaya in south. The southern limit of Higher Himalaya in general is defined by Main Central Thrust. This zone in general has high relief above 6000m with precipitous slopes and deep narrow valleys. This zone is less conspicuous east of Subansiri as it merges with Tethyan zone.

Lesser Himalaya, lies between Higher Himalaya in the north and Sub- Himalaya in the south, has elevation ranging between 2500m and 4000m. This zone is much wider than Higher Himalaya and trends E- W in western part closer to Bhutan and assumes a north easterly trend before taking a syntaxial bend to SE and abutting against Mishmi Hills along Tidding Suture in the eastern part. The northern limit of this zone is defined by Main Central Thrust (MCT) and southern one against Sub- Himalaya by Main Boundary Fault/ Thrust.

Sub- Himalaya comprises outer or southern most hill ranges that rise abruptly from Brahmputra Plains along another tectonic plain, Foot Hill Thrust, which is mostly concealed under Newer Alluvium. This zone extends from Bhutan boarder in the west Passighat in the east where it narrows down to 1-2 km width and ends up against Roing Fault in Dibang valley. The maximum altitude in this zone in general goes up to 1000m above mean sea level. This zone exposes Neogene – Early Quaternary sediments.

Figure-1: Map showing physiographic division of Arunachal Pradesh

2.1.2 Mishmi Hills

The Himalayan ranges on their eastern end abut against Mishmi Hills along Tidding Suture and meet another mountain chain- the Mishmi Hills. These Hill ranges trending NW-SE are continuation of hill ranges of northern Myanmar. Mishmi Hill ranges attain elevation of

2500m to 6000m in general and are drained by the Lohit and Dibang rivers of the Brahmaputra river system. The Mishmi hills towards southeast abut against the Naga Patkoi ranges of the Arakan Youma Mountains to the south along another tectonic plane – the Mishmi Thrust.

2.1.3 Naga Patkoi Ranges

These hill ranges of moderate altitude limit the southern extent of Upper Brahmaputra Plains and form water divide between Brahmputra and the Chindwin river of Mayanmar. These are the northern continuation of the sigmoidally curved northeast-southwest trending Naga – Patkoi ranges of the Arakan- Yoma mountain ranges. These ranges after their junction with Mishmi Hills along Mishmi Thrust follow an east-west to northwest-southeast trend. These are drained by Noa Dihing, Tirap and Namphuk that flow almost parallel to the strike of rocks. These ranges comprise Tertiary sequences of Assam and are believed to have come into existence during last phases of Himalayan Orogeny.

2.1.4 Brahmaputra Plains

The valley lying between the Himalayan ranges to the north and the Shillong Plateau – Naga Patkoi ranges to the south and filled up by the Post-Siwalik/ Dhikiajuli Quaternary sediments constitute the Brahmaputra Plain. The Mishmi Hills form its eastern limit. The plains trend NE-SW in the upper northeastern part but assume an E-W trend in lower reaches of Brahmputra and merge with Indo-Gangetic Plains west of Shillong Plateau.

Disposition of the above physiographic zones is depicted in **Figure-1**. As can be seen, the Tato-II hydroelectric project lies in the Lesser Himalayas sub division of the Arunachal Himalayas.

2.2 Geomorphology

The Himalayan mountain system is a conspicuous landmass characterized by its unique crescent shape, high orography, varied lithology and complex structure. The geomorphic regime is in a geodynamically active stage even though the rock masses have a long history of deformation, metamorphism and magmatism from Proterozoic to Quaternary. The present day landscape has been shaped during the Quaternary period by physical activities like glacial, post-glacial and fluvial actions. In the broad geomorphic classification, the project area lies in Mountain ranges (S1) characterized by moderately dissected, fine drainage textured, sharp crested ridges and is defined as S1e geomorphic unit of structural origin

(Ghosh et. al., 1989). The conspicuous geomorphic features observed in the area are that the rivers flow mostly transverse to the NW-SE, E – W and NE – SW regional trend. This unit is frequently traversed by strong transverse lineaments which often appear to offset the ridges. The southern boundary of this geomorphic unit with Shiwalik hills is very sharp and often marked by local longitudinal lineaments of prominence, indicative of faults/thrusts. The western boundary of this unit is gradational and the eastern boundary is marked by a syntaxial bend along the river Dihang or Siang, and also by the NW – SE lineament representing Lohit Thrust.

Most of the rivers draining the area originate in Trans Himalayan zone and descend down the snow clad Higher Himalayas before debouching into the Brahmaputra River, the most important river. The Brahmaputra River known as Tsang Po in Tibet originates in Kailash Range and flows easterly along the Indus – Tsang Po Suture parallel to general trend of Himalaya. It takes a U-bend near Namcha Barwa, flows south westerly and enters Arunachal Pradesh where it is known as Dihang or Siang. It takes another right angled turn towards southeast near Singing and flows across lesser Himalaya and Sub- Himalaya. It enters Brahmaputra Plains near Passighat. The trunk channel of Siang is controlled by the Siang antiform.

In Arunachal Himalayas, the Siyom and the Yamne rivers are the two major tributaries that drain the western and the eastern parts of the Siang valley. The Siyom River, which originates from Tunokar Ogo as a subsequent stream running parallel to the strike of the beds, flows south wards till it takes a right angle turn to the east near Yare. Shi Chu is a west-east flowing tributary of Siyom, joining it upstream of the proposed dam axis of the proposed Tato-II hydroelectric project. Siyom River joins Siang at Pangin. Yamne River is also subsequent river which flows southeastward and joins Siang near Rotung. Further downstream, the river Siang is joined by two major streams from east- Dibang and Lohit at Sadiya and assumes the name Brahmaputra.

The Siyom is a turbulent river with a generally steep gradient and flows through a narrow valley in the project area. Important tributaries of Siyom are Sheu nala, Tagurshit nala, and Sire nala which join the Siyom from the right side and Seath nala, along with two unnamed important nalas which join the Siyom from the left bank. All these nalas together form the drainage network of the project area.

The project area has a very rugged topography with sharp crested ridges and narrow valleys with altitude varying between 800m to about 4000m. Some of the well marked peaks in and around project area are Tarpungche (2787m), Pale (3200m), unnamed peaks (2045m, 2430m). Another unnamed peak (3015m), a part of Jomi hill, is located near the site of proposed powerhouse. The important Pari mountain range extending north - south exists south of the proposed powerhouse area.

The geomorphic units of the Arunachal Himalayas have been traversed by a number of lineaments, the major ones running transversely in N-S and NW-SE direction. In the eastern part, the geomorphic unit takes a sharp bend towards south, where a strong NW-SE lineament (Lohit Thrust) delimits the granitoid block and Mishmi Hills on the north.

2.3 Geological Setting

2.3.1 Geological Setup

The Arunachal Himalayas mainly encompass – Proterozoic crystallines, the Proterozoic folded covers, Palaeozoic cover sequence and volcanics tectonically reworked during Himalayan fold thrust movement. Northern part of this terrain is occupied by Trans-Himalayan tectogen with late to post tectonic granitoid batholiths (**Figure-2**). This packet is followed in the south by ophiolite and accretionary complex of the Tsangpo Suture Zone towards the west and development of an incipient ophiolite observed towards east. Further south, the Main Himalayan belt starts with poorly metamorphosed cover sequence of Tethyan belt, which is tectonically underlain by high and low grade assemblages. The most prominent geological feature in Arunachal Himalayas towards east is the Eastern Syntaxial Bend (ESB), across which the tectonic belts take a sharp bend and swerve from NE – SW in the west to NW – SE in the east across the Siang gorge. Wadia (1931) attributed this bend to bending of the Himalayan orogen against the NE projecting foreland of Shillong Plateau. According to another school of thought, it is a case of meeting of two different trending tectonic domains – one ENE-WSW trending in the west and the other NW-SE trending in the east. This syntaxial bend is built up of Proterozoic to Cenozoic rocks characterized by distinct lithotectonic belts. Within the Siang window, fossiliferous Cenozoic cover sequence along with basic volcanics is present. Structurally the syntaxial bend is a NNE-SSW trending anticlinal structure with many associated small antiforms and synforms.

Lithostratigraphically, the units exposed in the area belong to (i) Trans-Himalayan part in the north and (ii) Himalayan part in the south. The Tuting–Tidding Suture/ Tuting Tidding belt divides the Trans Himalayan and the Himalayan parts. Trans Himalayan part encompasses two main lithostratigraphic units – Tuting Granites in the north and Tuting Metavolcanics in the south separated by Yang Sang Chu Thrust (=Tsang Po Thrust). Tuting Granites extend NW-SE and continue southeastwards into the Dibang Valley where Mishmi Granodiorites, considered to be their geochemical variant, are exposed. Tuting Metavolcanics and associated basics and ultramafics are exposed mainly around Tuting and continue E-W to NW-SE up to Ningguing in the west and Mahangkota in the east where these are tectonically truncated. Regionally, the Tuting Metavolcanics continue southeasterly and join Tidding Formation to form part of the Tuting- Tidding Suture belt.

The Himalayan part comprises rock sequences ranging in age from Proterozoic to Cenozoic. The Precambrian sequences in Arunachal Himalaya have been grouped into the Sela Group and the Bomdila Group. Sela Group, the Palaeo- Proterozoic group of rocks, constitutes the northernmost part and regionally extends ENE-WSW to NE-SW up to Tuting in the east where it is truncated by the Tuting - Igo Fault. It is represented by high grade metamorphics (sillimanite - kyanite schist and gneiss), characterized by feldspathisation and tourmaline granite intrusion. The Sela Group rocks tectonically succeeds the Bomdila Group comprising medium grade metamorphic rocks and associated acid and basic intrusives along Main Central Thrust (MCT). The Bomdila Group in western part in Kameng & Subansiri has been sub-divided into the Khetabari, Tenga and the Chilliepam (Dedza) formations in ascending order. Khetabari Formation principally comprises quartzite, acid tuffs, phyllite and calc silicates in the lower part and quartzite, schist and para-amphibolite in the upper part. It is overlain by Tenga Formation which occurs as a linear belt from Bhutan border in the west to north of Daporijo in the east (Kumar, 1997). Chillepam Formation comprises a thick sequence of carbonates and lies unconformably over the Tenga Formation. In the same stratigraphic position, at different places it has been named as Menga Fm (Tripathi et al. 1983), Pangin Formation (Jain et al 1974), Dedza Fm (Anon 1974), Kabak Formation (Roychowdhury and Lakshminarayana, 1986), Niumi Formation (Das and Basu Roy, 1982). Unconformably overlying the Bomdila Group is Dirang Formation which is a thick sequence of low grade metasediments, exposed in the south and truncated in the north by the MCT.

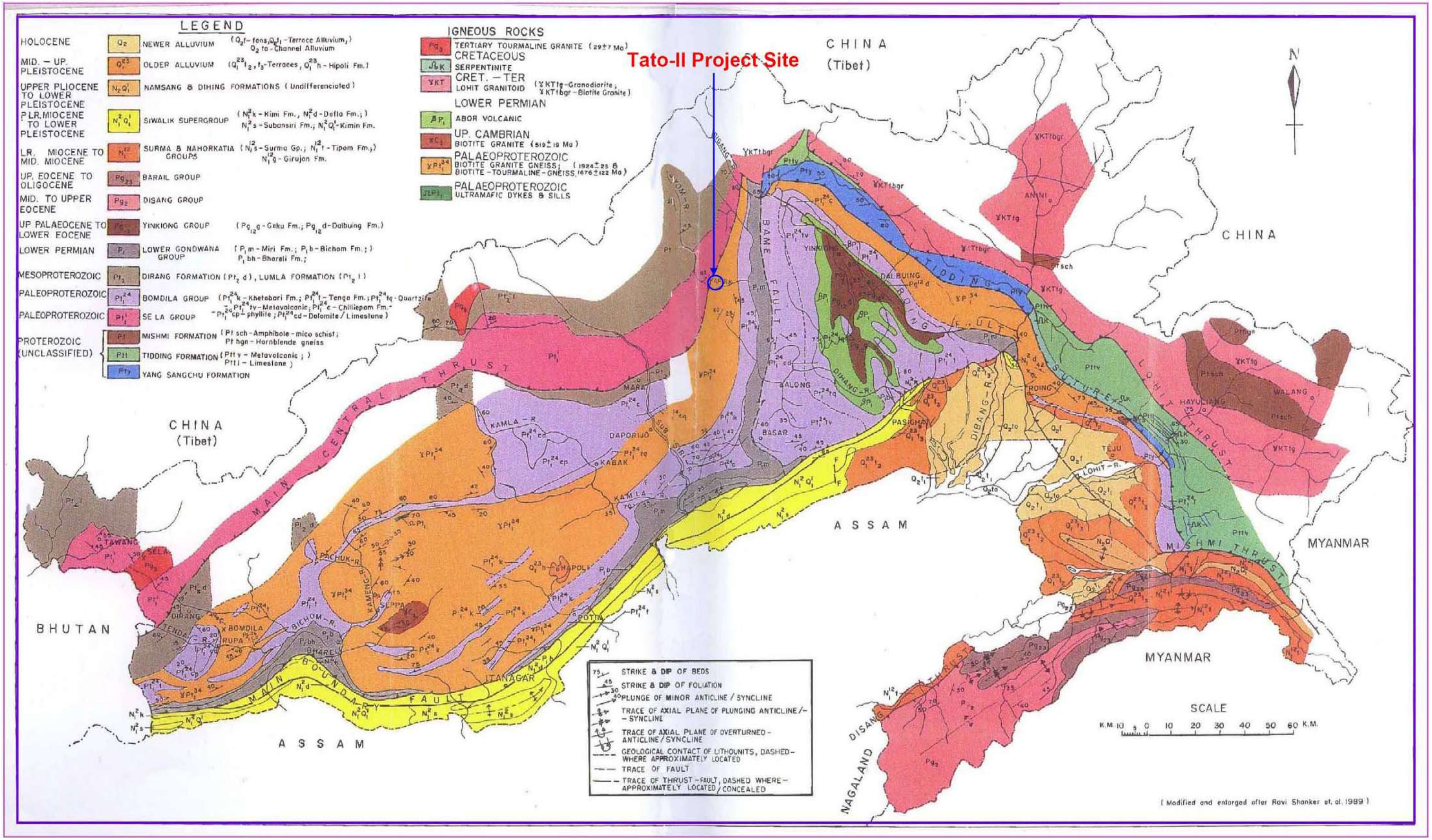

Figure-2: Regional Geological Map of Arunachal Pradesh (Modified after Ravi Shankar et. al. 1989)

However, in Siang valley, stratigraphically equivalent litho assemblages of the Bomdila Group of Kameng and Subansiri districts have been classified into three groups, namely, the Siang Group, the Siyom Group and the Rikor Group on the basis of metamorphic grade, deformational characteristics and litho-association by Singh (1993) and Kumar and Singh (2001). Kumar and Singh (1993) also correlated these with Proterozoic rocks in Dibang and Lohit districts in east and those belonging to Siyom Group with rocks belonging to Bomdila Group in the west. The rocks belonging to Siang Group here have been correlated with those belonging to Sela Group by Kumar (1997). Choudhuri et al (2009) named these as Higher Himalayan Crystallines (HHC) and correlated with Sela Group of rocks of Kameng and Subansiri districts. The Siang Group consists principally of high grade rocks which have distinct deformational and metamorphic characteristics. It includes sillimanite-kyanite schist, amphibolite, quartzite, marble, gneiss and migmatite. These rocks occur as a linear belt between Tuting Granites/ Tuting Metavolcanics in north and the rocks of Siyom Group in the south. The high grade metamorphic rocks belonging to Siang Group have been divided into three formations viz. Pari Mountain, Singing and Yang Sang Chu formations on the basis of lithological, metamorphic and tectonic characteristics. The Siang Group of rocks is separated from the rocks of Sela and Siyom groups by thrusts. The Siyom Group consists of low to medium grade metamorphics comprising schistose quartzite, schist, marble, and gneiss and metavolcanic. It is tectonically separated from overlying Siang Group by the Sike Nala Thrust; and in turn it tectonically overrides the Rikor Group including schistose quartzites, schists, slates, quartzites & limestone along the Siyom Thrust in the Siang Valley. However, the Siyom Group is underlain by Miri Quartzites in the Siyom Valley. The rocks belonging to Pari Mountain formation of Siang Group have been correlated with Ziro and Daporijo Gneisses of Subansiri valley by Singh (1993) whereas same have been kept under Higher Himalayan Crystallines by Choudhuri et al (2009) and under Sela Group by Kumar (1997). The rocks belonging to Siyom Group are considered equivalent to Potin - Khetabari Formations of Bomdila group.

The Paleozoic stratigraphy commences with the Gondwana Group of rocks, which rest unconformably over the Bomdila Group along its southern fringe and abut against the Sub-Himalayan rock sequences along the Main Boundary Fault (MBF). In the southern part of Arunachal Pradesh these rocks occur in an east-west to northeast-southwest trending narrow linear belt from Bhutan border in the west to Basar in the east. Further towards east the sequence takes an antiformal swing towards north and abuts against the Lohit Complex along the Tuting -Tidding suture in Siang valley. In this sector, its eastern limit is defined by the Bame Fault separating it from the Bomdila Group. Earlier lower part of these was mapped as those belonging to Buxa Formation thereby separated Miri Formation from Gondwana Group and assigned Yembung, Dite and Dime members to this Group.

Lithostratigraphically, the Gondwana Group has been subdivided into Miri, Bichom, Bhareli and Abor Volcanic formations in ascending order. Miri Formation (Nikte Quartzite of Singh, 1993) comprises a sequence of conglomerate, sandstone/quartzite, purple shale and diamictite and is conformably overlain by Bichom Formation yielding Lower Permian fauna. It is best exposed along Bame-Daporijo road between Bame and Sododoke. Abor Volcanics comprises a sequence of massive, vesicular to amygdaloidal and porphyritic basic volcanic rocks and associated intertrappeans which have yielded Lower Permian microfauna (Roychoudhuri et. al., 1984; Prasad, et. al., 1989).

There is no record of any Mesozoic rocks from Arunachal Himalayas. The Cenozoic stratigraphy is represented by the Yinkiong Group and the Siwalik Group of rocks. The Yinkiong Group is subdivided into the lower Geku Formation comprising volcanoclastic rocks with mafic volcanics followed by continental facies sequence yielding dicot plant fossils and the upper Dalbuing Formation yielding Lower Eocene fauna. The Yinkiong Group is terminated by Bame- Dumro Fault in south by Nellang thrust in the east and by Simang Simen Fault in the west of Eastern Syntaxial Bend.

The Siwalik Group occurs as a linear belt all along the foot hills from border with Bhutan in the west to Roing in the Dibang valley in the east where it ends against the Roing Fault. The Main Boundary Fault (MBF) defines the northern limit of Siwalik Group separating it from the Pre Tertiary rocks whereas the Brahmaputra Alluvium defines its southern boundary. This contact with Brahmaputra Alluvium is considered to be tectonic (Foot Hill Fault) at some places.

Brahmaputra Alluvium represents the Quaternary sediments exposed in the Form of Older and Newer Alluvium. Older Alluvium occupies the higher levels of the valley and is comprised of boulders, cobbles, and pebbles, oxidized sand and sandy clays. Newer Alluvium represented by Channel Alluvium is composed of unoxidised sediments of active channel.

The litho-stratigraphy (**Table-1**) and structure in Arunachal Himalaya as worked by various workers is described in details below.

Table-1: Stratigraphic Succession in Siang Valley

<table>
<tr><th>Age</th><th>Group</th><th>Formation</th><th>Lithology</th></tr>
<tr><td>Pleistocene to Recent</td><td></td><td>Alluvium</td><td>Riverine deposits</td></tr>
<tr><td colspan="4">-------------------------Unconformity or Foot Hill Fault---------------------------</td></tr>
<tr><td>Middle Miocene - Pleistocene</td><td>Siwalik</td><td></td><td>Sandstone, siltstone, shale with plant fossils and coal streaks.</td></tr>
<tr><td rowspan="2">Upper Paleocene to Lower Eocene</td><td rowspan="2">Yinkiong</td><td>Dalbuing</td><td>Sandstone, purple to green shale containing fossils and limestone containing foraminifers.</td></tr>
<tr><td>Geku</td><td>Dark green to grey amygdaloidal mafic volcanics, tuffs, micaceous siltstone, green and purple shale.</td></tr>
<tr><td colspan="4">--------------------------------Intrusive Contact--------------------------------</td></tr>
<tr><td rowspan="4">Lower Permian</td><td rowspan="4">Gondwana</td><td>Abor Volcanics</td><td>Massive, vesicular to amygdaloidal, porphyritic basaltic to andesitic basic volcanics.</td></tr>
<tr><td>Bhareli</td><td>Thick sequence of greyish feldspathic sandstone and grey to black carbonaceous shales with lenticular coal beds.</td></tr>
<tr><td>Bichom</td><td>Dark grey diamictite with minor quartzite</td></tr>
<tr><td>Miri</td><td>Conglomerate, sandstone/quartzite, purple shale and diamictite.</td></tr>
<tr><td colspan="4">--------------------------------Thrusted Contact--------------------------------</td></tr>
<tr><td rowspan="5">Paleo-Proterozoic</td><td>Rikor</td><td>Pangin

Boleng</td><td>Limestone and dolomite with thin phyllite bands
Alternate bands of limestone and quarzite

Alternate band of quartzite and limestone
Massive quartzite with thin muscovite-chlorite schist intercalations</td></tr>
<tr><td colspan="3">----------------------------------Siyom Thrust ----------------------------------</td></tr>
<tr><td>Siyom</td><td>Gasheng

Rumgong</td><td>Interbedded slate and limestone
Interbedded slate and quartzite

Schistose Quartzite with muscovite-chlorite schist and graphitic schist</td></tr>
<tr><td colspan="3">---------------------------------Sike Nala Thrust---------------------------------</td></tr>
<tr><td>Siang</td><td>Yang Sang Chu

Singing

Pari Mountain</td><td>Slate and marble
Garnetiferous graphitic schist
Sillimanite-garnet graphitic schist and staurolite- garnet graphitic schist

Sillimanite-staurolite-garnet schist and biotite ± garnet schist with minor quartzite with graphitic schist bands
Quartzite with minor biotite ± garnet schist, marble and amphibolite

Biotite ± garnet gneiss and migmatite</td></tr>
<tr><td colspan="4">--------------------------------MCT---------------------------------</td></tr>
<tr><td>Early Paleo-Proterozoic</td><td>Sela</td><td></td><td>Calc-silicates, marble, kyanite, sillimanite ± staurolite gneiss and schist, migmatite, gneiss, para- amphibolite with younger intrusions of hornblende granite, tourmaline granite and pegmatite.</td></tr>
</table>

Sela Group

The Sela belt is the northern most litho-tectonic belt exposed over a large area in western Arunachal Himalaya. It tectonically succeeds the Bomdila belt along Main Central Thrust (MCT). The Sela belt is represented by high grade metamorphics, characterized by extensive felspathisation and intruded by late tourmaline granites. Various nomenclatures have been assigned to these rocks by different workers in different parts of Arunachal Himalaya, such as, the Se La Group (Das et al, 1975; Verma & Tandon, 1976), Takpasiri Group (Dutta et al, 1983) and Siang Group (Jain et al, 1974). In Kameng, the high grade gneisses suddenly appear against medium grade meta sedimentaries of Bomdila Group and further north sillimanite gneisses are well developed. High grade metamorphites, such as sillimanite schist, kyanite schist, graphite schist calc-silicates etc are well exposed in the northern parts of Siang such around Singing - Angguing

Bomdila Group

The oldest rocks exposed in Lower Siang Valley in the area around the proposed project belong to Siyom Group. As stated earlier, these are considered extension of the rocks included in the Bomdila Group of Kameng and Subansiri districts in the west. The rocks belonging to Siang Group include high grade metamorphics and are exposed in the westernmost part of the Valley. These have been sub divided into Pari Mountain, Singing and Yang Sang Chu formations. These are considered to be succeeded by low to medium grade metamorphic rocks belonging to Siyom Group. The rocks belonging to Siyom Group predominate in southern and western parts of Siang Valley whereas the rocks belonging to succeeding Rikor Group dominate in eastern and northern parts. The rocks belonging to Siyom Group have further been divided into Rumgong Formation and Gasheng Formation. The lower Rumgong Formation includes schistose quartzite with muscovite- biotite –chlorite schist, graphite schist and phyllite. These are overlain by interbedded sequence of slate, quartzite and limestone belonging to Gasheng Formation. The rocks belonging to Rikor Group succeed those belonging Siyom Group. These are classified into Lower Boleng Formation and Upper Pangin Formation (Singh, 1993). The rocks belonging to Boleng Formation of Rikor Group are exposed mainly towards right bank of Siang River and comprise predominantly alternate bands of quartzite and limestone/dolomite in upper part and massive quartzite with thin intercalations of muscovite-chlorite schist, phyllites, siltstone and conglomerate in the lower part. Primary structures like bedding, crude graded bedding, cross bedding and ripple marks have been observed in the rocks belonging to Boleng Formation. Gupta et. al., (1981, 1982) have further sub divided Boleng Formation into two units viz. Boleng Quartzite and Sillekorong Quartzite on the basis of lithological association and metamorphic characteristics. Schistose quartzite and associated phyllites have been included in Boleng Quartzite Unit whereas non-schistose and less deformed, white to pink ortho-quartzites have been termed as Sillekorong Quartzite Unit by Gupta et. al. (1982). The later are exposed only in the areas east of Siang River and include dominantly white to pink, fine to medium grained thin to thick bedded quartzites with intercalations of shale and siltstone. A few altered basic sills have been observed traversing Sillekorong Quartzite at some places. A thick dyke of Gabbroic composition has been reported traversing Sillekorong Quartzite near Bodak by Gupta et. al. (1982). The Sillekorong Quartzites abut against the rocks belonging to Abor Volcanic Formation along Simang Simen Fault (Singh, 1993). According to Gupta and Misri (1983) the Simang-Simen Fault dies out within Abor Volcanics but according to Singh (1993) the same extends towards south along the course parallel to Simen River. The rocks of Boleng Formation are succeeded by those belonging to Pangin Formation. These include a sequence of alternate bands of limestone and quartzite in lower part and limestone and dolomite with thin phyllite bands in upper part. The rocks belonging to this formation are exposed in western part.

Gondwana Group

The rocks belonging to Gondwana Group are well exposed near Rengging in Siang Valley. There are different opinions about their contact with underlying rocks of Bomdila Group. According to Singh (1993) this contact is thrust while Mullick & Basu Choudhuri (1968) considered it to be gradational contact due to facies variation. Gondwana Group of rocks in this part of Arunachal Pradesh has been divided into four formations on the basis of lithological characteristics. These are Miri Formation, Bichom Formation, Bhareli Formation and Abor Volcanic Formation. The lowermost Miri Formation is represented by conglomerate, sandstone/quartzite, purple shale and diamictite. The rocks of Miri Formation are succeeded by dark grey diamictite with minor quartzite belonging to Bichom Formation. Rai and Srivastava (1994) did not include Miri and Bichom Formations in Gondwana Group and kept impure quartzites with limestones and dolostones in Buxa Formation. These are overlain by Bhareli Formation comprising a thick sequence of greyish feldspathic sandstone and grey to black carbonaceous shales with lenticular coal beds. The carbonaceous shales show shining on thin laminar planes and is highly crushed near the faulted contact. The feldspathic sandstone/quartzite is grey to green in colour and fine to coarse grained gritty type. The diamictite is usually massive, non-bedded and contains angular to subangular quartz and euhedral feldspar fragments. The rocks belonging to Bhareli

Formation are more prevalent in the area. The rocks of Bhareli Formation are succeeded by thick volcanic sequence comprising Abor Volcanic Formation.

Abor Volcanic Formation is extensively developed in Siang Valley. Abor Volcanic Formation comprises of massive, vesicular to amygdaloidal, porphyritic dominantly basaltic to andesitic basic volcanic rocks, a few sandstone and tuffaceous horizons and is exposed in the form of a belt extending NW-SE from near Yinkiong to Pugging, nearly N-S from Pugging to Pangin from where it swings in E-W direction up to Rotung. At Rotung, the volcanics show presence of silica filled regular-shaped vesicles, bulbous growth and clinkery nature. Two phases of volcanic rocks are reported from this area. The initial pouring gave rise to very fine grained basalts in volcanic breccia, whereas the later pouring resulted in dominantly vesicular hummocky or bulbous basalts. Welded and non- welded agglomerates are present in the Yembung Nala. The tuffs are dominant in the Yamne Valley. In this valley, the Abor volcanics extend from Damroh up to the confluence of Yamne and Siang rivers. Ganesan and Srivastava (1993) divided the Abor Volcanics into Pangi Volcanics and Rotung Volcanics. According to Ganesan and Srivastava (1993) the age of the volcanics is Paleocene to Early Eocene.

Yinkiong Group

Yinkiong Group is divided into Geku and Dalbuing formations. Geku Formation overlying the Siwalik rocks comprises of sandstone, siltstone, slate and phyllite. It occupies the central part of the Eastern Syntaxial Bend and is well exposed in Yinkiong along the Dite Dime-Yinkiong road section. From Yinkiong it extends towards south till it gets terminated by Bame Dumro Fault. It is surrounded by Abor Volcanics with tectonic contacts in the west and south directions. Dalbuing Formation, overlying the Geku Formation, comprises isolated outcrops of nummulitic limestone and shaly limestone. It is developed around Dalbuing area only.

Siwalik Group

Tectonically overlying the Gondwana Group of rocks are the rocks belonging to Siwalik Super Group/Group. Siwalik rocks are composed principally of white to green sandstone, calcareous sandstone, shales, silt and clay. These are best exposed in Pasighat area and occur as linear belt all along the foothills extending in the east into the Dibang Valley.

Alluvium

Alluvium in the form of Older Alluvium and Newer Alluvium is well developed around Pasighat in Siang Valley. Older Alluvium is best exposed near the confluence of Siang and

Dibang rivers comprising of boulders, cobbles, pebbles with oxidized sand and sandy clay. Newer Alluvium comprises of sediments of active channel.

2.3.2 Structure and Tectonics

The Himalayan tectogen has been divided into four distinct longitudinal tectonic belts on the basis of their characteristic geologic attributes coinciding with geomorphic divisions. These tectonic belts are separated from each other by distinct tectonic planes. From south to north, these are Frontal Fold Belt (FFB), Lesser Himalayan Belt, Main / Central Himalayan Belt (MHB), and Trans Himalayan Belt.

The Frontal Fold Belt (FFB) is the southern most tectonic belt comprising of Tertiary and Quaternary sediments, which includes Subathu and the Siwalik Group of rocks in Arunachal Himalayas. This belt is separated from Lesser Himalayan Belt (LHB) by a north dipping tectonic plane known as Main Boundary Thrust (MBT) in Arunachal Himalaya. The outcrop width of this belt is considerably reduced in eastern part of Arunachal Himalaya. This belt in the east abuts against a major NW-SE trending Roing fault (=Mishmi Thrust of Nandi et. al., 1975), east of longitude 96º E.

The Frontal fold Belt in the north is tectonically overlain by Lesser Himalayan Belt and the tectonic plane separating these in known as Main Boundary Fault / Thrust. It exposes Proterozoic metasediments with associated acidic intrusives in Upper Paleozoic and Paleocene - Lower Eocene succession in eastern part. The rocks of this belt show structures related to four or five deformational episodes (Saha et al, 1989; Singh and Sharma, 1991; Reddy and Kumar, 1991; Bhushan et al, 1991). The rocks exposed in this belt belong to Super sequences II, III, VI, VII, X and XI of Ravi Shanker et al (1989). The northern boundary of Lesser Himalayan Zone is marked by Main Central Thrust (MCT), a prominent tectonic feature of Himalaya. The proposed Tato Hydroelectric Project is located in Lesser Himalaya zone of Arunachal Himalaya. However, according to Kumar (1997),

The Lesser Himalaya towards north is succeed by Higher or Central Himalaya defined by MCT in the south and Trans Himalayan Thrust in north. Like Lesser Himalaya, the rocks exposed in this zone are Proterozoic metasediments and associated acid intrusives'. In addition, Upper Paleozoic rocks have been observed on the southern margin of this zone. As per Ravi Shanker et al (1989), the rocks belonging to Super sequences I, XIV and XV are exposed in this zone.

Tethys Himalaya located further north is separated from Higher or Central Himalaya by Trans Himalayan Thrust. This zone exposes rocks belonging to Super sequences III and XV of Ravi Shanker et al. and is bound by Indus - Tsang Po / Tidding Suture in the north.

Indus -Tsang Po Belt is located further north and consists of Cretaceous to Tertiary sediments and associated ultramafic, mafic, intermediate and acid magmatic rocks. The Lohit Granodiorite Complex and the Tidding formation have been considered a part of the Burmese plate and are separated from Himalaya by Tiding Suture. This belt is sub-divided into the Tidding Suture comprising serpentinite and ultramafites, and Lohit Granodiorite or Lohit Plutonic Complex separated by Lohit thrust.

The metamorphic rocks distributed over the Lesser and Higher Himalayan regions in Arunachal Pradesh have been divided into a lower Bomdila Group and an upper Sela Group (Anon 1974; Das *et al.* 1975; Verma & Tandon 1976) separated by the Main Central Thrust (MCT) (Thakur 1986; Singh & Chowdhury, 1990), (Kumar 1997). The Bomdila Group represents the Lesser Himalayan Crystallines (LHC) of Choudhuri et al (2009) that thrust over the Lesser Himalayan Sedimentary Sequence along the Bomdila Thrust and the Sela Group represents the Higher Himalayan Crystallines (HHC) which thrust over the LHC along the MCT.

The crystalline rocks exposed along the Dibang and Lohit Valleys, on the eastern limb of Syntaxis were earlier named as Mishmi Formation that include a thin, linear band of quartzites (Miri quartzite) at the bottom and the base of the Mishmi Formation is marked by a thrust known as Mishmi Thrust, which thrust over the recent alluvial sediments at some localities in Lohit River section (Thakur & Jain 1975). The contact between the quartzites and the overlying Mishmi Crystallines was marked as MCT (Gururajan & Choudhuri, 2003).These crystallines were subdivided into two tectonic units; The lower unit is dominated by mylonitic orthogneiss of granitic composition sand witched between the bands of graphitic phyllites with marble, quartzites, chlorite muscovite- biotite + garnet schists and boudins of amphibolite. The gneisses occur as highly deformed, mylonitic, fine-grained, platy gneisses towards the basal Bomdila Thrust and they become augen gneisses away from the thrust where the augens are made up of K-feldspars and plagioclase. The upper unit consisting of garnet, staurolite lenses and tabular sheets at different structural levels within the thick metasedimentary sequence of LHC consisting of mica rich quartzites, biotite schists with sporadic garnets, carbonaceous phyllites and schist with marbles and schistose basic metavolcanics or green schist facies amphibolites. The micaceous quartzites exposed between Panging and Along in Siyom Valley sections are highly deformed and contain a narrow shear zone consisting of small to medium sized quartz pebbles, which are elliptical in shape, were probably derived from flattening and stretching of the quartz veins and this pebbly horizon is tectonic in origin. Kyanite bearing graphitic schists with foliation parallel bands of quartzo feldpathic gneiss and thin slivers of garnet kyanite gneiss (Gururajan & Choudhuri, 2003). These crystalline rocks of the upper unit can be correlated with the HHC. Field investigations in eastern Arunachal Pradesh reveal that the mylonitic gneisses of the lower unit exposed on the eastern limb of the Siang Antiform represents the Lesser Himalayan Crystallines and the thrust at the base is marked as Bomdila Thrust that can be correlated with MCT-1 in Nepal (Arita, 1983).

On the western limb the crystalline rocks similar to LHC were called as Siyom Group (Singh, 1993). In comparison to the eastern limb, the mylonitic gneisses on the western limb do not occur as a continuous unit; however, it occurs as a narrow belt in the eastern limb. The HHC is well exposed along the Siyom River section in the western limb of the syntaxis. The upper boundary of the HHC is marked by the South Tibetan Detachment (STD). In the Siyom Valley in the western limb, the HHC is thrust over the quartzite, phyllite and garnetiferous schist of the Lesser Himalayan Crystallines along the MCT. The HHC can be broadly divided into two units: the lower unit that occurs immediately above the MCT is a kyanite-sillimanite bearing high grade gneissic sequence dominantly made up of orthogneiss and minor amount of paragneiss. These gneisses are associated with biotite rich layers and amphibolites. The amphibolites occur as thin bands and boudins, parallel to foliation. The gneisses can be classified in the field as augen gneiss and biotite rich gneiss with big crystals of garnet, and the gneisses in general exhibit migmatitic character. Minor amount of fine grained tourmaline bearing quartzo-feldspathic veins and pegmatites also intrude this unit. The biotite and quartz rich horizons and the biotite rich laminae of the gneiss contain garnet and sillimanite ± kyanite aligned parallel to the foliation. The upper unit consists of garnet- straurolite- kyanite and sillimanite bearing graphitic schists and pelitic schist, micaceous quartzite, calc-silicates, marble and boudins of amphibolite. The LHC of the Arunachal Pradesh can be correlated with the Daling - Gorubathan formations of Darjeeling-Sikkim (Ray, 1976) and Shumar Formation of Bhutan (Dasgupta 1995) or Daling- Shumar Group (Gansser, 1983) exposed in the Lesser Himalaya of Bhutan and Siyom Group of Singh and Chowdhury (1990) and Singh (1993). The mylonitic gneisses can be correlated with the Lingste gneissic bands occurring within the Daling Group of the Darjeeling- Sikkim Himalaya (Sinha-Roy, 1980) and with the gneisses of the Shumar Formation of Bhutan (Dasgupta, 1995).

The Higher Himalayan Crystallines (HHC) of Choudhuri et al (2009) is thrust over the Lesser Himalayan Crystallines along the MCT and they occur on both the limbs of the Siang Antiform. However, the HHC is several km thick in the western limb, while it is represented by a narrow belt in the eastern limb. The HHC is well exposed along the Siyom River section in the western limb of the syntaxis. The upper boundary of the HHC is marked by the South Tibetan Detachment (STD) in other parts of the Himalaya. Along the Siyom Valley in the western limb, the HHC is thrust over the quartzite, phyllite and garnetiferous schist of the Lesser Himalayan Crystallines along the MCT. According to Choudhuri et al (2009) the HHC can be broadly divided into two units: the lower unit that occurs immediately above the MCT is a kyanite-sillimanite bearing high grade gneissic sequence dominantly made up of orthogneiss and minor amount of paragneiss. These gneisses are associated with biotite rich layers and amphibolites. The amphibolites occur as thin bands and boudins, parallel to foliation. The gneisses can be classified in the field as augen gneiss and biotite rich gneiss with big crystals of garnet, and the gneisses in general exhibit migmatitic character. Minor amount of fine grained tourmaline bearing quartzo - felspathic veins and pegmatites also intrude this unit. The biotite and quartz rich horizons and the biotite rich laminae of the gneiss contain garnet and sillimanite ± kyanite aligned parallel to the foliation. The upper unit consists of garnet- straurolite - kyanite and sillimanite bearing graphitic schists and pelitic schist, micaceous quartzite, calc-silicates, marble and boudins of amphibolite. Towards the upper part the graphitic content of the schist is highly reduced and the pelitic schist with higher amount of muscovite. Further west of Mechuca, the pelitic schist is overlain by thick bands of augen gneisses, resembling the gneisses in the upper part of HHC in Bhutan (Daniel *et al*. 2003) and Kanchanjunga augen gneiss of Sikkim (Ray, 1976). The lower and upper units of HHC in Siyom Valley, can be compared with the lower high grade migmatitic Darjeeling gneisses and the upper Chunthang high grade metasediments made up of graphitic schist, calc-silicate, quartzite, marble and band of granitic gneisses exposed in Darjeeling-Sikkim region (Ray, 1976). They can also be compared with the high grade gneisses and Paro metasediments of the HHC of Bhutan Himalaya (Nautiyal, 1964; Gansser 1964; Thakur 1998; Daniel *et al.* 2003) ant rocks belonging to Siang Group of Singh (1993).

The HHC is represented in the eastern limb by a narrow discontinuous belt of high grade graphitic schists that tectonically overlie the Lesser Himalayan mylonitic gneisses. The basal part of the graphitic schist contains a zone of graphitic garnet-mica schist followed upwards by garnetstaurolite (± kyanite) and garnet- staurolite-kyanite and traces of sillimanite. The upper part is associated with thin bands of marble, granitic gneisses, slivers of garnet-kyanite gneiss and amphibolite boudins. In the Siyom Valley in western limb, the graphitic content is less in comparison to the graphitic schists of the eastern limb.

The major part of the upper unit of the HHC exposed in the Siyom section is either cutoff or overlapped by the ophiolitic mélange in the eastern limb. However, the MCT can be tentatively marked at the base of the graphitic schist at the garnet grade (Choudhuri et al, 2009). The entire crystalline sequence including the Lesser Himalayan Crystallines (LHC) are penetratively deformed and represent ductile deformation zone, exhibit inverted metamorphism and more over there is no break in metamorphism between the LHC and the overlying graphitic schist of the HHC.

From the above it appears that the rocks belonging to Siyom Group of Singh (1993) have been correlated with the Lower Himalayan Crystallines (LHC) of Choudhuri et al (2009) and those belonging to Siang Group with Higher Himalayan Crystalline (HHC). Jain et al (1974) designated the term Siang Group that included high and low grade metamorphics exposed over vast area in ESB. Singh (1993) based on distinct deformational and metamorphic characteristics included only high grade rocks in Siang Group and low to medium grade metamorphic into Siyom Group. Regionally the rocks belonging to Siang Group have been correlated with Ziro Gneisses and Daporijo Gneisses that have been kept in Bomdila Group in Subansiri valley in southwest and with Ithun Formation in south east. Similarly, the rocks belonging to Siyom Group have been correlated with those of Potin - Khetabari formations of Bomdila Group in Lesser Himalaya in Subansiri valley. Therefore as per Singh (1993) and many other workers, rocks belonging to both Siang and Siyom Groups can be correlated with those belonging to Bomdila Group and MCT is located further north. However, if the rocks belonging to Siang Group are correlated with those of Higher Himalayan Crystallines (HHC) of Choudhuri et al (2009), with those belonging to Sela Group Kumar (1997) and the rocks belonging to Siyom Group with Lower Himalayan Crystallines (LHC), the MCT may be aligned along their contact as has been mentioned by Choudhuri et al (2009) and Kumar (1997). It may also be mentioned here that the rocks belonging to Singing Formation that overly the Pari Mountain Formation belonging to Singing Formation have been correlated with Tetyan Lumla Formation of Tawng- Woming area by Kumar (1997). If the above observations of different workers are considered, the location of Main Central Thrust (MCT) in the area is not clearly defined. Kumar (1997) has grouped the rocks exposed upstream of Yapik in to Sela Group which can be considered equivalent to HHC of Choudhuri et al (2009) and indicated the presence of MCT about 4-5km downstream of Yapik similar to that indicated by Choudhuri et al (2009). If the above observations of different workers are considered, the location of Main Central thrust (MCT) in the area can be considered disputed and it may be taken that it is either located in Lesser Himalaya or Higher Himalaya in the vicinity of its southern margin. Petrographic study suggests that the rocks in the project area are devoid of high grade metamorphic minerals like kyanite, sillimanite etc. This correlates the rocks with Bomdila Group of Lesser Himalayas. Hence for all practical purposes the project area is considered located in Lesser Himalaya. Geological Map of Eastern Arunachal Pradesh is given in **Figure-3** below.

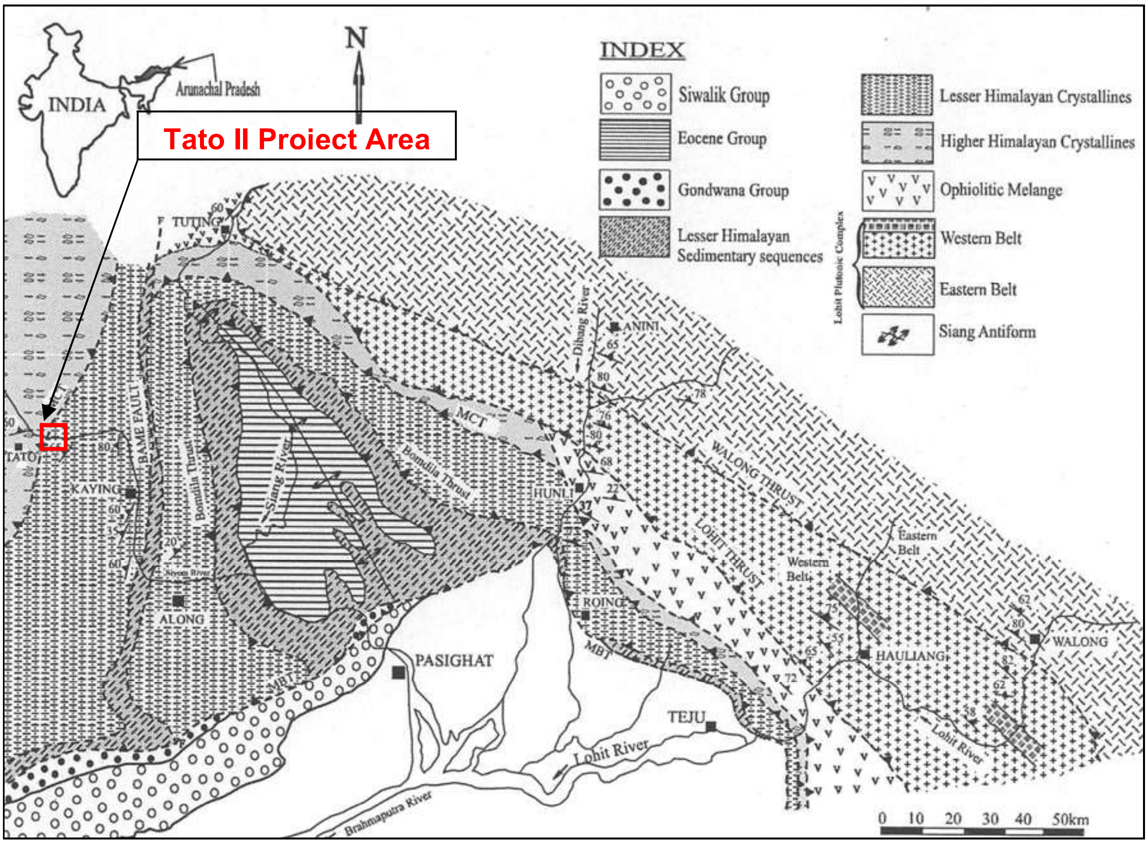

Figure-3: Geological Map of Eastern Arunachal Pradesh (modified afterSingh 1993; Gurujan & Choudhuri 2003, 2007)

2.4 Geology of the Project Area

The proposed Tato Hydroelectric project is envisaged on the river Siyom in the area that exposes the rocks belonging to Siang Group of Proterozoic age of Singh (1993). These rocks have been kept under Sela group by Kumar (1997). The rocks belonging to this group have been divided into three formations by Singh (1993) based upon lithological characteristics, stratigraphic disposition and tectonic relationships.

2.4.1 Siang Group

Lithostratigraphically, Siang Group is placed between Tuting Granite/Tuting metavolcanics in the north and Siyom Group in the south. It has a thrusted contact with the Siyom Group separated by Sike Nala thrust. Siang Group has been sub divided into three formations. The litho succession of Siang Group is given in **Table-2**.

Table-2: Lithostratigraphy of Siang Group (After S. Singh, 1993)

Group	Formation	Lithology
Siang Group	Yang Sang Chu	Not exposed in Siyom valley
	Singing	Silliminite garnet schist, quartzite, Amphibolite & Marble Quartzite with minor biotite ± garnet schist
	Pari Mountain	Augen gneiss, biotite ± garnet gneiss, Silliminite ± garnet gneiss and migmatite

The Pari Mountain Formation is the lowermost stratigraphic litho unit in the Siang Group and is composed of varieties of gneisses and migmatites. Quartzite and schist are found towards the upper part. In Siyom valley augen gneiss, biotite garnet gneiss and migmatites are observed in the Yapik - Tato section.

The Singing Formation is best seen in its type area of Singing and consists of quartzite, marble and amphibolite towards the lower part and silliminite - garnet schist in the upper part of the succession. In Siyom valley, the lower part is mainly represented by quartzite inter-banded with biotite garnet schist and the upper part by sillimanite- biotite- garnet schist with amphibolite and quartzite. Kumar (2005) correlated the rocks belonging to Pari Mountain Formation with those belonging to Sela Formation and those of Singing Formation including those of Pidi and Monigong Formations with those belonging to Lumla Formation of Tethys Himalaya.

Yang Sang Chu is the uppermost formation in the Siang Group and took its name from the Yang Sang valley, where it is best exposed (Singh and Malhotra, 1983). It has not been reported from the Siyom valley.

2.4.2 Structure in and around Siang Valley

The area has undergone poly phase deformation. Structural elements related to the three deformations have been recorded from Siang valley (Singh, 1993). The first deformation produced tight isoclinal folds (F1) with thick hinges. Axial plane foliation paralleling S0 in the limbs and cutting across S0 in the hinges of F1 folds have been recorded. Minor fold axes and intersection lineation define the linear structures related to first deformation. The second generation folds are isoclinal to close folds showing co-axial relationship with F1 folds. Crenulations and fracture cleavages (S2) paralleling axial planes of F2 folds define the planar structures related to second deformation. Minor fold axes and intersection lineation represent the L2 linear structures. The last phase of deformation produced broad warps and minor 'M', 'W', 'Z' and 'S' shaped folds and crumples. Broad warps are well preserved and exposed near Rengging-Pasighat.

An additional deformation phase, predating the above mentioned deformational episodes has been recorded in the Rumgong Formation by Gupta et. al. (1982). This deformation produced isoclinal, reclined, upright to inclined folds with axial plane schistosity.

The area shows a number of regional folds and faults apart from a few of local significance. These include, Main Central Thrust, Simang - Simen Fault, Yamne Fault, Bame-Dumro Fault, Rotung Synform and Simang antiforms and synforms. The location of Main Central thrust in this area is not clear. It could be located further north as per Singh (1993) and Singh and Chowdhuri (1990) where as if the views of Kumar (1997), Choudhuri (2009) and Ravi Shanker et al are considered, the MCT is located about 4-5km down stream of Yapik or in the area downstream of the site envisaged for powerhouse complex of the proposed Naying Hydroelectric project. The Simang - Simen Fault is a prominent fault extending from Supsing in north to Ratte in south. It trends almost N-S and separates Boleng Formation in west from Abor Volcanic Formation in the east. This fault has also displaced MBT near Ratte-Koyu in the south thus bringing the Abor volcanics against the Siwalik Group of rocks. Yamne Fault trends NW-SE and extends from Gobuick in the north to Dumro and further south. This fault restricts the Dalbuing Formation to east. Near Dumro and to its south, the fault has truncated the Abor volcanics. Another fault close to Rotung trending in NE-SW direction has also been recorded. An E-W trending fault named as Bame-Dumro Fault is located east of the confluence of Siang River with Siyom River affecting the contact between the Boleng Formation, Geku Formation and the Abor Volcanic Formation. Some minor faults trending in NE-SW and E-W directions are also common.

In the Yamne Valley, the terraces are buckled and faulted near Lagru. Broad warps are also present in the terraces near Padu, suggesting that the neotectonic activity is present in the area and appears to have taken place along major faults (Singh, 1993).

3 FIELD INVESTIGATIONS

The field investigations in case of Tato-II Hydroelectric Project were carried out earlier in two phases. After studying various alternatives, the layout at that stage was finalized and the investigations carried out. Surface and subsurface investigations carried out during the first included topographical survey of the project area, satellite imagery study, surface geological mapping and subsurface investigations comprising geophysical explorations, exploratory drilling and drifting at the sites of different project components. In addition to above, in situ rock mechanics tests including deformation modulus, block shear tests were carried out in the drifts excavated on the right abutment along the finalized dam axis. However, while finalizing the layout, it was observed that due to topographical and geological constraints, the intake structures could only be located about 200m upstream of dam axis. This location of the intake structure was not preferred on consideration of hydraulic and sediment management aspects. Keeping this in view, another dam site, dam site alternative 5 located about 500m downstream of earlier selected axis was adopted. The power intake in this case is located adjacent to dam axis in the left bank of the river Siyom (**Plate G-2**).

3.1 Topographical survey

Topographical survey of the project area has been carried out covering all the project components including the area that will come under submergence by reservoir. The diversion site and the powerhouse areas have been surveyed on 1:500 scale. The survey of headrace tunnel area has been conducted on a scale of 1:2500 and the reservoir area is surveyed in 1:4000 scales. River cross sections and longitudinal sections have been taken in 1:2500 (H) and 1:100 (V) scales. Altogether, topographic survey covers 1109 Hectare area extending elevations of about 1200m on both the banks at head works area, up to elevations of about 1400m on left bank for HRT and up to 1480m elevation on left bank in case of powerhouse area.

3.2 Satellite Imagery Study

Satellite imagery study was carried out for Tato-II hydroelectric project by VHK Consulting Services, Gurgaon. The Satellite data for IRS 1D/P6 LISS III and PAN sensors were procured from National Remote Sensing Agency (NRSA), Hyderabad. The objectives of the study are to derive and delineate drainage and snow cover map of catchment area, geological features of the project area, and geomorphological features of project area. The complete report is appended in **Volume-VIC, Report 1.**

3.3 Geological Mapping

The project area has a very rugged topography with sharp crested ridges and narrow valleys. The altitude in the area varies between 800m to about 4000m and most of the area is covered by thick vegetation. In general the project area has a very rugged terrain with limited accessibility. However, despite above constraints detailed geological mapping on desired scales was carried out at the sites of different components of the project as well as reservoir area. The detailed geological mapping of the diversion area covers all the alternative dam sites and those of other appurtenants was carried out on 1:1000 scale however same has been produced on 1:2500 scale.

Due to extremely rugged topography, nearly non-existence of accessibility and thick vegetation, only a limited data could be collected during geological mapping in and around HRT alignment and powerhouse area although same was carried out by geologists from SNC- Lavalin, Canada who are well experienced in rock climbing and mountaineering. During the course of geological mapping, efforts were made to collect the ground data to the extent possible through traverses in and around the powerhouse complex. The geological map has been prepared in 1:5000 scale.

3.4 Subsurface Investigations

Initially subsurface investigations involving 17 drillholes aggregating 1209.20m length and 4 drifts two on either bank at dam sites Alternatives 1 & 2 were carried out **(Table-3a and 4a).** However, after finalizing the alternative diversion site located about 500m downstream of the earlier alternative site, the layout of the project was finalized and the subsurface investigation programme comprising exploratory drilling and drifting with a view to delineate the overburden-rock interface and to assess the condition of the sub-surface strata at the site of different components of the project was formulated. Since the new layout involved change in diversion site only, the new investigation programme was designed for that only and investigations for other sites remained unchanged. The subsurface exploration programme prepared for the downstream alternative diversion site (Alternative dam site 5) included 09 drill holes and four exploratory drifts (two on each abutment), in addition to one drill hole at the location where the proposed HRT crosses a cross drainage, one drill hole to explore the surge shaft site and an exploratory drift at powerhouse site (**Plates G-12 & G-17, Volume-VIB**). The locations and depth of the holes are given in **Table-3**. The detail drillhole logs are appended in **Volume-VIB, Annexure-II**.

Out of the nine drill holes planned at the diversion site, five are located along the axis of the diversion dam, one at the intake site, two at the downstream end of the energy dissipation and one in the riverbed at the site proposed for upstream coffer dam. Four numbers of exploratory drifts were proposed on the abutments of the finally selected dam site. Out of these, two drifts LDR 1 and LDR 2 are located on the left abutment along the dam axis proposed and RDR1 and RDR 2 are on the right abutment along the proposed dam axis. GSI during technical examination of the DPR suggested to explore the abutments with one more drift on each bank as the height of dam is greater than 100m. Accordingly LDR-3 at El.990m and RDR-3 at El.1000m are planned to be excavated on left and right abutment respectively.

The locations and depth of excavation of drifts are given in the **Table-4.** The detailed 3-D logs of the drifts are appended in **Volume-VIB, Annexure-III**.

The schedule for balance explorations is given as **Plate G-28, Volume-VIB**.

Table-3: Details of Exploratory Drill Holes (Alternative 5 Dam Site)

Drill Hole No.	Location of Holes	Inclination of Holes	Co-ordinates		Ground Elevation (m)	Depth to bedrock (m)	Total Depth (m)
			N	E			
a. Diversion Site							
DH-1	Riverbed, towards left abutment, 29m upstream of Dam Axis	Vertical	24546.17	20357.66	902.44	26.35	64.1
DH-2	Riverbed, centre of the river, 25m upstream of Dam axis	Vertical	24530.48	20347.86	902.05	22.5	69.0
DH-3	D/s toe of Dam, towards left bank	Vertical	24462.48	20465.19	903.95	19.0	33.15
DH-4	Left abutment, along the Dam axis	Vertical	24580.76	20432.45	991.11	12.0	59.0
DH-5	Left abutment, along the Dam axis	Vertical	24543.38	20399.18	916.00	11.4	99.5
DH-6	Left bank, intake site	Vertical	24572.60	20363.82	915.00	31.0	58.3
DH-7	River bed, along upstream coffer dam	Vertical	24645.55	20305.86	907.00	10m into the fresh rock	In progress
DH-8	Riverbed, towards right abutment along Dam Axis	Vertical	24490.75	20352.20	901.00	24.0	39.3
DH-9	D/s toe of Dam, towards right bank	Vertical	24408.44	20440.36	900.00	10m into the fresh rock	In progress
b. HRT							
DH PH-2	At the intersection of HRT with Nala (RD. 3275m)	Vertical	23453.1773	23270.8084	1070.00	Upto HRT bottom	In progress
c. Surge Shaft							
DH PH-1	Centre of Surge shaft,	Vertical	23595.49	22945.30	1226.00	Upto bottom of surge shaft	In progress

Table-3a: Details of Exploratory Drill Holes

Summary of Geotechnical Investigations (Dam Sites Alternative 1 & 2)

Drill Hole No.	Location of Holes	Inclination of Holes	Co-ordinates		Collar Elevation (M)	Depth of OB (m)	Total Depth (m)
			N	E			
DDH-1	Left abutment Dam Axis (Option-I)	Vertical	25 187.530	19 877.97	1036.043	7.12	108.5
DDH-2	Right abutment Dam Axis (Option-I)	Vertical	24 938.490	19 709.216	1035.613	32.75	104.3
DDH-3	D/s of Dam axis at toe (Option-I)	Vertical	25 058.238	19 894.710	927.422	27.4	35.4
DDH-4	Centre of River bed (Option-II)	Vertical	24 958.640	19 973.842	922.000	32.1	96.65
DDH-5	Left bank of river bed (Option-II)	Inclined (60 degree from horizontal, towards river side)	24975.920	20039.170	954.000	22.3 again from 70 to 79.3	90.5
DDH-6	River bed right edge (Option-II)	Vertical	24941.717	19951.328	923.821	26.5	26.5
DDH-6A	River bed right edge (Option-II)	Vertical	24 942.090	19 951.593	924.783	31.2	90
DDH-8	Left abutment Dam Axis (Option-II)	Inclined (70 degree with horizontal, towards hill side)	25 050.000	20 100.000	1022.604	24	50.1
DDH-9	Left bank D/s of Dam Axis (Option-II)	Vertical	24 939.240	20042.760	923.734	27.5	51
DDH-10	Centre of River bed (Option-I)	Vertical	25 092.075	19 813.644	932.610	35	35
DDH-13	Left bank D/s Coffer Dam (Option-II)	Inclined (50 degree from horizontal, towards river side)	24885.000	20102.500	933.000	57.45	71
DDH-14	Right abutment Dam Axis (Option-II)	Vertical	24 866.200	19 839.094	1035.390	0.4	100.5
DDH-16	Left abutment Dam Axis (Option-II)	Vertical	24 982.533	20 052.240	965.757	24	60
DDH-17	Right abutment Dam Axis (Option-II)	Inclined (70degree from horizontal, towards hill side)	24 889.500	19946.250	990.152	11.2	100.5

Drill Hole No.	Location of Holes	Inclination of Holes	Co-ordinates		Collar Elevation (M)	Depth of OB (m)	Total Depth (m)
			N	E			
DDH-20	Right bank, Option-I Dam Axis	Inclined by 40 degree with horizontal towards valley	25045.612	19799.804	939.896	65.5	80
DHHRT-1	HRT (1st Nala)	Vertical	24937.42	20512.69	1085.07	6.75	73.25
DH-HRT2	HRT Intake	Vertical	25083.043	20038.185	990.229	11	36

Table-4: Details of Exploratory Drifts (Alternative 5)

Drift No.	Location of Drift	Proposed length (m)	Co-ordinates of the portal		Elevation (m)	Excavated Length (m)
			N	E		
a. Dam Site						
LDR-1	Left abutment, along the dam axis,	30	24565.34	20417.49	965.00	Completed
LDR-2	Left abutment, along the dam axis	30	24543.79	20395.75	940.00	Completed
LDR-3	Left abutment, along the dam axis	30	24594.96	20441.18	990.00	To be taken up
RDR-1	Right abutment, along the dam axis	50	24475.49	20334.06	940.00	In progress
RDR-2	Right abutment, along the dam axis	50	24472.31	20331.63	980.00	In progress
RDR-3	Right abutment, along the dam axis	30	24458.89	20317.3	1000.00	To be taken up
b. Powerhouse Site						
PHDR- 2	Powerhouse Site	430	22456.60	23473.91	830.00	269m completed; 200m logged; Rest in progress

Table-4a: Details of Exploratory Drifts (Dam Sites Alternative 1 & 2)

Drift No.	Location of Drift	Proposed length (m)	Co-ordinates		Elevation (M)	Excavated Length (m)
			N	E		
LDR-1	Left abutment lower Drift	50m	24960.956	20019.692	934.609	41.7 (Entirely in rock)
LDR-2	Left abutment Upper Drift	50m	24982.840	20053.253	964.983	55m; 14 In Overburden
RDR-1	Right abutment lower Drift	50m	24913.044	19971.943	945.346	30m and 12m cross cut
RDR-2	Right abutment Upper Drift	50m	24899.184	19951.394	977.244	55m
PHDR 1	Old powerhouse drift	300m	22842.025	22930.250	848.259	64m*; 4 m in overburden

3.5 In-Situ Field Tests

In situ field tests within the drifts located on both the abutments of dam site were undertaken by Adhar Engineering Consulting Services (AECS), Noida to derive deformation modulus in the left abutment drift and submitted a draft report. The results of block shear tests conducted in the drift at earlier dam axis are only available at this stage and are given in the **Tables 5 and 6** below. The detail report is appended in **Volume-VIC, Report 2**.

Table-5: Modulus of Deformation of rock mass at Dam site

Location	Direction	Modulus of Deformation	Stress Level	Remarks
Dam Site	Vertical	2.34	5.31 MPa	
	Horizontal	2.48	5.31 MPa	

Table-6: Shear Parameters of rock mass at Dam site

Location	Test block Specification	Peak Shear Strength parameter		Residual Shear strength parameter	
		C (Mpa)	Φ in degree	C (Mpa)	Φ in degree
Dam abutment drift (earlier site)	Concrete to Rock	0.25	40	0.12	39
Dam abutment drift (earlier site)	Rock to Rock	0.25	40	0.18	39

3.6 Laboratory Tests

Laboratory tests of rock specimens collected from different drill holes drilled at the earlier selected dam axis Alternative-2 were undertaken by AECS. It includes derivation of petrography of rock samples, uniaxial compressive strength, and modulus of elasticity, Poisson’s ratio, and shear parameters. In addition bulk density, water absorption, porosity, void index, grain density and slake durability index of rock samples have also been derived in the laboratory. The results are tabulated in **Table-7** and **Table-8** and the test report is appended in **Volume-VIC, Report 3**.

Table-7: Results of Rock Mechanic Property of Rock Specimen

S. No.	Drill hole No	Rock type as per Petrography	Average Uniaxial Compressive Strength (MPa)		Average Tensile Strength (Mpa) (Brazilian Test)	Modulus of Elasticity, E (GPa)	Poisson's Ratio, ν	Dry Condition	
			Dry	Wet				C (MPa)	ϕ (Degree)
1	DDH-1	Gneiss	49.06	39.85	5.67	9.92	0.37	5.20	37
2	DDH-2	Garnet Sillimanite Schist	43.51	21.47	9.55	17.46	0.29	-	-
3	DDH-4	Biotite Gneiss	34.35	31.94	10.16	9.31	0.11	9.20	38
4	DDH-6A	Feldspathic Gneiss	79.77	64.32	7.89	12.25	0.07	22.00	39
5	DDH-8	Garnet Biotite Schist	10.57	10.31	3.26	16.63	0.17	12.00	43
6	DDH-14	Garnet Biotite Schist	40.29	33.04	7.80	18.21	0.31	5.20	37

Table-8: Results of Bulk Density, Water Absorption, Porosity, Void Index, Grain Density & Slake Durability Index of Rock Samples

Sl. No	Drill Hole No.	Rock Type as per Petrographic Examination	Bulk Density (g/cc)	Average Bulk Density (g/cc)	Water Absorption (24 hours) (%)	Average Water Absorption (24 hours) (%)	Porosity (%)	Average Porosity (%)	Void Index (%)	Average Void Index (%)	Grain Density (g/cc)	Average Grain Density (g/cc)	Slake Durability Index (%)
1	DDH-1	Gneiss	2.61	2.69	0.56	0.58	0.56	0.57	0.16	0.16	2.79	2.78	99.25
			2.81		0.58		0.58		0.16		2.80		
			2.65		0.60		0.59		0.15		2.76		
2	DDH-2	Garnet Sillimanite Schist	2.61	2.58	0.34	0.35	0.68	0.68	0.28	0.28	2.77	2.77	98.0
			2.65		0.36		0.68		0.27		2.76		
			2.50		0.35		0.69		0.29		2.80		
3	DDH-4	Biotite Gneiss	2.65	2.68	0.49	0.50	0.74	0.72	0.30	0.31	2.81	2.80	97.99
			2.69		0.51		0.72		0.32		2.79		
			2.70		0.50		0.70		0.31		2.80		
4	DDH-6A	Feldspathic Gneiss	2.50	2.55	0.50	0.50	0.83	0.84	0.40	0.40	2.79	2.80	98.50
			2.55		0.52		0.86		0.41		2.80		
			2.60		0.48		0.84		0.39		2.81		
5	DDH-8	Garnet Biotite Schist	2.67	2.67	0.55	0.57	0.76	0.74	0.50	0.51	2.80	2.79	98.75
			2.68		0.57		0.75		0.51		2.79		
			2.67		0.59		0.73		0.52		2.78		
6	DDH-14	Garnet Biotite Schist	2.67	2.76	0.48	0.49	0.73	0.75	0.39	0.38	2.85	2.83	98.0
			2.76		0.49		0.76		0.38		2.82		
			2.87		0.50		0.78		0.37		2.83		

of Class II (Good quality), 60% of Class III (Fair quality), 10% of Class IV (Poor quality) and Class V (Very Poor quality) rock may be encountered in diversion tunnels. The poor rockmass situation is expected where shear or fracture zones will be encountered. The outlet portals of the tunnels are located about 460m downstream of the dam axis, where hard, competent, moderately jointed gneisses are exposed. The site is suitable for locating the outlet portals and may require some treatment to stabilise the slopes above. However, it is observed from the geological section along one of the diversion tunnels (that on the river side) that adequate rock cover may not be available for about 30m from the outlet portal and it may be designed as structural tunnel in this reach depending upon the extent of ground cover available.

4.6 Headrace Tunnel (HRT)

A 3876m long including 61m long conduit and 10.4m finished diameter headrace tunnel with the objective of conveying 384 cumecs of design discharge from diversion site to powerhouse has been proposed on the left bank of the Siyom River (Photo 12). Initially, the design discharge from intake structure located on the left bank of the river Siyom about 26m upstream of dam axis will be conveyed to a HRT by a 10.4m diameter and about 61m long feeder conduit. Immediately downstream of feeder conduit, the HRT in the initial reach upto RD 250m is aligned in $N54^0$ direction. The proposed HRT, downstream of RD 250m turns towards $N117^0$ through a broad curvature and is oriented along curved alignment upto RD 475m. Downstream of curvature, the HRT between RD 475m and RD 3335m is aligned in $N117^0 – 297^0$ direction. The HRT, downstream of RD 3335m, again turns towards S and follows a curved alignment upto RD 3770m. It is aligned in N-S direction downstream of curvature till it joins surge shaft (**Plate G-12**). The invert level of feeder conduits at the intake in the upstream end has been envisaged at EL 990.1m and at the downstream end at its junction with HRT at EL 989.95m. The overall gradient of the water conductor system works out to 1in 408.

The geological map of the dam site **(Plate G-2, Volume-VIB)** indicates that the bedrock is exposed on the hill slopes on the right bank of Siyom in this area quite extensively and large patches of overburden comprising slopewash deposits are also observed in lower and middle reaches. The bedrock exposed in the area comprises garnetiferous biotite gneiss belonging to Pari Mountain Formation of Siang Group with patches of slopewash deposits observed in between the bedrock outcrops. The slopes are steep and support moderately dense forest cover. The bedrock is foliated, jointed and slightly weathered on the surface.

The foliation in the area, in general strikes N24º - 204º and dips moderately towards NE. The area around the alignment of HRT in the reaches downstream of diversion has been geologically mapped by taking traverses on the hill slopes on left bank of the river (**Photo 12**). Keeping in view the rugged nature of terrain and near absence of approaches, a team of geologists having expertise in mountaineering/ rock climbing were engaged to carry out the geological mapping in the area. This team conducted traverses all along the alignment in this rugged terrain and collected geological data as far as possible with the help of GPS. Geological map of the area prepared on the basis of limited traverses has been appended as **Plate G-12 in Volume-VIB)** and geological section developed along the alignment of HRT as **Plate G-13 in Volume-VIB.**

The geological map **(Plate G-12, Volume-VIB)** and geological section along the alignment of the proposed HRT **(Plate G-13, Volume-VIB)** indicate that bedrock comprising garnetiferous biotite gneiss belonging to Pari Mountain Formation of Siang Group is exposed in the area around the proposed alignment of HRT extensively upto RD 1900m. However, patches of slopewash deposits can be observed in between the bedrock outcrops in this reach. Downstream of RD 1900m the hill slopes around the proposed HRT alignment are covered by slopewash deposits in general with isolated exposures of bedrock observed in between. It is also observed from geological map of the area around the proposed HRT alignment that the HRT along its route would cross three drainage courses of which only the nala crossing between RDs 3250m and 3350m appears to be significant. Geological section along the HRT alignment **(Plate G-13, Volume-VIB)** indicates that minimum of about 88m ground cover would be available above the overt of HRT at this crossing (**Photo 13**). The ground cover at the crossings of other drainages exceeds 150m in general.

The geological map along the HRT alignment (**Plate G-12, Volume-VIB**) indicates that in general the bedrock exposed along the HRT alignment comprises gneisses of various types that include quartzo-feldspathic gneiss, biotite gneiss and schistose gneiss. These are garnetiferous in general. Garnetiferous quartzo feldspathic gneisses are dark grey in colour, coarse grained and hard, compact in nature and appear to be of good quality. These are intercalated with schistose gneisses. Schistose gneisses show well developed schistosity as indicated by preferred orientation of micaceous minerals. The schistose gneiss is of medium strong to fair quality.

The foliation in the gneisses on an average dips 44º towards N294º with local variations in dip amount and direction. Dip ranges from 26º to 52º towards 260º to 300º. This variation may be attributed to local folding, a common feature in Himalayan terrain.

Besides foliation, the gneisses in the area are traversed by three prominent sets of joints. The joint sets along HRT are given in the **Table-14** below:

Table-14: Major joint sets along HRT

Joint sets	Strike	Dip	Dip Direction	Spacing	Persistence	Aperture	Condition
S1	N 204^0	44^0	294^0	Moderately Spaced (30cm to 100cm)	Medium to High	Tight to Open	Rough Undulatory
S2	N 353^0	44^0	083^0	Moderately to widely Spaced (20cm to 200cm)	Medium to High	Tight to Partly open	Rough Undulatory
S3	N 077^0	82^0	167^0	Moderately to widely Spaced (20cm to 200cm)	Low to Medium	Tight to Partly open	Rough Undulatory
S4	N261^0	77^0	351^0	Widely Spaced (60cm to 200cm)	Low to Medium	Tight to Partly open	Rough Undulatory

Considering the uniformity of foliation observed at various locations along the alignment of HRT during geological mapping, it is expected no major structural dislocation like fault is present in the area. Most of the drainages observed in the HRT area have very steep gradient and flow in the direction perpendicular to the Siyom River indicating strong influence of structure on the drainage pattern. Data from all pertinent rock outcrops have been recorded and analyzed with the help of Dips software. The stereographic projection and major plane plot of rock data have been prepared and given in **Figures 6 & 7**.

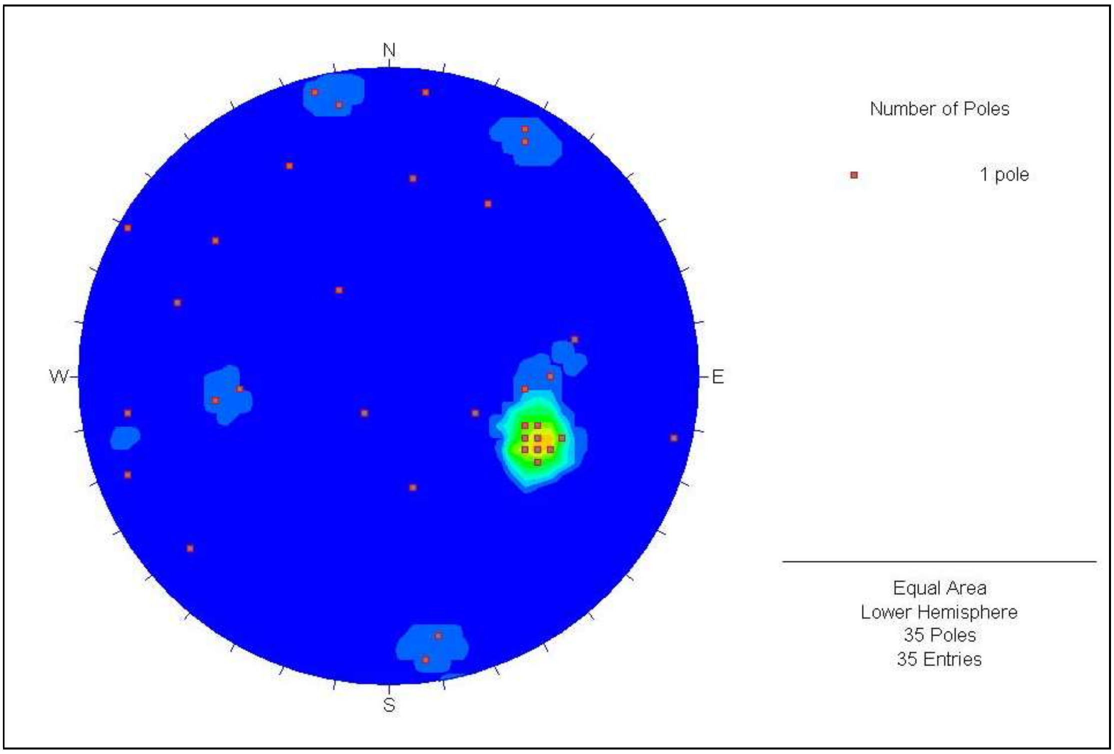

Figure-6: Stereographic projection of observed foliations and joint poles for HRT

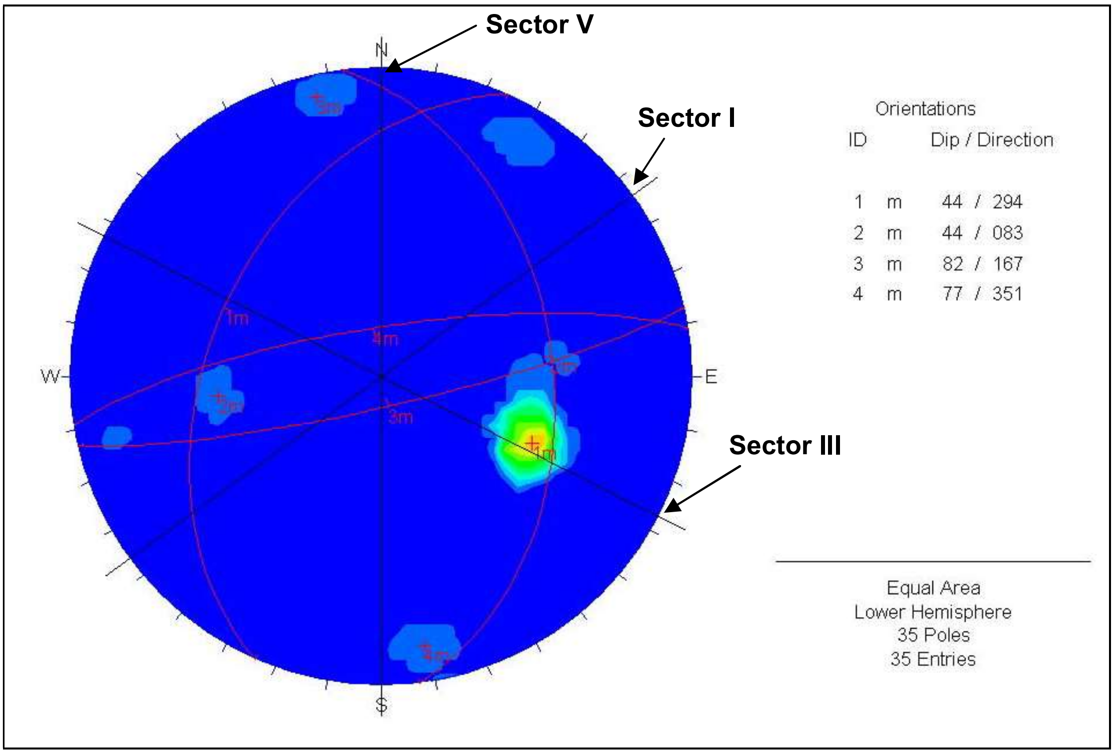

Figure-7: Joint set orientations and major plane projection vis-à-vis trends of Headrace Tunnel

The rosette diagram of the discontinuity data collected during geological mapping has been prepared **(Figure-8).**

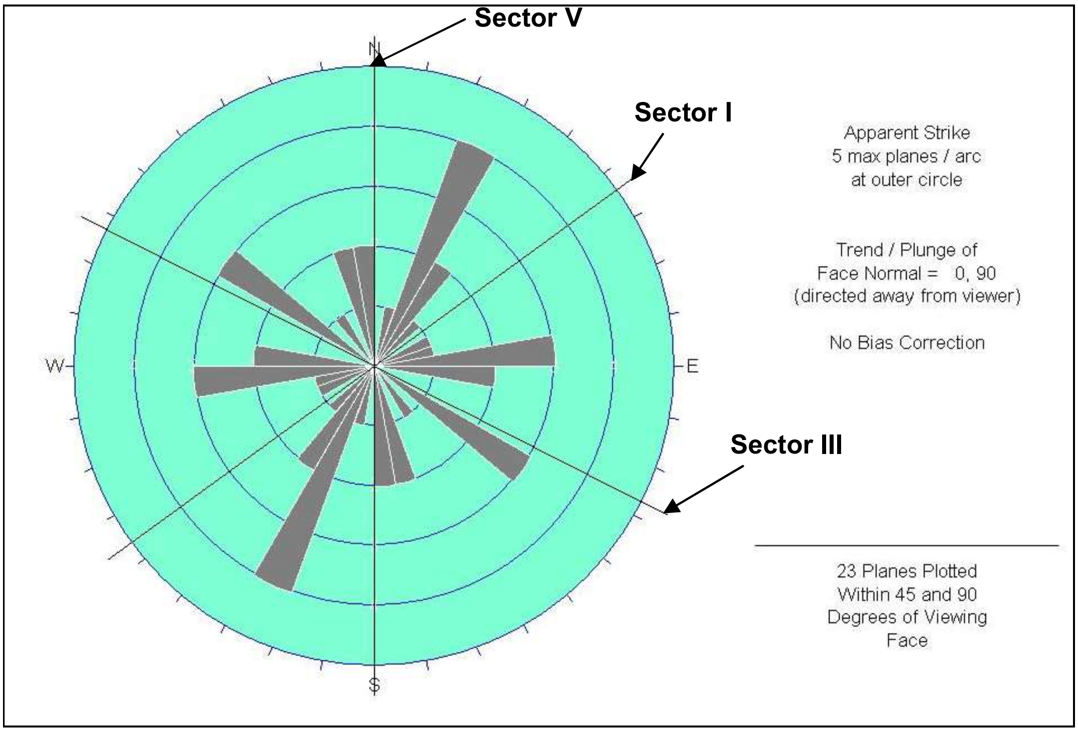

Figure-8: Rosette Diagram vis-à-vis HRT alignment

Since total length of this 10.4m diameter headrace tunnel is 3811m and two construction adits have been provided at both ends, the provision of an intermediate construction adit has not been considered necessary as less than 1.9km long tunnel from each adit can be excavated without much difficulty.

4.6.1 Subsurface Explorations

Besides surface geological mapping, the alignment of HRT is proposed to be explored through one drill hole. The objective of this drill hole is to establish the depth to bed rock and define the bedrock profile in the low cover reach in the bed of a cross drainage. The proposed drill hole **DH PH-1** has been located in the bed of nala intersecting the proposed alignment of HRT around RD 3275m in the downstream reaches. It is proposed to be drilled down to 100m depth so that overburden- bedrock interface is delineated and condition of the rock mass down to about 10m below the invert level of the proposed HRT is explored **(Plate G-12, Volume-VIB)**.

4.6.2 Geotechnical appraisal of Headrace Tunnel

The headrace tunnel, on the basis of number of bends and straight reaches can be divided into five sectors. Out of theses five sectors, the HRT in three sectors follows straight alignment where as same is aligned in curved alignments in rest of two segments. The HRT, initially between downstream end of feeder conduit and RD 250m in **Sector-I**, follows a straight alignment in N54^0 – 234^0 direction. This initial straight reach in Sector-1 is followed by a curved reach in **Sector-II** in which the HRT turns towards N117^0 through a broad curvature between RDs 250m and 475m. The curved reach in Sector-II is followed by straight reach between RD 475m and RD 3335m **in Sector-III**. The HRT in Sector- III is aligned in N117^{0}E- direction. HRT downstream of Sector - 3 is again aligned along a curved alignment between RD 3335m and RD 3875m in **Sector-IV**. Beyond RD 3875m, the HRT, in Sector-V follows N-S direction till it joins surge shaft at RD 3911m. The section wise assessment of tunneling conditions based upon the limited data available is discussed below. The rosette diagram of the discontinuities observed along the HRT alignment is given in **Figure-8**.

In case of **Sector-I**, immediately downstream of feeder conduit for a short length of 150m is aligned in N54^0- 234^0 direction. The geological map of the HRT area **(Plate G-12, Volume-VIB)** and geological section along the HRT alignment (**Plate G-13, Volume-VIB**) indicate that the hill slopes along the alignment expose bedrock extensively and some intervening patches of overburden comprising slopewash deposits can be observed. The ground elevation along the HRT alignment in this reach varies between less than1020m near the proposed site for inlet portal to about 1130m around RD 250m. This indicates that ground cover over the structure in this sector varies between less than 20m and about 130m. The rock cover in the initial 10-15m length of the HRT could be slightly on the lower side. It is suggested that the HRT in the initial reach, till adequate rock cover is achieved, may be designed as structural tunnel. As per **Table-14 and Figure-8**, alignment of the HRT in this sector makes an angle of 30º with the average strike of foliation. This is not considered a very favorable feature in general. It is also seen that HRT alignment in the initial reaches is askew to the major joint sets S2, S3 and S4 by 61º, 23º and 27º, respectively. It is seen that the alignment of headrace tunnel in this sector is not disposed very favorably in case of joints belonging to sets S1, S3 and S4 but same is disposed favourably in case of those belonging to set S2. This has to be kept in view while planning the excavation and supports for HRT as there is possibility of failures occurring along the discontinuity planes and along intersections in the roof and on SE wall.

In case of Sector II, the HRT between RD 250m and RD 475m turns gradually along a curved alignment towards N117^0. The geological map of the dm site area **(Plate G-2, Volume-VIB)** and geological map of HRT alignment **(Plate G-12, Volume-VIB)** and geological section along the HRT alignment **(Plate G-13, Volume-VIB)** indicate that the hill slopes in the area around the HRT alignment in this sector are partly covered by slopewash deposits and bedrock is exposed extensively in rest of the area. However, overburden covering the slopes appears to be thin (5-10m). The askewness of the HRT alignment with respect to foliation in the sector gradually changes from 30^0 at around RD 250m to 63^0 at the end of curvature around RD 475m. It is observed that the askewness of the foliation with respect to alignment gradually increases as on moves downstream along the curve. In case of joints belonging to set **S2**, the askewness with respect to HRT alignment changes gradually from 61^0 to 56^0. Same gradually changes from 23^0 to 40^0 in case of joints belonging to set **S3** and 27^0 to 36^0 incase of set **S4**. It is observed that there is slight decrease in angle between HRT alignment joints belonging to Set S2 where as same increase slightly in case of S3 and S4. The stability conditions become marginally better in case of S3 and S4 as one moves downstream from RD 250m

In case of Sector III, the HRT between bend 1 and bend 2 (RD 250m and RD 3335m) is aligned in N117^0- 297^0. The geological map of the area around HRT alignment **(Plate G-12, Volume-VIB)** and geological section along the HRT alignment **(Plate G-13, Volume-VIB)** indicate bedrock is exposed extensively along the alignment of HRT upto around RD 1900m and the hill slopes are in general covered by slopewash deposits except for a few reaches where bedrock outcrops are observed. The bedrock exposed in the area comprises well foliated, jointed biotite gneiss and banded gneiss belonging to Pari Mountain Formation of Siang Group. The bedrock is hard, compact and slightly weathered on the surface. Geological section along HRT **(Plate G-13)** and across HRT alignment along the nala **(Plate G-15)** indicate that the ground cover over the HRT in this sector varies between about 200m and slightly more than 560m in general except for a reach where it crosses a deep nala between RD 3250m and RD 3350m. The ground cover over the crown of HRT cover observed at the nala crossing is approximately 90m. One drill hole DH PH-1 is proposed to be drilled in the bed of this nala with the objective of defining the bedrock profile in the nala bed and assess the rock cover available over the structure. The drill hole is in progress. However, at present it can be concluded that adequate rock cover is available over the proposed HRT throughout its length in this sector. The alignment of HRT in this section is, in general, askew to the strike of foliation by 63^0, which is considered quite favourable. It is also observed from the **Plate G-13, Volume-VIB** that the alignment of HRT in this section is disposed askew to other joint sets by 56^0 (S2), 40^0 (S3) and 36^0 (S4) respectively. The inclination of the HRT alignment in this sector, though not ideal, can be considered favourable as far as strike of discontinuities is concerned.

In case of Sector-IV, the HRT between RDs 3335m and 3875m is oriented along a curved alignment and gradually turns from $N117^0$- 297^0 till it is aligned in N-S direction before joining the surge shaft. The geological map of the area along the HRT alignment **(Plate G-12, Volume-VIB)** and geological section along the HRT alignment **(Plate G-13, Volume-VIB)** indicate that the hill slopes along the alignment are in general covered with overburden and isolated outcrops of bedrock comprising biotite gneiss belonging to Pari Mountain Formation of Siang Group are observed in between the overburden patches. The ground cover over the proposed HRT varies between about 140m on the left bank of the nala and about 260m. This indicates that adequate rock cover would be available over the structure in this section. The gneisses exposed in the area are foliated and jointed. The foliation strikes in $N24^0E$ – $S24^0W$ with average dip of 44^0 towards NW. This indicates that the inclination of HRT alignment with respect to foliation in this curved sector changes gradually from 63^0 to 24^0. Similarly, **Table-14** indicates that the HRT alignment is askew to the major joint sets S2, S3 and S4 by 07^0, $77^0$and 81^0. It is observed that HRT is not aligned favourably in the downstream part of this reach as far as strike of joints belonging to S2 is concerned where as situation can be considered very favourable with respect to strike of joints belonging to sets S3 and S4.

In case of Sector V that includes a stretch of about 25m, just before joining surge shaft, the HRT is aligned in N- S direction. The geological map along the HRT **(Plate G-12, Volume-VIB)** and geological section along HRT **(Plate G-13, Volume-VIB)** indicate that bedrock is exposed in the area around the proposed alignment and at places the bedrock is covered by thin overburden comprising slopewash deposits. The bedrock exposed in the area comprises gneiss that is foliated and jointed. The Rosette Diagram of the discontinuities **(Figure-8)** indicates that the alignment of HRT is askew to the strike of the foliation by 24^0. HRT alignment makes angle of 7^0, 77^0 and 81^0 with joints belonging to sets S2, S3 and S4 respectively. The HRT alignment in this sector is not favourably placed as far as joints belonging to sets S1 and S2 are concerned and it is very favourably aligned with respect to strike of joints belonging to sets S3 and S4.

Although only limited data could be collected during the geological mapping along the HRT alignment, the same has also been used to get preliminary idea about pressure required for wedge stability vis-à-vis tunnel alignment. The analysis has been carried out by using Unwedge software of Geosciences. The results of wedge pressure analysis based on the joint systems 44^{O} / 294^{O}, 44^{O} / 083^{O} and 87^{O} / 167^{O} and 77^{0} / 351 are presented in **Figure-9** which indicate the pressure (Tonnes/m^{2}) required to obtain wedge stability with a factor of safety of 1.5 for different HRT orientations (alignment between N0^{O} and N180^{O}) with HRT plunge zero degree. For this wedge analysis, the unit weight of the rock mass has been taken as 2.65 tons/m^{3} as per laboratory test results. Shear parameter has been considered as identified in dam site drift i.e. angle of internal friction (ø) as 40^{0} and cohesion as 0.25 Mpa. From this analysis it is apparent that most suitable alignment for HRT may be from 130^{O} to 145^{O} with respect to north. Therefore the HRT in this case is not aligned along most desired direction in any of the sectors as same has been aligned keeping in view the topography and layout of the project. Therefore, it is expected that failure along the unstable planes and wedges can occur and the tunnel would be required to be provided supports immediately after excavation to avoid such failures. It is observed from **Figure-9** that the HRT is better aligned with respect to pressure axis in case of Sectors I & III and the alignment does not fit very well in case of Sector V. It appears that major portion of HRT is favourably aligned.

Optimization for Tunnel Axis Plunge = 0 degree

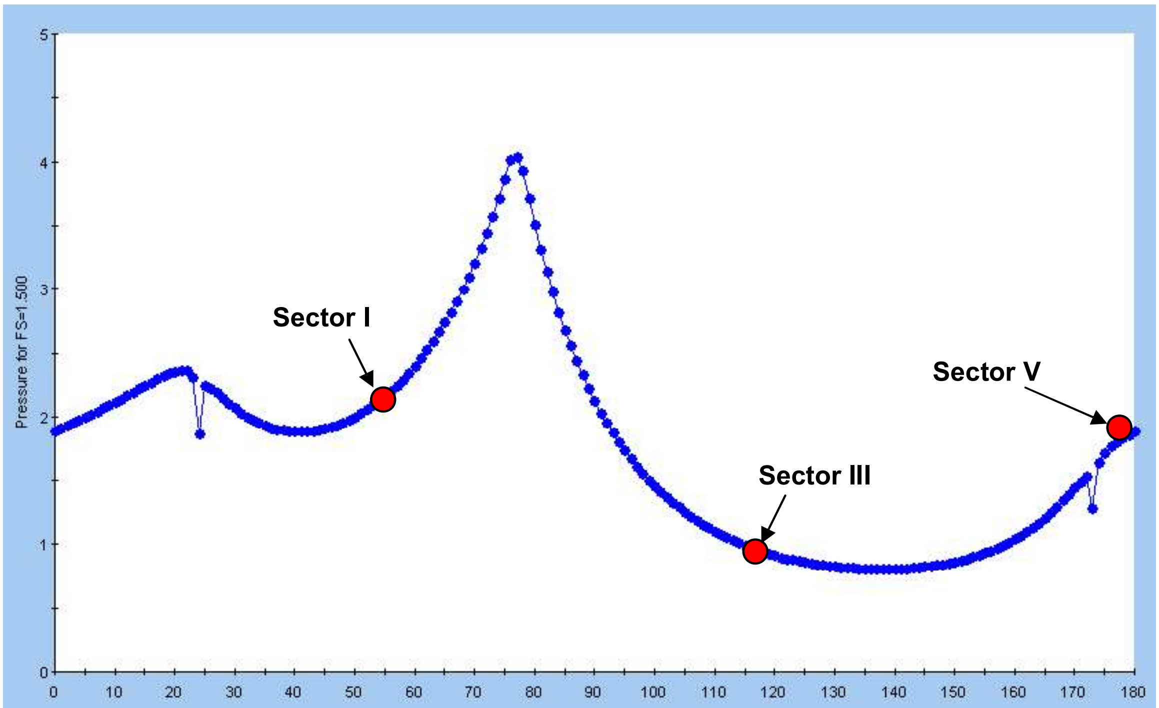

Figure-9: Pressure required for different Sectors in HRT orientation

Due to extremely rugged topography, nearly non-existence of accessibility and thick vegetation, only a limited data could be collected during geological mapping despite best efforts. However, this limited data has been utilized to get a tentative idea about rock mass quality along the HRT alignment. The rock mass in general consists of variety of gneisses i.e. garnetiferous quartz gneiss, schistose gneiss, quartzo - feldspathic gneiss etc. The rocks are hard, compact and slightly to moderately jointed with a few highly jointed zones. Permeability values in the drillhole data indicate very low permeability. However, water table encountered in different drill holes indicates that tunneling media will probably remain charged and provision of proper dewatering during execution needed. With this in view, a preliminary qualitative assessment of the rock mass along the headrace tunnel alignment has been attempted by using the empirical equations for the derivation of RMR. The RMR of the rock mass likely to be encountered in the HRT have been estimated on the basis of very limited data available. The preliminary assessment carried out on the basis of limited data indicates that in general, the rock mass of fair to good quality (Category II and III) is likely to be encountered in major portion along the HRT except in the reaches where shear zones/ fracture zones charged with water are encountered. Poor or very poor quality rock mass (categories IV & V) will have to be negotiated in such reaches. However, the rough estimation based on limited data indicates that rock mass belonging to Class II (Good) may be encountered in 20% of length, that belonging to Class III (Fair) in about 50% of length, Class IV (Poor) for about 25% in length and about 5% of length of HRT may encounter rock mass belonging to Class V i.e. rock mass of very poor quality.

Wedge analysis has been carried out by using ‘Unwedge’ software considering 11.4m excavated diameter of the tunnel and with different tunnel trend for different sectors such as 54^0 for sector I, 117^0 for sector III, and 180^0 for sector V. The parameters considered for the unwedge analysis are unit weight of rock as 2.65 ton/m^3, angle of internal friction as 40^0 and cohesion as 0.25 Mpa. Analyses carried out by considering different combinations of joint sets indicated that S4 does not have significant impact on formation of unstable wedges and has therefore been excluded from final results. The formation of different wedges is shown in **Figures 10, 11, 12, 13, 14, 15 and Tables 15, 16 & 17.** The results of wedge analysis in different sectors of HRT indicate that only the roof wedges (8) weighing 13.174 tons in Sector-I, 0.564 tons in Sector-III and 19.915 tons in case of Sector-V formed as a result of intersection of different discontinuities are unstable wedges with zero factor of safety. These can easily be stabilized by providing supports like shotcrete and rock bolting. It is imperative to say that other wedges are more or less in stable state.

It may not be out of place to again mention here that as the terrain is very rugged and difficult to access; the assessment has been carried out with the limited surface data collected during geological mapping. These values would be modified as and when more data becomes available either during detailed investigations or during actual execution of tunneling. Keeping the above constraints in view, the provision of advance probing during construction may be included in construction schedule to minimize the surprises.

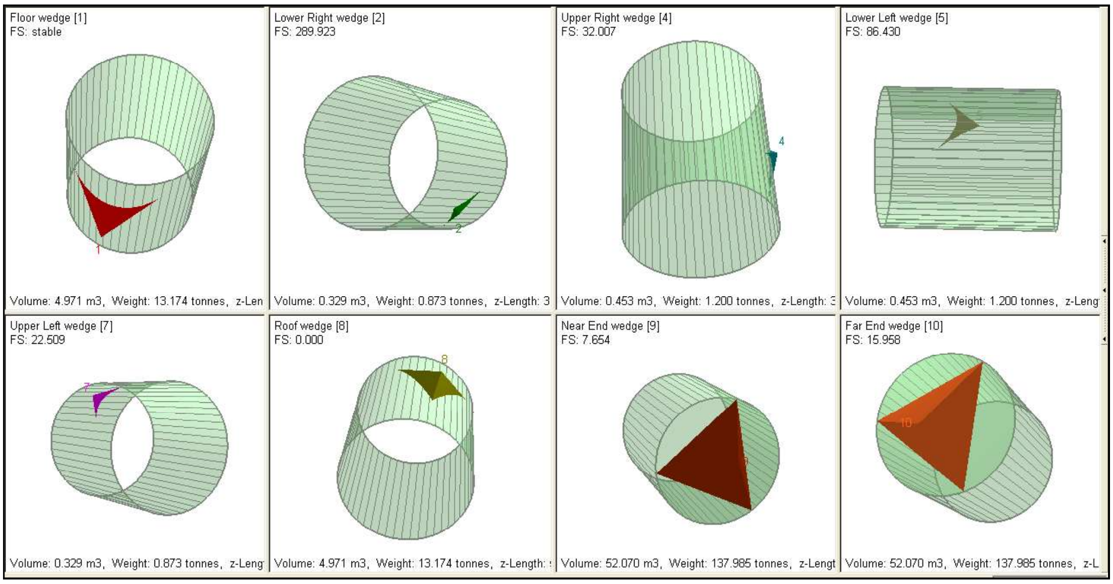

Figure-10: Different wedge formations for HRT Sector-I

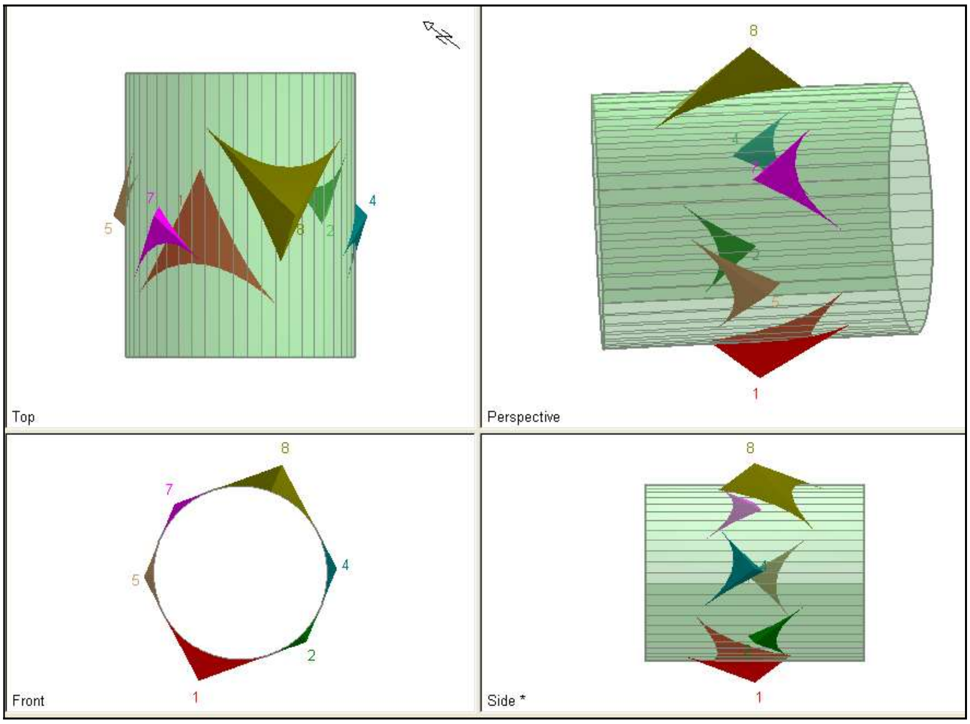

Figure-11: Perspective view of wedges for HRT Sector-I

Table-15: Details of Wedges formed in Sector-I of HRT

Wedge	Volume (m^3)	Weight (Tons)	Z- Length (m)	FS
Floor wedge [1]	4.971	13.174	5.91	Stable
Lower Right wedge [2]	0.329 m	0.873	3.24	289.923
Upper right wedge [4]	0.453	1.200	3.35 m	32.007
Lower Left wedge [5]	0.453	1.200	3.35 m	86.430
Upper Left wedge [7]	0.329	0.873	3.24	22.509
Roof wedge [8]	4.971	13.174	5.91	0.000
Near End wedge [9]	52.070	137.985	0.00	7.654
Far End wedge [10]	52.070	137.985	0.00	15.958

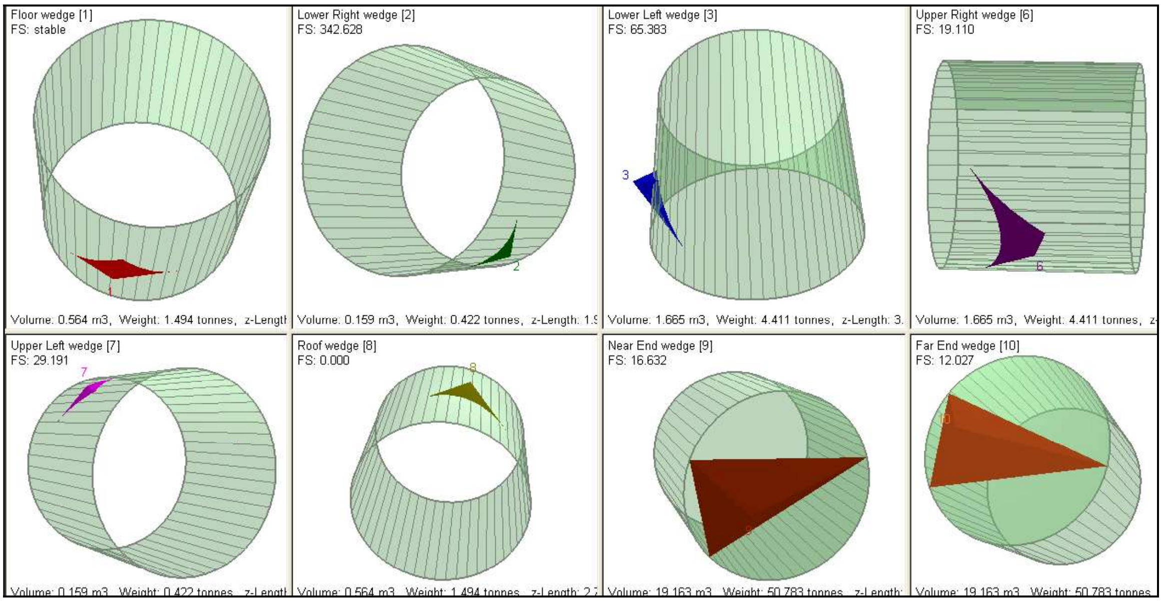

Figure-12: Different wedge formations for HRT Sector-III

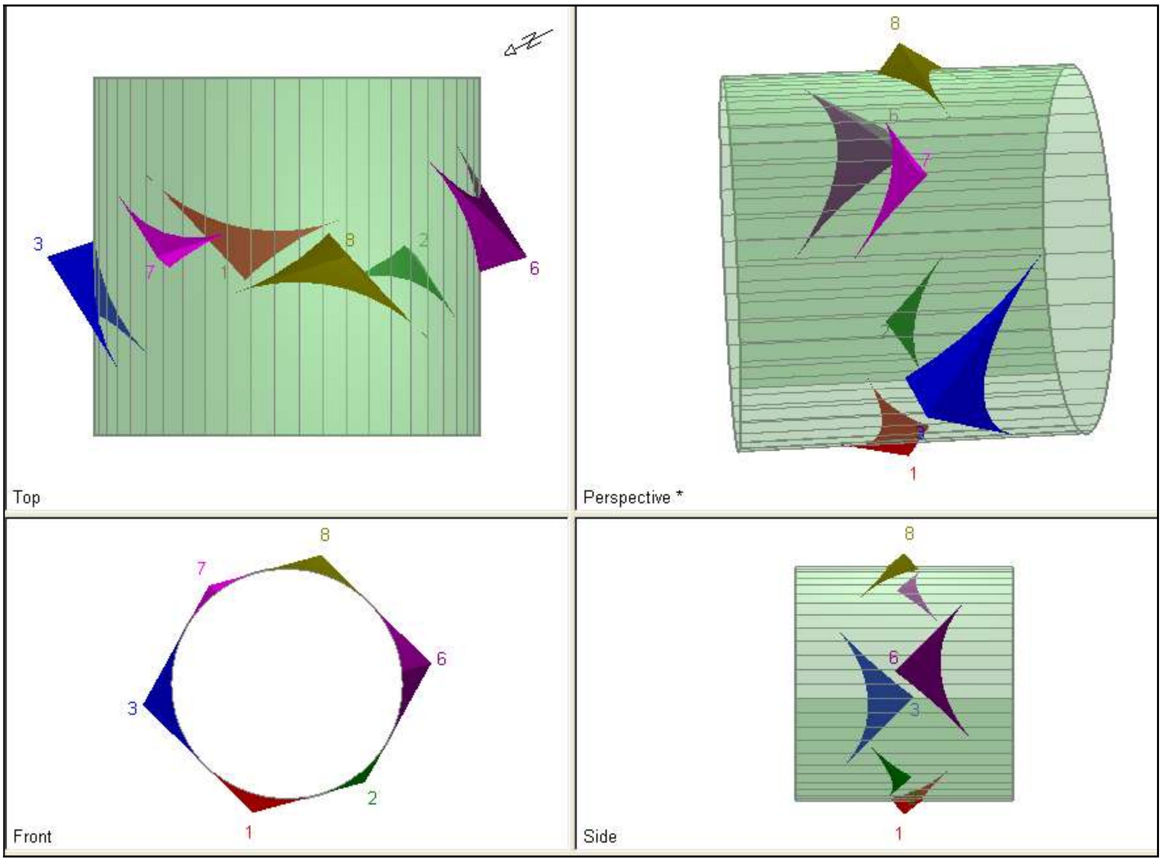

Figure-13: Perspective view of wedges for HRT Sector-III

Table-16: Details of Wedges formed in Sector-III of HRT

Wedge	Volume (m^3)	Weight (Tons)	Z- Length (m)	FS
Floor wedge [1]	0.564	1.494	2.75	Stable
Lower Right wedge [2]	0.159	0.422	1.94	342.628
Lower Left wedge [3]	1.665	4.411	3.32	65.383
Upper Right Wedge [6]	1.665	4.411	3.32	19.110
Upper Left Wedge [7]	0.159	0.422	1.94	29.191
Roof wedge [8]	0.564	1.494	2.75	0.000
Near End wedge [9]	19.163	50.783	0.00	16.632
Far End wedge [10]	19.163	50.783	0.00	12.027

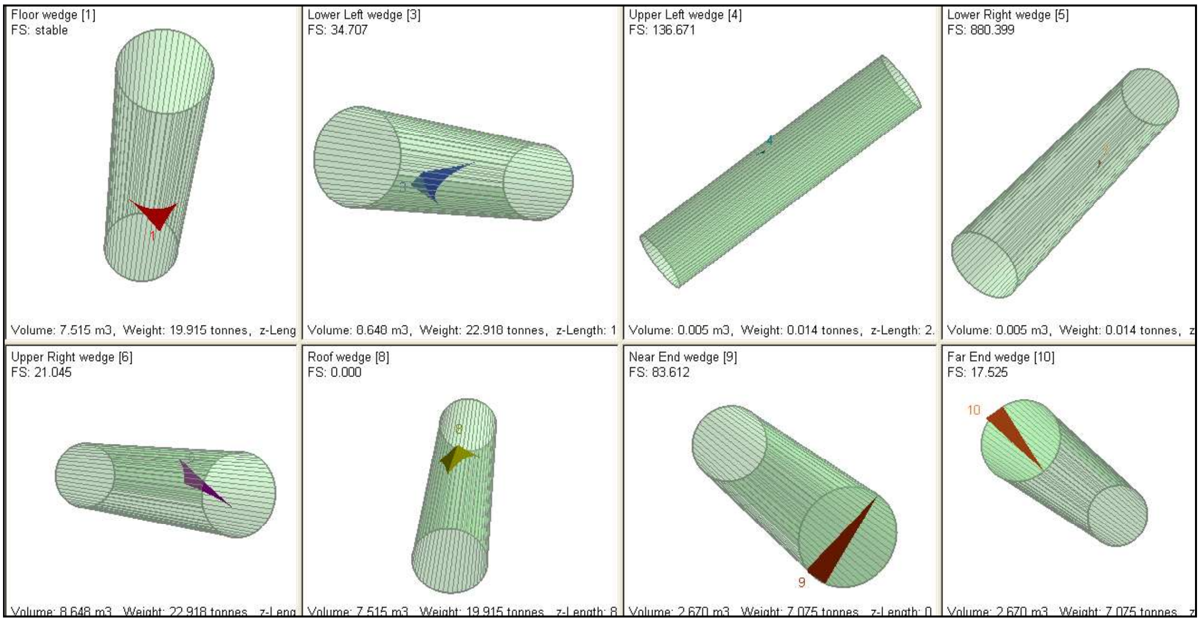

Figure-14: Different wedge formations for HRT Sector-V

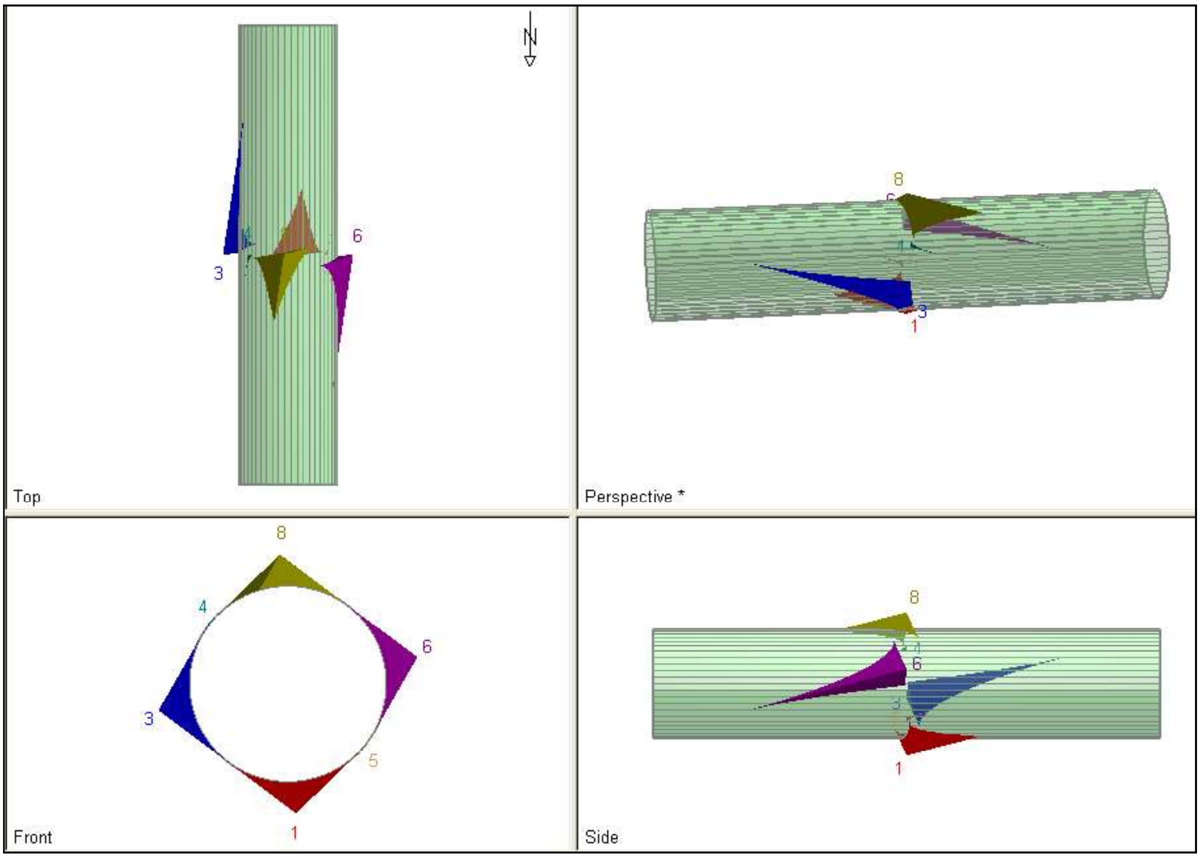

Figure-15: Perspective view of wedges for HRT Sector Vigure

Table-17: Details of Wedges formed in Sector-V of HRT

Wedge	Volume (m^3)	Weight (Tons)	Z- Length (m)	FS
Floor wedge [1]	7.515	19.915	8.03	Stable
Lower Left wedge [3]	8.648	22.918	14.32	34.707
Upper Left Wedge [4]	0.005	0.014	2.63	136.671
Lower Right Wedge [5]	0.005	0.014	2.63	880.399
Upper Right Wedge [6]	8.648	22.918	14.32	21.045
Roof wedge [8]	7.515	19.915	8.03	0.000
Near End wedge [9]	2.670	7.075	0.00	83.612
Far End wedge [10]	2.670	7.075	0.00	17.525

4.7 Construction Adits

The 10.4m finished diameter and 3876m long headrace tunnel including 61m long conduit has been provided two construction adits near both upstream and downstream ends. Provision of an intermediate construction adit has not been considered necessary as length of HRT to be excavated from each adit is less than 1900m that can be managed within proposed construction schedule and this activity is not expected to be critical as per construction schedule of the project on the whole. Geotechnical aspects of both the construction adits are discussed below.

4.8 Construction Adit to HRT at Dam Side

This adit has been proposed about 120m upstream of the dam axis on the left bank. The adit portal is located at El 987.59m and joins HRT at RD 123.64m at El 989.80m. So, it is a self draining adit of 149m long with two bends in between. Initially the adit is oriented in N54^0 E direction for 21m then turns towards N83^{0}E for a length of 90m and finally it is aligned in S36^{0}E direction for 38m to join HRT.

Geological map of the dam site area **(Plate G-2)** indicates that the left bank of the river Siyom upstream of dam axis has steep slope (55^0) and gneissic rock is extensively exposed in the middle reaches upto about El 1125m. Rock exposures of gneisses have also been observed along the river water edge. A small portion of the slope is superficially covered by slopewash deposits. At the portal location bedrock of gneiss is exposed, which is very hard, strong, and competent in nature. The rockmass in this area is traversed by three major joint sets besides foliation. The strike of foliation is $241^0 – 061^0$ with dip 41^0 towards 331^0.

Geological section along the adit **(Plate G-14)** shows that the portal is placed on the rock along the steep slope face at an El 987.59m. Gneissic rock is exposed along the slope above the portal. Foliation joint and joint set S3 dips towards hill in very low to moderate angle while joint sets S2 and S4 dip towards valley. So, while developing portal attention has to be paid on the valley facing joints i.e. joint sets S2 and S4, which may act as failure planes. Furthermore the joint set S2 dips at quite high angle towards valley and any slope cut lower than the dip of this joint will not pose any adverse impact. Therefore, the slope above the portal may require bare minimum support to get stabilized. The adit is initially aligned in N54^0 E direction for 10m and the strike of foliation is askew by 07^0 with the alignment and the other joint sets are askew by 89^0, 77^0 and 29^0 respectively for S2, S3 and S4 with respect to the alignment. So the adit is favourably aligned with respect to the joint sets S2, S3 and S4 but unfavourable with respect to foliation joint. The adit after turn is aligned in N83^0E for a length of 90m. In this section the strike of foliation is disposed at an angle of 22^0 with the alignment and the joint set S2 is askew by 62^0, S3 by 48^0 and S4 by 00^0 with the alignment of the adit. In this section the adit is more or less favourably oriented with respect to joint sets S2 and S4 but unfavourable with respect to foliation and joint set S3. In the last section of about 38m the adit orientation is S36^0E and it is askew by 83^0 with the strike of foliation and by 01^0, 13^0 and 61^0 with the strike of other joint sets. It shows that the orientation in this part is favourable with respect to foliation and S4 but unfavourable with respect to S2 and S3. Overall, it may be concluded that in most of the part the adit is favourably oriented but in the small sectors small wedges may be expected due to intersection of different joint sets which are to be stabilized and support design has to be adopted accordingly. From the surface geological mapping and drift data for dam site left bank, it is anticipated that the rock mass to be encountered along this adit will be of fair to good quality. 40% good and 60% fair quality of rock are expected to be encountered along the adit length.

4.9 Construction Adit to HRT from Downstream Side

This adit has been proposed on the left bank slopes of a nala existing on upstream side of powerhouse site. The invert of portal of this 7m(H)x 6.5m(W)sized, D-shaped and 301m long construction adit is located at EL 970m and it joins HRT at RD 3839m at EL 980.68m, about

40m upstream of junction of HRT with surge shaft. This adit initially, for a length of about 271m is aligned in N60^0E – S60^0W direction and then turns towards E to join HRT.

Geological map of the powerhouse area **(Plate G-17)** indicates that hill slopes on the left bank of Siyom and that of nala are covered by slopewash deposits at lower and middle elevation and bedrock comprising hard, compact and foliated and jointed gneisses at higher reaches. In general, the rocks are light to dark grey in colour and slightly weathered on the surface. Weathering is manifested by discolouration along the exposed surface. The gneisses are intercalated with thin quartzite bands, traversed by silica veins and quartz boudins and ptygmatic folds are common within the gneissic bands. The strike of foliation, in general, is almost north-south direction and dips towards west by 32^O and 48^O. The rock mass is traversed by two prominent sets of joints in addition to the joint set parallel to foliation. Detailed analysis of orientation of major joint sets observed in the powerhouse complex area **(Table-18)** indicates that the rock mass is traversed by three prominent sets of joints including those parallel to foliation.

Geological section along the alignment proposed adit to HRT **(Plate G-16)** shows that the hill slopes along the alignment are covered by slopewash deposits upto El 1080m and bedrock is exposed extensively above that. The portal of the proposed adit has been envisaged at El 970m where the hill slopes are covered by moderately thick overburden. The geological section indicates that the overburden at the site will have to be removed for a length of 10-15m for locating the portal in the bedrock. The overburden resting on the slope above the portal will be required to be stabilized by providing proper cut slopes and surface drainage. It is also observed from the geological section along the alignment of the proposed adit that adequate rock cover above the crown of the adit may not be available in initial 10-15m length. The supports in this reach would have to be designed accordingly.

The proposed adit upto RD 271m is aligned in N60^0 – 240^0 direction. Same in this reach is askew to the strike of foliation by 58^0 and by 47^0 and 18^0 as far as strike of joints belonging to sets S2 and S3 is concerned. It can be considered favourably aligned with respect to the strike of S1 and S2 but aligned unfavourably with respect to that of S3. Proposed adit, beyond RD 260m is aligned in E-W direction till it joins HRT. Its alignment is askew to the strike of foliation (S1) by 88^0 and to that of S2 and S3 by 77^0 and 12^0 respectively. It can be considered ideally aligned with respect to foliation and S2 but not as far as strike of S3 is concerned. It is indicated by surface mapping and exploratory drift to powerhouse, the bedrock belonging to good and fair quality (Rock mass Class II and III) will be encountered in general except for a few short reaches where poor quality rock could be encountered during the excavation of this adit. The supports may be designed accordingly.

4.10 Powerhouse Complex

The proposed powerhouse complex is located on left bank of the river Siyom about 2km downstream of confluence of Tagurshit Nala with the river Siyom (**Photo 14**). The complex includes a 31.5m diameter and 47m high restricted orifice type underground surge shaft; 4.5m diameter and 2 x 311.40m and 2 x 294.40m long 4 vertical pressure shafts; a 164m long, 22.5m wide and 48.5m high underground powerhouse with installed capacity of 700 MW; a 143m long, 16m wide and 25.5m high transformer cavern and 11m diameter and 562m long Tail Race Tunnel (TRT) for discharging the tail water back into the river.

Initially the tail race elevation for the project was proposed at EL 820m. Keeping this in view, powerhouse complex for the project was sited on the left bank of the river Siyom upstream of a fairly large left bank tributary of the river. The powerhouse at this location was suppressed to some extent as compared to riverbed. However, recent developments led to lowering of tail race elevation from EL 820m to EL 810m led to relocation of powerhouse complex further downstream on the left bank of the Nala. The surface and subsurface explorations carried out in the powerhouse area and geotechnical assessment of the powerhouse complex are discussed in the following paragraphs.

4.11 Surface and Subsurface Explorations

Surface explorations carried out in the powerhouse complex area include detailed geological mapping. Geological map of the area **(Plate G-17)** indicates that Siyom River in the area flows along a slightly meandering course from northwest to southeast. The topography of the area is rugged with alternating ridges and furrows. The hill slopes in the area are moderate to steep and are covered by grasses and shrubs in general. The gullies and drainage courses are covered by thick vegetations but isolated rock outcrops are seen along the ridges, which are concealed under grassland. The powerhouse is proposed downstream of a major left bank tributary nala of the river Siyom. There is an existing suspension foot bridge over river Siyom, which is located downstream of the proposed TRT outfall area. Left bank of the river, just upstream of the suspension bridge is defined by a fluvial terrace that extends for more than 100m. Thereafter, gneissic rock is exposed from the river water edge for about another 125m upstream. Another extensive fluvial terrace is present upstream of rocky escarpment defining the left bank of the river. The valley slopes on the left bank after the terrace in the area rise steeply (60^0 to 70^0) and are generally covered with thick overburden that supports dense vegetation along the depressions. The terrain is rugged and has very difficult access. Keeping the steep nature of slopes and absence of approaches, the Canadian geologists having expertise in mountaineering and rock climbing were drafted to carry out geological mapping in the area. At the first instance, the geological mapping along the river was carried out and planning was done for carrying out mapping in higher reaches. Efforts were made to collect the ground data to the extent possible through traverses in and around the powerhouse complex area. The geological map of the Powerhouse area (**Plate G-17, Volume-VIB**) shows that, the rocks exposed in the powerhouse complex area are hard, compact and foliated and jointed gneisses. In general, the rocks are light to dark grey in colour and slightly weathered on the surface. Weathering is manifested by discolouration along the exposed surface. The gneisses are intercalated with thin quartzite bands. The gneisses are traversed by silica veins and quartz boudins and ptygmatic folds are common within the gneissic bands. The strike of foliation, in general, is almost north-south direction and dips towards west by 58^O. The rock mass is traversed by two prominent sets of joints in addition to the joint set parallel to foliation. The orientation of major joint sets observed during surface mapping and logging of exploratory drift in the powerhouse complex area is given in the **Table-18.**

Table-18: Major joint sets around powerhouse complex

S. No.	Strike	Dip Direction	Dip Amount
1	012^0 - 192^0	282^0	58^0
2	036^0 - 216^0	126^0	30^0
3	089^0 - 269^0	179^0	76^0

The stereographic projection of poles and major plane plots of the discontinuity data collected during geological mapping and detailed logging of the drifts in the area are given in **Figures 16 and 17**.

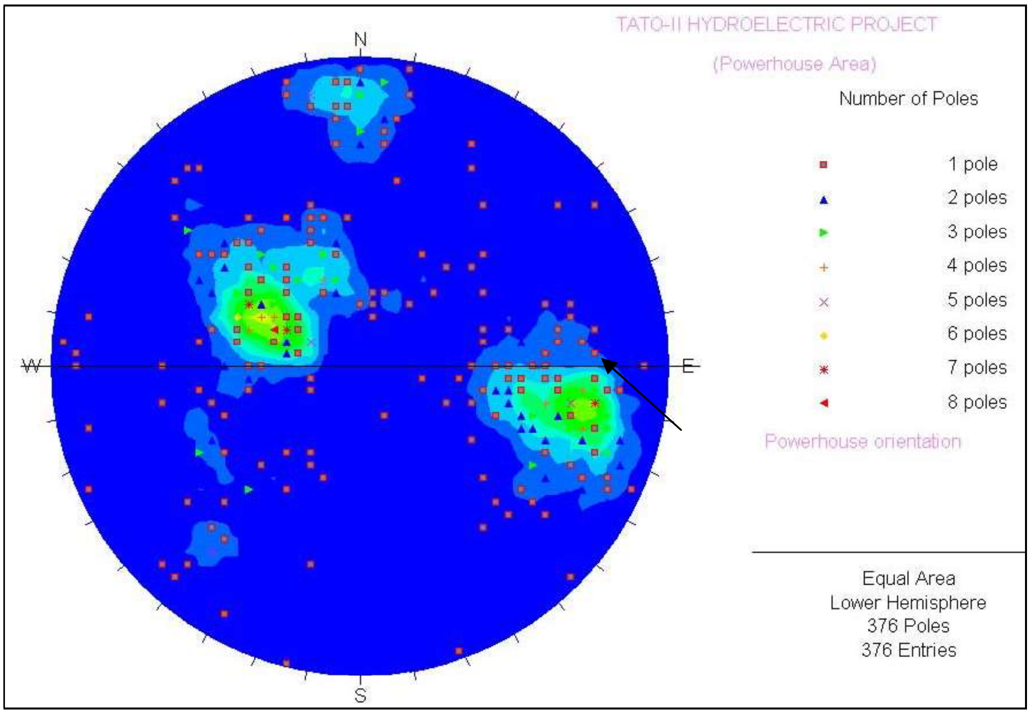

Figure-16: Stereographic projection of poles in and around powerhouse area

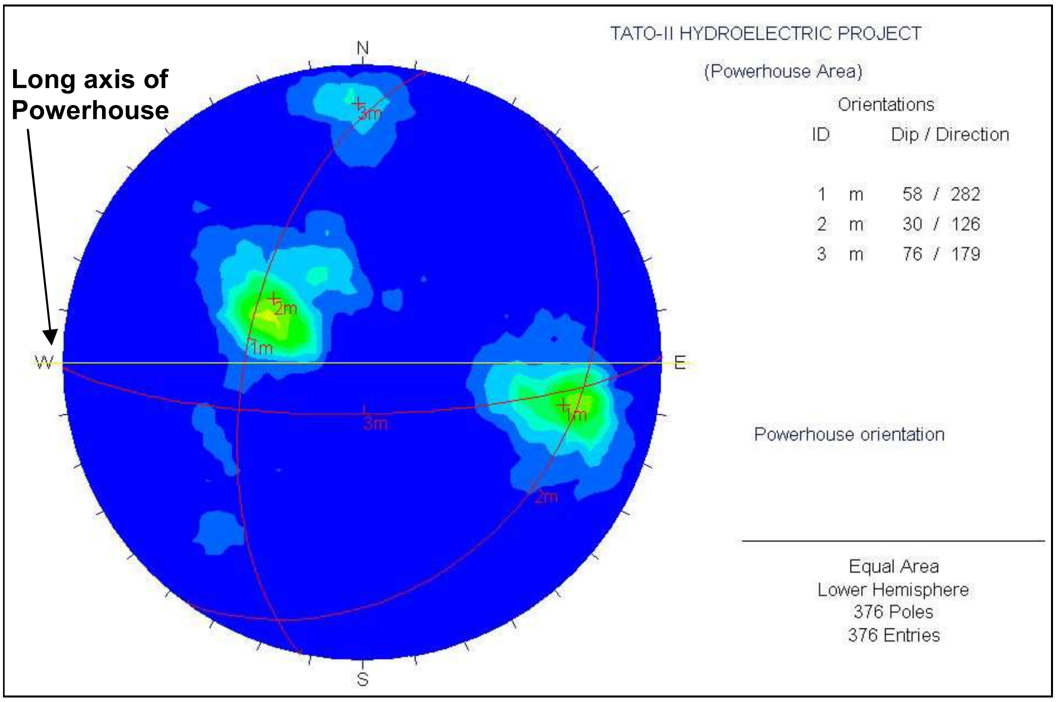

Figure-17: Joint set orientations and major plane projection around Powerhouse site

It is observed that hard, compact gneissic rocks are exposed along the river edge at patches and on the steep hill slopes in the area (**Plate G-17, Volume-VIB**) and same are expected to be encountered at the powerhouse cavern as well.

The subsurface exploration plan of the powerhouse includes an exploratory drift with a view to explore the actual rock mass condition and assess the support requirement. The portal of the exploratory drift for exploring the powerhouse site has been proposed on the back slopes on the downstream end of an existing terrace where gneisses are exposed at elevation of 830m. The location appears suitable for locating the portal for the exploratory drift as no slope stability problem is apprehended. The drift is envisaged to reach the actual location of the powerhouse cavern around its crown level was proposed to be oriented in N35^{O}E direction. The rock mechanic tests for determining in-situ mechanical properties of rock mass and extent and directions of in-situ stresses are proposed to be conducted when the drift reaches to the actual location of the powerhouse cavern.

The exploratory drift to powerhouse **PH DR-2** is located on the left bank of the river Siyom with invert at El 830m. This has been excavated for a length of 269m and logged up to 200m and further excavation is in progress. Detailed logging of the drift has been carried out upto the length excavated and detailed geological log of the drift has been appended as **Annexure-III.** Geological log of the drift (**Annexure-III**) indicates that it has been excavated as open cut for initial 2.0m. The drift follows N018^{0}direction for initial 15m. After RD 15m it turns towards N345^{0} and its alignment swings between N345^{0} and 355^{0} upto RD 31m. It is aligned in N50^{0} direction upto RD 50m. Beyond RD 50m its alignment swings between N006^{0} and 012^{0} upto RD 85m. It is aligned in N001 direction between RDs 85m and 122m and then it turns towards N015^{0} and follows same direction upto the length excavated. The drift upto the length excavated has encountered gneiss, schistose gneiss and garnetiferous gneiss along with thin biotite schist bands. The bedrock appears to be moderately strong to strong. It slightly weathered to fresh in general upto the length excavated except for the reach between RD 10m and 30m where rock encountered in the drift is fresh.

The bedrock encountered in the drift is traversed by three sets of joints in addition to some random joints. There are significant variations in the direction and amount of dips of individual discontinuities with the respective sets and this variation could be attributed to local folding.

The joints belonging to set S1 are oriented parallel to foliation. The strike of these joints in general varies between N075^{0} and N130^{0}. These dip by 40^{0} to 80^{0} towards the direction varying between 255^{0} and 310^{0}. However, Shallow dips of these joints have been observed at places. The spacing of joints varies between 5cm and 20 cm in general. However, zones in which these joints are very closely spaced have been observed especially between RD 17m and RD 85m. The joint surfaces are smooth to slightly rough and in general undulatory. The joints belonging to this set are stained initially for a length of 5.5m in the drift. These are tight in general except at locations where partial opening along these can be observed. No filling was observed in the joints belonging to set S1.

The joints belonging to set S2 have, in general, their strike varying between N010^0 and 70^0. These dip by 20^0 to 75^0 towards the direction varying between N080^0 and 160^0. The joints belonging to this set are spaced between 30mm and 200mm in general. However, zones having these joints very closely spaced have been observed at different locations, especially between RD 37.5m and RD 97.0m. These are rough in general and have undulatory nature at places. These show opening upto 10mm and are filled with soil up to RD 22.5m. Beyond RD 22.5m, these are tight in general with partial opening observed at places.

The strike of the joints belonging to set S3 varies between 080^0 and 130^0 in general. These dip by 20^0 to 70^0 towards the direction varying from 170^0 to 220^0. The joints belonging to this set are not very frequent and have not been observed through out in the drift. Initially, upto RD 5.5m these are widely spaced. However, their spacing varying between 10 and 70mm has been observed between RD 5.5m and 30m and then these have not been observed upto RD 89 and between RD 89m and RD 118m. In the reaches where these have been observed, these are widely spaced, rough and tight. The joints belonging to set S3 are not very prominent in the area and therefore these have not been considered significant while finalizing the orientation of the cavern.

In addition to above random joints with strike varying between N300^0 and 355^0 have been observed in the drift. These dip in general by 30^0 to 65^0 towards the direction varying between N030^0 and 065^0. The joints belonging to this set are not observed frequently in the drift. These are rough in general and have undulatory nature at places. These are tight in general with partial opening observed at places.

It is observed from **Table-19** that the rock mass in the exploratory drift upto RD 34m is traversed by shears varying in thickness from 5mm to 150mm. These shears in the reach are in general oriented parallel to joint sets S2 and S3. Keeping in view the orientation of the shears and opening along the valley ward dipping, possibility of slight slumping on this bank upto RD 21m can not be ruled out. The shears encountered in the drift beyond RD 34m are generally aligned along the foliation joints belonging to set S1. Since the drift is aligned sub parallel to the strike of foliation joints, long continuity of these shears in the drift is observed between RD 35m and RD 117m. The intensity of shears decreases beyond RD 117. It is expected that quality of rock would improve as the drift progresses further.

As far as seepage conditions are concerned, the drift is dry in initial 5.0m reach, between RD 56.5m and 77m, from RD 85.5m to RD 87.5m, 89.0m and 91.0m and between RD 96.5m and 125.0m. In rest of the drift wet and dripping conditions have been observed except for reach between RD 45.5m and 47.0m where flowing conditions were observed during the logging.

The joint volume and RQD observed all along the drift are given in the **Table-19**.

Table-19: RQD and Joint Volume (Jv) observed in the Drift

S No.	RD (m)	Jv	RQD (%)
1	0.00 – 9.0	20 -21	45.7
2	9.0 – 31.0	20 - 23	39.1
3	31.0 - 38.0	20 - 22	42.4
4	30.0 – 45.5	15 - 17	56.9
5	45.5 – 62.0	23 - 26	29.2
6	62.0 – 71.0	15 - 18	55.6
7	71.0 – 79.0	20 - 22	42.4
8	79.0 – 89.0	13 - 16	55.6
9	89.0 – 98.0	20 - 24	35.8
10	98.0 – 111.0	20 - 25	32.5
11	111.0 – 115.0	25 - 28	22.0
12	115.0 – 124.0	32 - 35	9.4
13	124.0 – 127.0	24 - 26	29.2
14	127.0 – 130.0	28 - 30	45.7
15	130 - 137	15 - 18	60.8
16	137 - 143	20 - 22	45.7
17	143 - 150	18 - 22	49
18	150 - 159	18 - 20	52.3
19	159 - 163	15 - 17	62.2
20	163 - 170	20 - 22	45.7
21	170 – 177.5	15 - 18	60.8
22	177.5 - 186	22 - 25	37.5
23	186 - 192	20 - 23	44.1
24	192 - 200	15 - 18	60.5

The RQD, seepage conditions, estimated strength and joint characteristics and parameters have been utilized to estimate the rock mass condition and quality of rock mass encountered so far in the drift. This could give reasonably good idea about the quality of rock mass likely to be encountered during the excavation of powerhouse cavern and other allied underground structures. The estimated quality of rock mass encountered along with RMR values and rockmass classes and quality are given in **Table-20.**

Table-20: Rock mass quality of the bedrock encountered in the drift

S No.	RD (m)	RMR	Rock Mass Class	Rock Mass Quality
1	0.00 – 5.0	46	III	Fair
2	5.0 – 25.5	37 - 40	IV	Poor
3	25.5 – 45.5	42 - 50	III	Fair
4	45.5 – 53.0	33 - 40	IV	Poor
5	53.0 – 77.0	43 - 53	III	Fair
6	77.0 – 79.0	37	IV	Poor
7	79.0 – 127.0	42 - 56	III	Fair
8	127.0 – 130.0	40	IV	Poor
9	130 - 137	50	III	Fair
10	137 - 141	40	IV	Poor
11	141 - 192	47 - 58	III	Fair
12	192 - 200	63 - 68	II	Good

It is observed from **Table-20** that the exploratory drift in the initial reaches upto RD 5.0m encountered fair quality rock mass belonging to Class III followed by poor quality rock mass belonging to Class III upto RD 25.5. It is observed from the detailed geological log of the drift **(Annexure-III)** that the rock mass between RD 5.0m and 25.5m is closely jointed and traversed by shears varying in thickness from 5mm to 150mm. Keeping in view the orientation of the shears and opening along the valley ward dipping, possibility of slight slumping on this abutment 21m can not be ruled out. The RMR values of the rock mass in this reach vary between 37 and 40 and therefore rock mass has been categorized as poor belonging to Class IV. The rock mass beyond RD 25.5m is moderately jointed and traversed by thin shears and belongs to class III (Fair). The rock mass from RD 45.5 to 53.0m belongs to poor category with RMR values ranging between 37 and 40. Beyond RD 53m the bedrock encountered upto RD 127m in general is of fair quality (Class III) with RMR values varying between 42 and 56 except for a short reach of 2.0m between RD 77m and 79m where rock mass belonging to Class IV (poor) has been observed. The rock mass belonging to poor quality (Class IV) was again encountered beyond RD 127m upto RD 130m. Rockmass belonging to Fair class (Class-III) are encountered between RD 130m to 137m and RD141m to 192m. Patch of Poor rockmass encountered at RD137m and continued upto RD141m. Good rockmass encountered as the drift driven forward from RD 192m upto the logged length of RD 200m. It is observed from the geological log of the drift that rock quality in general improves progressively inside and possibility of further improvement in quality of rock mass is there as drift proceeds further and it is possible that rock mass belonging to Class III and II may be encountered at the location proposed for powerhouse cavern. However, the rock mass of fair quality (Class III) with patches of poor rock mass is likely to be encountered in the adtits and other approach structures to powerhouse in the initial reaches.

5 GEOTECHNICAL ASSESSMENT OF POWERHOUSE AND APPURTENANTS

5.1 Surge Shaft

The HRT, aligned on the left bank of the river Siyom, would terminate at EL 980.60m into a 31.5m diameter, 47m high restricted orifice type surge shaft. The bottom of the surge shaft has been planned at EL 993.00m and top at El 1040.00m. Since it is an underground structure, the crown of the dome has been designed at EL 1054.70m. The geological map of the area (Plate G-17, Volume-VIB) indicates that different varieties of gneisses belonging to Pari Mountain Formation of Siang Group are exposed in and around the site proposed for the surge shaft. The bedrock exposed in the area is slightly weathered on surface, foliated and jointed. The foliation, in general, trends almost north-south with moderate dips towards west. The geological map of the area and geological section across powerhouse **(Plate G-22, Volume-VIB)** also indicate that the ground elevation at the site of proposed structure is around 1200m. This indicates that ground cover of about 143m is available over the crown of the structure, and same can be considered adequate. The rock mass likely to be encountered during the excavation will be jointed gneiss of good quality and no major problems are envisaged during the construction except in the reaches where shear zones are encountered. The gneissic rock is traversed by three major sets of joints. From the geological section (Plate G-22, Volume-VIB), it is apprehended that one of the major joint is oriented obliquely to the shaft and the other two are disposed transverse to it, which in general is favourable situation. However, formation of small unstable wedges is anticipated and these would be required to be supported immediately. With a view to assess the quality of rock mass one drill hole has been recommended to be drilled down to invert level of the surge shaft (DH PH-1). Further explorations proposed include one exploratory drift each at bottom and top elevations of the surge shaft that will be taken up during post construction stage before detailed designs are taken up.

5.2 Adit to Surge Shaft Top

An adit of 210m long is proposed to access the surge shaft top to facilitate its construction and later on it would use as ventilation and maintenance purpose. The adit portal is envisaged at an EL 1036m and it will join surge shaft at EL 1040m, which indicate that the adit will be shelf draining type (**Plate G-18**). As the area is covered by superfacial slopewash deposits, the bedrock would be available at shallow depth. The bedrock exposed in the area comprises quartzitic and biotite gneiss belonging to Pari Mountain Fprmation of Siang Group. It is observed from geological section developed along the proposed adit that initially the approach would have to be developed as an open cut till the bedrock is encountered. The adit would be aligned in E – W direction. The proposed adit would be aligned askew to the joints belonging to set S1 that are oriented parallel to foliation by 78^0, by 52^0 with respect to those belonging to set S2 and sub-parallel to the strike of joints belonging to set S3. The situation is very favourable as far as orientation of joints belonging to S1 and S2 is concerned. The portal is to be formed by cutting the steeply disposed slope and proper measure will be adopted to stabilize the upslope. The instabilities induced by the orientation of joints would be kept in view while designing the supports and construction cycle.

5.3 Adit to Valve Chamber

The underground valve chamber is has been proposed about 40m downstream of surge shaft. With a view to facilitate the construction, an adit has been proposed to access the valve chamber from EL 970m. It will join the chamber at EL 976.10m. The proposed adit is about 216m long and has self draining gradient. Initially, for a length of about 60m, it is aligned in 67^0 – 247^0 and then it bifurcates in to two ofwhich on goes to top of pressure shafts. The adit down stream ofjunction is aligned in E – W direction. The area on the left bank of Siyom has moderate slopes and is apparently covered by slopewash deposits (**Plate G-19**). The area around the proposed structure exposes the gneisses belonging to pari Mountain Formation of Proterozoic age. These are traversed by three major sets of joints (**Table-18**). It is observed that the proposed adioth the reaches would be aligned favourably with respect to the strike of joints except for in case of down stream reach where the alignment is askew to the joints belonging to set S3 by 2^0. However, this relationship between strike of joints and alignment of adit will be kept in view while designing the supports and evolving construction sequence.

The portal is to be developed by removing the slopewash mass resting on the competent gneissic rock. The rock mass is traversed by three joint sets including foliation. The orientation of adit is disposed obliquely with the strike of the joint sets and thus fair to favourable situation will be encountered during tunneling. However, while excavating slope to develop portal face, care needs to be taken for the joint sets S1 and S3 dipping valleyward and proper support is to be adopted to stabilize the upslope.

5.4 Pressure Shafts/ Penstock

The water from the surge shaft will be conveyed to powerhouse through four 4.5m diameter and about 2 x 311.40m and 2 x 294.40m long pressure shafts having vertical drop of

184.85m. The pressure shafts are proposed to be steel lined. These would encounter gneisses that are jointed which are expected to provide good excavation media in general as in case of surge shaft and no major problems are expected to be encountered during construction. From the geological section (**Plate G-22, Volume-VIB**) it is observed that the horizontal limbs of the pressure shaft/penstock are askew at low angle to the foliation strike and one major joint set but transverse to the third set, which is not very favourable situation. However, as the diameter of the tunnels is small, no major problem is anticipated except formation of some small wedges.

5.5 Powerhouse Cavern

The proposed 700MW installed capacity underground powerhouse includes a 164m long, 22.5m wide and 48.50m high machine hall, a 143m long, 16m wide and 25.5m high transformer cavern. Transformer hall is located about 45m wall distance from the powerhouse cavern towards downstream side. The cavity of 16m wide and 25.5 m height would encounter the same rock mass condition as in the powerhouse cavern. Initially, the Main Inlet Valves (MIV) was proposed to be housed in a separate valve chamber upstream of the powerhouse cavern. However, considering the location of four large caverns side by side in the limited space, it was thought of eliminating the Valve Chamber by providing inclined entry of penstocks into powerhouse cavern and accommodating MIVs within the cavern. Although this proposal led to increase in size of powerhouse cavern but it also resulted in elimination of MIV chamber. The final dimensions of Powerhouse cavern after elimination of MIV chamber proposed are 164m x 22.5m x 48.50m.

The analysis of discontinuity data collected from surface mapping and that from drift indicate that besides foliation two major joint sets in addition to some random joints traverse the rock mass in general (**Table-18**).

Based on the analysis of discontinuity data, the long axis of the powerhouse cavern orientation has initially been aligned at E-W. The geological map of the area and geological sections along and across the powerhouse cavern (**Plate G-17, G-21 and G-22, Volume-VIB**) indicate the extent of rock cover over the crown of the powerhouse cavern is around 265m which is adequate. The trend of long axis of powerhouse with respect to the joint sets is presented in the rosette plot (**Figure-18**) that the orientation of long axis of powerhouse is aligned at an angle of 78^{O} with the foliation and is askew by 54^{O} and 04^{O} respectively with other joint planes. From above it is observed that long axis is very favourably aligned with respect to foliation joints (S1) and favourably with those belonging to set S2. However, it is not at all favourably aligned as far as joints belonging to set S3 are concerned. However, it is observed that joints belonging to set S3 are not very prominent as compared to those belonging to other two sets and have therefore not considered very significant. Apparently, orientation of powerhouse cavern proposed appears to be favourable as far as trend of prominent discontinuities in the area is concerned. However, the final orientation of the powerhouse cavity will be further optimized when the discontinuity data from rest of the exploratory drift is obtained and analyzed in conjunction with results of in-situ rock mechanics test proposed to be carried out.

Wedge analysis has been carried out by using 'Unwedge' software considering 164.0m (L) x 22.5m (W) x 48.5m (H) of the cavern and orientation of long axis in N90^0 direction. The parameters considered for the unwedge analysis are unit weight of rock as 2.70 ton/m^2, angle of internal friction as 39^0 and cohesion as 0.18 Mpa. Analyses have been carried out by considering combinations of joint sets indicated that set S3 does not have significant impact on formation of unstable wedges and has therefore been considered important. Different wedges that could be formed by the intersection of different joint sets are shown in **Figures 19, 20, 21 and Table-21.**

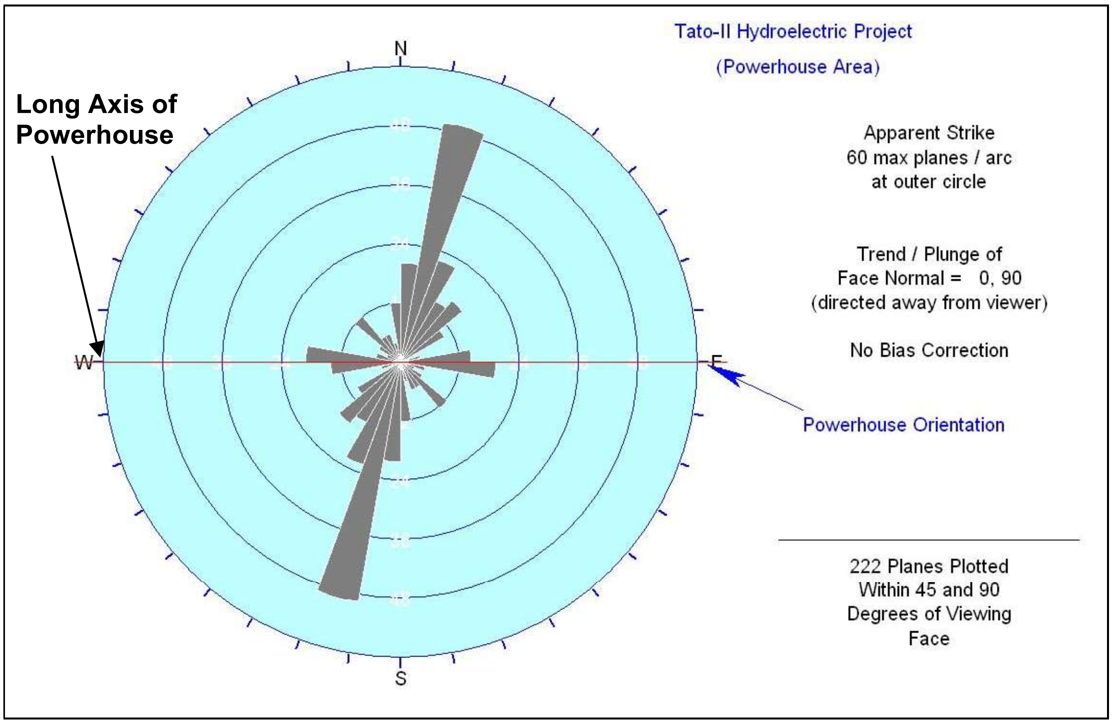

Figure-18: Rosette plot and Powerhouse orientation

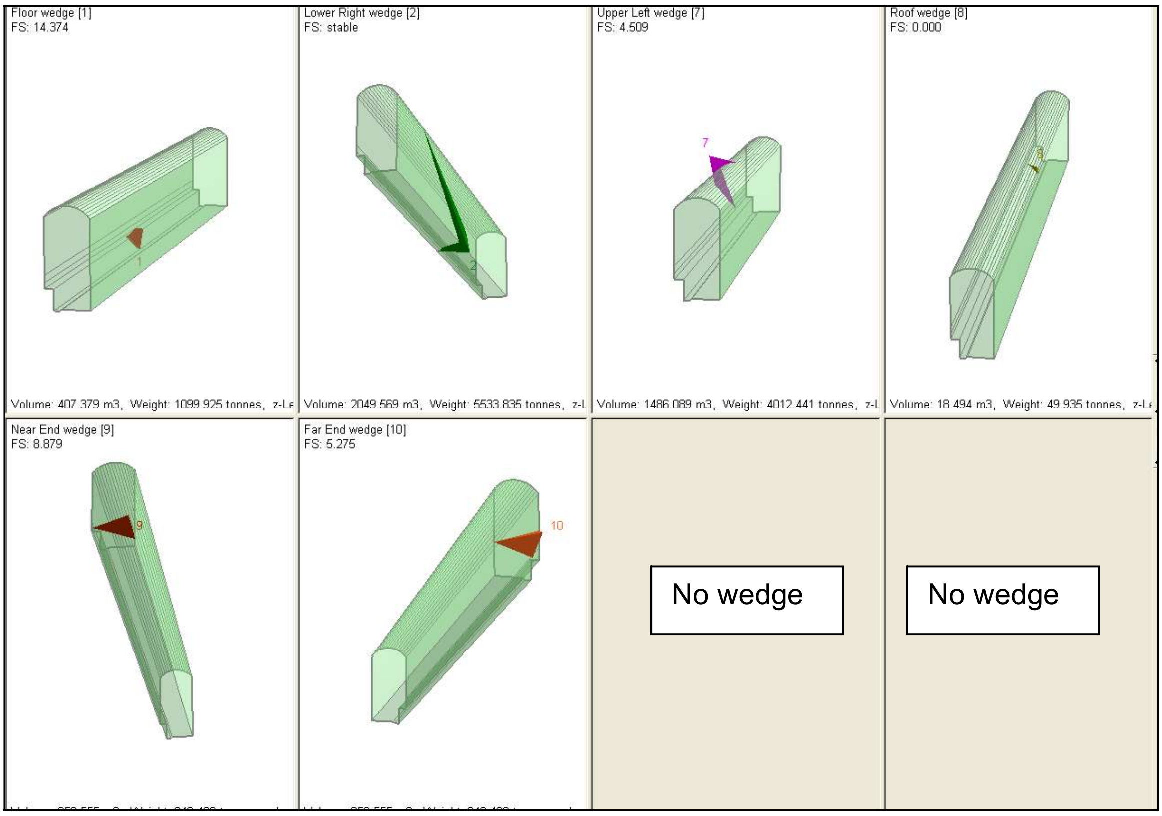

Figure-19: Different wedges anticipated in Powerhouse Cavern

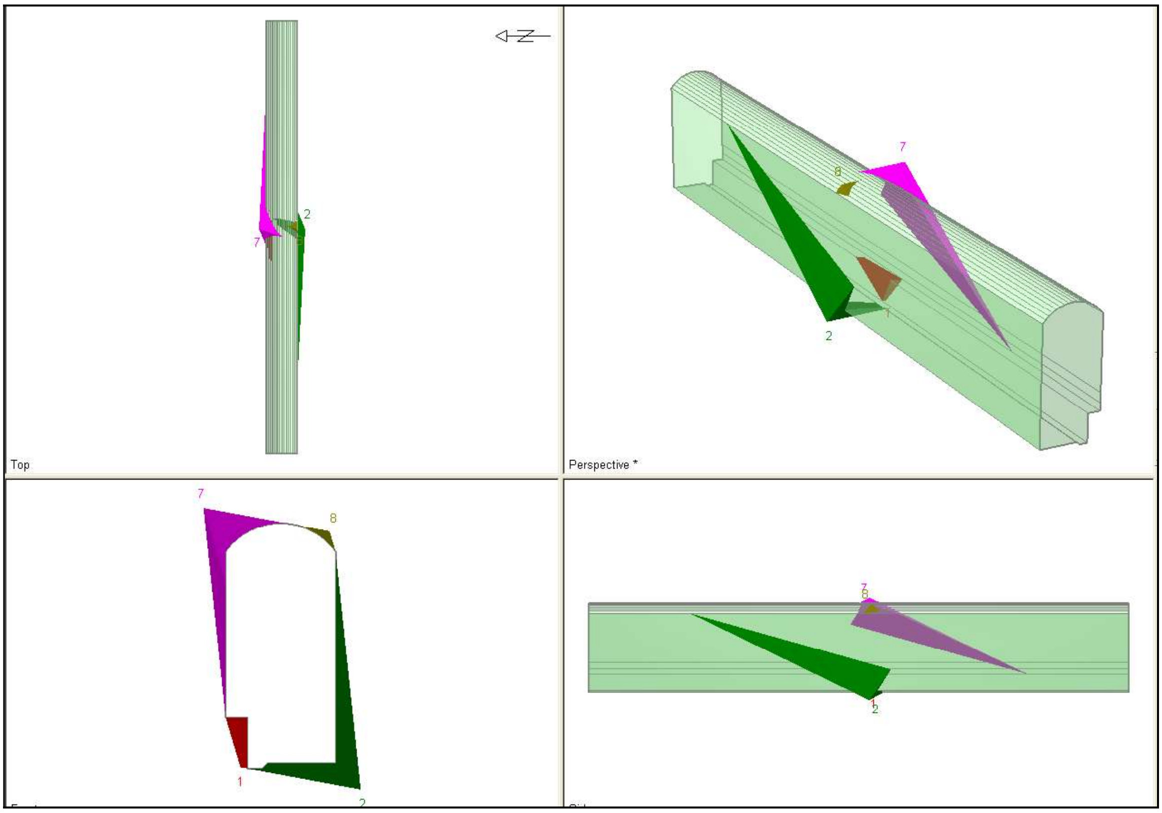

Figure-20: Different views of wedges anticipated in Powerhouse Cavern

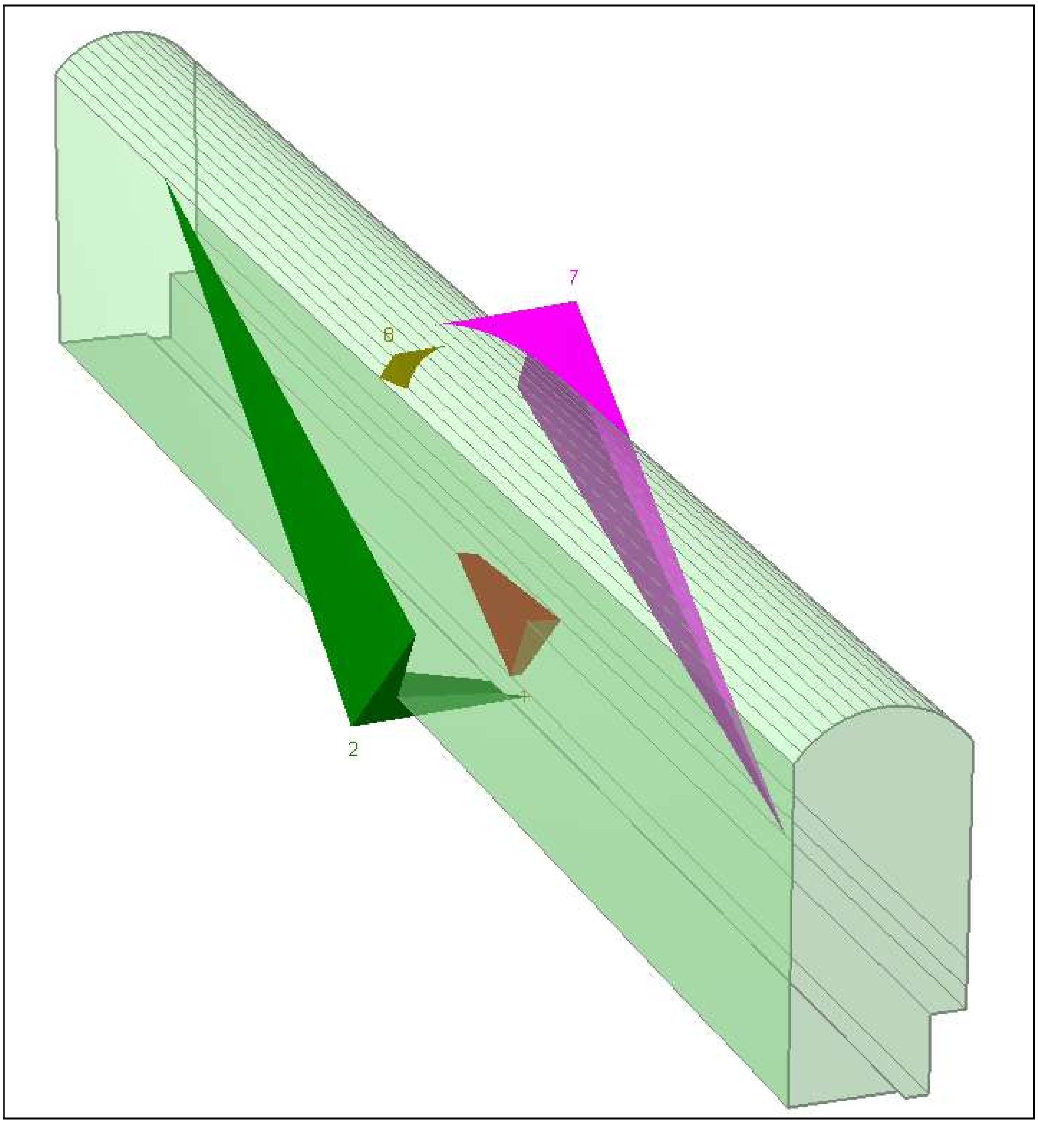

Figure-21: Perspective view of wedges for Powerhouse Cavern

Table-21: Details of wedge formed in Powerhouse cavern

S. No.	Wedges	Volume (m^3)	Weight (Tons)	Z-Length (m)	Factor of safety
1	Floor wedge [1]	407.379	1099.925	29.87	14.374
2	Right wedge [2]	2049.569	5533.835	112.79	stable
3	Upper Left wedge [7]	1486.089	4012.441	99.35	4.509
4	Roof wedge [8]	18.494	49.935	9.04	0.000
5	Near End wedge [9]	350.555	946.498	0.00	8.879
6	Far End wedge [10]	350.555	946.498	0.00	5.275

It is observed from **Figures 18, 19, 20 and Table-21** that six types of wedges are likely to be formed in the cavern. These are floor left and right wedges, upper left wedge, roof wedge and near and far end wedges. Of these all the wedges except for the roof wedge (8) are stable with minimum factor of safety 4.509. The roof wedge with factor of safety 0.000 is only unstable that is required to be taken care of and stabilised during excavation.

5.6 Main Access Tunnel and Adit to Pressure Shaft Bottom

Main Access Tunnel cum adit to pressure shaft bottom is proposed on the left bank of the river Siyom with a view to to facilitate constructions as well as to operate and maintain the powerhouse after commissioning of the project. The area on the ledt bank of Siyom in general has a rugged topography with valley slopes rising moderately from river bed (**Plate G-20**). The left bank in general is covered by thin slopewash deposits that support thick vegetal growth at lower elevations. The area at higher elevations exposes bedrock comprsing gneisses, which are hard, compact and competent in nature. The rock mass is traversed by three joint sets including foliation. This adit will take off from elevation of EL 825m and continue downslope to join powerhouse at service bay level and pressure shaft at bottom elevation after bifurcating from MAT. It is observed from geological section along the proposed adit (Plate G-20) that the adit, initially for a length of about 20m would be an open cut till it gets adequate rock cover. This about 550m long combined adit for MAT and bottom of pressure shafts can be divided into five reaches depending upon its orientation. The adit initially for a length of about 130m is aligned in N - S direction. In this reach it is aligned askew to the joint set S1 foliation by 12^0 which is not a desirable situation at all. Its alignment make an angle of 360 with the joints belonging ton set S2 and that of 86^0 with those belonging to set S3. Therefore it is not aligned favourably with respect to foliation, and most favourably as fae as alignmentof joints belonging to set S3 are concerned. Further down it turns towards west by 10^0 and is oriented in 350^0 –170^0 direction for a length of about 140m. In this reach the proposed adit old be aligned askew with the strike of joints belonging to set S1 and parallel to foliation by 22^0, by 46^0 with respect to those belonging to set S2 and by 86^0 wit respect to those belonging to set S3. The situation in this reach would be similar to that expected in the preceding reach. Similar geothchnical envrons are expected in the following reach beyong the curved reach where the proposed adit would be aligned in 002^0 - 182^0 direction. The adit in the last reach is aligned in 089^0 – 269^0 direction. It wouold be askew with the joints belonging to set S1 oriented to foliation by 770, by 53^0 with respect to the joist belonging to set S2 and by 63^0 ith respect to those belonging to set S3. It is observed that the proposed adit would be most ideally aligned with respect to joints in this reach. This situation would be kept in view while designing the supports and planning the construction methodology. From the geological section along the adit (**Plate G-20),** it is observed that the adit is initially orientated in of adit is highly askew with the strike of the foliation at major portion and is suitable for excavation but at short reaches askewness with respect to foliation is less, which may slow the process of excavation. Otherwise, no major problem at this stage is envisaged. The rock type to be encountered along this adit is expected to be of fair to good quality.

5.7 Pot Head Yard

The pot head yard is proposed to be located on the left bank of the river Siyom at about EL 850m. Geological map of the powerhouse area **(Plate G-17)** and geological section across the pot head yard **(Plate G-24)** indicates that in the area around the site proposed for the pot head yard the riverbank slopes rise at steep angle upto elevation about EL 850m and is disposed moderately above that. The bedrock comprising gneisses belonging to Pari Mountain Formation is exposed on the steep slope from river level to elevation of around EL 850m the hill slopes on the left bank of the river Siyom are covered by overburden comprising slopewash deposits. The bedrock is foliated and jointed. The topography of the area indicates that in order to locate 103m long and 50m wide pot head yard, the required space to be developed by excavating the hill slopes. This would lead to about 40m high cut slopes on the hill side of the pot head yard. These cut slopes exposing rock in lower portions covered by overburden will have to be treated suitably and provided proper surface drainage.

5.8 Tail Race Tunnel

A 11m diameter and 562m long Tail Race Tunnel (TRT) is aligned on the left bank of the river Siyom with a view to discharge the tail water back into the river. The TRT, initially after taking off from the powerhouse is aligned in west direction for about 100m. After this it turns towards S07^{0}E through a broad curvature and is aligned in same direction for 475m and then again turns towards southward and joins the river Siyom at EL 805m. The geological map of the area **(Plate G-17, Volume-VIB)** shows that the higher reaches of the area is covered by slopewash deposits disposed at moderate slopes. The thickness of overburden is expected to be shallow in this reach as rock exposures are seen towards upper and lower reaches. The bed rock comprising quartz biotite gneiss, garnetiferous gneiss belonging to Pari Mountain Formation is exposed towards lower reaches of the TRT, where TRT exit portal is to be located. The geological sections along and across the proposed TRT

(**Plate G-23 & G-25, Volume-VIB)** indicate that maximum rock cover available over the proposed TRT is about 250m in the initial reach near the powerhouse and same decreases gradually to 50 m about 540m away from same. Beyond this it gradually reduces to 20m near the exit portal. It is also observed from geological section across the proposed TRT **(Plate G-25)** adequate lateral cover on the riverside of HRT is available. Thereafter the tailrace may be designed as an open channel through the terrace deposits up to the river. The terrace comprises river borne shingles, boulders in sandy matrix. The rock mass condition likely to be encountered in the tailrace tunnel would be fair to good quality. At few zones where shear / fractured rock will be encountered, rock mass condition may be poor.