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जामरानी बाँध परियोजना, जिला नैनीताल (उत्तराँचल) के निर्माण पूर्व अवस्था के भूवैज्ञानिक अन्वेषणों पर वस्तुस्थितिकीय प्रतिवेदन

STATUS REPORT ON PRE-CONSTRUCTION STAGE GEOLOGICAL INVESTIGATIONS OF JAMRANI DAM PROJECT, NAINITAL DISTRICT, UTTARANCHAL

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भारत सरकार के आदेश से प्रकाशित
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Lucknow
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FOREWORD

The Irrigation Department, Government of Uttar Pradesh, has proposed a 130m high R.C.C. dam across Gola river near Jamrani village, Nainital district. This multipurpose scheme envisages storage of about 208.6m cum of water for providing irrigation of Bbabhar and Tarai areas of Nainital and Bareilly districts, drinking water to town-ships of Haldwani, Kathgodam, Lalkuan and to adjoining rural population besides generating 15 MW of hydel power. Investigations were initiated in 1968, for selecting the dam site. The pre-construction stage investigation began in 1980. The type of dam, to be adopted, is also discussed in the book along with investigation details.

This monograph comprises an account of the geology of Dam site, subsurface exploration details, observations on seismicity and neotectonics and its implications on the proposed structure in the Gola river in Nainital district of Uttaranchal State.

This book would serve as a useful document to researches in the geotechnical field.

(R.P. Srivastava)

Dy. D.G., N.R.

Lucknow

Dated : August, 2001

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जामरानी बाँध परियोजना, जिला नैनीताल, उत्तर प्रदेश के निर्माण पूर्व अवस्था के भूवैज्ञानिक अन्वेषणों पर वस्तुस्थितिकीय प्रतिवेदन

संकलक

वाई.सी. जोशी

सारांश

i) नैनीताल जिले के गिरिपाद स्थलों तथा रामपुर एवं बरेली जिलों के मैदानी भागों के लिये पीने के पानी के साथ-साथ औद्योगिक और कृषि उपयोग हेतु बढ़ती आवश्यकता पूर्ति के लिये 130 मीटर ऊँचे आर.सी.सी. बाँध निर्माण की योजना है। इस उद्देश्य हेतु लगभग 208.6 मिलियन घन मीटर बरसात का पानी एकत्र करके, काठगोदाम बैराज की नहरों के द्वारा वितरित किया जायेगा।

ii) जामरानी बाँध स्थल के लिये विस्तृत निर्माण पूर्व अवस्था के अनुसंधान और विभिन्न भूवैज्ञानिक पक्षों को लेकर अध्ययन किया गया है। इसमें निम्न कार्य सम्मिलित हैं: i) बाँध स्थल क्षेत्र का विस्तृत मानचित्रण ii) 44 बेधन छिद्रों द्वारा कुल बेधन 3407.6 मीटर और 8 ड्रिफ्टों, जिनकी कुल लम्बाई 277.5 मीटर है, के द्वारा भूगर्भीय अध्ययन iii) आधार शैलों के पारगम्यता गुणों को जानने हेतु बेधन छिद्रों का जल-दाब परीक्षण iv) ग्राउट परीक्षण v) शैल नमूनों के भूयांत्रिक प्राचल निर्धारण हेतु उनका स्वस्थानिक एवं प्रयोगशालीय परीक्षण अपद्ध निर्माण सामग्री हेतु सर्वेक्षण vi) जलाशय क्षमता अध्ययन vii) भूकम्पीय, नवविर्वतनीकीय और जलाशय प्रेरित भूकम्पों से सम्बन्धित अध्ययन।

iii) विस्तृत अध्ययन द्वारा यह निष्पादित किया गया है कि शिवालिक समूह के शैल जिसमें एकान्तर क्रम में बालुकाश्म, सिल्ट शैल और शेल चट्टानें, जो कि परिवर्म मोटाइयों के ढलान मलबे के नीचे दोनों अबटमेंट पर तथा नदी भाग में नदीय तलछट के नीचे दबी हैं, बाँध स्थल पर बाँध का आधार प्रदान करती हैं। इन चट्टानों में बालुकाश्म अन्य दोनों चट्टानों से अधिक मात्रा में है। बालुकाश्म कठोर से नरम है जबकि सिल्ट शैल कठोर हैं। शेल नरम है। यह शिलायें मुख्य ज्वाइंट्स के पांच समूहों द्वारा बेधित हैं। नदी खण्ड के उर्ध्व प्रवाह भाग में, आधार शैल कन्टूर संकरे कटाव को दर्शाती हैं जो बाँध के हील क्षेत्र में गहराता जाता है। इसी कारण बाँध आधार में भूमिगम शैल, हील भाग में ई एल 611 मीटर से नीचे तथा अनुप्रवाह भाग में ऊँची होकर ईएल 617 मीटर पर मिलने की आशा है। शिलाओं की अनुदैर्ध्य दिशा उ.पू.-द.पू. दिशा में 30° से 35° नीति के साथ है।

iv) शिलाओं की पारगम्यता 2 से 6 ल्यूजोन के मध्य आती है यद्यपि 56 ल्यूजोन तक का ऊँचा मान भी नापा गया है। ग्राउट परीक्षण दर्शाते हैं कि सिल्ट शैल ग्राउट मिश्रण लेने में सबसे ज्यादा सुगम है, उसके बाद बालुकाश्म आता है तथा शेल शिलायें सबसे कम सुगम हैं। आधार शिलाओं के भौतिकीय, विकृतीय तथा अपरुपण गुण निर्धारण हेतु प्रयोगशालीय एवं स्वस्थानिक परीक्षण किये गये हैं। बालुकाश्म की अबाधित संपीडन क्षमता (यू. सी. एस.) (शुष्क) 68 से 523 कि.ग्राम प्रति वर्ग से.मी. तथा सिल्ट शैल की 198 से 403 कि.ग्रा. प्रति वर्ग से.मी. है। बालुकाश्म का विकृतमान 0.4670 से लेकर 0.537 x 10^5 कि.ग्रा.

प्रति वर्ग से.मी. तथा सिल्ट शैल का 0.4049 से लेकर 0.4558 x 10^5 कि.ग्रा. प्रति वर्ग से.मी. तथा शैल शिलाओं का 0.3682 से लेकर 0.5728 x 10^5 कि.ग्रा. प्रति वर्ग से.मी. मापा गया है। परीक्षण द्वारा बालुकाश्म का संसंजन 0.3 से 2.8 कि.ग्रा. प्रति वर्ग से.मी. तथा ϕ 40° से 49° वहीं सिल्ट शेल का 0.7 कि.ग्रा. प्रति वर्ग से.मी. तथा ϕ 39° है। शेल का ϕ 40° से 58.6° तथा संसंजन 1.8 से लेकर 3.14 कि.ग्रा. प्रति वर्ग से.मी. है।

v) परियोजना क्षेत्र हिमालय के भूकम्पन विर्वतननिक क्षेत्र के फुट हिल भूकम्प प्रक्षेत्र में आता है जो इसके निकट उत्तर स्थित मुख्य हिमालयी भूकम्प क्षेत्र से अपेक्षाकृत मुक्त भूकम्पीय गतिविधियों वाला क्षेत्र जाना जाता है। मुख्य हिमालयी भूकम्प क्षेत्र इस क्षेत्र का मुख्य भूकम्पीय क्रिया का केन्द्र है। यह परियोजना स्थल उत्तरकाशी भूकम्प (1991) के समभूकम्प क्षेत्र V एवं VI में आता है। बाँध स्थल के उत्तर से जाने वाला मेन बाउण्ड्री भ्रंश जलाशय को 3.3 कि.मी. उर्ध्वप्रवाह में काटता है। पूर्व में पुनः लुगार गाड को काटता हुआ परियोजना स्थल से बाहर चला जाता है। इस भृंश को लुगार गाड में वर्तमान काल में क्रियाशील माना गया है। यह अनुमान लुगार गाड घाटी में समकालीन जलोढ निक्षेपो में फलक बन जाने के कारण लगाया गया है। यह सम्भव है कि यह नदीय तलक्षट, वृष्टि प्रस्फोट के कारण उत्तरी भागों की पहाड़ियों, जो कि अतिविभंगित एवं टूटी हुयी अमृतपुर ग्रेनाइट से लाये गये मलबे से बनी हैं। नदी की प्रतिकूल जलविज्ञान प्रवृति (Hydrological regime) के कारण यह मलबा साफ नहीं हो सका। इसी प्रकार के मलबे 1993 में गोला नदी पर बाँध स्थल के अनुप्रवाह में बाराक्षाला के समीप बने थे। किन्तु चौड़ा नाला और गोलाघाटी, उसके शीघ्र निष्पादन में सहायक रहे। परियोजना का, क्षेप भ्रंश प्रधान क्षेत्र में होना, शिवालिक शिलाओं की प्लास्टिक प्रकृति तथा अमृतपुर ग्रेनाइट पर पानी की कम ऊँचाई के कारण जलाशय प्रेरित भूकम्पन की सम्भावन क्षीण है। 'मेन बाउन्ड्री फाल्ट' की भ्रंश मृदा सामग्री जलाशय के जल के रिसाव को प्रोत्साहित नहीं करेगी।

vi) शिलायें अन्तरात्मक स्थिरण हेतु संवेदी हैं और इसे रोकने के लिये उपयुक्त अभिकल्पिक सावधानी आपेक्षित है।

vii) जलाशय के किनारे कसे हुये हैं। माना जाता है कि मेन बाउन्ड्री फाल्ट (एम.बी.एफ.) रिसाव को जल मार्ग प्रदान करेगा। किन्तु यह विचारणीय है कि भ्रंश पदार्थ साधारणतया रोक देगा। तब भी भ्रंश पदार्थ की पारगम्यता गुणों को निर्धारण हेतु अनुसन्धान की संस्तुति की गयी है। जलाशय क्षेत्र में तीन प्रमुख स्खलनों में एक मारकुडिया स्खलन कुछ कठिनाई खड़ी कर सकता है।

viii) 20 लाख घन मीटर आवश्यक निर्माण सामग्री के सापेक्ष केवल 17 लाख घन मीटर, बाँध अक्ष के 3.5 कि.मी. उर्ध्व प्रवाह से 3 कि.मी. अनुप्रवाह क्षेत्र तक में उपलब्ध है। शेष सामग्री प्राप्त करने के लिये नये क्षेत्र की खोज करनी होगी।

STATUS REPORT OF PRE-CONSTRUCTION STAGE GEOLOGICAL INVESTIGATIONS OF JAMRANI DAM PROJECT, NAINITAL DISTRICT, UTTARANCHAL

Compiled by

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ABSTRACT

i. A scheme envisaging construction of a 130m high R.C.C. dam across Gola river gorge near Jamrani village has been prepared for meeting the ever-increasing requirement of water for drinking as well as industrial and agricultural use in the townships at foot-hill in Nainital district and plains of Rampur and Bareilly districts. About 208.6m cu.m. of rain water is to be stored for the purpose and distributed through canals emerging from the Kathgodam barrage.

ii. Detailed pre-construction stage explorations and studies have been undertaken covering different geological aspects for the Jamrani site. These included (i) detailed large scale mapping of dam site area (ii) sub-surface exploration by 44 drill holes aggregating 3407.6 m and eight drifts of a total length of 277.5 m, (iii) water pressure tests in boreholes to determine permeability characteristics of foundation rocks, (iv) test grouting, (v) in-situ and laboratory tests on rock samples for determining their geomechanical parameters, (vi) construction material surveys, (vii) reservoir competency studies, (viii) studies pertaining to seismicity, neotectonism and reservoir induced seismicity (RIS).

iii. This exhaustive study has established that the Lower Siwalik group of rocks comprising alternating sequence of sandstone. Siltstone and shale bands, lying under varying thickness of slope debries on either abutment and riverine deposits in the river section, will constitute the foundation media for the dam. Sandstone beds, which preponderate over siltstone and shale are hard to soft while siltstone bands are hard. The shale is soft. These rocks are traversed by five sets of major joints. Bed rock contours indicate existence of narrow channel, within the river section in the upstream half. This channel deepens towards the heel portion of the dam. The deepest level of bed rock is therefore expected to go deeper than El. 611m in the heel portion which rises to El 617 m in the downstream region of the dam base. The rocks strike NW-SE with dips ranging between 30° and 35° towards NE.

iv. The permeability of rocks ranges between 2 and 6 lugeons, though high values up to 56 lugeons have also been recorded. Test grouting has indicated that siltstone bands are most amenable to grouting followed by sandstones and shale, the last being the least

amenable. Laboratory and insitu tests have been done to determine physical, deformational and shear parameters of the foundation rocks. Unconfined compresive strength (UCS) (dry) of sandstone and siltstone varies from 68 to 532 kg/cm^2 and 198 to 403 kg/cm^2 respectively. Modulus of deformation for sandstone is 0.4670 to 0.537 x 10^5 kg/cm^2, for siltstone 0.4049 to 0.4558 x 10^5 kg/cm^2 and for shales 0.3682 to 0.5728 x 10^5 kg/cm2. Shear tests give values of ϕ for standstone as 40° to 49° and cohension (c) values as 0.3 to 2.8 kg/cm^2. These values for siltstone are 39° and 0.7 kg/cm^2 respectively while for shale ϕ ranges from 40° to 58.6° and c lies between 1.8 and 3.14 kg/cm^2.

v. The project area lies in the foot hill seismic domain of ' seismotectonic zones of Himalaya' and has been knwon to be relatively free from seismic activity as compared to the 'main Himalayan Seismic Zone' which lies to the immediate north of it. The latter zone has been the centre of main seismic activity in this region. Isoseismals of V and VI of Uttarkashi earthquake (1991) cover the project site. The Main Boundary Fault passes to north of the dam site, crosses the reservoir nearly 3.3 km upstream. Further east it crosses Lugar Gad and goes out of the area. This fault at Lugar gad has been considered to be active in recent times. This surmise is based on scarp faces of the recent river deposits seen in Lugar gad valley. It is likely that these deposits were actually a result of a cloud burst which brought huge material from the northern hills consisting of highly fractured and sheared Amritpur granite and deposited them on river bed. Unfavourable hydrological regime of the river system could not wash them off. Similar deposits have been recently made near Barajahale, downstream of the dam site,in 1993. However, a wide nala and Gola valley facilitated their quick dispersal. Apprehension of reservoir induced seismicity (RIS) are ruled out due to the fact that project area falls in a thrust fault regime, plastic nature of the Siwaliks and low height of water column on Amritpur granite area. Fault zone material of Main Boundary Fault is not likely to facilitiate downward percolation of reservoir water.

vi. The rocks are prone to differential settlement and adequate design measure will have to be taken to check it.

vii. In so far as reservoir competency is concerned the apprehension that the Main Boundary Fault may provide a channel for see page cannot be abviated even though, it is felt that fault material will generally inhibit any such tendency therefore, exploration has been recommended to determine permeability characteristics of the fault materials. In spite of the above apprehension the reservoir rim is being presumed as tight because of the likely characteristics of the fault material. Out of the three major slides in the reservoir area, only one i.e., Markudia slide, is likely to pose some problem.

viii. Only 17 lac M^3 construction material is available against the requirement of total 20 lac M^3 within an area of 3.5 km upstream and 3 km downstream of the dam axis. New areas will have to be searched for getting the remaining material.

I. INTRODUCTION

Advent of planned growth has opened up new vistas of economic activities in different parts of our country. The foot hill region in Nainital district has been no exception to this and has witnessed tremendous growth in agricultural and industrial activities since independence. The small townships of yester years, in the region, which have grown in size and population of today are putting severe pressure on local natural resources, resulting in increasing demand for amenities which the pre-existing setup is not able to cope up with, leading to a perpetual deepening crisis in terms of civic activities of which a major factor is water availability. The townships of Kathgodam, Haldwani, Lalkuan etc. in the foot hills face such a dilemma with water scarcity assuming unmanageable proportions, especially during the lean summer months. Local ground water resources are too meagre, if not erratic, to meet the local requirements even for drinking purposes let alone for agricultural or industrial activities. Therefore it was decided to utilise, for these purposes, the immense rain water potential of the region which other-wise goes waste. A scheme has been devised to store such water in the Gola gorge and distribute it through canals. This scheme proposes the construction of a 130 m high R.C.C. dam across Gola river, near Jamrani village, to store 208.6 M. cum of water and a pickup weir called Kathgodam barrage located upstream of Kathgodam. It is from this barrage that water is preposed to be diverted for its intended usage. A 15 MW. hydel component is also proposed at the toe of the main dam using available water head.

A number of officers of Engineering Geology Division Geological Survey of India, Northern Region, have been associated with the geological investigation of the scheme since its inception in the year 1968. Numerous proposals, put forward from time to time by the Irrigation Department, Uttar Pradesh, have been briefly discussed in a relevant chapter of this report.

This write-up condenses the detailed information contained in the progress reports of Sri A.K. Srivastava, B.M. Hukku, C.L. Arora, H.M. Dayal, G.N. Jaitly, M.S. Jain, N.K. Mandwal, R. Anablagan, R.P. Tripathi, R.K. Sanwal, R.V. Iyer, Sushil Kumar, V.K. Sharma, V.S. Krishnaswamy and Y.C. Joshi and these are given in Bibliography for an synoptic over-view.

The author is indebted to Shri. A.N. Agarwal, Director (Retd). Engineering Geology Project-II, Operation Uttar Pradesh, Geological Survey of India for a critical examination of the write-up and invaluable suggestions he made during the progress of the work. He is also indebted to Shri V.K. Agarwal, Director, for having edited the manuscript.

II. PROPOSALS, LAYOUT AND SALIENT FEATURES

Exercises for selecting suitable site for a dam to harness the monsoon water of the Gola basin began in 1968, when relatively smaller height dams were taken up for feasibility studies (Plate-1). These were i) 61.7m high dam across Bhimtal Gadhera near Dunghsil village, ii) Ranibagh site and, iii) Amiyan site. The latter two were across the Gola river. Hukku and Srivastava (1968) found that these sites were geologically infeasible and recommended exploration and search for still better sites thus i) Jamrani site and ii) Bhuria site were added to the list. Investigations at these sites were thus started to establish geological feasibility during 1972-73, extensive investigations were carried out by Dayal (1973) and Dayal and Mandwal (1973). The Ranibagh site was found infeasible owing to high overburden thickness determined by the geophysical surveys (Arora et. al (1973) and Tripathi et.al 1980). Similarly, Bhuria dam site located at the eastern most extremity was also found to be infeasible owing to high bedrock depth ranging between 5 to 35 m. Therefore, the final choice fell on Jamrani site and investigations were taken up. Since 1972, both engineering as well as geological investigations have been concentrated on Jamrani site.

The Jamrani site is located nearly 10 km from Kathgodam. Initially, the proposed height of the dam was to be 152.4 m which was subsequently brought down to 130 m. All the preliminary as well as pre-construction stage geological investigations were conducted along the propose straight N2°E-S2° W tending axis. However, the 1990 (Memorandum No. J-1), it was revised and a curved axis (Palte-III) was finalised. This curvature was necessitated to avoid deep cutting of rocks, for spillway stilling basin, which was falling towards the left abutment when aligned normal to the initially proposed straight axis.

Selection of the type of dam at Jamrani, too has had a chequered history. As many as five, alternatives have been considered and discussed at various levels:

i) Rock fill dam with upstream concrete membrane.

ii) Rock fill dam with clay core.

iii) Hollow concrete gravity dam.

iv) Solid concrete gravity dam.

v) Roller compacted concrete dam.

The last mentioned type was finally chosen for the Jamrani site for reasons beyond the scope of this write-up. However, an interested reader can get the details in various memoranda issued by the project authorities.

Salient features of the project:

The rain-fed Gola river basin forms an important water regime in the south-eastern parts of Himalaya where it originates. At the proposed dam site, a catchment area of 450 sq. km. is lileky to be intercepted and 145 M cum. of live storage created. A network of numerous feeder canals starting from both the flanks of the Kathgodam barrage, will be utilised for taking the impounded waters to the fields situated on the southerly sloping flat grounds of Bhabhar and Terai belts of Nainital, Rampur and Bareilly district besides meeting the drinking water requirements of Haldwani, Kathgodam and surrounding rural areas. The important details of the scheme are as under:

I. Stream flow:

a)	Total drainage area	450 km^2
b)	Normal Annual rainfall in the catchment	2630 mm
c)	Design flood discharge	4200 cumec
d)	Routed design flood discharge	3630 cumec
e)	Maximum recorded flood	1895 cumec
f)	Average annual run -off	682 x 10^6 cumce
g)	Maximum annual run-off	1779 x 10^6 cumec
h)	Minimum annual run-off	220 x 10^6 cumec
i)	Capacity at full reservoir level RL 762.0 m	208 x 10^6 cum
j)	Capacity at dead storage level at RL 717m	64.3 x 10^6 cum
k)	Total live storage	144.3 x 10^6 cum

II. Levels

River bed level at dam site	635.0 m
Dead storage	717.0 m
Full reservoir level	762.0 m
Maximum reservoir level during design flood	763.6 m
Tail water level	
i) Minimum	632.0 m

ii)	Maximum (Routed discharge of 3630 cumec)	643.0 m
III.	**Structural details:**	
A.	**Dam:**	
a)	Type	Roller compacted concrete gravity dam
b)	Height above river bed	130 m
c)	Top level	765 m
d)	Length at top	480 m
B.	**Spillway:**	
a)	Type of spillway	Ogee spillway
b)	Waterway	4 bays of 13.25 m each
c)	Crest level	750 m
d)	Flip bucket	
	i) Lip elevation	643 m
	ii) Lip angle	30°
	iii) Radius	94 m
e)	Capacity at maximum reservoir level	3630 cumec
f)	Control equipment	Radial gate
g)	Size of gate	13.25 m x ~~23.5~~m. 13.5 m

III. REGIONAL GEOLOGY

A. Physiography and drainage

The proposed project area is located very close to the line separating two highly distinct physiographic units i.e. the frontal mountain ranges of the lesser Himalaya and the southerly sloping Bhabhar belt. The dam is located on the frontal mountain ranges while the Bhabhar belt, in the south, is a southerly sloping flat country, supporting growing townships of Kathgodam, Haldwani, Lalkuan etc. The northern mountain area is highly dissected with deep, narrow gorges with steep mountain as well as river bed slopes. Numerous *nalas* also drain this area. The *Gola river*, which origiants in the higher reaches of the Lesser Himalaya, further north, constitutes an important river basin system of this south-eastern part of Kumaon. Form the slopes of Motiya Pathar, the river flows in a general southerly direction, following a very sinuous course, to Khansun where it takes a westerly turn. At its junction with one of its major tributary *Kalsa Nadi*, it turns south again. This course is followed till it is joined by the westerly flowing *Lugar Gad*, another important tributary. Here it takes a U-bend and flows in a general north-westerly direction along a highly sinuous course. South-east of Amritpur, the river takes a southerly turn and continues to flow amid the hills for nearly 2 km before debauching into the fan belt of the Bhabhar region. At the project site, the river has cut a deep and narrow gorge (400± high from river bed) and flows westerly. Apart from the above mentioned tributaries, *Surgara nala, Ghat Gad* are other important tributaries draining the Gola basin. Innumerable small nalas with steep bed slopes are scattered throughout the area either joining Gola river or any of its major tributaries. The river bed slope varies from 14m/km at the proposed dam site, to 23m/km in the upper reaches, and the relief varies from 635 m to 2296 m.

The Gola river basin is rain-fed hence the discharge is very high during monsoons decreasing progressively till it becomes meagre (1.08 cumec) during summers. This meagre flow is not enough even to meet the existing demand of drinking water of the rural and urban population of the area.

B. Geological framework:

The project area, being located in the Himalayan region, is obviously influenced by a complex regional geological and structural setup. It is, therefore, necessary to recount briefly the regional aspect.

The Geological Survey of India has published a special volume No. 26(6) (1989) which contains the essence of the efforts put in by the officers of the survey in the past five decades or so. The regional geological sequence shown below has been broadly adopted from the chapter entitled "Stratigraphy and Sedmentation in Himalaya: A Reappraisal by Ravi Shanker et al. (1989). Geological map compiled by him (Plate-II op.cit) has following major litho-stratigraphic units in the Kumaon Himalayan.

RECENT	Lesser Himalaya	Higher Himalaya
	------------River Terraces/Alluvium-----------	
Neogene	Siwalik Group	—
Cretaceous-Palaeocene	Shell limestone	Balchal Dhura Volcanic/ Chikkim Formation
Cretaceous	—	Giumal Sandstone
Jurassic-Createceous	—	Spiti shale
Permian	—	Laptal Formation, Kioto Formation, Kuti Formation, Kalapani Limestone, Chocolate Formation, Kuling shale
Carb-Permian	Bijni Formation	—
Up Camb.-Lr. Carb.	—	Kali Formation, Muth Formation, Variegated Formation, Shiala Formation, Garbyang Formation, Ralam Formation
Proterozoic-Up. Camb.	Tal Formation Krol Formation Infra-Krol Formation Blaini Formation	Martoli Formation(?)
Proterozonic III (200-670 My)	Morar-Chakrata Formation Betalgaht Formation Biyali Formation	Amri Bijni Benali Setangal Formation — Martoli Formation
Proterozoic-II (1600-900 My)	Berinag Formation Tejam Formation Routgara Formation Bhimtal Formation	—
	-----------------------------Base not exposed-------------------------	
Proterozoic-I (2500-1600 My)	Almora Crystalline Askot, Baijnath Crystalline Ramgarh Formation	Central Crystalline
Archaean	------------Not yet recognised/absent------------------	

C. Structural framework

The above is a chronologically arranged sequence of sedimentation in the Kumaon-Garhwal region. However, tectonism, that the Himalaya has undergone, has cast its own imprint on the sequence. So, it is also necessary that regional features of tectonism be briefly outlined here. This aspect has been dealt with extensively by Gopendra Kumar et.al. in their paper entitled "Structure and Tectonics of the Himalaya" in same volume (opGSI Spl. Pub. No. 26). They have divided Himalaya in four major tectonic belts, each belt being bounded by prominent dislocation zone. These belts trend in nearly east-west direction. From south to north they are designated as follows:

North

Karakoram Belt

----------------------Shyok Suture----------------------

Indus-Shyok Belt and Lohit Complex Belt

Indus Tsangpo/Tidding Suture

Main Himalayan Belt

----------------Main Boundary Fault------------------

Frontal Fold Belt

South

Only the last two belts are important from project point of view. Therefore, a brief account of these two is being given.

The Frontal Fold Belt, in which the project is located, is bounded on south by the north dipping foothill fault (MBF-3) and the Main Boundary Fault (MBF-1) and it includes Tertiary rocks (Siwalik Group in the project area) and recent sediments. Another fault (MBF-2) has also been delineated within this belt. It has however, not been as yet possible to identify MBF-2 in the project area. In all likelihood it is absent in the area. The rocks in this belt are tightly folded.

The second belt, Main Himalayan Belt, is bounded by Main Boundary Fault (MBF-1) to its south and Indus Suture to its north. It comprises rocks ranging in age from Proterozoic to Quaternary. The Main Himalayan Belt itself contains a number of thrusts and one such major thrust called Main Central Thrust (MCT) separates high grade metamorphic rocks from low grade rocks, the Garhwal Group of rocks. South of the MCT, within the belt, the Garhwal Group of rocks are separated from Almora Crystalline rocks by a south dipping thrust called the North Almora thrust (NAT). Regional correlation has established that NAT is extension of MCT only. Likewise another thrust, called the South Almora thrust (SAT) separates Almora Crystallines from Ramgarh Formation.

A broad regional tectono-stratigraphic sequence, from south to north, thus can be built-up for the project area combining the above two discussions. It is :

North

Central Crystaline Rocks

---------------------------------------Main Central Thrust

Garhwal Groups of Rocks

---------------------------------------North Almora Thrust

Almora Crystalline Rocks

---------------------------------------South Almora Thrust

Ramgarh Formation

-----------------Main Boundary Fault/Thrust (MBF-1)

Siwalik Group of Rocks (Project is located in this group)

---------------------------------Main Boundary Fault-3 (MBF-3) (Foot hill fault)

Alluvium

South

IV. GEOLOGY OF DAMSITE

The dam site is located in a deep gorge carved out by the Gola river. The river flows in a nearly westerly direction at this site. The ridges on the either flanks of the river comprise sedimentry sequence of the Lower Siwalik Group of rocks belonging to Neogene era. The sequence, is broadly made up of alternating bands of sandstone, siltstone and clayshale (claystone). Of these sandstone has fairly large thickness while the other two are, in general, thin as well as impersistent in their dipwise and strikewise continuity. Detailed geological mapping of the dam site area was initially conducted by Dayal (1978) and subsequently by Anabalgan (1987 & 1988). The mapping included an area lying between 400m upstream and 450m downstream of the dam axis on the river bed and from river bed (elevation 635.0±m) to elevation to 810 ± m on the left abutment and up to elevation 830± m on the right abutment (Plate-III). Rock exposures are abundantly present on the right abutment, while the left abutment is found to be mostly covered with slope debris supporting fairly thick vegetation. The slopes of either abutment also present a contrasting picture at the site. While the right abutment is steeper with slope angles ranging from 50° to 60°, the left abutment is much gentler with slope angles from 40° to 45°.

Among the Lower Siwalik rocks occurring in the dam site area, sandstones are predominant and comprise the maximum thickness as compared to siltstones and shale bands. The sandstones, at the dam site, are grey and brown coloured, fine to coarse grained and at places micaceous in nature. They, in some sections, become friable possibly due to poor cementation or compaction. Clay shale (claystone) is grey, brown and purple in colour and displays shrinkage cracks. In some contact zones, between clay shale and sandstone, thin (10 to 15 cm) shearing is observed. Siltstones are dark grey, moderately hard and well cemented.

Strike of the rocks is, in general, NW-SE with the amount of dip ranging between 30° and 50° in the north-east direction i.e. towards the right abutment and upstream. No marked variation in the disposition of bands, exposed on the abutments, is observed. This has been verified by Anabalgan (1988) by drawing trace of the clay shale bands exposed on the right and left abutments. Thus, any major dislocation along the Gola river has been ruled out. Though a major regional tectonic element passes close by through the right abutment in the dam site area, yet the foundation rock exposed on either abutment do not show any marked impact. No significant shearing or shattering of rocks is observed, nor any tilting or dragging of beds is observed anywhere. Inversion of dips is altogether lacking.

A detailed study was undertaken by Anabalgan (1988) to evaluate pattern of joints and their consequent influence on the geomorphology as also on excavation at the time of construction. He examined nearly 400 joints discontinuties, and the following pattern (Table-I) emerged, in order of preponderance.

Table - I : Details of Joints at Dam Site Area

Disconti-nuity	Maximum of pole con-centration	Strike	Dip direction
Bedding	15%	N50°W-S50°E	47° due N40°E, i.e. upstream
Joint J-1	10%	N39°E-S39°W	68° due N51°W, i.e. downstream
Joint J-2	10%	N60°E-S60°W	60° due N30° W, i.e. downstream
Joint J-3	3-5%	N70°W-S70°E	57° due S20° W, i.e. towards left bank
Joint J-4	3%	N80° E-S80° W	57° due S10°E, i.e. towards let abutment

This study establishes that the bedding joint is the most common joint in the dam site area. Its upstream disposition indicates that it will not favour seepage, instead the clayshale beds occupying this attitude will check the seepage through the foundation.

V. SUB-SURFACE EXPLORATIONS

Surface exploration of the dam site as described in the previous chapter did not provide information about all the inputs required for preparing a safe and economical design of the dam. Thickness and nature of overburden in the river bed as also on the abutments, nature of bed rock, its permeability characteristics, depth of weathering, depth of stripping, depth of sound rock, presence and location of any weak zone etc. are the major geological parameters required to be known beforehand. These information are normally obtained by drilling holes and exploratory drifts. Therefore, a well planned sub-surface exploration is considered essential for any project

Some sub-surface exploration of the dam site was conducted during the preliminary stage investigations when the geological feasibility of the dam site was examined between 1972 and 1980 by Dayal (1973, 1974, 1975 & 1978). During this period, nearly 20 boreholes were drilled in the dam site area. These holes are located on the dam axis and at the sites proposed for the appurtenant structures. With the finalisation of dam axis at Jamrani village, work on other sites was stopped. The pre-construction stage investigations can be said to have begun in 1980. Between 1980 and 1987, sub-surface exploration did not pick up momentum and only 7 holes were drilled and geologically logged. In 1987, a review of the pre-construction stage investigations was done. Anabalgan (1988) submitted a detailed geological note on the status of geological studies at the Jamrani dam site. He considered the sub-surface exploration carried out, so far, to be inadequate, and accordingly a detailed sub-surface exploration programme was suggested for better evaluation of the foundation conditions prevailing at the dam site. The programme categorised holes as A, B and C as per their priority. 'A'; holes were designated as axis holes, 'B' holes were within the dam body on either side of the axis and 'C' holes were beyond the dam body. A total of 44 drillholes were suggested and drilled. Similarly four new drifts, two on each abutment were also recommended in addition to the four already excavated. Pace was thus set for an extensive pre-construction stage explorations which involved nearly 45 new holes and 4 drifts (Plate -IV).

The suggested pre-construction stage exploration programme began in the year 1988 and was nearly completed by 1993. The cores and drifts were logged by Sharma (1990, 1991, 1992), and Sushil Kumar and Joshi (1994). Geological logs of holes drilled between 1980 and 1988 are contained in the reports by Iyer et al. (1984) and Anabalgan (1987, 1988).

This exhaustive programme resulted in drilling and logging of a cumulative length of 3407.16 m of croes. Similarly, 277.5 m of drift length was 3-dimensionally and geologically, logged.

The Geological Survey of India had also recommended, in 1991, excavation of cross drifts at the end of drifts No. DL-3, DL-4 and DR-3, DR-4. This was done basically to know geologcial conditions from heel to toe. The project authorities had commenced excavation of cross drifts by the time matter came for review in 1994. After discussion, excavations of cross drifts DR-3 and DL-3, where it had already begun, were modified. The cross drift at DR-3 was suggested in place of the downstream portion of DR-3, DL-3 had nearly been excavated. Excavation of cross drift at DL-4 was axed and a new drift, for 25m, length, was instead recommended. Besides, DR-4 which had been excavated up to 17m length was recommended to be extended up to 40 m length initially.

Details of the locations of the boreholes and drifts are given in Plate-IV. Due to exhaustive nature of the exploration, it is not possible to give the borehole logs and drift logs in detail, Instead, only summarised, but complete, logs are provided in Appendix-II. Reference can be made to the progress reports referred to above for run-wise details of borehole logs.

A DRIFTS

A total of eight exploratory drifts have been excavated along the dam axis. These are of 1.8 m x 2m size and range in length from 17 m to 40 m and have been three dimensionally geologically logged on 1: 100 scale. The drifts DR-1, DR-3 and DL-3 have been utilised for in situ determination of deformation and shear characteristcs of the foundation rocks. A brief description of each drift is given below.

Drifts on right abutment

DR-1 : This drift is located at elevation 692.20 m and has been excavated in the N5°E direction. Its length is 40 m. It essentially lies in fine to medium grained sandstone with bands of clayshale and siltstone. The general strike of rocks is N35°W-S35°E with 35°-40° northeasterly dips. The following sets of joints were observed:

Sl.No.	Dip amount	Direction	Remarks
1.	50°-60°	S5°-20°W	Clay filled
2.	45°	S50°E	
3.	45°	S30°E	
4.	75°	N80°W	
5.	60°	S70°W	
6.	60°	S10°-30°E	
7.	60°-70°	N40°-55°W	

Open joints are observed up to 25 m length and weathering is noticed up to 15 m.

DR-2 : It is located at elevation 761.5m and excavated in N12° direction for a length of 35m. Fine to medium grained sandstone with bands of clayshale/siltstone comprise the rock in the drift. Strike of the rocks is N30° to 37°W-S30° to 37°E, with 35° to 40° dips. Open joints are observed up to 24 m and weathering up to 18 m. Important joints are :

Sl.No.	Dip amount	Direction	Remarks
1.	70°-80°	S20°-30°E	Clay filled
2.	40°	S65°	
3.	40°-60°	N40°-50°E	
4.	35°	N70°W	
5.	80°	N60°W	
6.	75°	N25°W	

DR-3 : It is located at elevation 645.0 m and excavated up to 40 m in length in N5°W direction. Rock in the drift consists of coarse grained, pebbly, poorly cemented, friable sandstone/sand rock and fine to medium grained, compact and competent sandstone with coal strigners. General strike of rock is N35°W-S35°E with 37° north easterly open joints have been observed up to 22 m and weathering for 10 m length.

DR-4 : It is located at elevation 713.0 m on the dam axis and excavated for 17m in north direction. Fine to medium grained sandstone with bands of clay shale comprise the rock in the drift. General stike is N20° to 30° W-S20° to 30°E with north easterly dip. Open joints were seen up to 12 m till the time the drift was logged. Authorities have been advised to complete the excavation upto 40 m length.

Drifts on left abutment

DL-1: This is located at elevation 689.12 m and excavated for 33.5 m in S10° E direction. Medium grained sandstone trending in N35° to 45° W-S35° to 45° E direction with 30° to 40° north easterly dips comprises the rock in the drift. Slumping is observed up to 24.5 m and weathering up to 17m. Important joints dip at i) 55° in N35°-40° W directions, ii) 75° in N30° W direction, iii) 23° in

N-75° E and iv) 40°-S50°-60° W directions.

DL-2 : It is located about 25 m downstream of the dam axis at elevation 781 m and excavated in S20° W direction for 17 m and then up to 32 m in the S50° W direction. Hard, fine to medium grained sandstone with clayshale/siltstone bands comprise the rock in the drift. Strike of the rock is N40° W-S40°E with 40° to 45° north easterly dips. Slumping is observed up to 28.0 m.

DL-3 : It is located at elevation 645 m and excavateed up to 6 m in S11° E direction and upto 4.0 m in S2°E direction. Fine to medium grained sandstone with (plastic) clayshale at RDs 13.0 m to 26.2 m and 37.3 m to 40.0 m comprise the rock in the drift. General strike of the rock is N20° to 30°W-S20° to 30°E with 40° narth easterly dip. Slumping is observed up to 32.8m. Water dripping has been observed in the entire drift especially along the clayshale and sandstone contact. A flow of 2.0 lit/min water has been noted along a N50°W-S50°E trending joint which dips in N40° E direction at 60° at RD 33m.

DL-4 : It is located at elevation 721 m and has been excavated along a very sinuous axis for unknown reasons. The fine to medium grained sandstone with shale bands comprises the rock in the drift. A thin shear zone with clay gouge (2 cm) has been observed at RD 21.9m. Weathering is observed up to 18.0 m.

B. CROSS DRIFT

At DL-3

A cross drift has been excavated with its heading at 40 m from the origin in a direction normal to the axis of DL-3 towards toe side for 19.5 m length at elevation 645m. Fine to medium grained sandstone with shale constitutes the rock type in the cross drift. Two shear zones with clay gouge varying in thickness from 5 cm to 20 cm have been recorded at distances 1 m and 6.6 m. Heavy water seepage is noted at the former zone while only oozing of water is seen at the latter. The strike of the beds varies from N20° to 80° W-S20° to 80° W with 44° to 60° northeasterly dips.

VI. RESULTS OF EXPLORATION

Geology from sub-surface exploration

Drilling : In all, 44 holes have been drilled. These holes have revealed that the bedrock lies buried under varying thicknesses of overburden or slope scree. Thickness of the slope scree varies from 1.5 m to 13 m and from 0.6 m to 6 m on left and right abutments respectively, while the overburden thickness ranges between 7 m and 27 in the river bed portion. Slope scree comprises pieces of sandstone, siltstones/clayshale with silt and clay while river overburden consists of boulders cobbles, pebbles of crystalline and sedimentary rock admixed with silt and clay.

Under this cover, the bedrock, comprising alternating sequence of sandstone, siltstone and clayshale with 35° to 55° dips occur. Rocks are intersected by inclined joints. The sandstones are fine to coarse grained, compact and hard to very soft, even becoming friable. The core recovery is generally very good ranging up to 100%. Siltstones are very hard where core recovery is good to very good. Shales are soft with generally poor core recovery though full recovery is also observed. Modified core recovery (MCR) of sandstones is, in general, very good being in the range of 70% to

100%, but sections of poor MCR values have also been observed, MCR of siltstone and shale is poor to good as these rocks tend to disintegrate into pieces once exposed to air/water.

Drift : Eight dirfts, 4 on each abutment, have revealed details as taublated below : (Table -II)

Table - II : Summarised Geological details of the drifts

Drift Sl.	Rock type	Slumping/ sripping detph
DR-1	Fine to medium grained sandstone	25 m
DR-2	Fine to medium grained sandstone	24 m
DR-3	Coarse to fine grained sandstone	22 m
DR-4	Fine to medium grained sandstone; excavated up to 17 m only against recommended 40 m.	-
DL-1	Medium grained sandstone	24.5 m
DL-2	Medium grained sandstone	28.0 m
DL-3	Fine to medium grained with clayshale; seepage observed along contact	32.8 m
DL-4	Fine to medium grained sandstone	18.0 m

Bedrock configuration

The Gola river at the Jamrani dam site has cut a deep narrow gorge. the river portion measuring a width of 75m is completely covered with the river borne overburden comprising rock pieces, varying in size from boulder to pebble, mixed with silt and clay. No exposure of in-situ rock is seen from downstream to upstream in the dam body area, therefore, to delinate the depth of bedrock at different places in the dam body a bedrock contour plan has been prepared with the help of data obtained from 21 boreholes drilled in the river portion (Plate -IV). Perusal of this contour plan revales that the bedrock topography in the dam base area is undulatory in nature. River bed has been incised by a narrow channel in the middle of the river section. This channel appears to be following the general strike direction. The bedrock levels in this channel range between El. 614 m and El. 615 m. 25m on either side of the axis. Beyond this distance, on downstream side, levels rise to El. 617 m while those on the upstream side fall; and about 15m further upstream of the proposed 'heel' of dam El. 611 m is recorded, which is the deepest recorded by drilling. However, it is certain that the elevation of bedrock continues to fall further eastward thus forming a plunge pool.

Permeability of foundation rocks

Cyclic water percolation tests have been conducted in all the boreholes as per the B.I.S. specifications. The results are shown in the log sheets of holes attached with the concerned progress reports. In this paragraph, these results are briefly summarised to give an over all picture of the permeability of the foundation media. Since there is a wide scatter of the boreholes at the dam site area, Sharma (19991, 1992) after analysing the permeability results concluded that-

1. In general, the permeability values vary from 1 lugeon to 39 lugeons on the left abutment, from 0.2 lugeon to as much as 56 lugeons on the right abutment and from 0.2 lugeon to 38 lugeons for the river bed portion.

2. The permeability values decrease below 30 m depth.

It may be pointed out here the higher values are restricted to few sections only. Sushil Kumar and Joshi (1994), analysing the data of three holes, came to conclusion that irrespective of rock type the permeability values ranged between 2 lugeones to 6 lugeons, through higher peak values like 30 lugeons were also recorded in few section. Graphic plot of permeability values against depth (Plate-V) shows that sandstones display maximum variation from 2 to 6 lugeons Higher values of 6 lugeons are seen in sections where sandstone is soft to friable in nature. Siltstone and shales show permeability values up to 4 lugeons.

Test Grout

Test grouting has been carried out by the project authorities to determine efficacy of consolidation and curtain grouting of the foundation rocks. This exercise begain in 1985-86 when Anabalgan (1987) studied the problem. Subsequently Sharma (1991, 1992) and Sushil Kumar and Joshi (1994) also studied the results of the test grouting. The test grouting has been done at the following places:

1. Test platform located on the right bank about 35 m upstream of the dam axis (Anabalgan).
2. Test platform located 10 m downstream of the dam axis on the right bank at elevation 63.59 m (Sharma)
3. Test platform located downstream of the dam axis on the left bank at elevation 660m (Sushil Kumar and Joshi).

The procedure and results are not being discussed here. The conclusions arrived at after analysis of the test data are:

i. The foundation rocks are amenable to grouting and a grout curtain can be effectively emplaced to check seepage.

ii. Sandstones show an extremely variable and erratic behaviour. Some sections do not show any improvement upon grouting while in others improvement ranges between 20% to 80%,

iii. Shales have rather poor degree of grouting efficacy (33%), but, then, in the case of shales it is known that they have poor grout acceptability.

iv. Siltstones exhibit highest degree of grout acceptibility which ranges from 60% to 75%,

v. The poor results shown by sandstone may be attributed to thick mix used (1:6 to 1:10) for grouting. Spacing may also be a significant reason, and

vi. Efficacy of consolidation grouting cannot be checked by performing water tests. Thus, the project authorities were advised to perform pre- and post-grouting load bearing tests.

Engineering properties of foundation rocks

Extensive laboratory and in-situ tests have been conducted by organisations like Geological Survey of India, C.S.M.R.S., New Delhi and I.R.I., Roorkee to determine physical, deformational and shear characteristics of the foundation rocks of Jamrani dam. In-situ tests performed to determine deformation characteristics are plate loading tests, Flat Jack tests and Goodman Jack tests. These tests have mainly been done in open and in drifts. The results of these tests have been tabulated below: (Table III & IV).

Table - III : Result of Tests done on the right bank of the river.

Type of test	Location	Deformation Value		Remarks
		Ed kg/cm^2 x 10^5	Ee kg/cm^2 x 10^5	
Cyclic Plate Load Test	**Rock Sandstone**			
	Sandstone band B-River bank	0.007	0.007	Average of three cycles
	Band-C River bank	0.034	0.203	Average of three cycles
	Band-E River bank	0.067	0.19	Average of three cycles
	30.6 m in DR-1	0.040	0.117	Average of four cycles
	32.85 m in DR-1	0.065	0.260	Average of four cycles
	37.5 m in DR-1	0.031	0.432	Average of three cycles
	32.35 m in DR-1	0.197	0.421	Average of four cycles
	Clay Stone			
	Band-A River bank	0.008	0.056	Average of four cycles
	19.5 m in DR-1	0.036	0.102	Average of four cycles
	23.15 m in DR-2	0.200	0.492	Average of three cycles
	24.65 m in DR-1	0.044	0.0167	Average of four cycles
	20.0 m in DR-1	0.123	0.173	Average of four cycels
	27.2 m in DR-1	0.35	0.158	Average of four cycles
	Band-F River bank	0.097	0.386	Average of four cycles
	Siltstone			
	Band-D River bank	0.02	0.154	Average of three cycles

Reference : Iyer et al (1984)

Perusal of this table shows that values of modulus of deformation and elasticity of the foundation rocks vary considerably in the test performed during 1980. They are very low as well. The average values of deformation modules of sandstone, on the river bed side range from 0.007 x 10^5 kg/cm^2 to 0.067 x 10^5 kg/cm^2 to 0.097 x 10^5 kg/cm^2. Whereas, within the drift DR-1, values of deformation modulus of sandstone range between 0.031 x 10^5 kg/cm^2 to 0.197 x 10^5 kg/cm^2 and those of claystone show a variation between 0.044 x 10^5 kg/cm^2 and 0.20 x 10^5 kg/cm^2. Physical meaning of this variation is simply that the on-river bed-tests were probably conducted on weathered samples or ill-prepared samples.

However, the plate jacking tests performed by the CSMRS in drifts DR-1, DR-3 and DL-3 during 1990 brought out a strikingly different picture. The table here gives only concise information. Details are available in their reports. The value of deformation modulus is very high as compared to that obtained by cyclic plate loading tests. The average of the deformation modulus for sandstone varies from 0.4670 x 10^5 kg/cm^2 to 0.537 x 10^{5}kg/

Table - IV : Results of Tests done in the drifts DR-3 and DR-1

	Pressure kg/cm^2	Ed kg/cm^2 x 10^5	Ee kg/cm^2 x 10^5
Sandstone bands	24	0.4670	0.5145
in DR-3 and DR-1	36	0.4854	0.5345
	48	0.5083	0.5486
	60	0.5371	0.5930
Siltstone bands	24	0.4049	0.4054
in DR-3 and DR-1	36	0.4190	0.4906
	48	0.4412	0.4990
	60	0.4558	0.5086
Shale in DR-1	24	0.3682	0.5155
	36	0.4833	0.6443
	48	0.5728	0.7364
Clay shale in DL-3		0.086	0.173

Reference CSMRS Report No. 11/11/92, August 1992

cm^2. For siltstone, it range from 0.4049 x 10^5 kg/cm^2 to 0.4558 x 10^5 kg/cm^2. It will be noted here that there is not very large difference in the values for sandstone and siltstone. The modulus value for shale ranges from 0.3682 x 10^5kg/cm^2 to 0.5728 x 10^5kg/cm^2.

CSMRS has also conducted Goodman jack test in borehole Nos. 27, 1, B and C and concluded that the values of modulus of deformation vary from 0.044 to 0.058 x 10^5 kg/cm^2 at a stress level of 45-55 kg/cm^2 with an average value of 0.05 x 10^5 kg/cm^2.

Numerous in-situ shear tests have been performed by CSMRS, New Delhi and I.R.I., Roorkee on the foundation rocks themselves and their contact with concrete. The results of these tests are tabulated below (Table V).

Physical characteristics

The physical parameters of the foundation rocks have been determined in the laboratory of Geological Survey of India from time to time. Parameters determined are unconfined compressive strength (wet and dry), density, water absorption, porosity. Some of the results are shown in the Appendix-I. Perusal of the results brings forth the characteristic relationship between the physical condition of rock and the strength it has. The sandstones reveal a wide range of variation in their characters. Their density varies from 2.32 to 2.68 gm/cc while the water absorption ranges between 1.11 to 4.35%. The unconfined compressive strength (UCS) shows a variation between 68 kg/cm^2 and 532 kg/cm^2, in dry state. The UCS values in the wet condition will be further lower as is shown in some cases. The lower values of 68 kg/cm^2 is shown by friable sandstone while the higher value of 532 kg/cm^2, is given by fine grained compact sandstone. Micaceous sandstone shows low UCS value of 130 kg/cm^2 and a high water absorption of 4.35%. The breccia like sandstone (Pebbly sandstone) gives a value of 141 to 255 kg/cm^2 (dry). Tendency of disintegration has been observed in

Table - V : Results of the shear Tests done in drifts and on the left Bank of river

Sl. No.	Location	Rock Type	Normal stress level	Shear parameters
1.	DR-2	Siltstone (24 hr. saturation)	11.14 kg/cm^2	C=0.7 kg/cm^2, ϕ = 39^0
2.	DR-2	Sandstone (24 hr. saturation)	2.1 kg/cm^2	C=0.8 kg/cm^2, ϕ = 67^0
3.	DR-1	Clay stone (24 hr. saturation)	10.54 kg/cm^2	C=2 kg/cm^2, ϕ = 67^0
4.	DR-1	Clay stone (72 hr. saturation)	7.42 kg/cm^2	C=1.8 kg/cm^2, ϕ = O=41^0
5.	Testing on right bank RL 643.17 to 643.73 m	Sandstone	14.47 kg/cm^2	C=1.8 kg/cm^2, ϕ = 50^0
6.	Test pit on left bank at RL 640.30 to 651.9 m	Sandstone	15.8 kg/cm^2	C=6.3 kg/cm^2, ϕ = 40^0
7.	DR-3, 21 m to 28 m	Sandstone	-	C=-1.15 MPa, ϕ = 61.5°
8.	DR-1, 21 to 25.3	Clay stone	-	C=3.14 kg/cm^2, ϕ = 58.6°
9.	DR-1	Sandstone	-	C=0.3 kg/cm^2, ϕ = 69.40°
10.	DR-4	Siltstone	-	C=0.7 kg/cm^2, ϕ = 39°
11.	DR-4, 21.75 to 27.2 m	Sandstone	-	C=0.8 kg/cm^2, ϕ = 67°
12.	DR-1	Clay Stone	-	C=2 kg/cm^2, ϕ = 40°

Results from Serial No. 1 to 6 taken from Memorandum No. J-1, May, 1990; 7 from C.S.M.R.S. Report No. RM-11/2/93, September, 1993; 8-12 from Progress report Iyer et. al. (1984).

Test results from Serial No. 1 to 9 are rock to rock and 10 to 12 are concrete to rock.

some samples. The siltstone shows very distinct characteristics of disintegration upon being wetted for two or more days. The UCS values range between 198 kg/cm^2 and 403 kg/cm^2 (dry). The UCS values of shale samples could not be determined due to their soft nature. The implications of these tests on foundation are described in Chapter VIII.

VII. SEISMICITY AND NEOTECTONICS

Seismicity

The project area falls in the seismically active Himalayas. It is but natural that an exhaustive study be made to know the seismic behaviour of the area. In the past decade, the seismic behaviour of the Himalaya has been intensively studied leading to a greater articulation and understanding of its seismic nature. Unraveling of major lineaments and their seismic status have led to delineation of seismotectonic domains is the NW Himalaya.

Narula's map (1991) on seismotectonic domains of NW Himalaya shows five such domains. The whole of Kumaon region falls in two of the domains, viz. i) Main Himalayan seismic zone and ii) foot hill seismic zone. The first domain includes areas north of the Main Boundary Fault while the second domain includes the area between the Main Boundary Fault and Foot Hill Fault (also designated MBF-3). The project area falls in the second domain, regarding which Narula opines that it is "a zone of flexing of Indian crust giving rise to normal fault related sporadic seismic activity". The first

Table - VI : Earthquakes (M>6) falling within 200 km of Jamrani dam site.

Sl. No.	Date	Latitude in degree N	Longitude in degree E	Depth (km)	Magnitude (M)	Distance (km)
1.	26.5.1816	30.00	80.00	-	6.0	85
2.	16.6.1902	31.00	79.00	-	6.0	200
3.	13.6.1906	31.00	79.00	-	6.0	200
4.	26.61916	30.00	81.00	-	7.0	150
5.	27.7.1926	30.50	80.50	-	6.0	155
6.	0.4.6.1945	30.30	80.00	-	6.0	120
7.	28.12.1958	30.09	79.86	-	6.3	85
8.	31.12.1958	30.09	79.86	-	6.3	95
9.	27.6.1966	29.62	80.83	33	6.0	130
10.	27.6.1966	29.70	80.89	36	6.0	140
11.	28.12.1979	30.82	78.57	23	6.0	195
12.	29.7.1980	20.56	81.07	-	6.1	140
13.	20.20.1991	30.57	78.86	12	6.6	190

domain mentioned above is also highly significant from the angle of seismic activity. As we will know later in this chapter that it is the area where maximum activity has taken place in the last one hundred years or so. This domain contains different tectonic elements like MCT, NAT, SAT etc. detailed earlier. Strain is thought to be building up on these elements especially along M.C.T.

Sharma (1991) has prepared an exhaustive inventory of earthquake events that occurred in the area in the past 106 years or so and also those occurring within a radius of 200 km from the project area (Plate-VI). Perusal of this plate brings forth following points:

Up to a radius of 25 km from Jamrani site - No earthquake record.

Between 25 km-50 km distance - Only 3 epicenters

Between 50 km-75 km distance - Only 5 epicenters

Between 75 km-100 km distance - 16 epicenters

From the above, it is clear that the main area of activity has been in the main Himalayan seismic zone or the first domain, and these second domain has been free from any earthquake. The tectonic elements like MCT, NAT and SAT, occurring in the first domain have been shown to be seismically active.

The poject area falls within the isoseismal V of the Bajang-Dharachula earthquake (No. 12 of the above table) and between V and VI of Uttarkashi earthquake (No. 13).

Neotectonism

Extensive field investigations during the past two decades by the officers of Geological Survey of India and other organisations have resulted in the recognition of the phenomenon of neotectonism in Himalayan region. Evidences of movemnet involving recent sediments (overburden) have been found at a number of places. This phenomenon relates to activity that seems to be taking place even today along the major tectonic elements of Himalaya. Record of such an acivity was observed by Sharma and Tangri (in the chapter entitled "Neotectonic Activity in the Himalaya" by Narula et al. of Sp. Pub. No. 26 (1989) pp. 119) where fan deposits of *Lugar gad* have been dissected and southern block has risen changing the course of river from south to west. This activity is reported along the traces of Main Boundary Fault passing through *Lugar gad*. This evidence indicates that this tectonic element (MBF) is susceptible to movement. Anabalgan (1988) also studied this site and holds that the feature represents neotectonic activity of a local nature, extending over a short distance only. However, Pant (in Anabalgam 1988) has questioned the hypothesis and pointed to lack of any effect on the nearby rock exposure.

This question has to be restudied and examined. The contention of Sharma and Tangri, as reported by Narula et al., that this neotectonic activity changed the course of Gola river from south to west appears to be far-fetched.

Moreover, the large scale map of the reservoir area (Plate-VII) prepared by Sharma (1992) brings out the geological details very clearly. North of *Lugar gad,* hills comprise highly fractured and jointed, brittle rock of Amritpur granite. Sharma during his analysis of stability of reservoir rim, has recorded maximum number of debris cones resulting from washing away of materials of Amritpur granite. Further, hydrological regime of *Lugar gad* is very limited as compared to that of *Gola river*. The confluence of the two is in the west of the site where neotectonic activity has been reported. It is likely that due to a heavy torrent caused by a cloud burst, there was massive movement of rock material from rocks (Amritpur granites) north of Lugar which was blocked by high levels of water of *Gola river* further west. Thus, a huge debris cone formed which was subsequently cut by the nala waters to give the present shape. Such events have taken place in recent past also. In 1993, during heavy rains a huge amount of material was brought down into *Gola river* by *Barajhala nala* causing suspension of work. Since Gola valley is fairly wide here, material got dispersed without forming any significant scarp.

It is, therefore, suggested that this evidence of neotectonic activity should be only accepted after a careful examination.

Careful examination of the possible neotectonic activity in the area began way back in 1974-75 when Dayal (1976) undertook joint treverses with the officers of Geodetic and Research Branch of Survey of India, Dehradun. The purpose was to indicate suitable sites to them for precision leveling by sensitive instruments to decipher any such movement along the Main Boundary Fault. At Jamrani project area, two pillars on either side of the fault were recommended near Patharia, about 2 km downstream of the axis, while one pillar on either side of the fault was suggested near Amrtipur further downstream. Four more pillars, two on each side of the fault, were added to the Patharia site by Sushil Kumar and Sharma (Plate-VIII) Precision leveling has been done by Survey of India officers and they have not recorded any movement along the fault so far.

Apart from these, an array of micro-earthquake recorders have been installed by Central Water and Power Research Station (CWPRS), Pune and they are monitoring the micro-earthquakes.

Implications of seismicity on the proposed structure

The seismicity of the area, based on the tectonic/neotectonic activity broadly described above is briefly discussed here, viz-a-viz its implications. In past fifty years, the damages that the seismic events can cause to civil structures has led to a through study of the seismicity leading to improvements in the designs of structures against earthquake effects. In fact, now-a-days, such an exercise is an elaborate state-of -art in itself and is beyond scope of the present work. Basically, it utilizes the historical seismicity of the area, data retrived from expensive instrumention and tectono-stratigraphy of the region, to determine the parameters of safety. The Bureau of Indian Standard recommends detailed investigations in accordance with IS:4967-1968 to arrive at these safety parameters.

The Jamrani Dam Project, is located in a seismically quiesent zone categorised as 'Foothill seismic domain' where the recorded history of earthquakes indicate a very sporadic activity of low magnitude (≤4). However, immediately north of the site lies a seismically active belt known as Main Himalayan seismic zone'. Most of the present activity is related to this zone. The seismicity of an area, in general, is explained by two terms i) Magnitude which is a quantitative measure and ii) Intensity which is a subjective term defined by the degree of damages produced on the terrain and man-made structures by the earthquake waves.

Records (28) of nearly past one hundred years of the Kumron and adjoining areas reveals that the earthquakes ranging in magnitude ≥4≤ 5 are common and more than 50% of the recorded shocks, followed by those having magnitude (i) ≥5≤ 6 and ii) <4 which constitude between 20% and 25% each. Earthquakes ≥6≤ 7 comprise only 4% and there has been a rare shock of magnitude 7.0 (1916) in the area. These earthqukes (where macroseismic surveys were conducted after the event) have produced intensities up to VI at the dam site. Even some of the major earthquakes like the Assam earthquake (1897), Kangra earthquakes (1905) and Bihar-Nepal earthquake(1934) produced intensities of V to VI (R.F.Scale) in the project area. The peak ground acceleration attained at this intensity ranges between 50cm to 100 cm/sec^2 (0.05g to 0.1g). It should be noted that these values are mainly based on surmise and not specifically worked out for the project. It is suggested that the probable peak ground accreleration and other seismically related design parameters, specific to the project may be worked out before undertaking any construction.

VIII. GEOTECHNICAL IMPLICATIONS OF GEOLOGICAL FEATURES

Surface as well as the sub-surface exploration by 44 drillholes scattered throughout the dam body and beyond and by eight drifts, four on each abutment, has brought out a significant amount of geological data. In the present chapter, an attempt has been made to bring out the implications of these features vis-a-vis the proposed superstructure. In order to highlight the sub-surface data, following sections have been drawn.

a) Geological Section along the proposed dam axis (straight) Plate-IX

b) Geological Section -A-B on the left abutment (Plate-X)

c) Geological Section C-D on the right abutment (Plate-X)

d) Geological Section E-F on the right abutment (Plate-X)

e) Tentative foundation grade geological plan of the river portion at elevation 610.0m (Plate-XI).

Perusal of the above plates reveals that bedrock should be available at i) 1.5 m to 13 m depth in the left abutment, ii) 0.6 m to 6 m depth in the right abutment and iii) 7 m to 27 m depth in the river portion. The deepest portion of the bed rock in the river section would lie towards the heel of the dam. The five sets of joints present in the bedrock (refer Chapter-IV), are likely to spoke varying problems. In the left abutment (Plate-IX), owing to its disposition, the bedding joint is the controlling joint as it dips towards valley. Presently, it controls the slope of the hill on the left abutment. Presence of thin clayshale bands would pose serious planar failure problems and suitably designed cut slopes will have to be provided for safe and successful excavation. Similarly, joints J-3 and J-4 will create the problem of block failure in the right abutment (Plate-IX). Seepage through joint J-4 which runs nearly parallel to the river is likely, but fortunately this joint is the least common of the five. Other joints may not pose much problems.

The depth of stripping ranges between horizontal 18 m to 32 m in the left abutment and 22 m to 25 m. in the right abutment (Plate-IX). The vertical stripping ranges from 10 m to 20 m and 11 m to 30 m for the left and right abutments, respectively.

The tentative foundation grade geological plan (Plate-XI) at elevation 610 m, reveals zebra type stripes of sandstone and shales where swelling and pinching are common both along the strike and dip. The physical characteristics indicate the variation observed in the rock types. As has already been discussed, the UCS (in dry state) varies between 68 and 532 kg/cm^2 for sandstones and 198 kg/cm^2 to 403 kg/cm^2 for siltstone. For shales it will be even less. This clearly indicates that the foundation rocks are prone to differential settlement. Their response to the stresses created by the superstructure will not be uniform. Moreover, the siltstone and shales disintegrate when exposed, thus losing whatever strength they have in a confined state. It is, therefore, logical to conclude that suitable treatment for the claystone, siltstone and friable sandstone would be necessary. This can be achieved by providing dental treatment and also by consolidation grouting. But it will have to be established, by performing load bearing test, whether consolidation grouting is enhancing the strength. The amenability of these rocks to cement grouting has been established by test grouting. The cement intake was maximum for siltstone, followed by sandstone and the least for shale. It is a bit intriguing that the sandstones did not accept as much grout as they are generally supposed to. It will not be out of place to suggest here to repeat the test grouting at least in sandstones during construction phase of the project because they constitute nearly 75% of the foundation rock.

The deformation tests have yielded rather very interesting results. The modulii of deformation for sandstone and siltstone is nearly same and Memorandum J-1 goes on to say that sandstone, siltstone and shale are not as different as their names suggest implying that geomechanically they are more or less same, which is not logical geologically. Values of physical characteristics are more reliable than these values which place there rocks on the same pedestal, geomechanially.

IX. CATCHMENT AREA GEOLOGY AND SEDIMENTATION

The catchment area of the project, covering about 439 sq. km, has been studied with the specific purpose of bringing out erodibility attributes of the rocks occupying the area as they principally govern the siltation process of a reservoir. Saran (in Dayal

1978) prepared photogeologic base map which was (1978) subsequently utilised in preparing a broad geological map with emphasis on erodibility of each rock tyep.

The catchment region is highly mountainous with relief ranging from El. 635 m to El. 2296 m. The *Gola river* with its chief tributaries like *Kalsa*, *Lugar Gad* and numerous other small nalass and rivulets draw and dissect the terrain. The catchment is completely rain fed.

The geology of region (Plate-XII) is much more complex than that of the dam site. Two contrasting rock groups. viz. Ramgarh Formation comprising a variety of crystalline rocks and the Lower Siwalik group of sedimentary rocks consisting of sequence of sandstone, siltstone and shale bands occupy the area. These two groups are separated by a major fault zone called the Main Boundary Fault (MBF). The rocks of the first group occupy as much as 94.03% of the area, while those of the second group occur only in 5.75% of the area. The balance is constituted by loose sediments strewn over the slopes and valleyes. The Ramgarh Formation consists of crystalline rocks like granites, quartizites, garnetiferous mica schists, limetstones, phyllites and basic rocks.

From the geologic overview given above, it is only natural to conclude that maximum load of loose sediments, of varying size and shape, would be derived from the crystalline rocks only, while sedimentary rocks of Siwalik Group would yield only a small amount, and that too from the southern portion through *Lugar Gad.*

Dayal (1978) studied the size and shape of the sediments that would be derived from rocks by erosional process. The size/shape is mainly governed by the discontinuity pattern and its spacing. The crystalline rocks falling close to MBF have been affected by severe closely spaced jointing though such an effect is not prominent in the sedimentary Siwalik rocks. Besides discontinuities, other important factors are length and elevation of outcrop available, its gradient and total length of sediment travel befor it gets deposited and the degree of weathering the rock has undergone. Accordingly, Dayal (1978) concluded that crystalline rocks will yield sediments varying in size from fine to coarse. Siwalik rocks will yield mainly fine sediments. The analysis he made is of qualitative nature only and to substantiate his conclusions he had recommended ten silt and discharge observation stations to be established in Gola, Kalsa and some other major tributaries. It is imperative that few hydro-meteorological stations should also be installed to study the rainfall pattern in in the catchment area since rains are the ultimate carrier of the loose material. It is felt that these recommendations should be carried out and completed before the commencement of the construction work on the project.

X. RESERVOIR

The 130 m high R.C.C. dam will create a reservoir which would cover a maximum area of about 4.7 sq km at full reservoir level of 763 m and extend up to 8.85 km along the *Gola river* and about 1.3 km along the *Lugar gad* in the south-eastern extremity. Width of the reservoir at the FRL would range between 150 m and 750 m. For any dam, it is necessary to established the competency of the reservoir in all respects viz. i) against possible seepage through any discontinuity or leakage through saddles along the rim, ii) stability of rim with respect to changes of landslides etc. and iii) possibility of occurrence of reservoir induced seismicity (RIS). Officers of Geological Survey of India has studied these problems thoroughly and a brief recount of each is given below:

A. Geology of the reservoir area:

Dayal (1978) began the work of geological mapping of the reservoir area in 1975 and continued it up to 1978. He brought out only salient features of the reservoir geology. Anabalgan (1987,1988) also undertook this work. However, Sharma (1992) carried out detailed geological mapping on 1:7500 scale (Plate-VII) covering an area of about 4.764 sq. km. This mapping has revealed that the reservoir area comprises Lower Siwalik rocks (same as found in the dam site area) on the southern portion and crystalline rocks, which include Amritpur grainte associated with rhyolite and aplitic veins, on the northern flanks, of the reservoir. The main tectonic feature i.e. Main Boundary Fault Thrust (MBF-1) separates the two. The general strike of the Siwalik rocks is NW-SE with 30°-50° north easterly dips. The Main Boundary fault crosses the reservoir about 3.8 km and 3.5 km upstream of the dam axis in the *Gola river* and *Sakula nala* sections respectively. Trace of this major fault is everywhere concealed under debris with width varying from few metres to as much as 75 m. Its strike at the Sakula nala section is N40° to 50°W-S40° to 50°E and N70°W-S70° E in the Hairakhan-Lugar section. The dip of the fault is assessed to be 40° towards north-east. This fault assumes significance with respect to the tightness of the reservoir as it gets exposed near *Churani nala*, in the downstream of the dam, at elevation 750m (approximate) and further downstream near *Kula nala* about 2 km downstream of the dam axis. There are apprehensions that the fault zone may provide a conduit for impounded water to leak out of the reservoir. In order to determine the nature of the fault zone material and its permeability characteristics Anabalgan (1987) recommended one hole, DH-26, at *Churani nala* at elevation 759.3 m. However, the contact between the Amritpur granite and the Siwaliks could not be convincingly established. The interpreted 5.7 m thick granite rock occurring below 2.8 m thick overburden was recovered only in small pices and water percolation tests were conducted in Siwalik rocks only between depth 11.5 m and 20m, which indeed did not represent the fault zone material. Accordingly, in 1993 a new borehole was recommended for drilling at the same *nala*, using Dh-26 barrel, as observation well. A pit was also suggested at the same location for physical examination of the fault zone material. The recommendations are yet to be implemented. It is emphasised that these recommendations are followed and results properly analysed to know the nature of fault zone vis-a-vis possibility of leakage.

The clay/shale bands in Siwalik rocks are supposed to act as an effective barrier against any seepage through the left rim of the reservoir. On the right rim, the closely fractured crystallines, may provide avenues for seepage which may call for some treatment like clay blanketing of the slope surfaces especially the bare ones.

B. Stability of reservoir rim against landslides.

Landslides are a common natural hazard in the Himalayan terrain and can assume dangerous proportion in so far as stability/safety of a dam is concerned. Therefore, it is obvious that such landslide-prone zones in the reservoir rim are delineated well before the project is constructed and suitable treatments to stabilise them are provided. This aspect was first initiated by Dayal (1978) who prepared an inventory of the slides. Shrama (1992) undertook a detailed survey and carried out large scale mapping of some of the slides. He has also delineated debris cones/fans. The following table (VIII) highlights the features of the slides falling in the reservoir area.

Table - VIII : Brief details of important slides in the reservoir area

Sl. No.	Name of slide	Location from dam site	Approx. dimension width x height (m)	Description
1.	Khaljhala slide	1.6 km on right bank	90m x 160m	It is a major active slide. Rocks involved are sandstone with 1-2m thick clayshale/siltstone bands. Strike is NW-SE with 40° dip towards NE i.e. into the hill. Three major steep (65°-35°) valley dipping (SW or SE) joints result in formation of wedges which abetted by steep gradient is the cause for landsiding. Further studies have been recommended.
2.	Sakula slide of Sakula nala	2.7 km on right bank	80m x 100m	Slide extends from nala bed to about 80 m height at an inclination of 35° followed by two bars between 80 m and 100 m. Rock involved in sliding is friable sandstone overlain by Amritpur granite. Fault zone is pulverised. Failure seems to have occurred due to poor strength of rocks. Retaining walls may be provided.
3.	Markudia slide	6.5 km left bank	300m x 125m	Highly sheared and fractured basic rocks and granites; poor rock strength together with wedge formation is the principal cause of slide. It is likely to get disturbed and has to be stabilised by terracing and erection of retaining walls all along the width of slide and plantation of suitable trees/bushes.

A number of debris cones and fans have been delineated. Twelve cones have heights ranging from 26 m to 130 m in the reservoir area. Highly fractured and sheared Amritpur granite has provided maximum number of such deposits. It may be due to the fact that heavy torrential rains brought down loose pieces of such rock and piled them on the bed. These cones/fans will not pose any stability problem in the reservoir. Details of these features are contained in the progress report of Sharma (1992).

C. Reservoir induced seismicity (RIS)

The seismic activity induced by the impounded reservoir water has, indeed, become the single factor in the ongoing war against dams.It has widely assumed negative connotations hence any dam that is coming up now has to meet stringent tests against occurrence of such a phenomenon. It is not that this phenomenon is universal. For one single such phenomenon, numerous examples can be cited where such events have not taken place at all. But this is not a valid argument in science. One has to approach the issue with an open mind. We must know what causes R.I.S. The causes as opined by workers on R.I.S. are as follows:

i) percolation of water along the fault zone lubricates the material facilitating their failure by reduction in strength,

ii) dead weight of water can cause tremors, and

iii) the percolation of water down a fault zone adds to the pore pressure which coupled with the existing natural tectonic stress can trigger an earthquake.

At present, the scientists no longer believe that the first two causes can trigger an earthquake. However, the third cause is considered to be main mechanism causing an earthquake. This mechanism is presumed to be linked with rate of reservoir filling, duration of such loading, maximum water level reached and duration for which this highest level is retained Other circumstantial evidence indicates that 'thrust fault regime' tneds to inhibit such an activity. The propensity of rocks to store strain for a considerable period seems to increase the chances of occurrance of R.I.S. Studies on R.I.S. in India have indicated that the Himalayan region (especially the foothills), where nearly 11 major dams have come up, is almost free from this phenomenon. This has been attributed to 'thrust fault regime' and weak rocks which do not store strain. Therefore, it is a general opinion that in the Himalayan region, the threat of natural seismicity is much more than that posed by R.I.S. (Gupta 1992).

The rock distribution in the Jamrani reservoir area is nearly uniform, i.e. Siwalik sedimentary rocks constitute about 47% while Amritpur crystallines about 53% of the reservoir area. One major fault zone (up to 55 m wide) traverses the reservoir area. The fault zones is generally charcterised by pulverised material/gouge which does not permit seepage of water. However, it will be worthwhile to know its permeability characters as has already been recommended earlier. While the Siwalik rocks are plastic in nature, the Amritpur crystallines are brittle. The former will inhibit the percolation of water to depth, while the latter can allow it if the fractures, joints etc. extend down below and are open. The regional stress regime in the area is compressional.

XI. CONSTRUCTION MATERIAL

For the proposed R.C.C. dam, the project authorities have estimated that near 20 lac M^3 of coarse and about 6 lac M^3 of fine aggregates would be required. Sharma (1990) undertook investigations for locating such aggregates in the natural deposits that occur in the Gola river between 3.5 km upstream and 3 km downstream of the axis. The aggregate sizes have to conform to the following specifications fixed for Jamrani R.C.C. dam.

4.75-19 mm size	20%
19-38 mm size	35%
38-50 mm size	45%

In the area between Raunsil and Barajhala, nearly 0.5 to 3.5 downstream of the dam axis, the weight percentage of aggregates of differenet size is as under:

More than 80 mm size	49%
80-50 mm size	8%
Less than 50 mm size	40%

In the upstream area, the weight percent is as follows:

More than 80 mm	52.9%
80-50 mm size	8.9%
Less than 50 mm size	38.16%

I.R.I., Roorkee have also conducted material survey and have concluded that in the area i) fine aggregate would be 26%, and ii) coarse aggregate up to 50 mm size would be 17% and iii) above 55mm size 56.5%.

From the above it is clear that project authorities will have to look beyond the area surveyed so far to completely meet their requirements. Present studies have estabilished following quantities ony:

a) Fine aggregate 4.10 lac m^3

b) Coarse aggreagate-

i) Less that 50 mm size 2.6 lac m^3

ii) Between 50-80 mm size 8.75 lac m^3

The qualitative studies of these samples have to be done. As many natural aggregates occurring in the river bed are crystalline rocks, it will be necessary to establishe their petrographic bonafides against possible Alkali-reaction. It must be done prior to their use as aggregates for R.C.C. dam.

Sharma has recommended further geophysical surveys by seismic and resistivity methods to assess potential source areas for construction material.

Prior to finalisation of R.C.C. dam, project authorities had proposed rock fill dam or a concrete dam, Iyer et al. (1984) had examined availability of construction material for these two types of dam. They held that the required quantities could be obtained locally within 3 km downstream of the axis. Anabalgan (1987) had also suggested the possibility of using Amritpur granite exposed north of the dam site above elevation 1000 m ± for concrete aggregate. This area can be approached along the Anna- Babiyar road. Here a fairly wide stretch (3 to 5 km) of granite rock is exposed. This granite if it meets the Alkali-reaction test, can be crushed and used.

For rockifill dam proposal, Iyer et al (1984) undertook extensive surveys, especially for clay material required for core. They felt that the required quantities of river borne material (22.7 lac m^3), filter material (10.7 lac m^3) could be obtained from river bed by screening. Crushed rock (28.94 lac m^3) could be sourced from Barajhala quarry about 2.5 km downstream of dam axis. Only, availability of clay material (9.9 lac m^3) appeared doubtful and thus extensive field work was done by them for locating good and sufficient deposits. The clay deposits are available on hill slopes. They identified 5 such borrow areas and estimated quantities as given below (Table-VIII).

The study does established that enough quantity of clay material is available within 6 km distance downstream of the dam axis.

XII. CONCLUSIONS AND RECOMMENDATIONS

The Irrigation Department, Government of Uttar Pradesh had proposed a 130 m high R.C.C.

Table - VIII : Details of clay deposits of the borrow areas

Area	Quantity estimated	Location
K- Area	7,32,000 m^3	500m downstream of the dam axis of, on left bank of Gola river, between El 640m and El 840.0m.
L-X-Area	2.77,000 m^3	North of above, between El 640m and El 850m.
L-Area	3,08,000 m^3	North of above, between El 635m and El 755m.
G-Area	21 lac m^3	6 km downstream of the axis on the left bank of Gola river between El 604m and 920m.
A-Area	Not given	6 km downstream of the axis on the right bank of Gola river above the Kathgodam-Jamrani road.

dam across Gola river near Jamrani village,, Nainital district, Uttaranchal. This multipurpose scheme envisages storage of about 208.6 M. cum of water for providing irrigation of Bhabhar and Tarai areas of Nainital and Bareilly districts, drinking water to townships of Haldwani, Kathgodam, Lalkuan and to adjoining rural population besides generating 15 MW of hydel power.

Since 1968 as many as 5 proposals were examined and investigated, before selecting the present site. The pre-construction stage investigation began in 1980. The type of dam, to be adopted, was also discussed and investigated in detail and finally Roller Compacted Concrete Dam (R.C.C) was chosen thus bringing the latest technology in Dam Building to the country.

The large scale map prepared for the dam site reveals that the Lower Siwalik rocks comprising alternating sequence of sandstone, clayshale and siltstone constitute the foundation rocks covered under varying thickness of slope scree on the abutments and riverine deposits on the river bed. The general strike of the rocks is NW-SE with 30° to 50° NE, i.e. upstream dips. The rocks are intersected by five sets of joints.

Pre-construction stage sub-surface investigations included drilling of 44 holes yielding a total of about 3407.16 m of croe. Eight drifts, four on each abutment at different elevations, totaling a length of 277.5 m, have also been excavated. Geological logging of the cores and 3-D logging of the drifts have been done. Analysis of the data obtained reveals that the bedrock consisting of alternating sequence of sandstone, siltstone and shale, is covered under a slope scree of thickness from 1.5 m to 13 m and 0.6 m to 6 m on the left and right abutments respectively. In the river bed portion, the riverine overburden, 7m to 27m thick, covers the bedrock. The bedrock contours prepared for the river bed portion, indicate the presence of a deep narrow plunge pool upstream of the heel of the proposed structure. In the river bed, rock will be available above 611.0 m elevation in the upstream while to the downstream it will be available above 617 m elevation. The maximum thickness of sandstone band is observed to be 40 m. Siltstone and clay shale bonds have a maximum thickness of about 7 m. The core recovery in sandstone in general, is very good being in the vicinity of 70% to 100%. Siltstone and shales have poor to good core recovery, through cent per cent recovery sections are observed in them also. The sandstones are hard to soft, siltstones are hard and shales are soft. The surface as well as sub-surface studies have shown that the foundation rocks are not at all structurally disturbed, though a very important structural element, namely Main Boundary Fault, passes within a kilometre north of the dam axis.

The permeability of the foundation rocks ranges between 2 and 6 lugeons in general, though high values up to 56 lugeons have also been observed. Test grouting has indicated that the rocks are amenable to grouting. Siltstone has maximum amenability followed by sandstone, and shales have the least. Load bearing tests have been recommended to established the usefulness of consolidation grouting of foundation rocks.

Numerous laboratory and in-situ tests have been done on foundation rocks. The tests have revealed that the UCS (dry) of sandstone ranges between 68 and 532 kg/cm^2 while for siltstone it varies from 198 to 403 kg/cm^2, exhibiting the variations in the rocks. However, the modulii of deformation determined for sandstones (0.4670 x 10^5 kg/cm^2 to 0.5371 x 10^5 kg/cm^2), siltstones (0.4049 x 10^5 kg/cm^2 to 0.4558 x 10^5 kg/cm^2) and shales (0.3682x 10^5 kg/cm^2 to 0.3728 x 10^5 kg/cm^2) have been considered as nearly the same. Shear tests show that ϕ for sandstone varies from 40° to 69°, for siltstone it is 39° and for shale it varies between 40° and 58.6°. Cohesion ranges between 0.3 and 2.8 kg/cm^2 for sandstone, 0.7 kg/cm^2 for siltstone and between 1.8 and 3.14 kg/cm^2 for shale.

The project site is located in the foot hill seismic zone of seismotctonic domains of NW Himalaya. This domain is followed north ward by 'Main Himalayan seismic zone'considered as the most active seismologically. No major earthquake has occurred near the dam site. However, the Main Boundary Fault has been considered to have undergone neotectonic activity. Occurrence of scarps in the *Lugar valley* disturbing recent deposits is taken as evidence. However, attention has been drawn that such deposits can be formed by material brought by excessive rains caused by cloudbrust and unfavourable hydrological regime of the river system. Moreover, constant precision levelling of pillars erected downstream of the dam site across the Main Boundary Fault, has not indicated any movement for more than decade.

Synthesising the data for geotechnological implications, it can be said that the foundation rocks are susceptible to differential settlement and measures will have, to be adopted against it. Abutment excavation will pose problems where planar failure due to dip slope joints on the left abutment and blocks failure due to wedges in the right abutment are apprehended. These will have to be tackled by designing suitable cut slopes. No major seepage through joints is apprehended; curtain grouting will check whatever seepage takes place.

The reservoir area comprises Lower Siwalik rocks (47%) and Amritpur granites (53%). These rocks are separated from each other by the Main Boundary Fault/Thrust which crosses the reservoir above 3.5 km to 3.8 km in upstream of the dam axis. Reservoir rim does not have any saddle. Three major slides and nearly twelve debris cones and fans have been observed in the reservoir area. Of these, only one slide i.e. Markudia slide, may create reservoir rim stability problem, chances of any seepage through the Main Boundary Fault, which gets exposed downstream, are considered dim, yet exploration has been recommended along this fault to determine permeability characteristics of the fault zone material. Apprehension has been raised about reservoir induced seismicity upon filling of reservoir. Based upon the experience at dams in other parts of the country on similar foundations, compressional stress regime, plastic nature of Siwalik rocks and relatively low height of impounded water on the brittle Amritpur rocks it is coucluded that the geoseismotectonic setup does not indicate that Jamrani dam project would become a victim of reservour induced seismicity.

Nearly 20 lac m^3 of varying size of aggregate is required for R.C.C. dam. Investigation between 3.5 km upstream and 3 km downstream of the dam axis in the river bed portion have revealed that nearly 17 lac m^3 material is available. For the rest, suitable deposits will have to be located elsewhere.

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APPENDIX - I

GEOMECHANICAL CHARACTERISTICS OF ROCKS AT JAMRANI DAM PROJECT

Sl. No.	Rock type	Borehole number Depth(m)	Density (gm/cc)	Water absorption (%)	Unconfined compressive strength (Dry) (kg/cm^2)	Remarks
1.	Sandstone (Finegrained)	C-7 45-58	2..59	1.53	532	Single test, brittle failure along bedding plane.
2.	Sandstone (Friable)	C-7 6.75-9	2.33	2.56	68	Single test.
3.	Sandstone (breccia like)	C-7 12-15	2.66	-	141	Two tests.
4.	Sandstone (breccia like)	C-7 30-33	2.68	1.11	255	Two tests.
5.	Sandstone (micaceous)	A_2(i) 27.34-27.58	2.32	4.35	130	Single test; High moisture contents is due to absorption by mica flakes.
6.	Sandstone (Fine grained)	A_2 (i)	2.49	3.06	311	Single test
7.	Sandstone	A_2 (i)	2.58	3.90	303	Single test
8.	Siltstone	C-7, 63-66	2.58	+	403	Two tests
9.	Siltstone	C-7, 29.47-30.6	2.62	+	198	Single test
10.	Siltston	A-2(i)	2.74	0.67	286	Single test

+ samples completely disinitegrated when in water.

APPENDIX - II

Summarised Geological Logs of the Bore Holes Drilled at Jamrani Dam Project Site

Sl. No.	Drill Hole Number	Location of Hole	Collar Elevation (m) asl	Depth of Hole (m)	Bed rock elevation (m)	Thickness of overburden (m) and its nature	Summarised Geological Log and Engineering Geological Details	Remarks
1	2	3	4	5	6	7	8	9
1	A-1 DH 41	At the centre of river bed, on axis	636.47	163	614.47	22, River borne material comprising boulder & pebbles of crystalline rocks and sandstone admixed with sand, silt and clay.	An alternating sequence of sandstone, shale and silt stone bands with bedding inclination of 35^{0} is intercepted in the hole. Fairly thick sandstone bands are recorded between (i) 22-43.5m. (ii) 50-90.5 m and (iii) 106-119.8m depths with thin shaly intercalations. Appreciably thick siltstone bands are seen in two sections at (i) 43.5-50.0 m and (ii) 100-106 m depths. One chocolate clay shale band is observed at 90.5-97 m depth. Below 119.8m till end of hole, sequence is made up of mainly siltstone with bands of sandstone and sandrock. Core recovery in sandstone and siltstone ranges between 67% and 100%. A very good recovery of 85% to 100% has been recorded for shales. The bedrock is fresh. Thin clay seams/shear zones are noted at depths 127 m and 136 m. Water percolation tests have given fairly high permeability values 8 to 13 lugeons up to 91 m depth, though sections with lower values recorded at higher elevation.	

1	2	3	4	5	6	7	8	9
2.	A2(i)	On dam axis river bed towards right abutment	636.67	70.8	623.174	13.5, River borne material	A sequence of sandstone, siltstone and shale band showing bedding inclinations between 30^o and 50^o is intercepted. Thick sandstone bands with minor shale/siltstone bands are recorded at depth (i) 13.5-66.1m (ii) 74.9-97.14 m and (iii) 122.5-139.99m. Fairly thick silt stone bands are observed in sections at depths (i) 66.1-74.9m. (ii) 97.14-100.57 m and (iii) 117.09-122.9m. only. one thick shale band is recorded between depths 108.5 & 114m. Sandstones are weakly to moderately compact, while siltstones are hard to very hard. Shales are soft. Top 11m of sandstone and shows weathering, rest is fresh. Core recovery in sandstones ranges from 51% to 93%. Siltstone shows a recovery of 62% to 100% while for shale it varies between 25% and 89%. Premeability values range from 2 to 6 lugeons, though in the section between 18m and 21m, it is 10 lugeons. Three core samples of sandstone give Uniaxial Compressive Strength (UCS) between 130 and 311 kg/cm^2. USC for siltstone is 286 kg/cm^2.	Section between 24 and 72m depth has been utilised to work out groutability characteristics of the foundation rock. The test has established that rocks are amenable to grouting and efficacy ranges from 20% to 80%. In order of efficacy siltstones achieve maximum followed by sandstone and shales

1	2	3	4	5	6	7	8	9
3.	A-3 DH-35	On dam axis	638.19	151	621.19	17.0, Riverine overburden	A sequence of sandstones. siltstones and shale bands comprise the rocks intercepted in the hole. The bedding inclination ranges from 40° to 45°. Major thick, sandstone bands are recorded at depths (i) 21.8-36.5m, (ii) 46.5-72m,(iii) 94-120.3m and (iv) 133.3-145.5m. A 6m shale band occurs between 88 and 94m. The rest of the hole length comprises thin bands of siltstones, sandstone and shales. The core recovery in sandstones ranges between 23% and 95%, for siltstone it is 92% and for shale 49% to 85%. Permeability values are high upto 33m depth due to openness of joints. Though values fall to 2 and 5 lugeons down to 72m depth beyond which no test was conducted.	
4.	A-4 DH-30	On dam axis	687.54	70	685.14	2.4; Slope debris	A sequence of sandstone. siltstone and shale bands with major sandstone bands occurring at depths i) 23-34 m and ii) 39-70m. are recorded in the hole. In the rest of the hole length, thin bands of these rocks are present. Soft sandstone (friable) also forms an important thickness of second sandstone band. Core recovery in sandstone is 90% to 93%, while for siltstone and shale it varies between 74% and 91%. Permeability values are erratic and no definite pattern can be discerned.	

1	2	3	4	5	6	7	8	9
5.	A-5 DH-29	On dam axis	689.7	70.5	688.5	1.2; Slope debris.	The 69.3 m core length of the hole comprises three thick sandstone bands at depths i) 12-20.4m ii) 32.5-51 m and iii) 63.5-70.5m. One hard compact siltstone band occurs at depth 51.0-63.5 m. Rest of the hole length is made up of bands of shale, siltstone and sandstone. Core recovery in sandstone ranges from 57% to 98% and in siltstone from 96% to 97%. Permeability values down to depth 33m range up to 18 lugeons due to open jointed nature of rock. Below this they are generally between 3 lugeons to 1 lugeon.	
6.	A-6 DH-36	On dam axis	707.5	70.5	702.5	5.0; Slope debris.	The 65.5m of the hole length contains three sandstone bands at depth i) 6-24.5m ii) 36.5-44.5m, and iii) 54.2-6.3 m. One 10m thick siltstone band is noted at depth 44.5-54.2m. In the rest of reach shale, siltstone, sandstone bands are present. A clay seam (30 cm) is noted between 60.2 and 60.5 m depth. Core recovery in sandstone varies from 68% to 86% while in siltstone it is 92%. Premeability data available down to 46m depth, indicates very high values (up to 35 lugeons) due to open joints.	

1	2	3	4	5	6	7	8	9
7.	A-7 DH-38	On dam axis left bank	721.37	70.1	-	-	The 70.1 m length begins with a 15.8m. thick sanstone band. Other band of appreciable thickness is observed at depth 25.8-50.7m. In the rest of the length general sequence of thin sandstone, siltstone and shale bands is observed. Bedding inclination varies between 40^{o} and 43^{o}. Core recovery in sandstone is 69% to 100%. Siltstones are hard and show a recovery of 70% to 99%. Up to 21m depth permeability value up to 11 lugeons are recorded. This may be due to open joints. Low values of 2 to 3 lugeons is recorded below this depth till hole ends.	
8.	A-8 DH-37	On dam axis right abutment	802.25	80	800.75	1.5; Slope Debris	Two major sandstone bands occuring at depths i) 4.5-28.5m and ii) 31.7-72.5m comprise the important lithounits of 78.5m drill hole length. The rest of the length is made up of bands of shale, siltstone and thin sandstone. Bedding inclination varies from 40^{o} to 42^{o}. Core recovery in sandstone varies from 90% to 92%. Permeability values for sections tested vary from 2 to 3 lugeons.	
9.	A-9 DH-39	On dam axis	766.63	70.2	765.13	1.5; Slope Debris	Three major sandstons bands occurs at depth from i) 1.5 to 12m, ii) 15.9-44m and iii) 57.5-70.2m. In the rest of the sections, siltstone and shale bands constitute the rock. Bedding inclination ranges from 37^{o} to 40^{o}. Permeability ranges between 5 and 10 lugeons down to depth of 21 m. Below this it is less than 5 lugeons.	

1	2	3	4	5	6	7	8	9
10.	B-1 DH-42	Downstr-eam of dam axis	636.03	70.05	620.03	16; Riverine Deposits	One major sandstone band, with thin sale and siltstone bands, comparises the rock in the hole. Bedding inclination is 40^{0} and core recovery (average) is 84%. Permeability up to 22m depth is 10 lugeons while in the section from 22 to 70m depth, it ranges from 5 to 7 lugeons.	
11.	B-2 DH-34	Downstr-eam of dam axis	636.4	70.75	623.65	12.75; Riverine Deposits	One major sandstone band occurring between 22.1m and 62.5m depth constitutes the principal lithounit in the hole. In the rest of the hole, shale, silstone, and sandstone bands comprise the rock. Bedding inclination is 47^{0}. Core recovery in sandstone ranges from 95% to 98%. Permeability values range between 1 and 4 lugeons, except between depths i) 31 and 34m, ii) 61-64m where they are between 3 and 9 lugeons.	
12.	B-3 DH-57	Upstream of dam axis	636.2	70.15	623.2	13; Riverine overburden	Except between depths 66.15m and 70.15m where thin shale and silstone bands occur. Bedding inclination is 35^{0}. Permeability values are moderately high throughout the hole, ranging from 4 to 8 lugeons.	
13.	B-4	Not drilled.					—Not drilled—	

1	2	3	4	5	6	7	8	9
14.	B-5 DH-32	Upstream of dam axis (Heel)	636.2	71.15	624.91	21; Riverine deposit	Two sandstone bands occur between depths i) 21-25.5m and ii) 30.5-70.15m. At 31.5m depth, a 20 cm shear seam is recorded. Core recovery in sandstone ranges from 43% to 95%. Permeability values are up to 4 lugeons except between depths 51m and 54m where they go up to 6 lugeons.	
15.	B-6 DH-51	—	635.32	70.2	616.62	18.7; Riverine overburden	Three sandstone bands are recorded at depths i) 18.7-44m, ii) 48.5-54m and iii) 61.2-70.2m. In the rest of the sections, siltstone, shale and sandstone bands occur. Core recovery in sandstone ranges from 85 to 93%. Permeability values are high and range from 13 to 14 lugeons.	
16.	B-7 DH-49	Downstream of axis on right abutment	728.26	72.3	725.76	2.5; Slope debris	Two sandstond bands occuring at depths i) 2.5-17m and ii) 45-72.3m are the major rocks of the hole. In the rest of the length-shale/siltstone/sandstone constitute the rock. Core recovery in sandstone ranges from 85% to 95 % permeability valutes are up to 4 lugeons.	
17.	B-8 DH-46	Upstream of axix on right abutment	674.22	72.4	669.22	5; Slope debris	Hole comprises bands of sandstone, siltstone and shales of varying thickness. Core recovery range up to 91% (sandstone). Permeability values are low (up to 3 lugeons).	
18.	B-9 DH-47	Downstream of axis, on right abutment	711.68	72.4	707.68	4, Slope debris	Mainly sandstone with only 15% of sitlstone/shale bands, is recorded in the hole. Core recovery 83% to 92% (sandstone). Permeability values are moderate, ranging from 4 to 8 lugeons.	

1	2	3	4	5	6	7	8	9
19.	B-10 DH-43	Downstream of axis	642.12	70	636.12	0.6	One major sandstone band occurs at depth 20.5-59.5m. In the rest on the sections, sandstone, siltstone and shale bands are recorded. Bedding inclination is 42^{0}. Core recovery in sandstone ranges from 70% to 91%. Siltstone/shales show recovery between 64% to 100%. Permeability values upto 59.5m depth are upto 5 lugeons. Below this depth they come down to 3 lugeons.	
20.	B-11 DH-40	Upstream of axis on left abutment	643.65	70.15	633.15	10.5; Slope debris.	One major sandstone band occurs between 36 m and 63.7m depths. In the rest of the length, bands of sandstone, shale, siltstone are recorded. Permeability values are high (up to 9 lugeons).	
21.	B-12 DH-45	Downstream of axis on left abutment	-	70.1	-	4.5; Slope debris	One sandstone band (ave. core recovery 77.5%) occurs between depths 4.5m and 20m. In the rest of the hole, a sequence of bands of sandstone/siltstone/shale constitutes the lithounits. A clay/shale band (ave. core recovery 92%) is seen between 66.5m and 70.1m. Permeability values are low (1-2 lugeons).	
22.	B-13 DH-44	Downstream of axis on left abutment	654.36	75.5	641.86	12.5; Slope debirs	A sequence of sandstone, shale and siltstone bands occupies the hole between 12.5m and 75.5m depths. Permeability values range upto 6 lugeon.	

1	2	3	4	5	6	7	8	9
23.	B-14 DH-48	Downstream of axis on left abutment	–	70.3	–	3; Slope Debris	Between depths 3m and 38.2m a thick sandstone band occupies the hole, downwards a sequence of sandstone/siltstone/shale comrpises the rock in the hole. Bedding inclination observed is 40^o. Permeability values are low (1 to 2 lugeons). However, below 60m depth it increases up to 3 lugeons is recorded.	
24.	B-15 DH-58	Upstream of axix on left abutment	–	72.2	–	7.5; Slope bebris	Between 9 m and 48.6 depths, a thick sandstone band is observed. In the rest of the length, a sequence of sandstone, siltstone, shale bands is seen. Bedding inclination is 40^0 core recovery ranges between 63 % and 77 %. Joints are open upto 56m depth. Permeability values up to 18m depth range from 1 to 3 lugeons. However, it increases up to 7 lugeons downward. The high permeability values may be due to thin seams which got washed off during drilling.	
25.	B-16 DH-52	Downstream of axis	634.93	71.2	616.93	18; Riverine overburden	A sequence of sandstone, shale and siltstone, bands occupies the hole betwen 18m and 71.2m depths. Bedding inclination is 35^o. Core recovery in sandstone ranges from 82% to 95%. Siltstone and shales show a core recovery ranging from 88% to 91%. Permeability values range from 3 to 5 lugeons. Though higher values of 7 and 8 lugeons are also recorded.	

1	2	3	4	5	6	7	8	9
26.	B-17 DH-50	Downstream of axis	635.4	153.0	617.4	18; Riverine overburden	In 135m length of the hole, 3 major sandstone bands have been recorded at depths i) 35.5-44.8m ii) 50.5-59m and iii) 140-153m. rest of the hole length is made up of alternating sequence of sandstone, siltstone and shale bands of varying thicknes. Bedding inclination is 30^0. Shear seams and clays seams are recorded at the depths i) 31-31.5m, ii) 22.5m (40 cm) and iii) 23m (20 cm). Average core recovery in sandstone ranges between 88% and 97% and in siltstone from 92% to 97%. Permeability value down to depth fo 108 m is up to 7 lugeons. Below it falls to 6 lugeon.	
27.	B-18 DH-53	Downstream of axis	634.47	71.5	614.47	20m; Riverine overburden	Two sandstone bands at depths i) 20-31m and ii) 49.5-60m. In the rest of the length a sequence of a sandstone, shale and sitlstone bands is seen. Section up to 50m depth is characterised by low permeability (1-2 lugeons). Down wards this value goes up to 4 lugeon.	
28.	B-19 DH-54	Downstream of axis on left abutment	655.22	70.4	642.72	12.5; Slope debris	A sequence of sandstone, Shale and siltstone bands with bedding inclination of 30^0 is met. Core recovery ranges from 90% to 97% in sandstone and 77% to 83% in siltstone and shale. Rocks are tight (1 to 2 lugeons) down to 45m. Below this the value increases slightly to 3 lugeon	

1	2	3	4	5	6	7	8	9
29.	B-20 DH-59	Downstream of axis on left abutment	733.27	71.3	729.27	4; Slope debris	One major sandstone band is seen between depths 20.7m and 53.0m. in the rest of the length a sequence of sandstone, shale, siltstone bands is seen. Sandstone shows core recovery between 10% to 90%. In siltstone/shale it is 10% to 88%, permeability is mainly 1 to 2 lugeons, bedding dip is 35^0. Core loss may be due to defective drilling.	
30.	C-1 DH-55	Upstream of axis, on river bed	635.74	70.0	628.79	7; Riverine overburden	Two major sandstone bands are seen at depths i) 7-43m and ii) 45.7-70m. Thin shale and siltstones bands are present as intercalations. Average core recovery ranges from 73% to 90%. Permeability value down to 43m depth ranges between 2 and 4 lugeons. Between depth 61 and 67m higher values up to 13 lugeons are seen.	
31.	C-2 DH-56	Upstream of axis, on river bed	638.39	70.2	611.2	27; Riverine deposit	A sequence of sandstone shale and siltstone bands, with one thick sandstone band occuring betwen 35.5 m and 70.2 m depths, is recorded. Core recovery in sandstone ranges from 43 % to 92%. In siltsone it is 90 to 93 % Premeability values range from 7 to 12 lugeons.	
32.	C-3 DH-60	Downstream of axis, on riverbed	634.5	70.2	614.2	20.2; Riverine deposit	A sequence of shale, sandstone and siltstone bands. with bedding inclination of 37^o is recorded. Core recovery ranges from 91% to 96%, permeability values range from 2 to 4 lugeons. Value of 5 lugeons is seen in sections between 64m and 70.2 m depth.	

1	2	3	4	5	6	7	8	9
33.	C-4 DH-61	Downstream of axis, on riverbed	634.59	70.5	615.69	18.9; Riverine deposit	A sequence of sandstone, shale and siltstone is seen, in the hole. One major sandstone band is seen between depths 29m and 35.5m. Core recovery in sandstone is between 95% and 98% and in shale/silstone, it is 89% and 94% respectively. Permeability goes upto 4 lugeons.	
34.	C-5 DH-62	Downstream of axis, on riverbed	634.12	70.6	616.62	17.5; Riverone overburden	A sequence of sandstone, siltstone and shale beds with bedding inclination of 37^{o} is noticed in the hole. Between depths 48 m and 64.5m. one major sandstone band is recorded. Core recovery in sandstone ranges between 93% and 94% and in siltstone/shale from 79% to 95%. Permeability values are high (up to 7 lugeons).	
35.	C-6 DH-63	Downstream of axis, on left abutment	667.17	70.15	655.17	12.0; Slope debris	A sequence of sandstone, shale and siltstone having a bedding inclination of 25^{o} occupies the hole. The permeability values are low going upto 3 lugeons.	
36.	C-7	Downstream of axis, on left abutment	692.21	70.0	692.21	—	A sequence of sandstone, shale and siltstone with bedding inclination from 25^{o} to 45^{o} is seen in the hole. Two major sandstone bands seen between depths in 0-10.2 and ii) 43.98-57.33m. Average core recovery in sandstone is 77% in siltstone 62% and in shale 41%. Permeability values are relatively higher (upto 10 lugeons) down to depth of 57m. below which they come down to 2 lugeons. Uniaxial compressive strength.	Uniaxial Compressive Strength values of sandstone vary from 68 kg/cm^2 to 532 kg/cm^2, for siltstone 198 to 403 kg/cm^2 siltstone shows disintegration on being exposed

1	2	3	4	5	6	7	8	9
37.	C-8	-do-	714.88	70.0	714.88	—	The hole begins with a 26m thick sandstone band which is followed by a sequence of sandstone, siltstone and shale bands. Bedding varies between 20^{o} to 40^{o}. Average core recovery for sandstone is 76% that of siltstone 50% and for shale 61%, permeability values up to 45m depth ranges up to 6 lugeon, while below this depth it ranges from 1 to 4 lugeon.	
38.	C-9 DH-66	-do-	656.5	70.0	654.25	2.25; Slope Debris	Two sandstone bands of appreciable thickness are observed in the sequence of sandstone, siltstone and shale bands occupying the length of the borehole. They occur at depths i) 2.25-11.0m and ii) 25-45m. Permeability tests are randomly performed. Values are high down to a depth of 42m (10 lugeons to 21 lugeons). Between 54m and 70m depths, they come down to 1 lugeons.	
39.	C-10 DH-67	Downstre-am of dam axis, on right abutment	765.11	70.11	759.11	6.0; Slope debris	Two sandstone bands occuring at depths i) 6.31m and ii) 45-70.1m cover major length of the hole. The rest of the hole is made up of thin bands of shale/siltstone and sandstone. Core recovery in sandstone ranges from 83% to 97%. Siltstone/shale shows a recovery of 88%. Permeability values down to 45m depth range between 4 and 9 lugeons. It declines to 1 to 2 lugeons below this depth.	

1	2	3	4	5	6	7	8	9
40.	C-11 DH-68	Upstream of dam axis, on right abutment	684.05	71.1	682.05	2.0; Slope debris	Two sandstone bands occurring at depths i) 15.5-27.5m and ii) 58.7-71.1m occupy the hole. Thin shale/siltstone and sandstone bands comprise the rest of the hole. Bedding inclination is 35^{O}. Permeability values range between 4 and 7 lugeons. Values of 9 and 10 lugeons are also seen in a few section up to a depth of 15.5m.	
41.	C-13 DH-70	Upstream of dam axis, on left abutment	706.78	71.0	702.78	4; Slope Debris	The 67m of the hole length comprise two major sandstone bands occurring at depths is 4-22m and ii) 46-71m. The rest consists of a sequence of thin shale, siltstone and sandstone bands. Bedding inclination is 25^{O}. Average core recovery in sandstone ranges from 76% to 91%. In siltstone/shale it is 91%. Permeability values are low (1 to 3 lugones).	
42.	C-14 DH-71	Upstream of dam axis, on left abutment	757.95	70.2	751.95	6; Slope debris	One major sandstone band, occurring between the depths of 6m and 39.5m, forms main unit of rock in the hole. The rest of the hole length is made up of thin bands of shale, silstone and sandstone. Bedding inclination 42^{0} is recorded. Core recovery in sandstone ranges from 86% to 92% while in siltstone/shale it is 85%. Permeability values are low (1 to 3 lugeons).	

1	2	3	4	5	6	7	8	9
43.	C-12 DH-69	Upstream of dam axis, on left abutment	646.36	70.0	633.66	3; Slope debris	Mainly sandstone with thin shale and siltstone bands inter calations is recorded in the hole. Bedding inclination varies from 40^{o} to 42^{o}. Core recovery in sandstone ranges from 44% to 94%. Permeability values are low ranging between 1 and 2 lugeons.	

Plate I

JAMRANI DAM PROJECT, NAINITAL DISTT, UTTARANCHAL
INDEX PLAN SHOWING LOCATIONS OF VARIOUS PROPOSALS OF PROJECTS IN GOLA BASIN

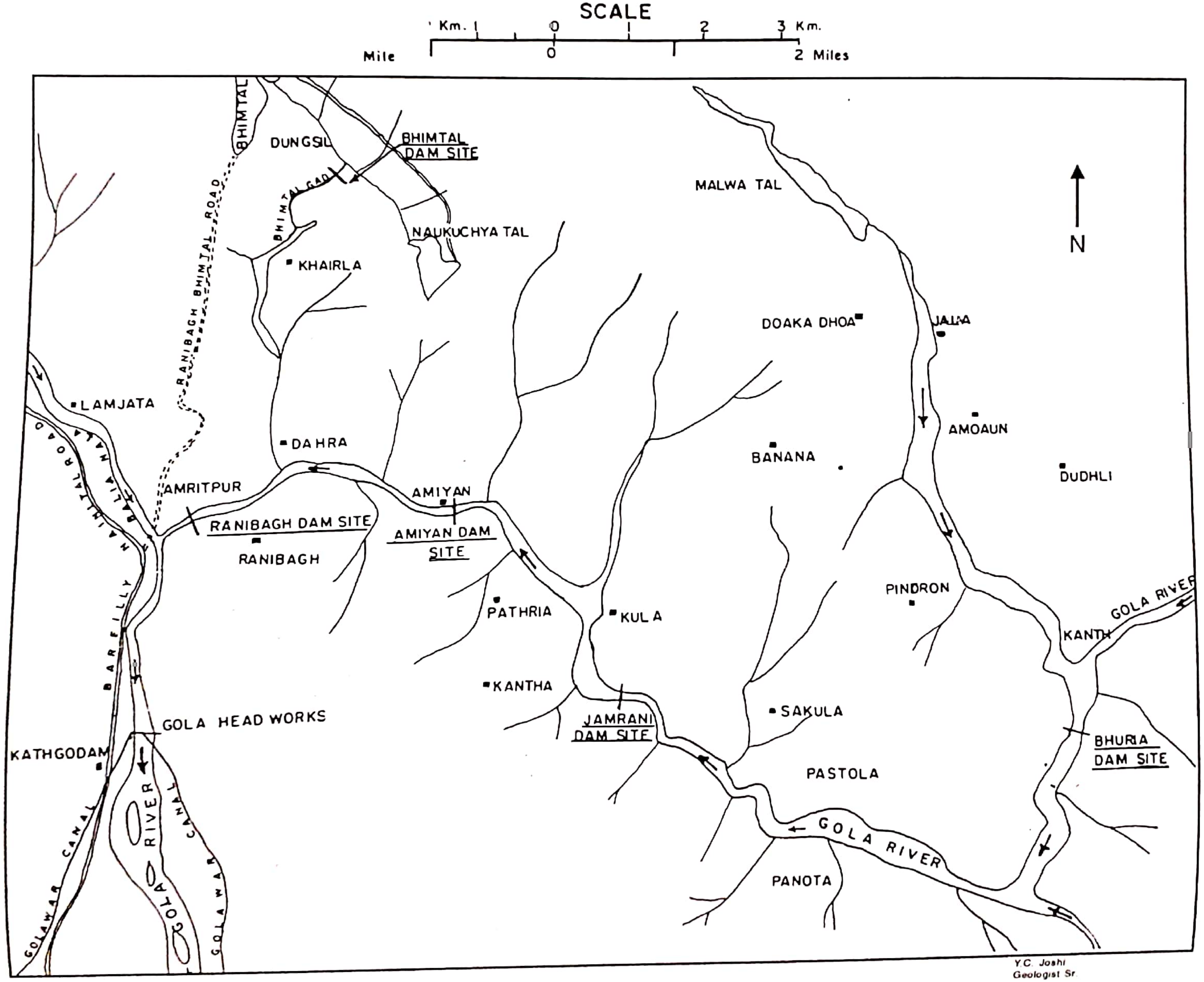
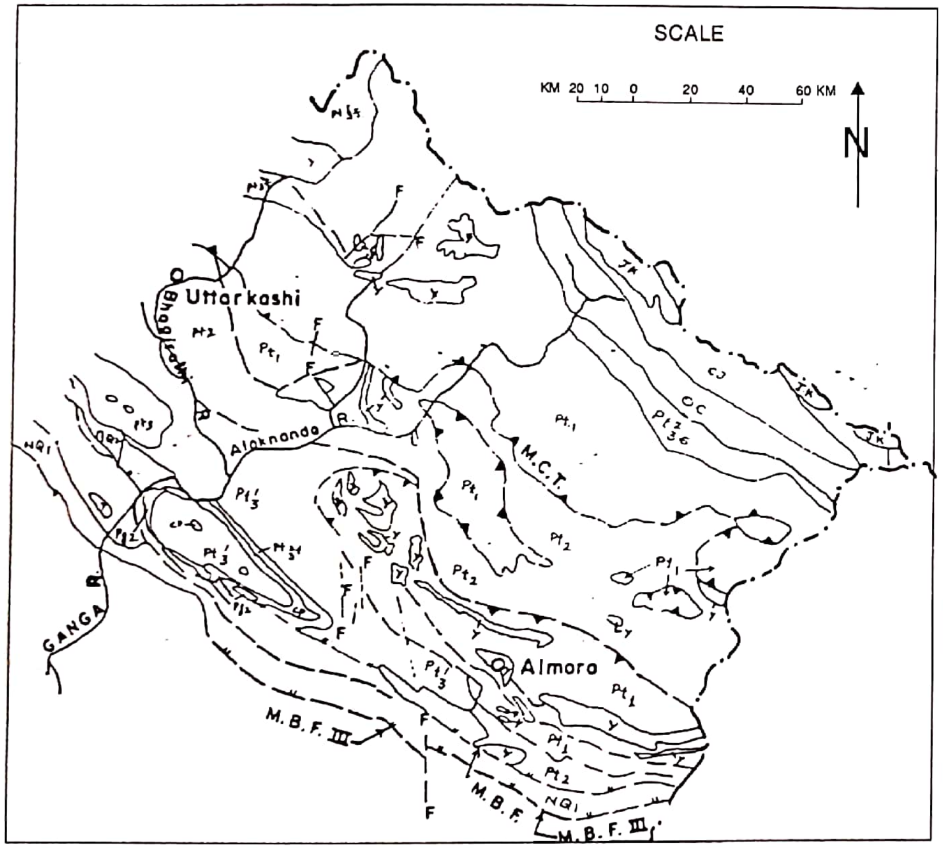


Plate II

GEOLOGICAL MAP OF KUMAON REGION (PART OF SHEET NO. 1, PLATE-1)



	LESSER HIMALAYA	HIGHER HIMALAYA
	HIMACHAL & UTTAR PRADESH	GARHWAL & KUMAUN
Q_2	RIVER TERRACE, ALLUVIUM MORAINE	
NQ	DUN GRAVEL SIWALIK GROUP	
PG_2	NUMMULITICS / SUBATHU FORMATION	
JK		GIUMAL SANDSTONE SPITI SHALE
CJ	BOULDER SLATE FORMATION (LOWER BIJNI FORMATION)	LAPTAL Fm KALAPANI KIOTO Fm CHOCOLATE MUTI Fm KULING SHALE
OC		KALI Fm SHIALA Fm MUTH Fm GARHYANG Fm VARIEGATED Fm RALAM Fm
$Pt_{3\epsilon}$	TAL Fm BLAINI FORMATION KROL FORMATION INFRA-KROL FORMATION	MARTOLI Fm.
$Pt_3^!$	AMRI/BIJNI/BANALI/SETAN-GAL FORMATION	
Pt_2	BERINAG Fm TEJAM F1m ROUTGARA Fm BHIMTAL F11m	
Pt_1	ALMORA CRYSTALLINES ASKOT, BAIJNATH CRYSTALLINES / RAMGARH Fm	CENTRAL CRYSTALLINES
	BASE NOT EXPOSED	
Y	GRANITE & GRANITOID COMPLEX	

GEOLOGY After Ravi Shanker, G. Kumar, S.P. Saxena (1989)

Plate III

JAMRANI DAM PROJECT, DIST NAINITAL, UTTARANCHAL

GEOLOGICAL PLAN OF THE DAMSITE AREA WITH DAM LAYOUT (NEW AXIS)

SCALE 10m 0 20 30m

N

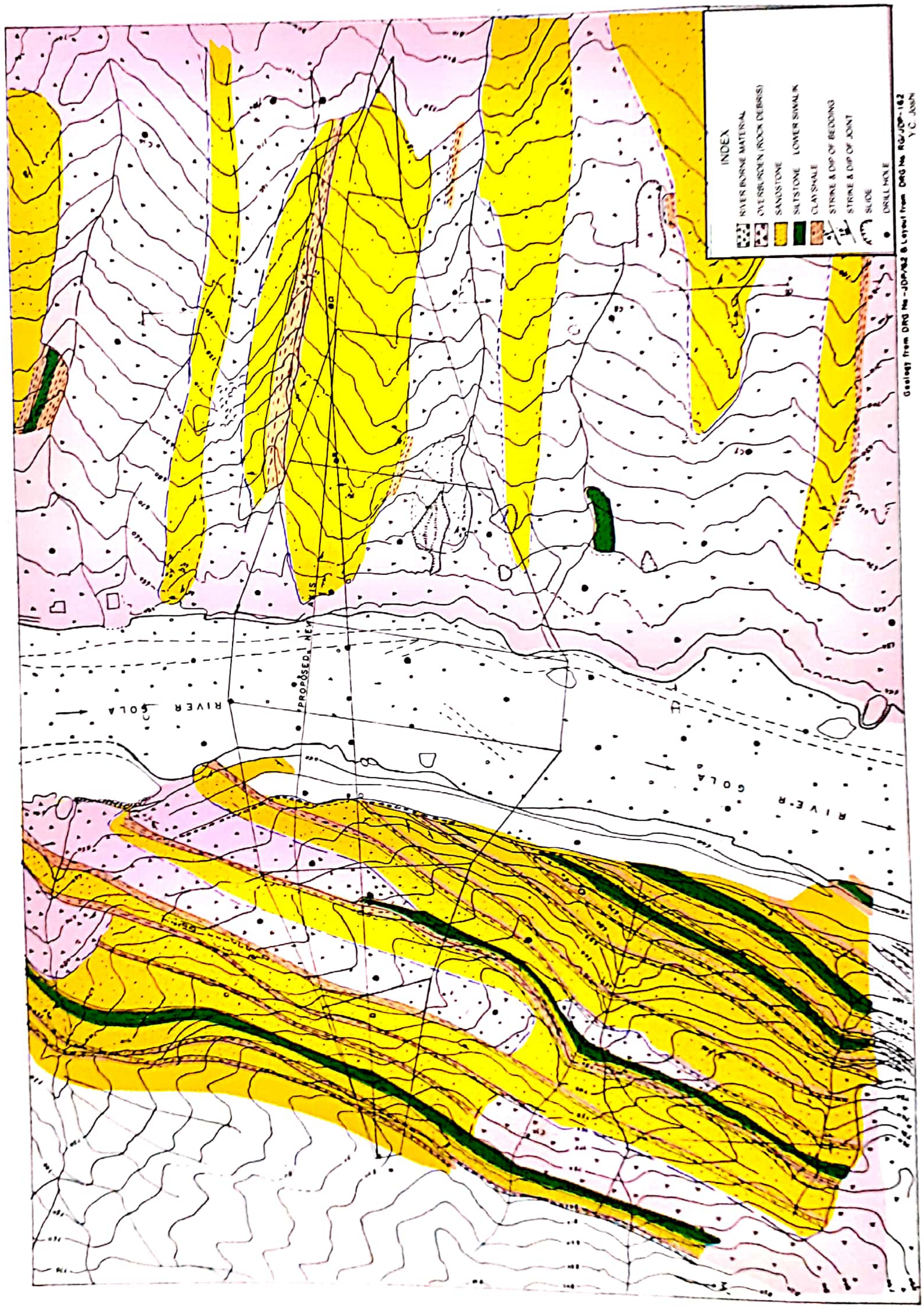


Plate IV

JAMRANI DAM PROJECT NAINITAL DISTT, UTTARANCHAL PLAN SHOWING LAYOUT OF DAM, LOCATION OF BORE HOLES EXPLORATORY DRIFTS AND BED ROCK CONTOURS IN RIVER SECTION

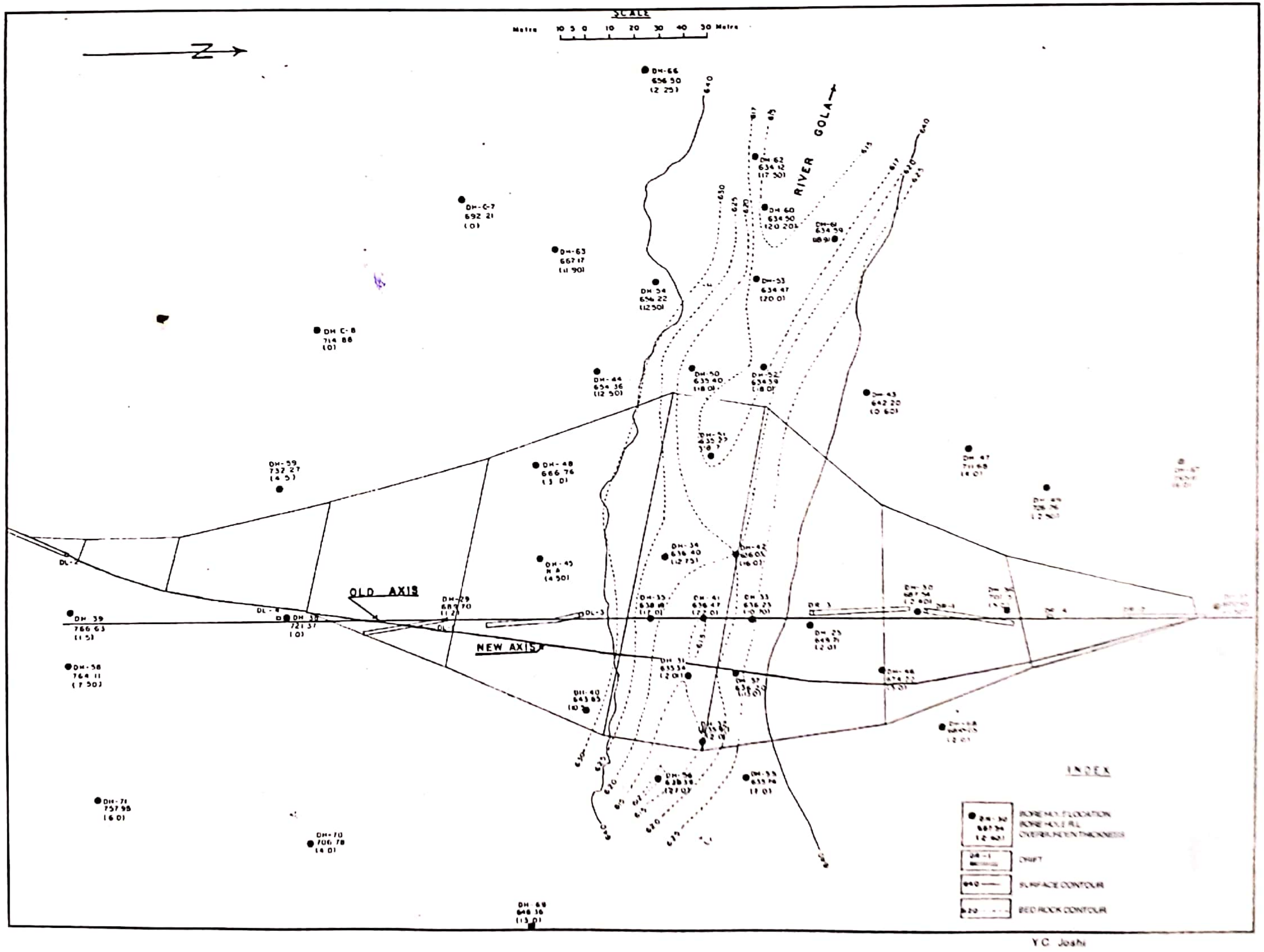
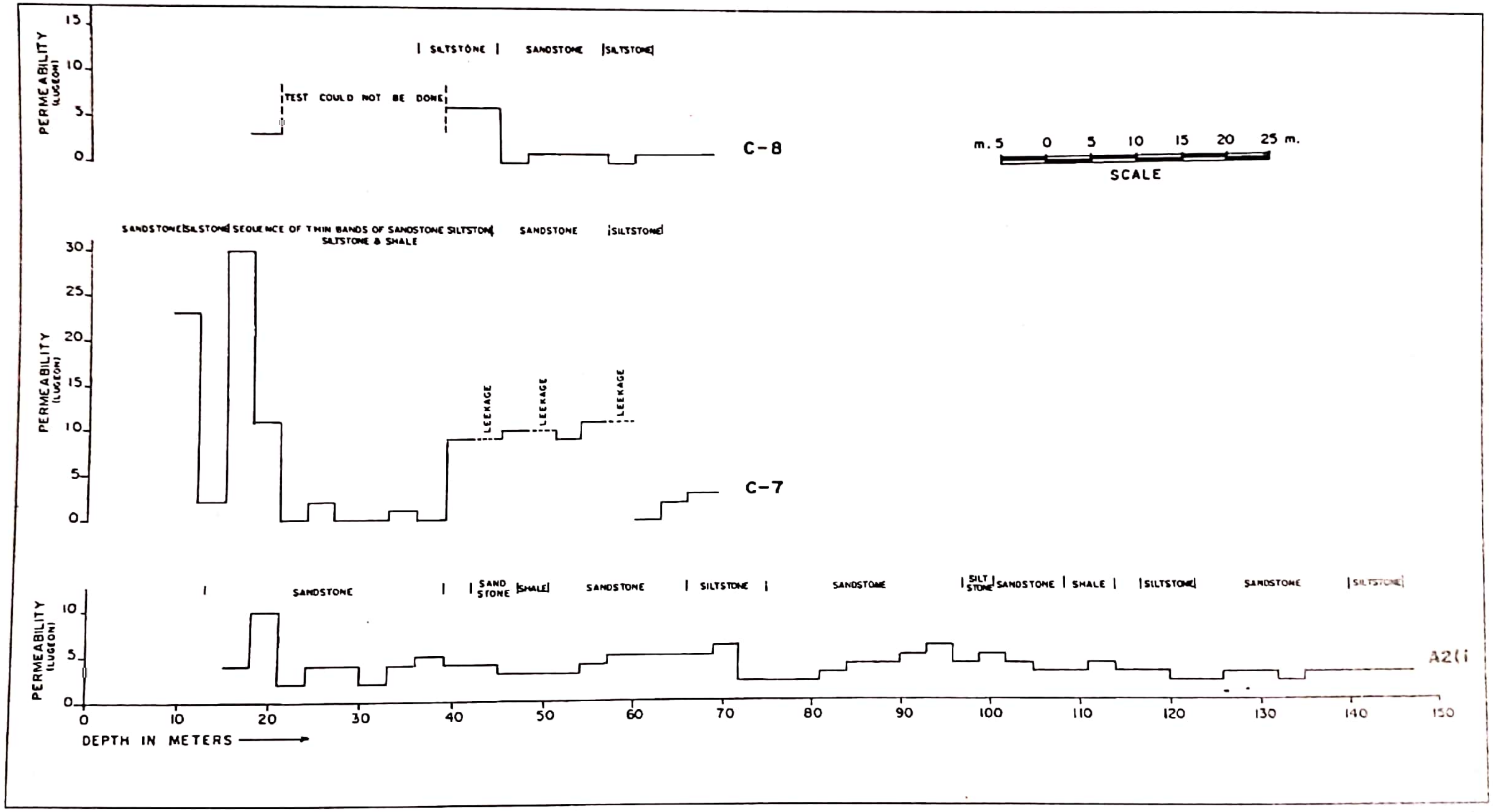


Plate V

JAMRANI DAM PROJECT, DISTRICT NAINITAL, UTTARANCHAL
PERMEABILITY CHARACTERISTICS OF VARIOUS ROCK TYPES ENCOUNTERED IN BORE HOLES



Y.C. Joshi
Geological Survey of India

Plate VI

JAMRANI DAM PROJECT

EARTHQUAKE EPICENTRES AND PRINCIPAL TECTONIC FEATURES WITHIN 200 KM. RADIAL DISTANCE OF THE DAM SITE

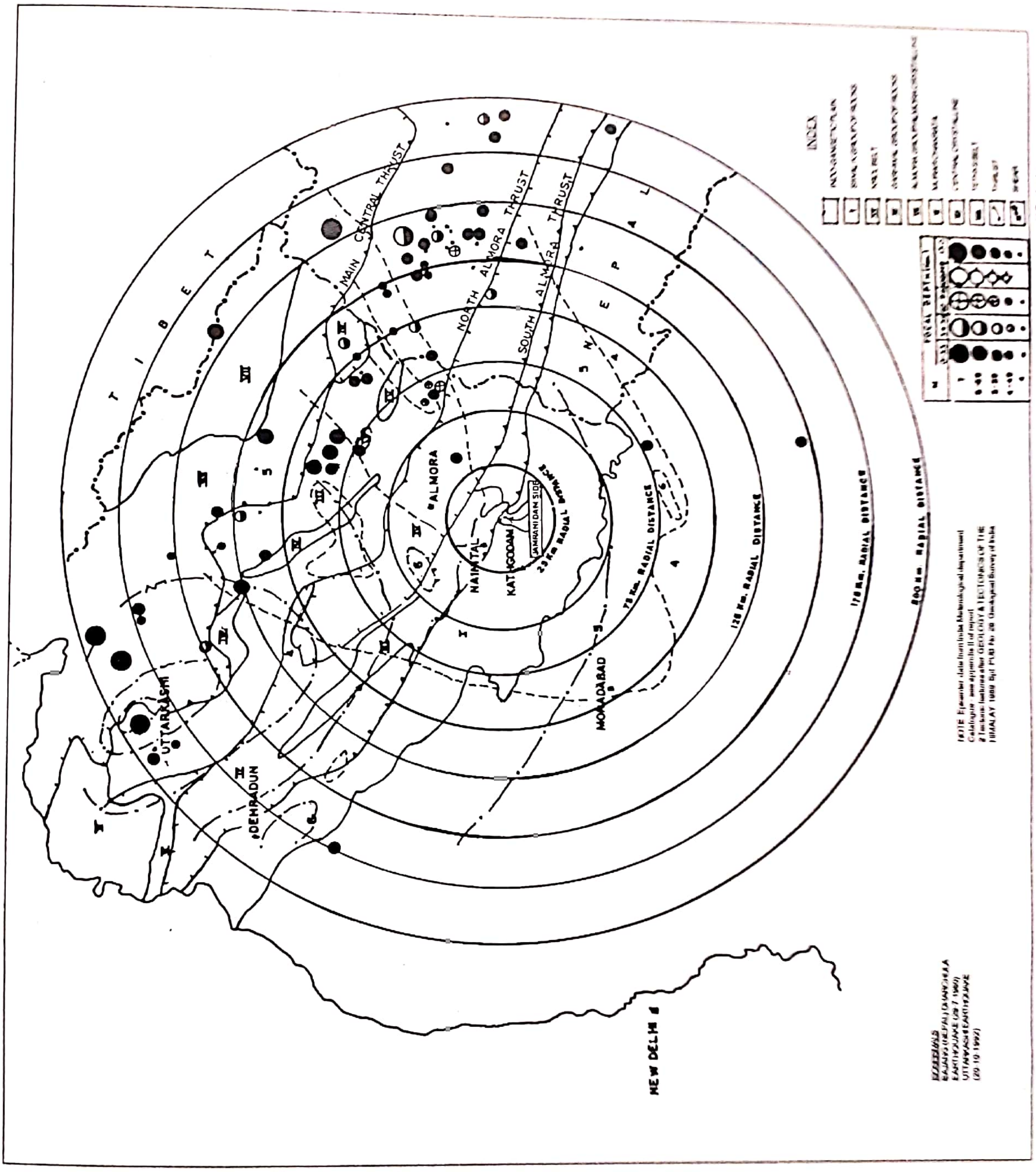


Plate VII
JAMRANI DAM PROJECT
GEOLOGICAL MAP OF THE RESERVOIR AREA

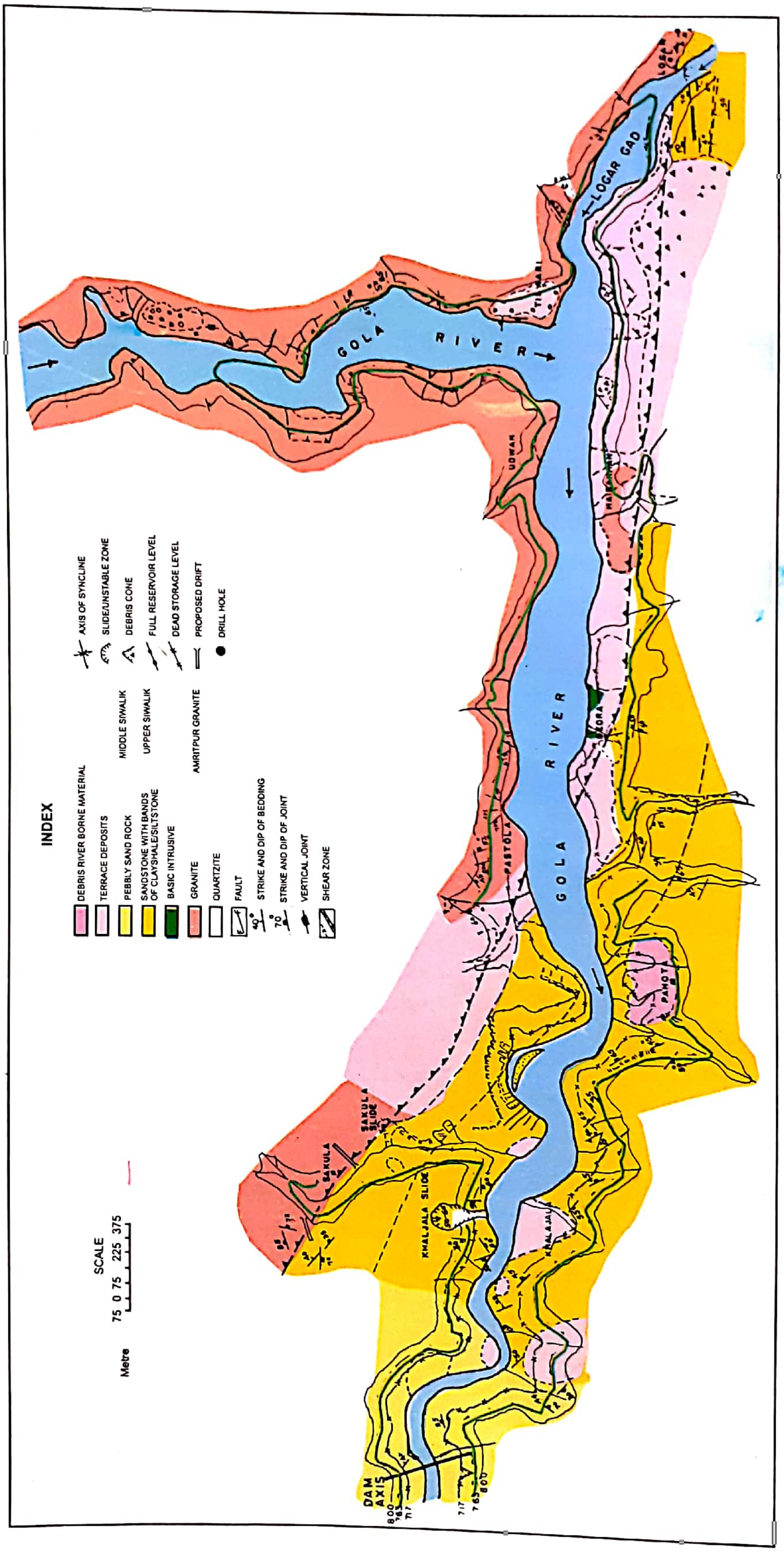


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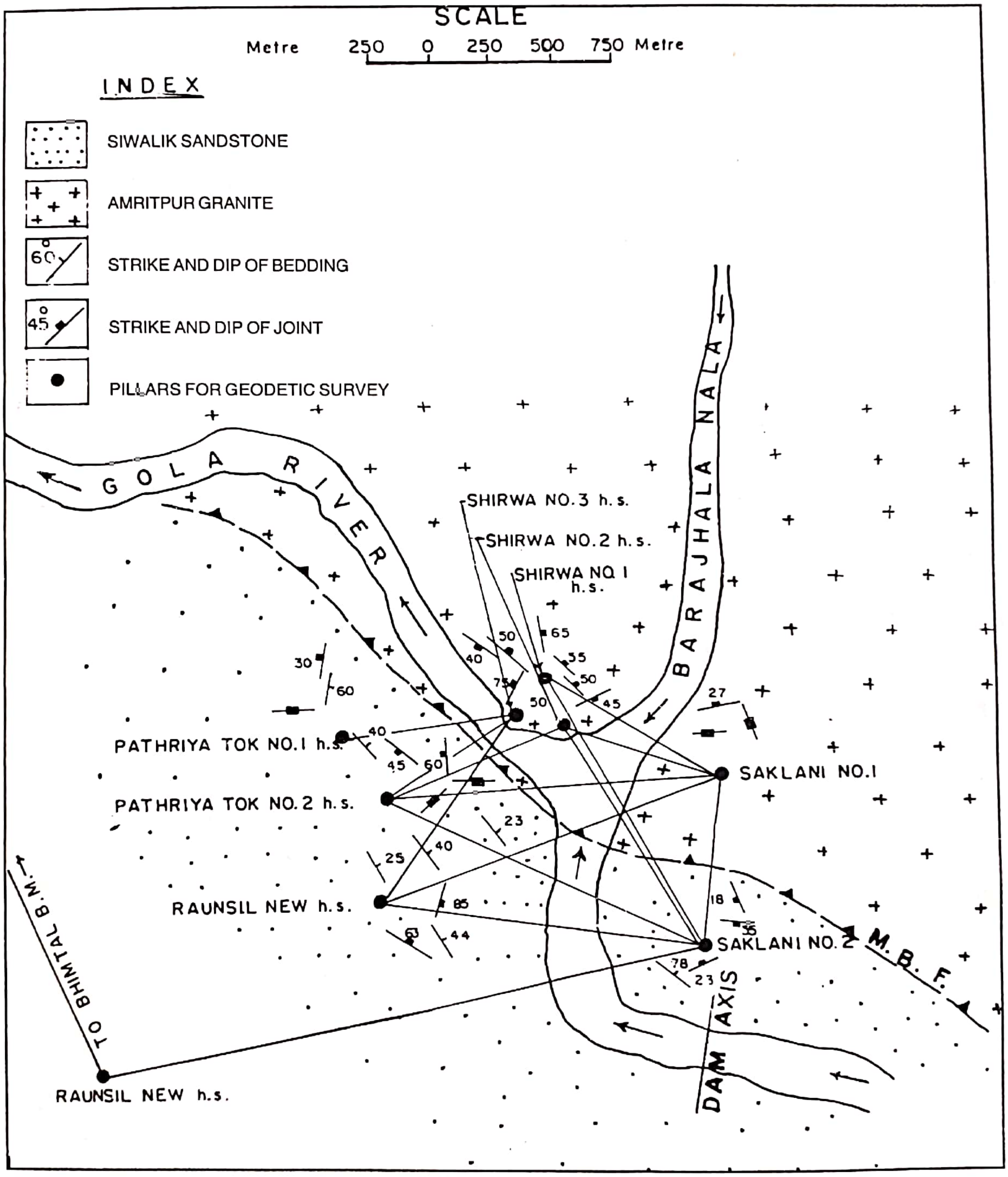
Plate VIII

JAMRANI DAM PROJECT NAINITAL DISTRICT, UTTARANCHAL
LOCATION MAP OF PILLARS ACROSS MAIN BOUNDARY FAULT
DOWNSTREAM OF DAM FOR PRECISION MEASUREMENT OF LEVELS



SUSHIL KUMAR
V.K. SHARMA

Y.C. Joshi

Plate IX

JAMRANI DAM PROJECT NAINITAL DISTT, UTTARANCHAL

GEOLOGICAL SECTION ALONG THE PROPOSED DAM AXIS (STRAIGHT)

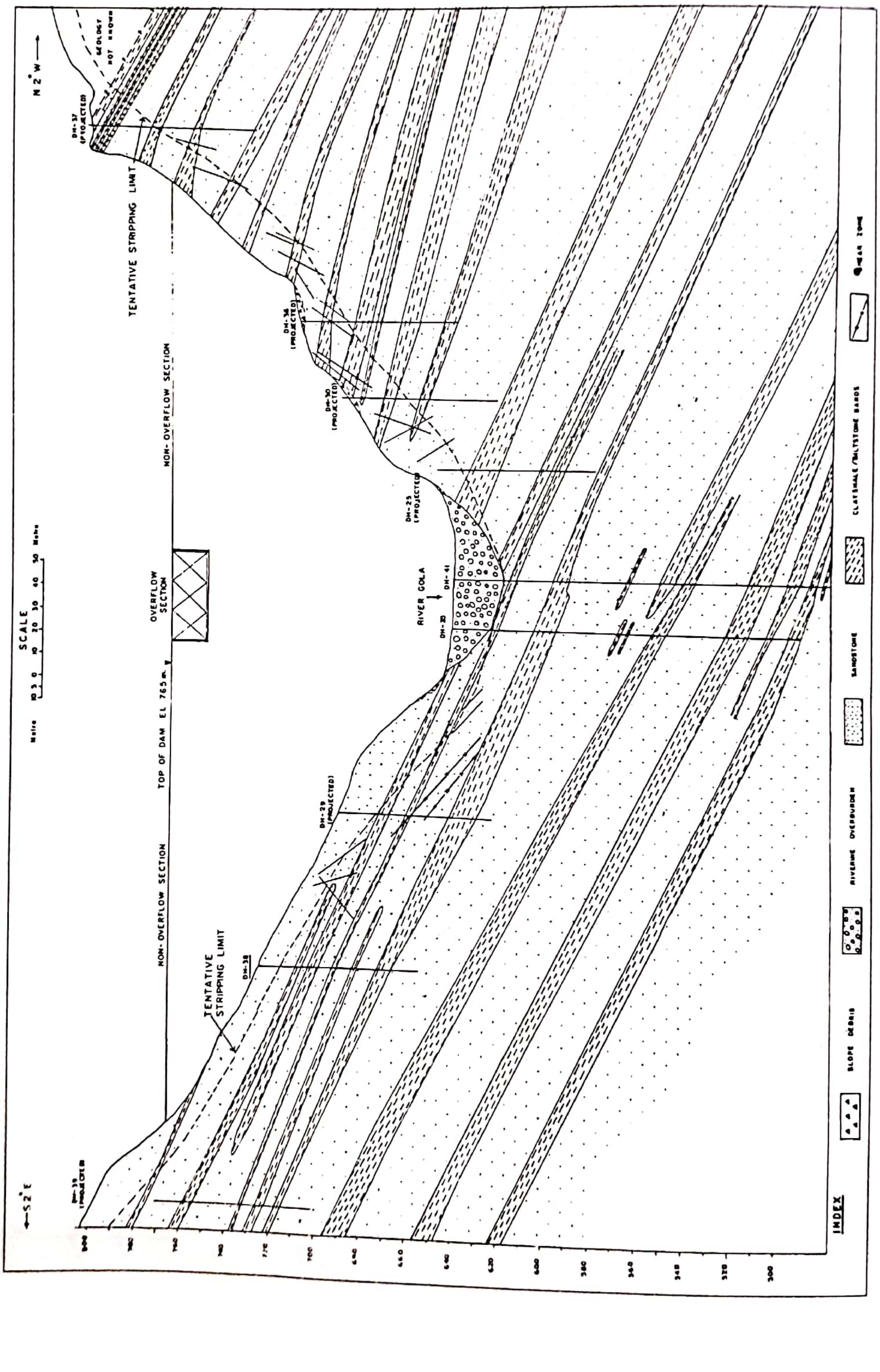


Plate X

JAMRANI DAM PROJECT NAINITAL DISTT, UTTARANCHAL
GEOLOGICAL CROSS SECTIONS ALONG AB, CD, AND EF ON LEFT ABUTMENT, RIVER BED AND RIGHT ABUTMENT RESPECTIVELY

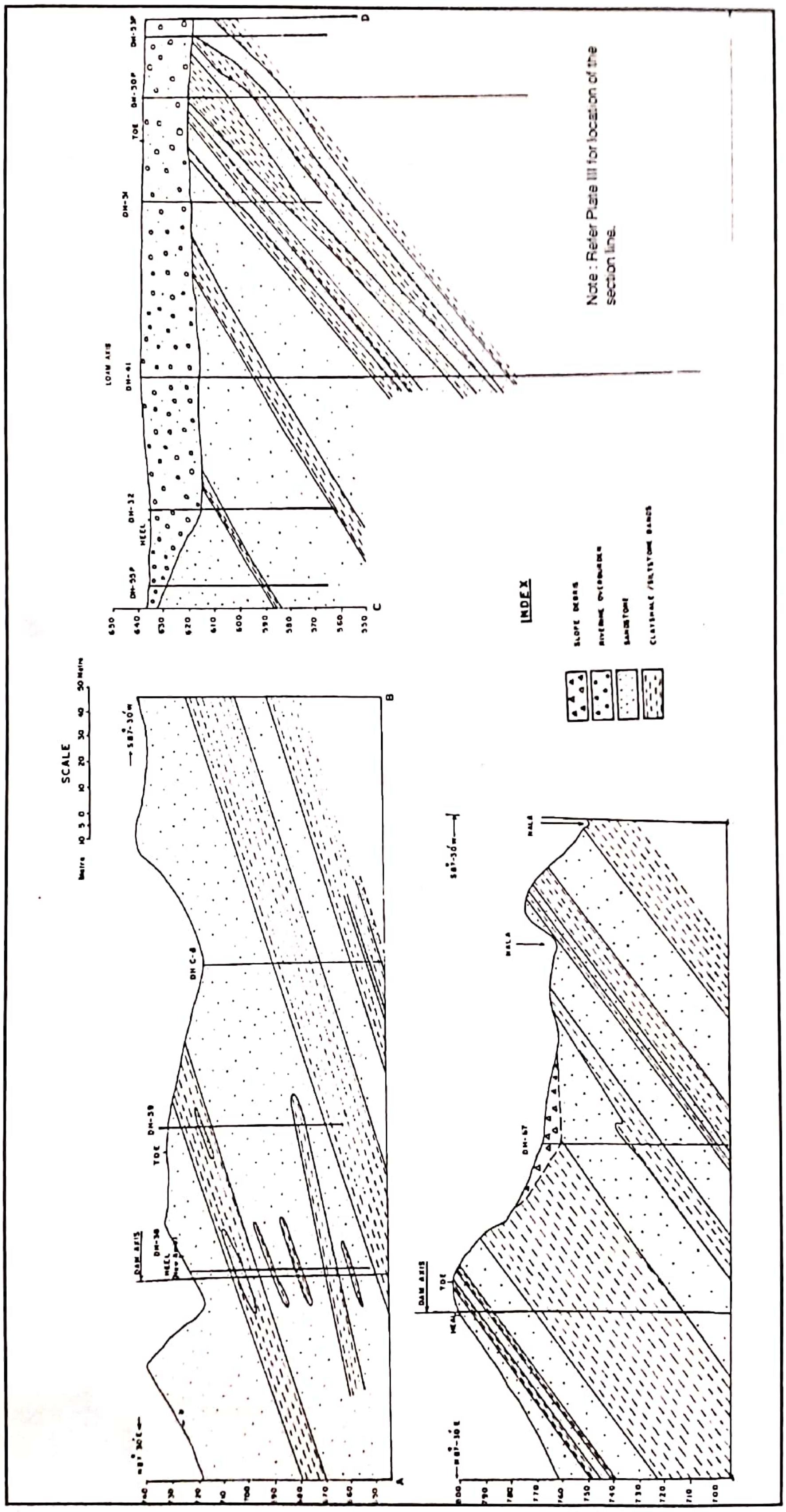


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Plate XI
JAMRANI DAM PROJECT
PROJECTED GEOLOGICAL PLAN AT AN ASSUMED FOUNDATION GRADE
(RL. 610 m)

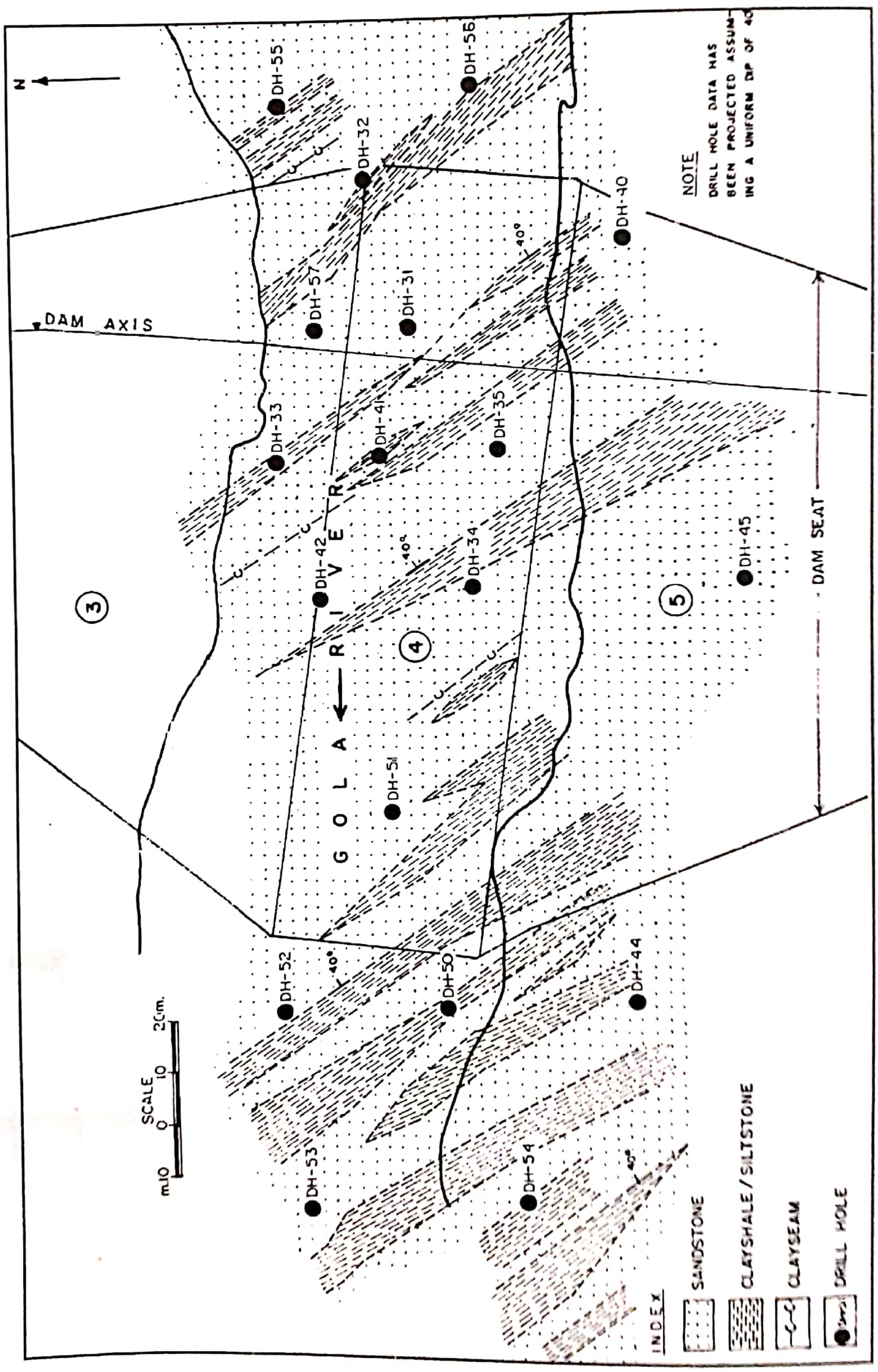
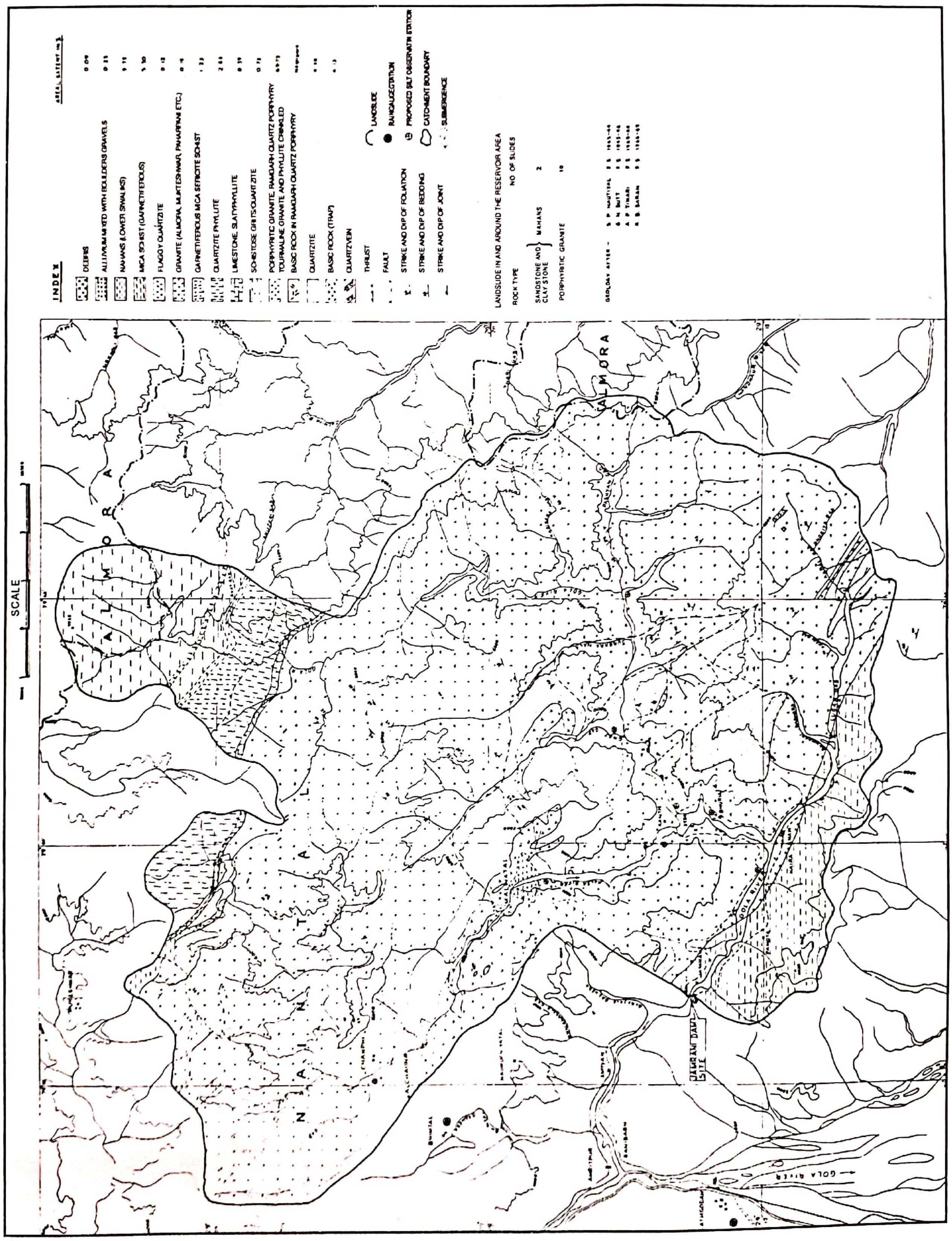


Plate XII

GEOLOGICAL MAP OF THE CATCHMENT AREA OF THE PROPOSED JAMRANI DAM, DISTRICT NAINITAL



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