HYDROCHEMISTRY OF MELTWATERS DRAINING FROM BARA SHIGRI GLACIER LAHUL VALLEY, HIMACHAL PRADESH

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KAILASH CHANDRA DALABEHERA

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI 110 067, INDIA
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C E R T I F I C A T E

The research work embodied in this dissertation entitled " HYDROCHEMISTRY OF MELTWATERS DRAINING FROM BARA SHIGRI GLACIER, LAHUL VALLEY, HIMACHAL PRADESH" has been carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work is original and has not been submitted in part or full for any other degree or diploma for any University.

(K.C. Dalabehera)

Candidate

(Prof. L.K. Pande)

(Dr. S.I. Hasnain)

Dean, SES

Supervisor

Prof. L. K. PANDE
Dean
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi-110067.

JAWAHARLAL NEHRU UNIVERSITY
New Mehrauli Road
New Delhi - 110 067

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INTRODUCTION

Himalayas, the worlds mightiest mountain system, has wide altitudinal range and diverse orientation. Himalayas, the abode of eternal snow, are the largest store house of snow and glaciers outside the polar regions. These glacier masses are unique for being nursed in the steep and highest valleys of the world and they feed all the major north Indian rivers. About 2.6 percent of the mountain catchment of the Himalayas is covered by the glaciers and snow fields, which in summer seasons, on melting, keeps the Himalayas river system perennial.

Role of meltwater:

The water from glaciers and snow masses is important and at times critical to processes which control erosion, water quality and sedimentation. Water can usually exist only in the glacial environment when the temperature is close to melting point. Water, especially when charged with solutes, is thermodynamically unstable. Water is also of primary importance to glacier flow, both by creep and basal sliding. The flow of melt water at bed, at times with high velocity and under great pressure causes

significant mechanical erosion with the production of channels and potholes. Meltwater also plays an important role in flushing chemical impurities through the glacier, while at the sole i.e. the lower most part of the glacier where it touches the bed rock, channels in contact with bed and the crushed particles allow chemical exchange and ionic enrichment. The meltwater composition is of importance and interest from several viewpoints. Besides chemical weathering beneath the Alpine glaciers the channel analyses of meltwaters from Glacier d' Argentiere, French Alps show the enhanced solutional activity in winter (Vivan and Zumstein, 1973). The reason for the relatively high concentration of solutes in winter may be the existence of subglacial ground water systems. The hydrochemical characteristics of water derived from a particular environment is different from the other. Exact characterisation of hydro chemistry of certain environment is, however, difficult since water from other sources is often present. However, the difference in ionic concentration in the meltwater, its cause and relation with the environment can be studied. According to Church (1974) in Baffin Island, increasing glacierisation of catchments appears to be associated with increased concentration of dissolved materials,

some derived from the ground environment around and under the ice, and some from suspended sediments.

The solute and suspended load in the runoff from mountain catchments,can be investigated for the assessment of the role of meltwater in the subglacial environment. Water passing through the catchment, drains through a range of lithological environment, the rate and mechanism of solute release are different for different ranges. The solute load of a stream draining from the glacierised catchment, also, reflects the chemical, lithological and climatological environments of the area concerned. The solutes in the melt water can assess the chemical erosion within the glacial environment. The suspended sediment plays an important role in the mineralogical and chemical composition of meltwaters. There is a high correlation between sediment yield and runoff, the correlation coefficient being 0.98 (J.Bahadur).

Objectives:

For studying the glacial hydrochemical processes of a Himalayan glacier, Bara Shigri, Lahul Valley, Himachal Pradesh was chosen. This glacier is transverse type, according to the classification of

Mason (1930).   Samples of Bara Shigri glacier meltwater, during the ablation period were collected and analysed.

The present study aims to provide:

a) hydrochemical characteristics of the meltwater,

b) the approximate assessment of solute concentration during the sampling period,

c) the total suspended load concentration and chemistry,

d) mineralogy of the suspended sediments,

e) grain size distribution of the bed sediments,

Importance :

Meltwater from the glaciers act as natural resource for the supply of water to the 19 major Indian rivers, constituting about 70 percent. The presence of snow and glaciers is very much important. Studies on Himalayan glaciers (Bahadur,J.) show that the total annual precipitation is poorly related with the elevation. The ratio of rainfall to snowfall decreases with increase in the elevation. But the water yield increases with the increase in the percentage of glaciated area, ranging from 0.95 m.to 2.16 m. for 14% to 72% of glacier cover in the catchment. The studies on glacial hydro-geochemical processes is important for

delineating the geology, the hidden treasure of ore deposits, glacial erosion and sedimentation etc. of the area. For a better knowledge on the mechanisms of chemical denudation , it is important to study the solutes in the runoff and the different environments of solute origin. The hydrological characters, i.e. water velocity, turbulence, suspended and bed load sediments etc., of the meltwater streams are important for the management of hill-side dams and reservoirs. Again, the Himalayan mountain system and its environment has a dominating influence on the meteorological conditions of Indian sub-continent. Yet the Himalayan snow and glaciers, the vast potential for resource development in India, where the present status of research and investigation is still in its infancy.

REVIEW OF LITERATURES

1.1 Introduction:

The role of hydrochemistry in glacier environment is important and at times critical to processes which control erosion and sedimentation. About 80% of the hydrosphere is contained by the oceans, 19% is in the rocks and sediments, 1% is in the form of ice sheets and glaciers, 0.002% is in the streams and lakes and rest is in the atmosphere (Garrels and Mackenzie, 1971). Out of this small percentage of earth's fresh water reserve, approximately 80% is in the from of snow and polar ice caps covering an area of 29 x 10^6 Sq. Km. The very small fraction of meltwater, coming from the ice sheets and the glaciers of the hydrosphere, has various functions i.e., helps in the glacier flow, both by creep and basal sliding (Duval 1979, Weertman). The flow of meltwater causes significant mechanical erosion under great pressure and high velocity.

1.2 Sediment and Chemical load in Glacial meltwater:

The chemical analysis of glacial meltwaters collected at the discharge site of the glacier terminus, show their richness in dissolved chemical species, which is indicative of effective hydrochemical

Table 1.1

Average suspended sediment discharge by continents.

Continents	Suspended sediments (t/Km2 /Yr)	Discha (10 t
Africa	27	0.5
Asia	600	16.1
Australia	45	0.2
Europe	35	0.3
North America	96	1.9
South America	63	1.2

Gregory and Walling (1973)

Table 1.2

Erosion rates for the continents

Continent	Load (10 t/yr)			Rate (t/km2 /yr)		
	Chemical	Sediment	Total	Chemical	Sediment	Total
Asia	1490	14500	15990	32	302	334
Africa	710	490	1200	24	16	40
Europe	460	250	710	42	23	65
Australia	20	210	230	2	21	23
North America	700	1780	2480	32	85	117
South America	550	1100	1650	28	56	84
Continental earth	3930	18300	22230	23	108	131

Garrels and Mackenzie, 1971.
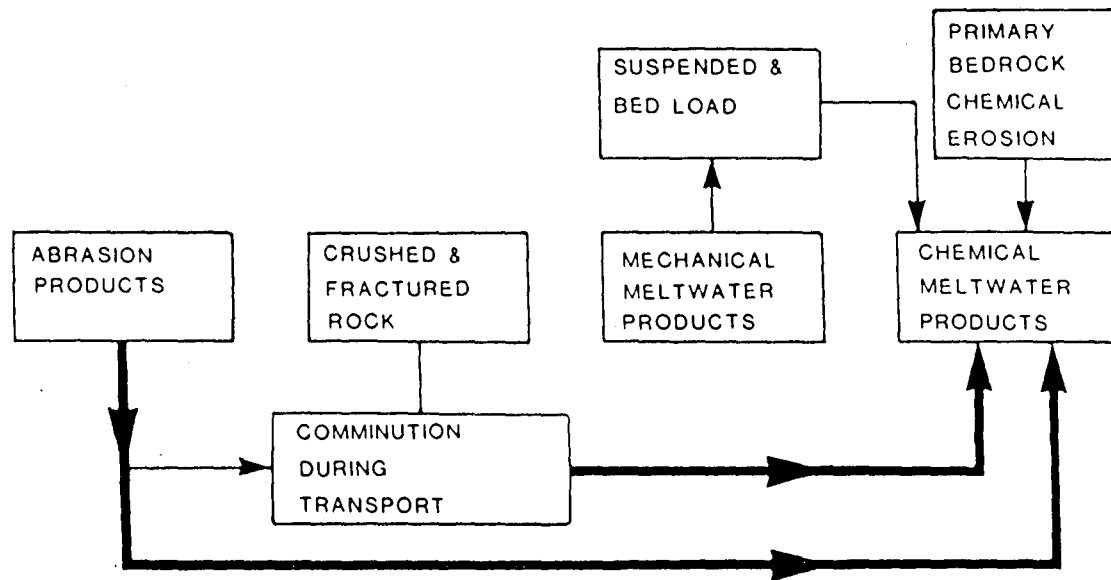
Figure 1.2 Flow chart indicating the multiple sources of and interactions between the sources contributing chemical products to glacial meltwater.

reaction within the glacial environment. Both dissolved and suspended load in the glacial meltwater are the byproduct of chemical denudation. Regarding the chemical composition of material transported in solution Mayback says that 80% of the dissolved load in the fresh water systems is generally made up of just four components (HCO_3, SO_4, Ca^{2+} and SiO_2) with a number of lesser constituents, constituting the remainder. Among these four Ca^{2+} and HCO_3 represent the dominant cation and anion respectively in most fresh water systems.

There are three major mechanisms controlling world surface water chemistry which can be defined as atmospheric precipitation, rock dominance, and the evapo-crystallisation processes (R.J.Gibbs). In glacierised catchments the meltwater quality is determined by chemical composition of ice and snow resulting from atmospheric influences and also by terrestrial factors (Collins,1979). Although detailed studies of geochemistry of glacial meltwaters are limited, sufficient determinations exist to indicate some general trends and that the apparent rate of denudation by glacial waters is highly significant in the order of 50-70% of the world average chemical

Table 1.3

Chemical compositon of rain and snow on ice sheets and glaciers.

S.No	Glacier	Ref	Na	K	Ca	Mg	Sio2	HCO3	So4	Cl.
1.	Rainfall									
	Chamberlin, Alaska	1	300	100	700	100	-	5000	400	0
	Berendan, Bc.	2	65	52	600	24	-	-	-	950
	S.Cascade, Washington U.S.	3	90	39	60	12	-	-	-	-
2.	Snow fall									
	Byrd station , Antarctica	4	31	1.5	1.5	4	-	-	-	60
	Green land	4	21	2.1	5.4	5	-	-	-	31
	Mizuho Platean, Antarctica	4	140	1.2	2.8	2.1	-	-	-	-
	South Pole	4	3	8	8	6	-	-	-	1
	South Cascade Washington	3	51	0	100	0	-	-	-	-
	D-10, Terre Adelic Antarctica	5	439	14	12	16	-	-	94	646

Ref:-1. Rainwater and Guy (1961)   2. Eyles et,al. (1982)
     3. Reynolds and Johnson (1972)   4. Morozum et,al. (1978)
     5. Delmas et,al. (1982)

Table 1.4 Chemical composition of glacial meltwater ($\mu g\, l^{-1}$)

Glacier	Ref.	Na	K	Ca	Mg	SiO$_2$	HCO$_3$	SO$_4$	Cl
Chamberlin Creek, Alaska	1	0.15	0.10	4.00	0.80	0.35	10.5	8.20	0.45
Gorner, Swizerland	2								
Superglacial		0.20	0.24	0.46	0.08				
Gornera		0.34	0.61	4.37	1.00				
Berendon, BC, Canada	3								
Superglacial		0.01	0.02	1.97	0.04	0.15			0.91
Subglacial		0.10	0.11	8.55	0.13	0.21			0.93
Matanuska, Alaska	4	1.30	0.40	9.20	0.75	1.20			
Castner, Alaska		1.25	1.10	20.00	5.10	0.80			
Norris, Alaska		2.40	0.75	0.65	0.80	0.55			
Emmons, Washington, US	5	1.51	0.85	2.10	0.40	8.00			
Nisqually, Washington US	5	1.54	0.57	2.07	0.74	4.28			
Rhone, Switzerland	5	0.34	0.95	4.10	2.56	1.14			
Boverbreen, Norway	5	0.16	0.38	0.70	0.08	0.48			
Taylor, Antarctica	5	6.90	1.14	17.90	0.94	0.20			
Wright, Antarctica	5	2.14	0.40	0.00	0.09	0.20			
Grindelwald, Switzerland	5	0.22	0.62	17.50	0.53	0.66			
S. Cascade, Washington, US	6	0.29	0.88	3.00	0.39	1.50	9.20	2.40	0.25

Refs.
1 Rainwater and Guy (1961)
2 Collins (1979b)
3 Eyles et al. (1982)
4 Slatt (1972)
5 Keller and Reesman (1963)
6 Reynolds and Johnson (1972)

denudation [(i.e., 27 gm^{-2} a^{-1}) Livingstone,1963]. Raynold, Noye, Johnson (1971) say that the cationic denudation of South Cascade glaciers watershed (930mE/m^2 yr) is substantially higher than the world average, (390mE/m^2 yr) Slatt (1970). Rainwater and Guy (1961) and Keller and Reesman (1963) have reported significant quantities of dissolved solids in glacial meltwater streams.

The solute enrichment may also take place by the exchange of ions adsorbed on the surface of particles, during flow over and through the clay minerals. The clays usually possessing negative electrical charges attract the cations present and then the reaction between the cations easily takes place in the meltwater. The most important reactions in meltwater involves monovalent and divalent cations :- $Na^+-->Ca^{2+}$, $Na^+--> Mg^{2+}$, $K^+--->Ca^{2+}$, $K^+->Mg^{2+}$. This ionic exchanges are well demonstrated by the experiments of Lemmens and Roger (1978). Fig 1.1 . Potassium is adsorbed much more strongly then Na^+. Lorrain and Souchez (1972) have shown that a significant quantity of principal cations in meltwater may be adsorbed on the surface of sediment particles in suspension. He found the ratio of absorbed cation to dissolved cations, for water from Moiry glacier Switzerland, to
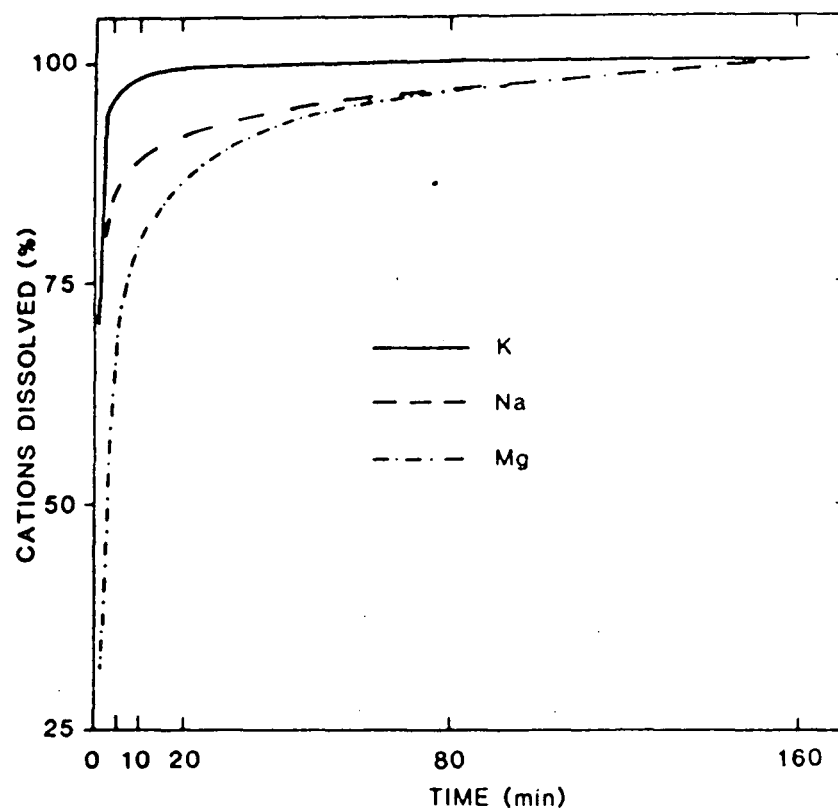
Figure 1.1 Experimental determinations of the rapid chemical enrichment of glacial meltwaters after contact with fine-grained till materials (from Lemmens and Roger, 1978).

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upto 30%   Similarly, studies by Collins (1979b) and
Eyles et,al. (1982) confirm the ionic exchange between
melt water and suspended particles.   The quantity and
variety of constituents reflect the geological setting
traversed by the meltwater and physical and chemical
processes involved in the erosive processes (Drewry-
1986).

On studying various Alpine glaciers, Rainwater and
Guy (1961), Collins (1979), Behren et,al.(1971, 1975)
and Elliston (1973) have divided the total flow in two
subdivisions, one being, water passing through the
subglacial channels having ground environment and the
other meltwater running off rapidly by englacial
channels, without undergoing chemical change.

The total mass of material eroded per unit area
from the glacier bed may be expressed as:

$$Y = a (M_a + M_c + M_m + M_g) \, da$$

Where M_a = Mass of material eroded by
abrasion.

M_c = Mass of crushed and fractured
material.

M_m = Mass of material removed by
meltwater erosion.

M_g = Mass of chemical substances
resulting from meltwater erosion.

Table 1.5 Estimated subglacial erosion rates for selected glaciers based upon measurement of suspended sediment transport

Glacier	Mean erosion rate $[mm\ a^{-1}]$	Source
Muir, Alaska	19 0	Reid (1892)
Muir, Alaska	5 0	Corbel (1962)
Hidden, Alaska	30 0	Corbel (1962)
Engabreen, Norway	5 5	Rekstad (1911-12)
Storbreen, Norway	0 1	Liestøl (1967)
Heilstugubreen, Norway	1 4	Corbel, (1962)
Hoffellsjökull, Iceland	2 8-5 6 (max)	Thorarinsson (1939)
Kongsvegen, Svalbard	1 0	Elverhoi et al (1980)
St Sorlin, France	2 2	Corbel (1962)
Imat, USSR	0 9	Chernova (1981)
Ajutor-3, USSR	0 7	Chernova (1981)
Fedchenko, USSR	2 9	Chernova (1981)
RGO, USSR	2 5	Chernova (1981)

$$a = \text{Area of glacier bed.}$$

$$Y = \text{Mass per unit area/time.}$$

Investigations based on the long term measurement of sediment and solute transport by meltwater from glaciers give brief and good idea of total erosion. Ostrem et,al. (1975 to 1982) having measured the annual sediment yield from a number of glacier basins in Norway derive the average erosion rate to be between 0.07 and 0.61 mm/area.

Chemical denudation in glacial environment is substantially more potent. The transport of dissolved salts is the more important factor in mass loss yielding 26 tonnes $Km^{-2} a^{-1}$, equivalent to a surface lowering of 0.01 mm. a^{-1}, Rapp (1960). Studies on geochemical denudation for the Berendon glacier basin in British Columbia, Canada, derived at 1050 ME $m^{-2}a^{-1}$, about 2.5 times the approximate world average denudation rate (equivalent to 0.25 mm. of surface lowering per year (Eyles et,al) 1982.

1.3 Previous works on Himalayan Glaciers:

Present day Himalayan glaciers occupy an area of 14.9 million km^2. (10% of the worlds land area). The Central Asian Mountain glaciers cover an area of over

one million km^2 and out of this over 50,000 km^2 of the areas is covered by Himalayan glaciers. There are 22 major river systems originating from Himalayan glaciers having their mountain catchment area of over 10 million km^2. (J.Bahadur 1987).

It has been observed that the river discharge of Himalayan snow fed river of a unit area is roughly twice that of peninsular rivers of South India (J.Bahadur 1987). This is mainly due to perennial contribution from snow melting and glacial drainage.

Although different other aspects i.e. survey of glaciers (H. Walker and Pascoe, 1906) morphological studies, geological and mineralogical studies on Himalayan glaciers have been studied, since few decades back, the hydrochemical works on meltwater draining from glacierised basins in the Himalayas has been undertaken only two years ago by Hasnain and others. Working on Chhota Shigri glacier, Lahul valley, Hasnain et,al.(1987) report that at low flows the meltwaters are highly enriched in solute concentration which maybe due to the chemical weathering beneath the glaciers and at high flows with low solute content. Collins (1979a) reports that, the daily sediment concentration maxima are both before and after the water discharge peak and

TABLE - 1.6
Principal Glacier Fed River Systems Of Himalaya

Sl. No.	Name of River	Major River System	Mountain Area (Km^2)	Glacier Area (Km^2)	Percentage glaciation
1.	HINDUS		268,842	8790	3.3
2.	JHELUM		33,670	170	5.0
3.	CHENAB	INDUS	27,195	2944	10.0
4.	RAVI		8,029	206	2.5
5.	SUTLEJ		47,915	1295	2.7
6.	BEAS		14,504	638	4.4
7.	JUMNA		11,655	125	1.1
8.	GANGA		23,051	2312	10.0
9.	RAMGANGA	GANGA	6,734	3	0.04
10.	KALI		16,317	997	6.01
11.	KARNALI		53,354	1543	2.9
12.	GANDAK		37,814	1845	4.9
13.	KOSI		61,901	1318	2.1
14.	TISTA		12,432	495	4.0
15.	RAIKAD	BRAHMA PUTRA	26,418	195	0.7
16.	MANAS		31,080	528	1.7
17.	SUBANSIRI		18,130	725	4.0
18.	BRAHMAPUTRA		256,928	1080	0.4
19.	DIBANG		12,950	90	0.7
20.	LUHIT		20,720	425	2.01
	TOTAL		1,001,294	25724	2.6

the highest water discharge are accompanied by sediment concentration minima. Drewry (1986) says that the hydraulic factors responsible for pronounced variations in the concentration and discharge of sediments in the meltwater are (a) very high stream velocity (due to strong pressure gradient) (b) marked discharge variation (both seasonal and diurnal) and increased water viscosity due to low temperature . According to Millman (1980) the natural factors controlling the suspended load of rivers are, (a) relief of the drainage basin, (b) area (c) amount of discharge, (d) geology of the drainage basin (e) climate etc.

AREA OF STUDY

2.1 Location and accessibility:

Bara Shigri glacier is situated in the Central Himalayan ranges and lies in the Lahul Spiti district, Himachal Pradesh, forming a part of toposheet No.52 H/12, between the latitude 32° 8' N to 32° 18' N and 77° 32' E to 77° 49' E.

The Kaza-Manali road across the Rohtang pass (13,050 ft.) provides accessibility to the area, through Bara Shigri as such has no direct road connection.

2.2 Physiographic Setting:

Bara Shigri the very name indicates the " boulder covered ice" flows north wards and debouches into the Chandra river where its southerly course is deflected westwards close to Spiti border. This is the largest glacier in the Lahul valley, Bara meaning big and Shigri meaning glacier in Lahul dialect. The region is flanked by the Chandra river valley in the north and Pir Panjal range in the south.

Dimensions:

The glacier snout lies at an elevation of 3860 mts. and the highest point in the accumulation zone is

Dissertation

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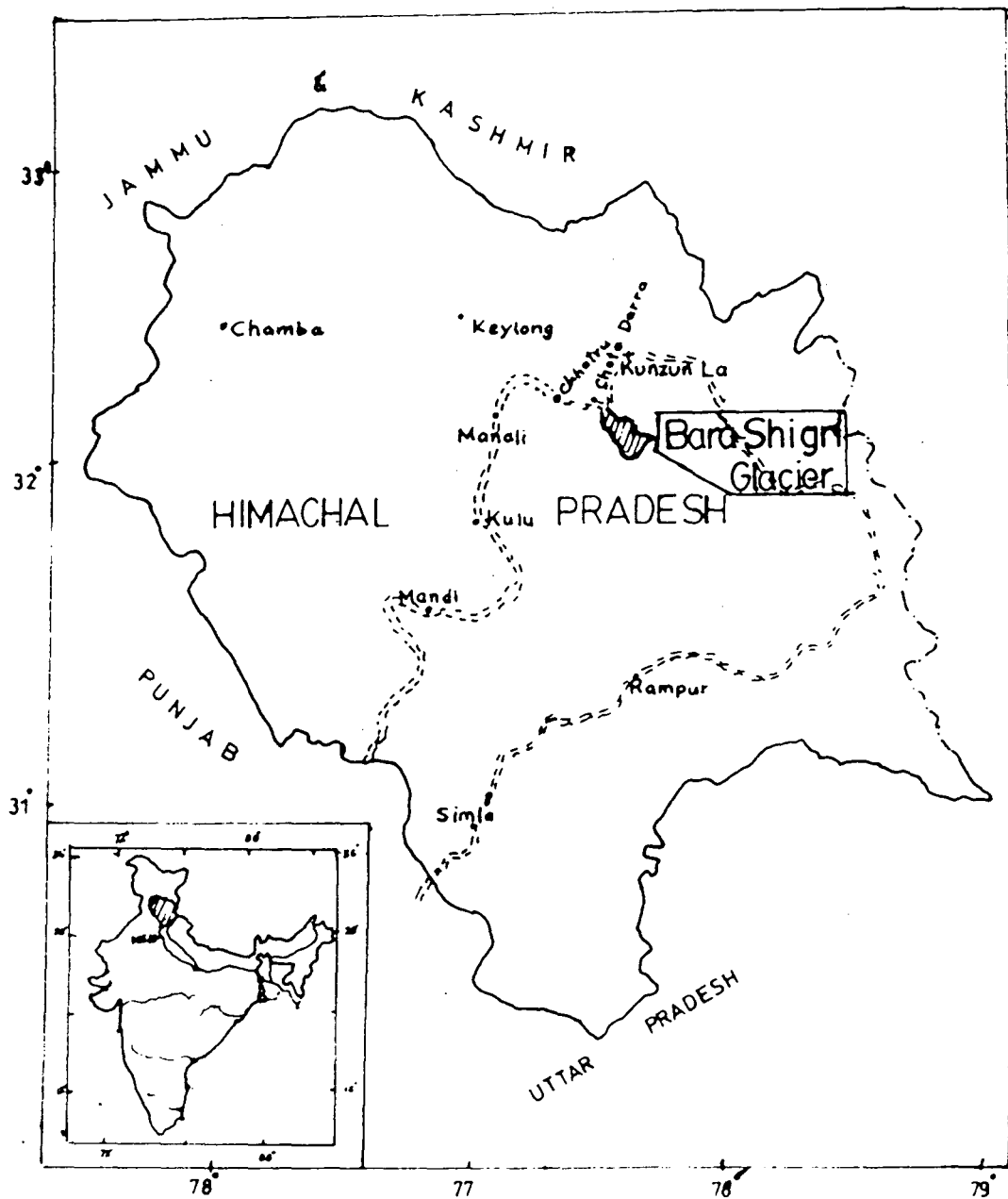
2.1   Location of Bara Shigri glacier.
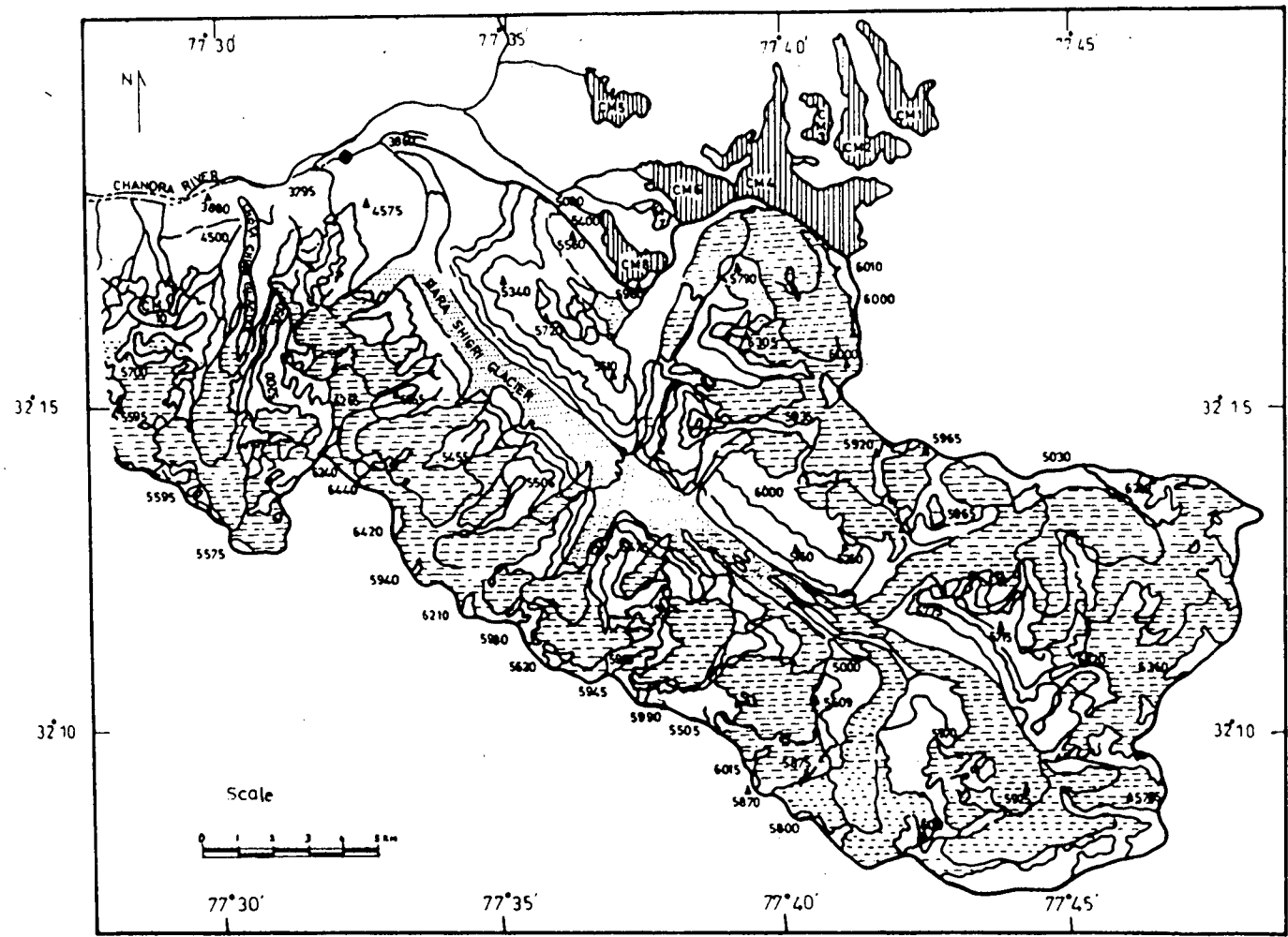
LEGEND

	ACCUMULATION AREA		PERRENIAL SNOWFIELDS / HANGING GLACIERS
	ABLATION AREA		BASIN BOUNDARY
	LAND WITHOUT GLACIER SNOW/ICE		SAMPLING STATION
			CONTOUR LINES (Height in Meters)

2.2   Physiographic map of Bara Shigri glacier.

at 6820 mts., the altitudinal difference is 2960 mts. The glacier is about 29 km. long and 11 km. wide. The total area of the glacier basin is 63.5 square kms. The glacier flows in a valley more or less uniform in width upto its confluence, and then becomes wider due to the presence of longitudinal crevasses aligned roughly along $5^{O}N$ to 25° W - $5^{O}N$ to $25^{O}E$. The source region of the glaciers starts about 12 km. South of the Shigri and the area of accumulation and ablation appear to be about 20 sq.km. and 2 sq.km. respectively. The glacier has a fall of 300m. over a distance of 2.5 km . The glacier has a steep gradient from snout upto mid-ablation zone which goes on decreasing towards south and becomes gentle in accumulation zone.

2.3 Geomorphology:

The surface topography and other topographic features in Bara Shigri glacier have been discussed here under the following main heads:

Surface topography:

The maximum area of glacier is covered by the accumulation zone. The glacier surface here,is wider near its upper and middle portions than that of the lower. The general slope of the glacier surface in

lower portion of accumulation zone is more steep towards east margin than towards the normal slope of the glacier valley. The accumulation zone of the glacier is being fed by the five main tributary glaciers, of which three are in western side. The glacier surface in ablation zone is smaller in length but much larger than the snout zone.

Drainage:

At present, the main stream emerges out of the ice cave along the western most margin of the snout at considerable pressure. The stream appears to have several interconnected channels within the glacier and, the crevasses, particularly along the longitudinal crevasses, which have facilitated the movement of the water within the glacier. During ablation period some water channels flow over the accumulation zone as well as under the surface of the ice. At the zone of ablation the channel activity is much more vigorous and all flow in the direction of valley glacier. Most of the meltwater channels flowing over the glacier surface penetrate through the various deep pits, ice holes, and ice caves and travel the whole distance up to the out let at snout by running under the surface of ice. The melt water draining from the glacier during the

ablation period is so much that at the confluence site, with the Chandra river, the Bara Shigri stream looks almost like the former.   The turbulent nature of the stream is more than the Chandra river.

Moraines:

As its name implies the Bara Shigri glacier is so heavily covered with surface moraine that ice is not visible for long stretches, except along the crevasses and in ablation areas.   The most prominent moraines in Bara Shigri glacier are the lateral moraines especially those running along the western margin of the glaciers extending from the lower portion of the accumulation up to the upper part of the snout zone.   The surface moraine varies in thickness approximately from 0.9 m. to 2 m.   They are composed predominantly of granitic rocks, but towards the right lateral parts they are mostly slates and schists. The medial moraine is dark in colour and consists predominantly of schists and slates.   Besides these moraines, several glacial drift deposits i.e. wind blown detritus, crevasses filling and fluvio- glacial deposits occur in the area.

2.4 Geological setting:

Bara Shigri glacier is situated over the Central Crystallines of Pir Panjal range of Himachal Pradesh.

GEOLOGICAL MAP OF BARA SHIGRI
GLACIER BASIN
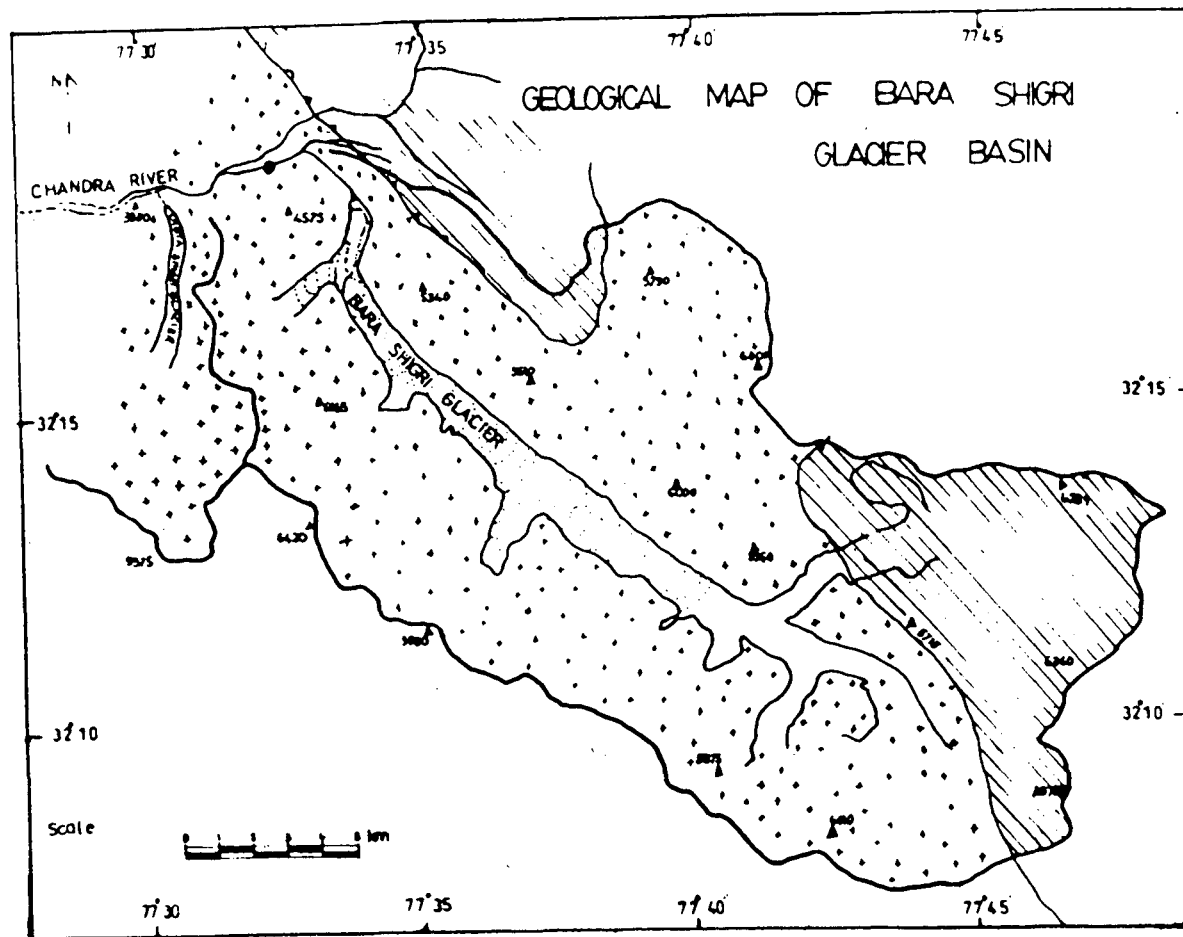
Legend:
- ROHTANG GNEISSES
- HAIMANTAS
- BASIN BOUNDARY
- SAMPLING SITE

2.3   Geological map of Bara Shigri glacier basin.

This area is considered to be the crystalline axis which is mostly made up of meso to katazonal metamorphites, migmatites and gneisses,and in places by granitic rocks of different composition and younger ages. But at some places, the eastern side of the Bara Shigri glacier,the older Paleozoic granitic rocks are exposed, over which the Haimantas rest with a tectonic break.

The rock formations that are prevalent in the glacier basin area belong to the following stratigraphical divisions:

Cambrians   Haimantas

--------------------Tectonic break --------------------

Pre-Cambrians   Higher Himalayan

Crystallines.(Rohtang

Gneissic complex).

Of the above two formations the Rohtang Gneissic Complex is the major formation covering an area of 82%.

Higher Himalayan Crystallines:

The rocks exposed in and around the glacier area are mainly composed of granitic gneisses. Augen gneiss, quartzo-felspathic granites, kyanite-schist, garnet-

biotite schist and amphibolites with intrusive granites, granodiorite and pegmatite veins.

Rohtang Gneissic complex:

This formation is widely composed of granitic gneiss, augen gneiss, kyanite schist, porphyritic granite and amphibolites. At places the rocks are associated with pegmatite and aplitic veins. The leucocratic tourmaline granites, cross-cutting the regional gneissosity , are considered to be the youngest among the Central Crystallines and are considered to be of Tertiary age. Towards the eastern side of the Higher Himalayas the rocks gradationally change to schistose composition from a gneissic one. Garnet-gneiss and garnet-biotite schist are exposed at the zone of contact between gneiss and schist. The schistose rocks consist of garnet-biotite schist, quartz-sericite schist, schistose quartzite etc. The quartz-sericite schist are of granitic parentage and later on,the process of sericitisation took place. There is also widespread occurrence of white vein quartz with or without tourmaline, generally associated with quartz-sericite schist.

Haimantas:

In the eastern side of the glacier area the unfossiliferous thick sequences of pelites and psammites with intrusive granite, forming the basal part of the Tethys-Himalayan sequence of Spiti basin, are grouped under the Haimantas. The rock types are biotite-schist, phyllite, slate, schistose-quartzite with thin bands of grit and limestone.

2.5 Climate:

Temperature and precipitation:

In general the glacier basin experiences the acrimonious climate as this region falls between the Main Himalayas and Mid-Himalayas. The entire region experiences extremes of temperature, rainfall and heavy snowfall. During winter it snows up to an elevation of about 1500 m, but the snow does not lie for long below 2500 mts. Above 4500 mts there is almost perpetual snow. Thus the topographic configurations i.e. the longitudinal Pir Panjal, and the altitude from the mean sea level controls the different aspects of the climate. The winter season is from the middle of November to March which is followed by the spring that lasts up to the end of the May. The next four months

may be termed as summer season. October and the first half of the November constitute the transitional season.

The monsoon winds hardly penetrate into the region. Most of the precipitation is in the form of the snow in the winters, which may be due to the influence of the winds from the Arabian Sea.

The study area has no meteorological observatory. The rainfall and temperature data from Keylong station show that the maximum mean temperature occurs in the month of July and August and the minimum temperature is in the month of February which indicates that the warmest months are from June to September. The weather conditions observed at the sampling site was mainly fair,though very few occasions of foggy weather, drizzling cloudy sky were recorded. The temperature variation recorded, during the sampling period at the sampling site was $20.2^{O}C$ to 2.4^{O} C . The maximum day temperature is at around one 'o' clock . The main factor in making the temperature low is the altitude.

Humidity:

The air is generally dry over the area, particularly in the summer and transition seasons. In winter also the air is very dry except during the

spells of rain or snowfall . The humidity during ablation period was very less (45%) at 12 hr. and was maximum (72%) at around 2 hr.

Winds:

The winds in Chandra valley are stronger than those over the Bara Shigri glacier,but at higher elevation winds are stronger at the latter. The wind direction varies diurnally. In the morning hours the wind blows from south-west and is feeble. In the afternoon the wind is strong and blows from west. The wind directions at the surface depends very much on the nature of the terrain.

2.6 Soils:

Depending on the altitude and climate, the soils on the whole are young and thin especially in the uplands. The mica- schist present in the parents rock gives rise to stiff reddish loam or red clay. This type of soil is mainly siliceous and aluminous and fairly rich in potash. Organic status is almost low.

2.7 Vegetation:

The vegetation of the region is chiefly dependent on the temperature, rainfall, elevation and soil

characteristics. However, the major influencing factor in this region is varying altitude and climate. Due to the absence of the vegetation, the area has reached to the peak of soil erosion. Whatever, the flora found, only in the summer, is of dry Alpine type and of Central Asiatic Siberian character. The vegetation whatever found is only upto 4250 mts. At some places below the snout height frequent good patches of green grass and wild flowers are seen in extensive beds.

2.8 Mineral resources:

Polymetallic mineralisation of Sb, Pb, Zn and pyrite, though antimony belongs to distinct mono-metallic episode of mineralisation in the Bara Shigri area , occur almost in the peripheral zone of the granitic rocks. The mineralisation is localised along the fractures. Mineralisation occurs at three topographic levels between 4250 mts and 4650 mts each separated from the other by bands of quartz-sericite schist. In all there are about seventy veins of various dimensions out of which nearly 20 show preponderance of stibnite over lead and zinc ores. The maximum width of a vein is about 10 cm. The areal extent and the depth of persistence of stibnite are erratic.

METHODOLOGY

Samples of meltwater from Bara Shigri glacier stream were collected in washed polythene bottles during the ablation period of 1988 (Aug. 14 to Aug. 24). Due to inaccessibility of and ruggedness of the terrain sampling was done on alternate days. The site was selected about 2.5 km away from the confluence of Bara Shigri glacier with Chandra river. The sampling location is shown in fig 2.2 .

pH and alkalinity were measured immediately in the field by Phillips pH-meter. The EC were measured in the laboratory by Schott Gerate(G857). The samples were filtered through 0.45 um membrane filter for collecting the suspended sediments and the filtered water was used for detailed analysis.

3.1 Water Analysis:

PH and Electrical Conductivity (EC):

pH of water samples were measured by pH-Conductivity meter, Phillips pH - meter. The pH electrode is active and stable only after wetting. For this purpose, it must be immersed for at least ten hours in 0.1 N HCl or in a buffer of pH 4 to 7 . During short interruptions the electrode should be

immersed in KCl solution, diluted HCl or a buffer of pH 4 to 7.   Before using, the reference part of the electrode is topped with a 3.5 M KCl solution.   After rinsing the electrode with distilled water, it was immersed in a buffer solution of pH 6.87 (25° C), the CAL knob was adjusted then the SLOPE knob was adjusted after immersing the electrode in a buffer solution of pH 4.01 (25° C).   After the instrument is calibrated, pH of each water sample was determined.   Three readings of each sample were recorded to get an accurate result.   The samples were stirred during measurement to promote homogeneity.

EC was measured by Schtt. Gerate(G857).   The instrument was first calibrated and set for 0.01M KCl standard (1287   at 25 c).   Three readings of each sample were taken.

Bicarbonate:

The bicarbonate was determined following the potentiometric titration method.   Standards of bicarbonates(ranging from 2 to 100)were prepared. 30 ml of each standard and samples were titrated against 0.006 N HCl.   The end point of the reaction is attained when the solution comes to a pH of 4.5 .   A graph was plotted for standard concentration vs. volume consumed.

Then the concentration of the samples weredetermined from the graph plotted.

Chloride:

Chloride was estimated by Mohr's titration method. Standard solutions of chloride of various concentrations were prepared. 25 ml. of each water and standard solutions were titrated against 0.06 N Silver Nitrate solution. Potassium chromate was used as an indicator. The colour change is from yellow to pink . Knowing the value of silver nitrate consumed by each sample, the concentration of chloride in each sample was ascertained from the graph of standard solution of chloride vs. volume of silver nitrate consumed.

Sulphate:

The sulphate concentration was determined by titration method after Fritz and Yamamura (1955) and Haartz et,al. (1979). Before titration, the samples were passed through a cation exchange resin to remove interfering cations and the titration was carried out in 80 % ethanol, to keep the Barium sulphate in solution. In order to activate the resin, 30% HCl is passed through the column. After that it was rinsed with 100 ml. distilled water. Then approximately 70

ml. of unacidified standard and sample was passed through the column. The first 40 ml. of the sample was discarded and the rest was collected for the analyses.

Sulphate standards of various concentrations were prepared by using sodium sulphate. 10 ml. of each standard and sample were taken, 40 ml. of ethanol was added to it. This was titrated against 0.005 M Barium perchlorate in 80% ethanol (prepared by taking 2 gm. Barium perchlorate in 200 ml. deionised water and 800 ml. of ethanol). Thorin was used as indicator. The color change at the end point being pink.

Phosphate:

Phosphate was determined by the ascorbic acid method. Phosphate standards of concentrations ranging from 0.01 ppm. to 0.1 ppm. were prepared from KH_2PO_4. 40 ml. of each standard solution and sample is taken, 5 ml. of molybdate antimony solution and 2 ml. of ascorbic acid solution was added (strictly in that order). The mixture was diluted to 50 ml. and the optical density was measured at 650 nm. using Spectron 1001 spectrophotometer. Molybdate solution was prepared by dissolving antimony tartarate in 400 ml. of 4 N- H_2SO_4 and making the total volume upto 500 ml. with the same acid. Ascorbic acid (0.1 M) was prepared

by dissolving 2 gm. of ascorbic acid in 100 ml. of distilled water.

Silica:

The dissolved silica concentration was determined by the molybdo-silicate method. Standard solutions of different concentrations ranging from 0.1 ppm. to 5 ppm. were prepared by dissolving $Na_2 SiO_3$. 20 ml. of each standard and water sample were taken, 10 ml. of Ammonium molybdate solution and 15 ml. of reducing reagent was added. Ammonium molybdate solution was prepared by dissolving 2 gm. of Ammonium molybdate in 10 ml. distilled water and 6 ml. conc. HCl and the total volume was made upto 100 ml. by diluting it with distilled water. Reducing reagent was prepared by mixing 100 ml. metol sulphite solution, 60 ml. of 100% oxalic acid and 120 ml. of 25% sulphuric acid and the total volume was made upto 300 ml. using distilled water. Metol sulphite solution was prepared by dissolving 5 gm. of metol in 210 ml. of distilled water and 3 gm. of sodium sulphite was added and the total volume was made upto 250 ml. using distilled water.

The samples were stirred and kept for 3 hours to complete the reaction. The optical density was

measured for standard and water samples at 650 nm.
using Cecil spectrophotometer.

Major cations :

Ca,Mg were analysed in the absorption mode and Na,
K were analysed in the emission mode by GBC 902, double
beam Atomic Absorption Spectrometer using different
concentrations of standards of corresponding elements.
To avoid chemical interferences, suppresants were used.

The organic materials were removed from suspended
sediments by treatment with 35% Hydrogen peroxide after
the material has been wetted with buffered Sodium
acetate (pH 4.8) (Jackson 1973). The bed sediments
were weighed before and after the treatment with H2O2.
The weight loss was taken to be the amount of total
organic mater present in the sediments. The sediments
free from organic matter were used for different
studies like mineralogy and chemistry etc.

3.2 Sediment Chemical Analysis:

The sediments were analysed for Sio2, Al_2O_3 by
preparing Solution (A) following the procedure of
Shapiro and Brannock (1962). Rest of the major and

minor elements were determined in solution by GBC 906
A.A.S.

The USGS standard rocks SCO-1, SDC-1 were analysed
alongwith bed and suspended sediments to check the
accuracy and precision of measurements. A detailed
description of methods adopted are discussed below.

Silica, Alumina and Phosphate:

Solution-A:

0.025 gm. of fine sediment powder was taken in a
50 ml nickel crucible and 3 to 4 pellets of NaoH were
added to the crucible. The crucible was gently heated
on a burner for 5 minutes and then it was heated to
dull redness for 30 minutes. Then the crucible was
allowed to cool down to room temperature and 30 ml. of
water added and kept overnight. Then the solution was
transferred to a 250 ml. beaker with the help of
policeman, 5 ml of 1:1 HCl and 100 ml of water were
added. The solution was boiled till it was clear and
the total volume was made to 250 ml. by adding
distilled water.

Determination of Silica.:

8 ml. of the solution A, reagent blank solution ,
standard solution and the sample solution were

transferred to a 250 ml. volumetric flask. 50 ml. of distilled water was added to all the flasks. 2 ml. of Ammonium molybdate solution (prepared by dissolving 7.5 gm of Ammonium molybdate in 75 ml., of distilled water and adding 25 ml of 1:4 H_2SO_4) was added and kept for 10 minutes. 4 ml of tartaric acid solution (prepared by dissolving 2.5 gm of reagent in 250 ml of distilled water) was added by sluicing the flask. 1 ml. of reducing agent (prepared by dissolving 0.7 gm of sodium sulphite in 10 ml. of water and then 0.15 gm. of 1 amino-2 Napthol 4 sulphuric acid was added and stirred well until dissolved. 9 gm. of sodium bisulphate was dissolved in 90 ml. of water and this was mixed with the first solution) was added and the volume was made upto 250 ml. by adding distilled water. The sample were stirred properly and kept for 30 minutes. The concentration was measured for standard as well as samples at 650 nm in Cecil spectrometer.

Determination of Alumina:

15 ml. of the Solution A reagent, blank solution, standard solution and the sample solution were transferred to 100 ml. volumetric flasks. 2 ml. of Calcium chloride solution was added. 1 ml. of Hydroxylamine hydrochloride (prepared by dissolving 5

41

gm. Hydroxylamine hydrochloride in 50 ml.distilled water) was added by sluicing the flask. 1 ml. of Potassium ferricyanide (0.75%) was added to each flask and mixed. 2 ml. of Thioglycolic acid solution (4%) was added and kept for 5 minutes. 10 ml. of buffer solution (prepared by dissolving 10 gm. of Sodium acetate in water and adding 30 ml. of glacial acetic acid and diluted to 500 ml.) was added and kept for 10 minutes. 10 ml. of Alizarin red solution 0.05% was added to each flask and the volume was made to 100 ml. by adding distilled water. The samples were stirred properly and kept for 50 minutes. The concentration was measured for standards and sample at 470 nm using the Cecil spectrometer.

Determination of other major and minor elements:
Solution (B):

0.025 gm. of the sediment sample was transferred into the teflon crucible and 0.5 HNO_3, 1.5 HCl and 5 ml. HF were added and kept in oven for one to one and half hours at 100° C. Distilled water was added to the crucible after the bomb is cooled and was kept again in the oven for an hour and then cooled and diluted to 100 ml. using plastic jar. The digested samples were analysed for major and minor elements by AAS.

3.3 Mineralogy:

Slides of both suspended and bed sediments were prepared by drop on slide technique (Gibbs -1967a) and run on Phillips X-ray diffractometer using Cu - K radiation and Ni filter.

Identification of minerals from XRD chart:

Illite:

The main basal peak of the illite is at 10 A^O with other peaks at 5 A^O and 3.3 A^O. The peaks remain unaffected upon glycolation and heat treatment.

Chlorite and Kaolinite:

These two minerals give peaks almost at the same spacing and hence their identification becomes difficult. Biscays (1964), pointed out that kaolinite in addition to two strong peaks at 7.16 A^O and 3.58 A^O, gives always a very small peak at 2.38 A^O. Similarly, chlorite in addition to 7.05 and 3.54 A^O peaks, shows a relatively smaller peak at 4.7 A^O. Therefore, whenever the chlorite peak at 4.7 A^O is present, the peak at 7 A^O and 3.5 A^O is considered as kaolinite peak.

Quartz:

Quartz gives a strong peak at 3.34 A^O and another smaller peak at 4.26 A^O.

Alkali Feldspar:

It shows a characteristic peak at 3.25 A^O.

Plagioclase Feldspar:

The peak at 3.20 A^O is considered for the identification of plagioclase feldspar.

Dolomite:

The peak at 2.89 A^O is identified as dolomite.

Montmorillonite:

It is identified by its 001 peak at 17 A^O in the Mg-saturated and glycolated sample. Sometimes the broad nature of this peak is due to variations in expansion after glycolation and variations in crystallinity. Montmorillonite has its 0012 peak at 12.4 A^O in the K-saturated sample.

3.4 Grain size Analysis for bed sediment:

Graphic methods (by Folk and Ward, 1957) of computation for average (mean) size distribution,

sorting, skewness, and kurtosis were adopted for the grain size analysis of bed sediments. Values of each parameter were calculated with the help of the following:

(a) **Mean size** $Mz = \dfrac{\theta 16 + \theta 50 + \theta 84}{3}$

(b) **Standard deviation (sorting)**

$$@ = \frac{\theta 84 - \theta 16}{4} + \frac{\theta 95 - \theta 5}{6.6}$$

(c) **Inclusive graphic skewness**

$$SKi = \frac{\theta 16 + \theta 84 - 2\theta 50}{2(84 - \theta 16)} + \frac{\theta 5 + \theta 95 - 2\theta 50}{2(\theta 95 - \theta 5)}$$

(d) **Graphic Kurtosis**

$$Kg = \frac{\theta 95 - \theta 5}{2.44(\theta 75 - \theta 25)}$$

The values of corresponding 95, 84,75,50,25,16 percentile were calculated from the cumulative freq distribution curve.

RESULT AND DISCUSSION

4.1 Major Ions.

The Bara Shigri meltwater is analysed forall the major ions. According to Drewry (1986), the six principal ions (calcium, sodium, magnesium, bicarbonate, chloride, sulphate) usually make up more than 90 percent of the total dissolved solids, whether dilute or highly saline. In meltwater the occurrence of such constituents indicates effective hydrochemical reaction within the glacial environment, principally at the bed of the ice masses. Meltwater from the study area also account for more than 60 % of its total solute content to HCO_3 and Ca^{2+}. A marked decrease in ionic concentration is observed from low flow towards high flow. This is because, during high flow the snow melt is rapidly converting into runoff and diluting the solution concentration. The detailed ionic characteristics are discussed in this chapter.

pH & Electrical conductivity:

The average pH of the meltwater draining from the Bara Shigri glacier basin is 6.9 which indicates almost neutral nature of water, but it ranges from 5.2 to 7.8. The pH is slightly higher than that of the nearby

Table 4.1

Chemical analysis of Bara Shigri Meltwater, (in mg/l)

SAMPLE NO.	DATE	TIME HRS.	pH	EC	HCO3	CL	SO4	PO4	NA	K	MG	CA	-(meq)	+(meq)
1	14	11	7.09	32	13.6	1.8	3.4	.11	1.4	1.8	1.9	4.4	.32	.29
2	14	12	6.8	20	14.2	1.4	3.2	.27	1.4	1.8	1.0	8.1	.38	.34
3	14	14	6.9	20	12.6	1.5	2.9	.12	1.5	1.5	1.6	4.0	.29	.26
4	14	15	7.0	22	10.5	1.6	2.9	.10	1.3	1.5	.9	3.8	.17	.23
5	16	11	6.4	37	8.4	4.6	3.7	.13	4.4	4.2	1.6	8.3	.28	.58
6	16	12	6.7	35	13.6	1.4	3.9	.17	2.3	3.6	.19	7.1	.33	.37
7	16	14	6.2	31	9.2	2.4	3.4	.13	1.7	1.7	.74	5.0	.21	.27
8	16	15	7.3	24	9.4	2.3	3.1	.11	1.8	2.0	.01	4.2	.23	.24
9	18	11	6.2	40	7.3	4.2	3.6	.12	2.1	2.7	1.4	7.0	.26	.39
10	18	12	5.6	43	5.1	4.6	4.2	.13	2.7	3.6	2.1	9.6	.25	.54
11	18	14	6.7	27	6.3	2.6	3.7	.12	1.8	2.5	1.8	6.8	.22	.39
12	18	15	5.2	33	4.2	4.2	3.2	.10	1.9	1.1	1.4	5.8	.21	.33
13	20	11	6.9	33	12.6	1.5	2.9	.11	1.7	2.3	.35	5.4	.29	.28
14	20	12	7.0	30	11.5	2.2	2.6	.12	2.1	3.1	.06	6.8	.30	.34
15	20	14	7.7	27	10.5	1.5	2.8	.12	1.8	2.8	.28	6.6	.25	.31
16	20	15	7.0	22	8.4	1.6	2.6	.09	1.7	2.0	1.1	4.5	.22	.29
17	22	11	7.1	31	12.6	1.9	3.8	.11	2.0	2.1	1.4	5.9	.31	.35
18	22	12	7.8	31	12.6	1.5	3.5	.11	1.7	2.3	.45	6.1	.27	.30
19	22	14	6.7	26	9.4	3.1	3.3	.07	2.1	3.9	2.7	7.7	.27	.49
20	22	15	6.7	22	8.4	2.1	3.2	.83	0.9	1.4	2.1	4.3	.26	.27
21	24	11	6.7	31	14.7	2.1	3.4	.10	2.2	2.3	1.4	6.8	.34	.42
22	24	12	6.9	42	12.6	2.6	3.7	.11	2.9	3.0	.9	5.3	.32	.37
23	24	14	7.0	21	8.4	1.9	2.9	.10	2.5	2.3	0.4	4.6	.32	.30
24	24	15	6.5	21	9.4	1.4	2.8	.96	1.9	2.4	0.8	6.2	.23	.34

Chhota Shigri glacier (pH-6.5, Hasnain) and is significantly higher than the pH of meltwater from Northern Cascade Mountains, (pH-5, Reynold & Johnson 1972). Analysing the meltwater streams from nine Alaskan valley glaciers, R.M.Slatt says, the cold waters have a basic pH. This implies that pH is dependent on the bed rock type of the drainage basin.

The conductivity of Bara Shigri meltwater is highest during the early hours and the lowest is at late afternoon. The conductivity varies from 43 μ cm^{-1} (which is indicative of chemically enrichment of the meltwater) to 20 μ cm^{-1} . An inverse relationship between temporal variation in conductivity and the discharge of the meltwater is observed. During the sampling period the average electrical conductivity at low flow is 33.8 μ cm^{-1} and that at high flow is 2.4μ cm^{-1}. Every day at 12 O' clock sampling time the EC was found to be highest followed by a gradual decrease . This is because at the starting point of the high flow (due to rapid melting of the snow of the day) the meltwater carries away the rapidly diluted solute and suspended load present beneath the glacier.

4.1.1 Major Anions:

Bicarbonate:

Chemical analyses of meltwaters invariably show that the bicarbonate is the dominant constituent. Bicarbonate is the dominant anion in all the waters, (Meyback, 1981) and is the main constituent helping chemical denudation. HCO_3 contributes 64% of the weathering and denudation in water systems (Berner and Berner). This is the maximum by weight percentage among all the ions in the Bara Shigri meltwater, the average concentration being 10.27mg/l.

Reynolds & Johnson (1972), suggest, in the South Cascade glacier watershed, carbonation is the principal mechanism governing the composition of the meltwater. For eg. $CaAl_2Si_2O_3 + 2CO_2 + 3H_2O = Al_2Si_2O_5(OH)_4 + Ca^{2+} + 2HCO_3$ carbonation takes place from the reaction between dissolved CO_2 in the meltwater and the rocks containing carbonate minerals. The quantitative presence of dissolved CO_2 in glacial meltwater may be due to high partial pressure, the release of entrapped CO_2 from ice, extreme turbulence which continuously recharges water with CO_2 and low temperatures.
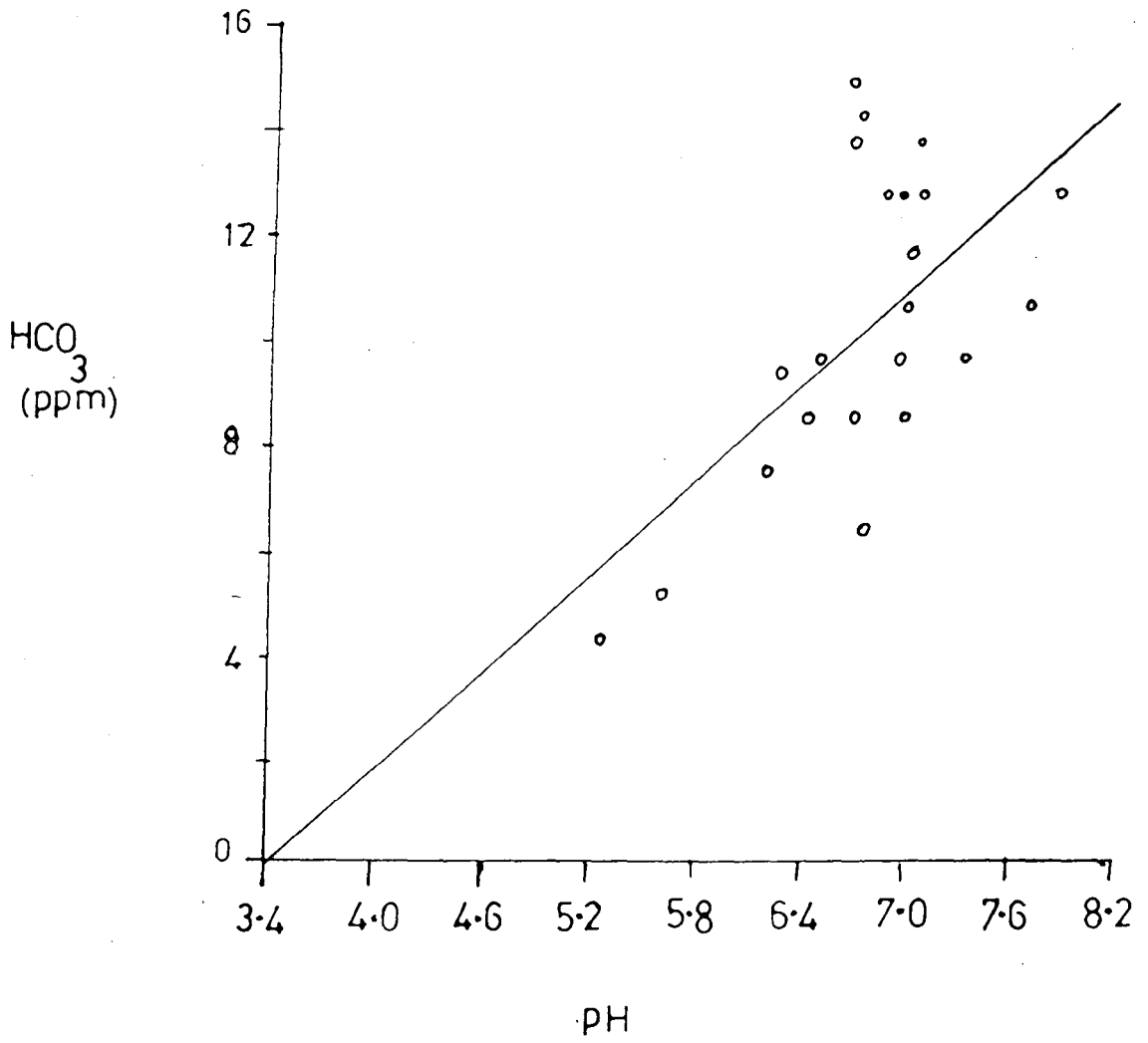
4.1   HCO$_3$ vs. pH.

The Bara Shigri glacier meltwater shows a direct relationship between the pH and bicarbonate content. As the alkalinity increases, the pH too increases, the correlation coefficient being 0.62,(Fig. 4.1). The bicarbonate content of Bara Shigri glacier is slightly more than that of Chhota Shigri (0.135 meq. Hasnain, 1987) The reason for this is that the former drains also from the metasedimentaries (phyllites, slates) which are easily erodable.

Chloride:

Chloride in natural waters is extremely mobile and soluble in solution Cl has a very uneventful geochemistry. Thus sources of chloride in meltwaters can be from (a) Cyclic salt i.e. the sea salt carried inland in the atmosphere and deposited in the form of rain or snow and (b) from weathering of Halite. Here, as in Bara Shigri glacier there is no Halite deposit the source is supposed to be from the former one . Zverev & Rubeikin (1973), estimate the average contribution of Cl of atmospheric origin in all USSR rivers to be 21 %. Chloride content in the snow fall at Byrd Glacier, Antarctica and Greenland is 60 mg/L and 31mg/L respectively (Morzumi, et.al,1978). Bara Shigri meltwater shows little richness in chloride

concentration (2.3mg/L than the subglacial meltwater of Bevendon, B.C., Canada (0.93mg/L) Eyles et.al (1982), and Chamberlin Creek, Alaska (0.45mg/L   ) Rain water and Guy (1961).

Sulphate:

Sulphate in meltwater may be derived from weathering of pyritic rocks and atmospheric processes. About 2.5mg/L SO_4 is added to the rivers by atmospheric processes and 8mg/L to 9mg/L is from weathering of rocks (Gorham 1966, Junge and Werby 1958). About 33% of the total sulphate in the fresh water system is derived from weathering of pyritic rocks, (Berner and Berner). Sulphate is the second dominating anion in the meltwater draining from the study area. The sulphate concentration is about 3 may be derived from the oxidation of the pyritic rocks, as the eastern side of the Bara Shigri glacier contains base metal deposits i.e. Stibnite, Pyrite , Zinc etc. (V.P.Sharma and Padhi, 1963). The sulphate concentration in meltwaters may help weathering by forming natural acids. Drewry (1986) says, the meltwater from Antarctic snow is a very dilute mix of natural acids (H_2SO_4 and HO_3).

Phosphate:

Phosphate is the minor anion, concentration being about 0.17mg/L found in the meltwater from the study area. This minute amount may be derived from weathering of small pegmatitic bodies that are associated with the ore mineralisation.

4.1.2 Major Cations:

Calcium:

Calcium is the most dominant cation in the melt water from Bara Shigri Glacier. The evidence for calcium dominance in fresh water is found in Livingstone (1963), and for glaciated areas specially in Slatt (1972) and Lorrain and Souchez (1972). Here, the study area meltwater also contains abundant Ca^{2+} content i.e. about 52% of the total cations fig.4.2. The meltwater from Gornea, Switzerland constitutes calcium concentration about 50% to 63.6% of the determined cations (Collins 1979), R.M.Slatt says for any sample a large ratio for an ion is indicative of high relative mobility of that ion. Ca may be released to the meltwater more readily and in greater absolute quantities than other ions by partial dissolution of suspended load. Here the meltwater
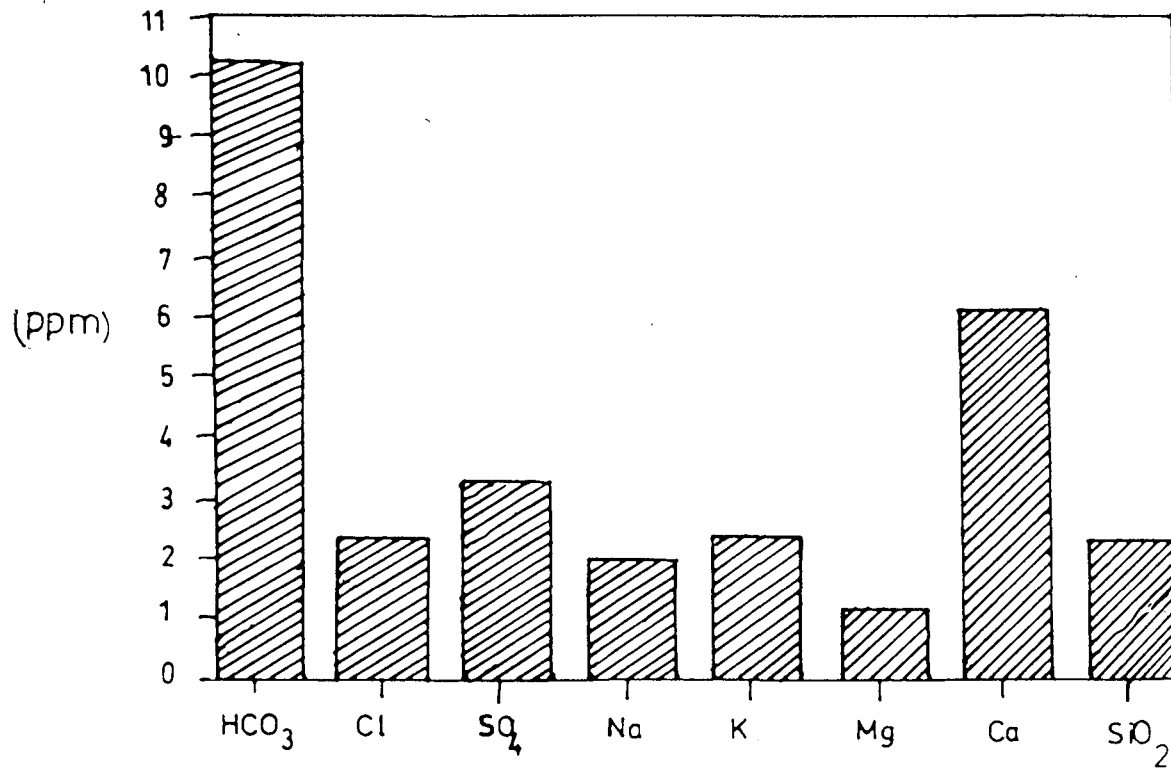
4.2   Bar diagram representing dissolved chemical consti-
       tuents.

constitutes about 6 of Ca_{2+} and may be derived from Ca-silicates like pyroxenes, amphibolites, biotites etc. The world average of calcium from Ca-silicates is about 18% and from calcite and dolomite is about 52% , (Berner and Berner) . The high concentration range of Ca^{2+} (3.8 to 9.6)mg/L makes it clear,that Ca^{2+} is highly enriched in subglacial meltwater.

Potassium:

Potassium takes second position in cationic concentration after Ca^{2+} in Bara Shigri glacier meltwater. The average concentration of potassium is about 2.4mg/L and there is almost a least variation in ionic concentration during the sampling period. But there is a slight variation in concentration in low flow and high flow. Na^+ and K^+ show a direct relationship with electrical conductivity , implying the latter's direct relationship with ionic concentration. But there is a slight variation in concentration in low flow and high flow. Na^+, K^+ show a direct relationship with electrical conductivity, implying the latter's relationship with ionic concentration. Potassium comes predominantly from weathering of silicate minerals. Mayback (1984), estimates that in silicate weathering, 1/4th of K^+
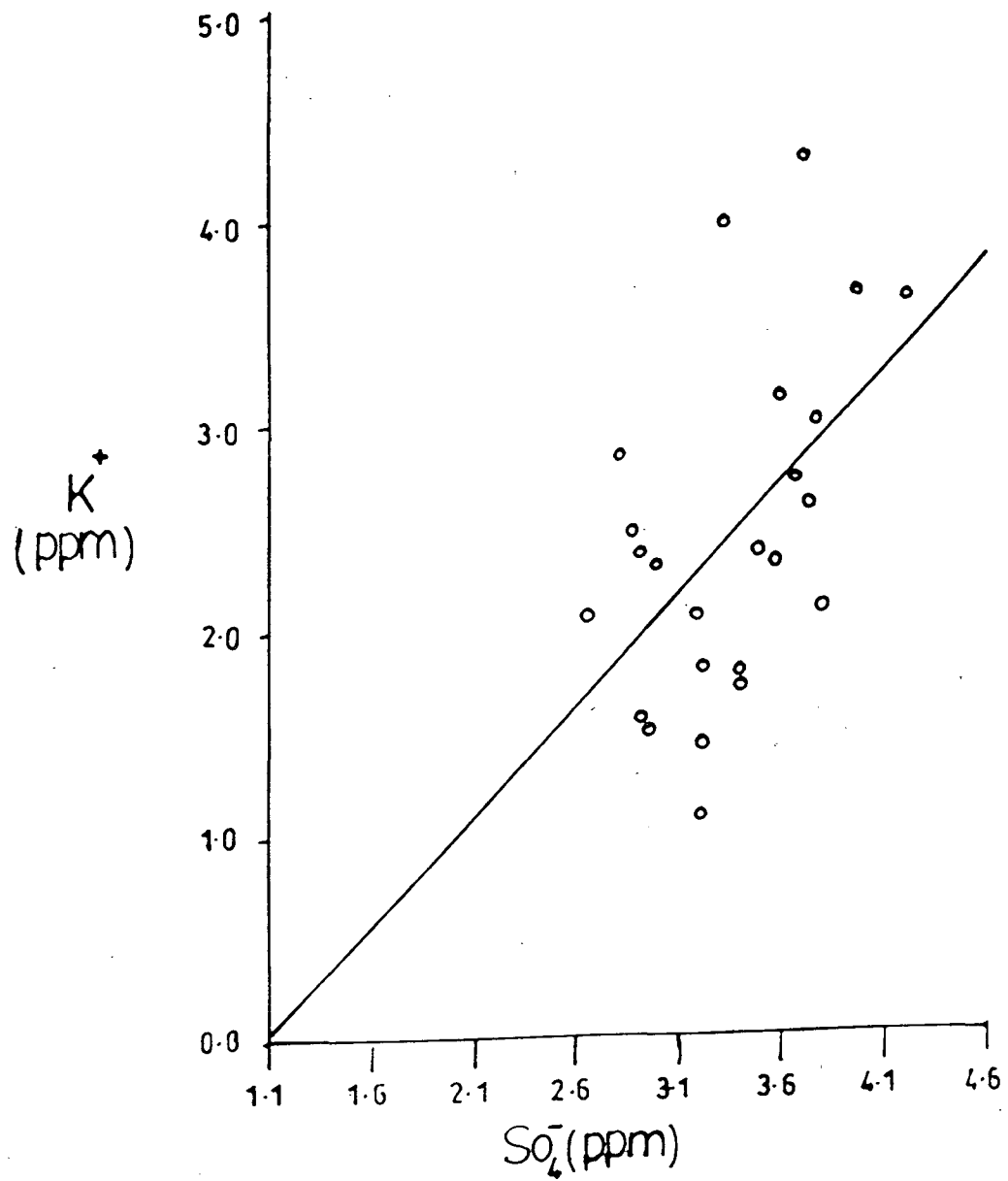
4.3   Potassium vs. Sulphate.

comes from igneous and metamorphic silicates. The presence of sulphate concentration and its significant correlation (correlation coefficient 0.54) with K^+ may be the cause of K^+ concentration in Bara Shigri melt water. fig 4.3. The predominance of potash felspar over sodic felspar in the host rocks of the glacier, indicates the granitic composition (V.P.Sharma-1965). Thus the granitic composition of the subglacial lithology controls the cationic concentration of the meltwater and so K^+ ion is comparatively more than Na^+ ion.

Sodium:

Analysis for sodium shows there is almost a stable concentration throughout the sampling period. The concentration of Na^+ in the Bara Shigri meltwater stream range from 0.95 to 4.462 mg/L and average being 0:88 meq., which is more than that from nearby Chhota Shigri glacier 0.36 mg/L (Hasnain) The reason may be the variation in drainage lithology. Sodium may be derived from both plagioclase component of Rohtang gneisses and phyllite-schist and slate of Haimantas. About 22% of the of sodium comes from plagioclase, (Berner and Berner). The significant correlation fig. 4.4 (Pearson's correlation) between sodium and chloride
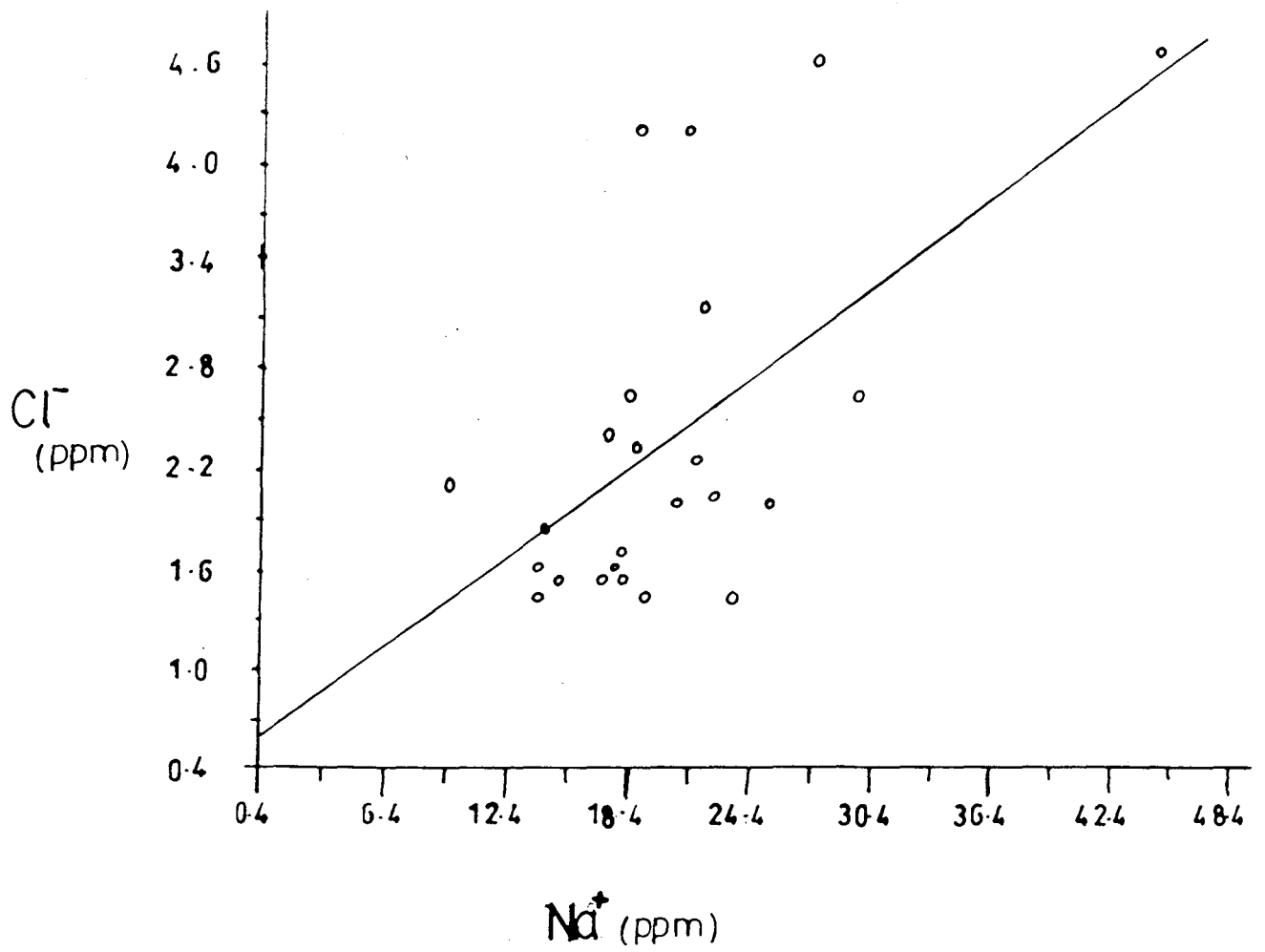
4.4   Sodium vs. Chloride.

leaves little doubt that the atmospheric precipitation of Cl^- content enhances the weathering of Na^+ bearing country rocks.

Magnesium:

The meltwater from the study area shows least Mg^{2+} cationic concentration. The concentration of Mg^{2+} ranges from 0.059mg/L to 2.72mg/L and the average comes to about 1.1 . In fact the concentration 0.044mg/L is higher than that from Chhota Shigri glacier (0.009 Hasnain).

4.2 Dissolved Silica:

Dissolved silica comes almost entirely from silicate weathering. Though the silicate minerals are plentiful, the analysis shows that the silica concentration is comparatively less than the other cations. This is because of the resistant nature of silica to weathering over the Ca and Mg ions which leach out easily from the minerals containing them. The most common order of solution (Polynov) is Ca>Na>Mg>K>Si>Ai>Fe. Here the dissolved silica concentration of Bara Shigri meltwater, the average being 2.21mg/L , is less than Ca. There hardly any

TABLE 4.2

Some physical and chemical parametes of Bara Shigri meltwater.

Sample No.	Water temp.(^{O}C)	Suspended sediment conc. gm/l	TDS mg/l	Dissolved silica mg/l
1	2.0	0.9	30.4	1.4
2	2.0	1.0	33.3	2.1
3	2.5	0.9	27.6	2.0
4	3.5	0.7	22.0	-
5	2.5	0.8	38.1	2.5
6	2.7	1.4	35.1	2.7
7	3.0	1.1	34.1	2.3
8	3.0	1.0	26.0	1.9
9	2.0	1.7	31.4	2.8
10	2.5	1.9	35.2	3.1
11	3.0	1.1	28.5	2.6
12	3.0	1.2	24.5	2.5
13	2.5	1.4	29.9	2.8
14	2.7	1.3	3.8	2.5
15	3.0	1.2	28.2	2.2
16	3.4	0.9	24.2	1.8
17	2.0	0.5	32.1	2.2
18	2.0	0.7	28.7	2.3
19	2.5	0.8	34.7	2.3
20	3.0	0.6	25.5	2.1
21	2.0	1.8	35.4	2.1
22	2.5	2.0	33.5	2.2
23	3.2	1.5	25.2	1.9
24	3.5	1.3	28.0	1.8

MAJOR DISSOLVED COMPONENTS OF RIVER WATER
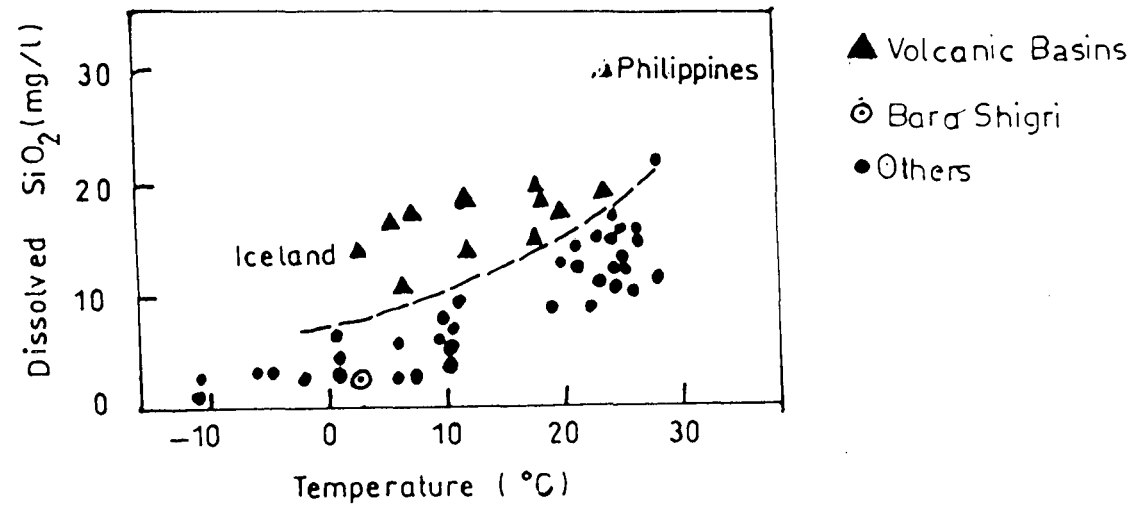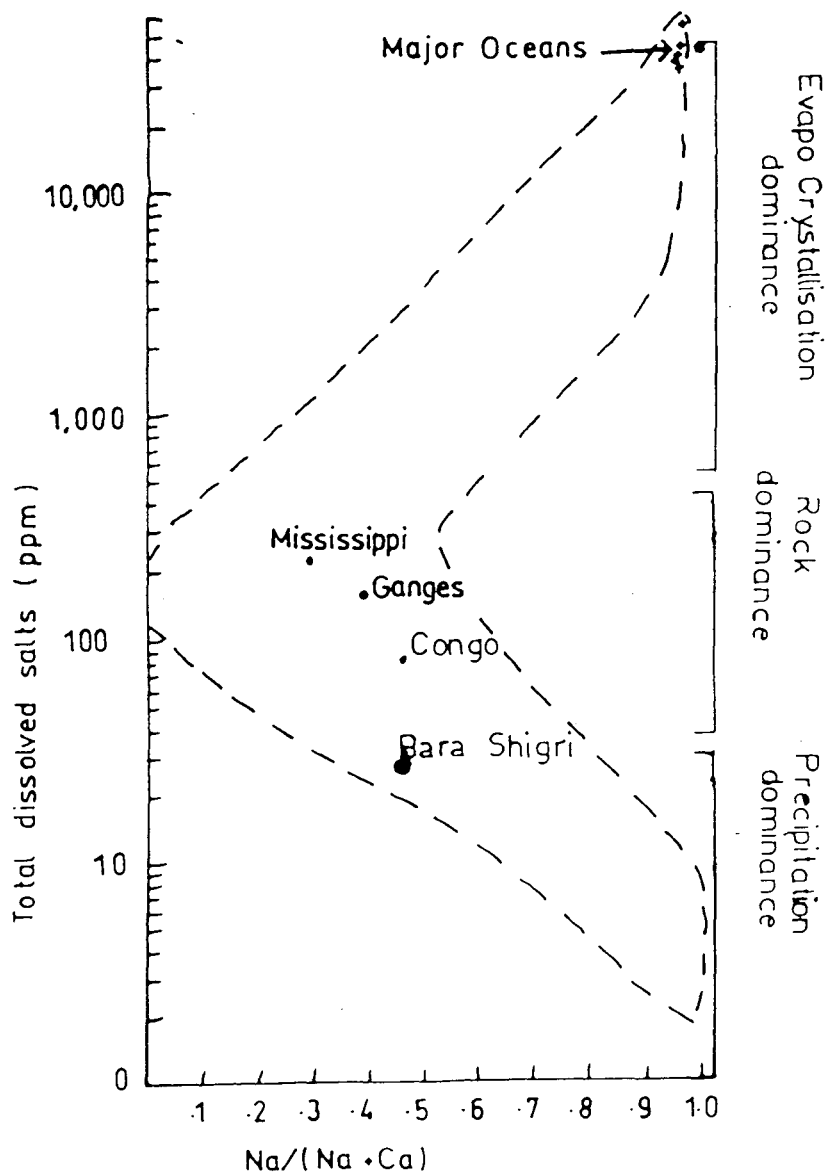

4.5   Variation in dissolved silica content of world river
       (mg/l SiO$_2$) with average temperature of drainage
       basin   (°C) for non-volcanic and volcanic basins
       (After Meyback 1980).

variation in concentration, which implies a steady flow of ions during that period.

Meyback states that the greater (river average temperature <4°C) have a silica concentration of about 3±2 mg/l, temperate rivers (Temp. 4° to 19° C) have a silica concentration 6±3 mg/l tropical (>20°C) contain about 13±4 mg/l of silica. The average temperature of meltwater from Bara Shigri stream is about 2.6°C during the ablation period. This points out that the dissolved silica content of rivers is determined by the average temperature of the drainage basin, and by the geology of the glacier basin fig.4.5 Thus it is apparent that the temperature of the watershed directly controls the amount of silicate weathering.

4.3 Total Dissolved Solids:

Water is an excellent solvent. This property of water plays a vital role in transportation in the geochemical cycle. Water with its dissolved constituents (O_2, CO_2 and humic acid) weathers rocks and carries the resulting ions towards the downstream. Water also acts as an excellent solvent for many polar organic and inorganic materials. The effectiveness of water in the dissolution processes is due to its high dielectric constant. Dissolution proceeds until an

Major Oceans ➔

Evapo Crystallisation dominance

Rock dominance

Precipitation dominance

10,000

1,000

100

10

0

Total dissolved salts (ppm)

Mississippi

.Ganges

.Congo

Bara Shigri

·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0

Na/(Na+Ca)

4.6   Variation in weight ratio, Na/Na+Ca as a function
       of Total Dissolved Solids, showing the precipitation
       dominance in study area (Redrawn after R.J. Gibbs,
       1970).

equilibrium concentration is achieved which depends upon temperature and pressure. It is also that the stream solute levels vary through time as well as in space, because the catchment processes which generate streamflow and its dissolved content are dynamic rather than static in nature . In glacial environment at such a low temperature the chemical activity is generally not intense (Reynold & Johnson 1971). But Slatt (1970), Rainwater and Guy (1961), and Keller and Reesman (1963), have reported significant quantities of dissolved solute in glacial meltwater streams. The total dissolved solid, on an average, during the sampling period, from the study area, meltwater is about 30.02 mg/l. The solute present in the meltwater are derived and also acquired during the passage of waters through the sub glacial channels and ice-rock interface (Trudgill 1986) . The Total solute concentration of world average river water is 120 mg/l and 99.6 mg/l as given by Livingstone (1963a) and Mayback (1979). The solute content from Bara Shigri is generally low as compared to Indian rivers which are more alkaline in nature and carry more concentrated salts, Subramanian (1979). The main cause for the low solute content may be due to the presence of granitic to granodioritic host rock of the glacier,which are

less prone to chemical weathering. But the total dissolved solids of Bara Shigri melt water is slightly higher than that of the nearby Chhota Shigri glacier (i.e. 24.5 mg/l, Hasnain et.al.) and this is because, about 22% of the former is meta-sedimentary rocks (slate, phyllite schist etc.) enhancing the chemical weathering and thus the solute content.

The solute in meltwater of the study area is highly enriched by bicarbonates and calcium, which is general world wide. The percentage of HCO_3 and Ca^{2+} in the total dissolved solids is about 41% and 19% respectively.

4.4 Suspended Sediments:

Suspended Sediment Load:

The sediment movement occurs through a combination of solution suspension and bed load transport. Abrasion, crusting of bed rock and attrition of clasts by strong particle- particle interaction produce a wide range of sediments at the sole, ie. at the lowermost part of an ice mass . These erosion products may be entrained by subglacial water and transported as suspended mater or bed load, accompanying the material removed directly by
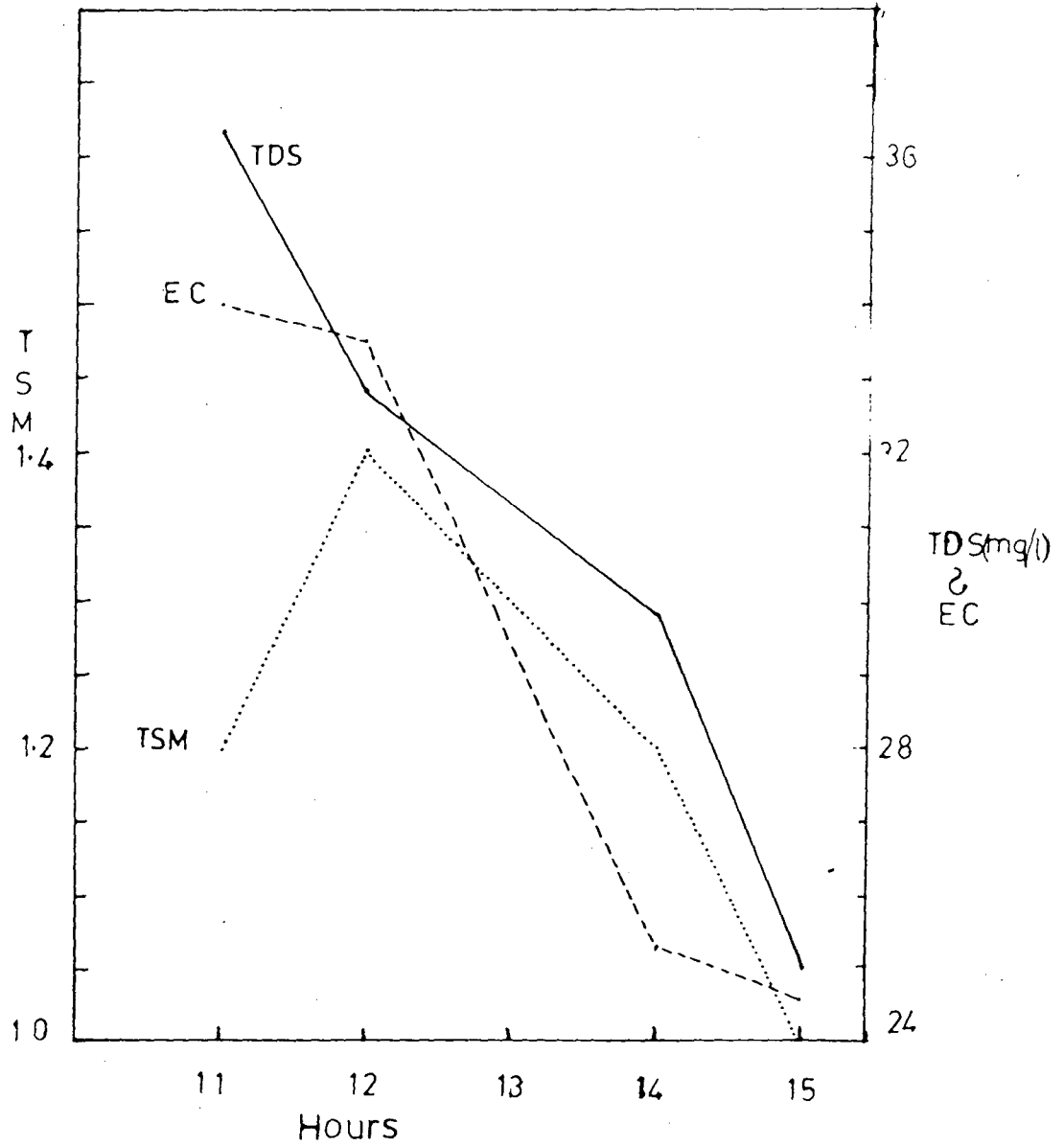
4.7   The relationship between TDS, EC and TSM in Bara Shigri meltwater.

meltwater. Under increasing discharge during ablation periods, meltwater channels may also carry the sediments stored in the lowermost layers of the glaciers. According to Livingstone, world wide average of suspended sediments carried by rivers is 3.3×10^6 ton/yr. Himalayan rivers carry large sediment load because they drain on the readily erodable foothills (Berner & Berner). Mayback says 10 to 20% of sediments are drained by Himalayan rivers from the continent. Garrels and Mackezie (1971) point out that the suspended yield seems to increase exponentially with mean elevation. The total suspended material supply of Ganges is rock type rather than relief dependent.

The observation of the Bara Shigri meltwater is generally low in early hours (as the area could not be measured due to the high stream velocity and local difficulties). The fig 4.7 shows that in early hours suspended sediment content is relatively low and at 12 hours,the suspended sediment curve rises following a gradual fall till peak of discharge. This implies that the daily sediment maxima is both before and may be after (as, unfortunately the peak discharge could not be done) the water discharge peak. Here the minimum sediment concentration is accompanied by the highest
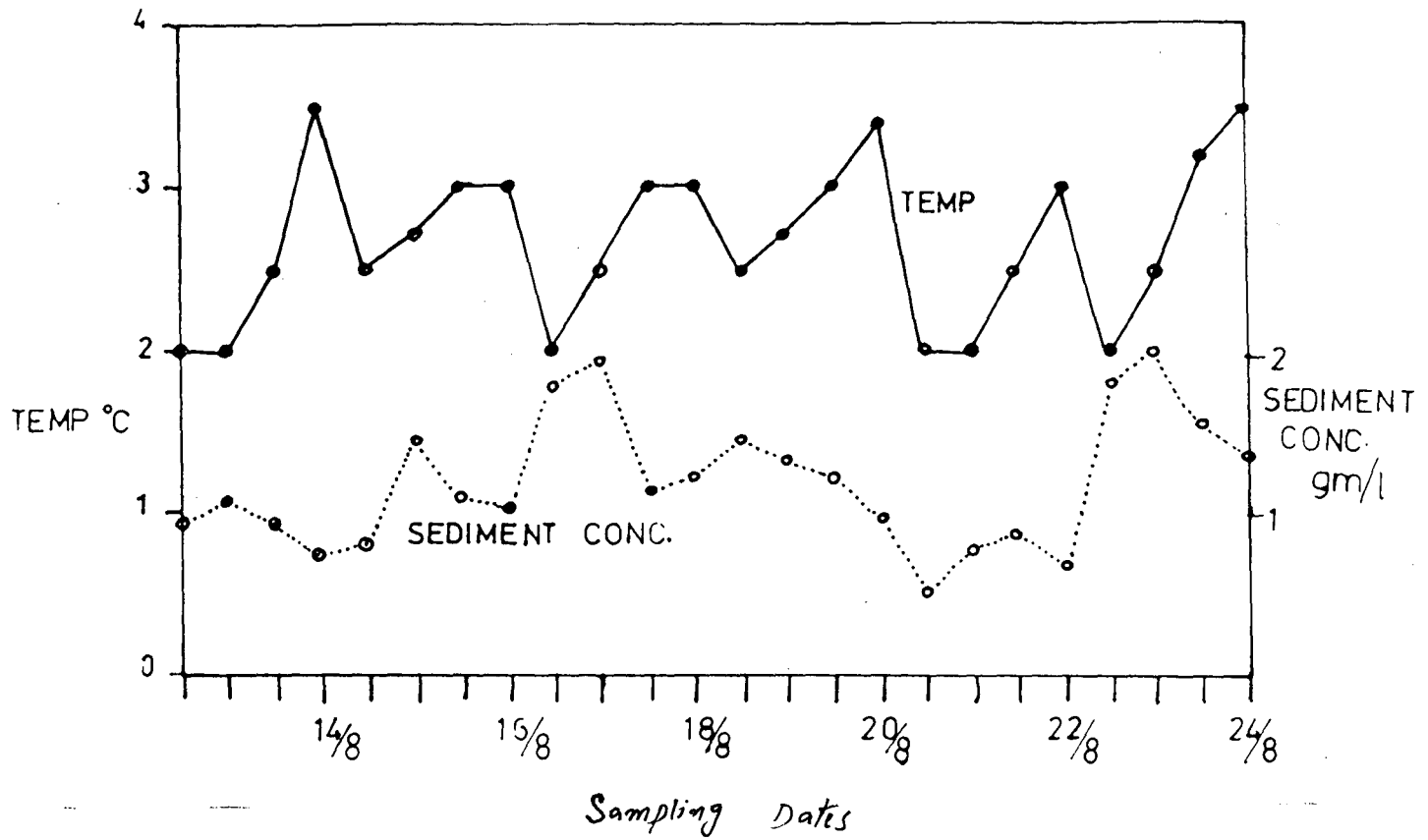
4.8 Inverse relationship of meltwater temperature and sediment concentration.

discharge of meltwater. This type of was work carried out by Collins (1979a), Church(1974).

From fig 4.8 it can be inferred that the sediment concentration peaks before the high flow. Thus it is interpreted that the initial rapid removal of sediments from the glacier bed is followed by exhaustion of debris supply. Drewry (1986) says that such a type of phenomenon is common to most meltwater streams issuing from glacier terminus and is the result of rapid suspension of loose sediment at the glacier bed during the early part of the rising stage of the discharge. Thus it can be inferred that the sediment concentration in meltwaters depends on sediment supply and hydrological conditions of the glacier basin. Reynold and Johnson say, the high altitude and high valid are generally attributed to glaciation and mass wasting there by enhancing the chemical attack on bed rock. But Metacalf (1979) says that the peak discharge of sediment takes place, especially during early summer. The reports that sediments transported during 5 minutes in mid-summer (June) was equal to the total sediment yield from Nisqually glacier, Washington, U.S.A.

TABLE 4.3

Suspended sediment chemistry (in ppm)

Sample No.	Si	Fe	Ca	K	Na	Mg	Al
1	245	81	4.55	4.19	4.36	4.65	0.479
4	217	78	4.03	2.87	3.54	3.17	0.510
15	232	82	6.04	3.94	3.20	5.34	0.517
18	256	83	5.52	3.58	2.51	5.99	0.567
23	196	85	7.12	5.74	5.35	3.90	0.522
26	210	79	5.87	4.39	4.29	3.09	0.563

The average suspended sediment concentration of meltwater from the Bara Shigri drainage basin is about 1.19gm/L which is slightly more than that of the Chhota Shigri glacier (Hasnain). The reason for this may be the difference in lithology.

Suspended Sediment Chemistry:

The glacial meltwater suspended matter is enriched in less soluble elements (ie. Fe, Si) . In fact, silica in suspended matter is less enriched relative to surficial rocks and this is due to resistance of quartz (SiO_2) to weathering.

Suspended sediments were analysed for some major elements (table 4.3). Among the elements studied the major is silica followed by Fe. There could hardly be any correlation of daily conc. be drawn. But the concentration decreases, from the time of high flow, towards the low flow, but some times (20.8.88, 15 hours) the concentration of almost all the elements increases in the low flows. This may be due to high melting of glacier and snow mass helping in dissolution of elements. There is appreciable amount of Zn, Cu found, which may be derived from the polymetallic mineralisation, in the Bara Shigri glacier basin. Alumina content is very low in comparison to river

suspended sediments . Subglacial carbonate and silica deposits have been recognised by Kers (1964), Ford (1970) and Hallet (1975) . It is possible that alumina may be deposited subglacially as amorphous precipitate trapping the glacial flour, at temperature very close to $0^{O}C$ and pressure not exceeding a few bars, and pH close to 7 . This type of studies were done by Krauskopf, K. 1956. The XRD report on clay minerals also indicate total absence of gibbsite (table). Thus it can be inferred that the chemical exchange for the deposition of alumina , may be occurring at the base of the glacier.

4.5 Mineralogy of the Suspended Sediments:

Mineralogy of suspended sediments were identified by using the XRD method. The list of minerals determined by XRD method is given in the table. In suspended sediments the clays dominate and among the clays illite is predominant and ranges from 17% to 47% the average being about 40%, chlorite takes second position after illite.

Working on Scandinavian glacial clays, Collini (1956) says, the glacial clays are composed of

TABLE No :4.4

Percentage of minerals in suspended sedidments

Sample No.	Illite	Chlorite	K-felspar	Quartz	Kaolinite	Mg-calcite	Montmori-llonite	Plagio-clase
1.	17	8.8	11.2	38.3	1.97	1.72	1.2	38.3
3.	44	15.8	3.4	12.5	12.90	7.00	-	3.1
4.	47	25.4	2.7	14.0	20.60	5.20	-	4.4
5.	43.5	14.8	2.0	16.7	11.70	7.90	-	3.0
7.	42.6	15.2	3.7	13.0	11.40	5.80	-	5.87
9.	41.6	14.1	16.0	10.3	14.90	6.20	0.3	4.90
19.	38.9	17.7	10.8	15.8	9.0	4.20	-	3.30
21.	30.6	18.4	1.9	13.6	13.1	10.40	-	4.18
22.	46.2	14.3	5.5	26.9	1.97	1.72	-	3.18

high proportion of illite and accessories . In Switzerland, Vernetc 1959), Allens and Johns (1960) showed the glacial deposits were composed of illite and chlorite, montmorillonite, and illite, chlorite, vermiculite respectively.Rosengvost (1955) said about the neo-formation of illite from the products of glacial weathering of crystalline rocks. Weathering and denudation at the early stage of weathering cycle may also be the cause of formation of illite.

In clay minerals the percentages generally decreases from low flow to high flow which is again due to the dilution factor. The other minerals are quartz, potash-felspar, plagioclase, dolomite, kaolinite, montmorillonite etc. Thus there exists an inverse relationship between illite in one side and plagioclase and quartz on the other. The correlation coefficient between illite and plagioclase found to be -0.86.

Collini (1956), pointed out that the great abundance is not only by the weathering of mainly crystalline and metamorphic rocks, but they attribute the clays to the erosion of Mesozoic rocks which the glaciers reworked easily. Thus it is apparent from here that there is a double possibility of origin of glacial clays, ie. chemical evolution or mechanical

reworking. Thus clay mineralogy reflects climate, relief and secondary lithology of the drainage basin.

4.6 Grain Size distribution of bed sediments:

The grain size destributionof the Bara Shigri stream bed is given in table . The distribution of each size fraction reflects. the terrigenous sedimentation, hydrodynamic environment and the distance of travel of sediments.

Mean Sizes:

The mean size indicates the central tendency or the average size of the grains. Grain size indicate the amount of energy imparted to the grains, which depends upon the current velocity or turbulence of the transporting medium. The average grain size of bed sediments of the area is 1.76 and it ranges from 1.04 to 2.3. The grain size indicates the sediments to be coarse sediments .

Sorting:

This is the measure of the spread of the values about the mean which reflects fluctuation in energy (velocity conditions) of the agent of deposition. Greater the fluctuation in energy, greater

Table 4.5

Grain size analysis of bed sediments (units in θ)

Sample no	Mean	Std.Dev.	Skewness	KurtoSis
1B	2.17	1.08	-0.17	1.33
2B	2	1.20	-0.27	1.07
3B	1.04	1.29	-0.12	1.03
4B	2.3	1.18	-0.22	1.2
5B	1.7	1.04	-0.47	1.06

the standard deviation and poorer is the sorting. It
is used for the interpretation of the environment of
deposition. The beds sediments are poorly sorted. The
minimum value for sorting is 1.04 and the maximum being
1.29 .

Skewness:

It measures the symmetry of the frequency of
distribution and marks the position of mean with
median. It tells, how closely grain size distribution
approaches the normal of Gaussian probability curves,
more the arc the more normal is the curve. If the
skewness is negative the sample is coarsely skewed
meaning the mean is shifted towards the coarser side of
the median. When skewness is positive the sample is
finely skewed, the mean is shifted towards the finer
side of the median.

The Bara Shigri stream bed sediments are
negatively skewed implying their coarseness . Sample 5B
shows strong negative skewness. The skewness varies
from - 0.12 to -0.36 and average being -0.28.

Kurtosis:

It is the measure of peakedness of a
frequency curve. The sediments are leptokurtic to
mesokurtic , indicative of initial stage of erosion and
weathering.

SUMMARY

It is observed that there is an marked variation in the chemical composition of the meltwaters draining from Bara Shigri glacier at high and low flows. At low flow the meltwaters become enriched in solutes, which may be due to chemical weathering beneath the glaciers. High flows are associated with dilute meltwaters. At 12 o' clock sampling time, it is observed that all the dissolved components of meltwater are increased by weight percentage followed by a gradual decrease. This is because at the starting point of high flow, the meltwater carries away the rapidly diluted solute and suspended load present beneath the glacier. Bicarbonate, sulphate, chloride and calcium account for 72% of the ions present in the meltwater from Bara Shigri, out of which Ca^{2+} (52% of the cations) and HCO_3 (64%of the total anions) are the dominating cation and anion. This indicates the chemical mode of weathering of the parent rock. The bicarbonate anion shows a direct relationship with the pH of the meltwater, indicating the relationship between acidity and alkalinity. The sizeable amount of chloride present in the meltwater is suggested to be from atmospheric precipitation. The high concentration of sulphate in the glacier meltwater confirms the presence of

sulphide ore minerals that is pyrite , stibnite etc., (as those have already been reported). Calcium is suggested to come from chemical weathering of Ca-Silicate. Sodium has a correlation with chloride, correlation coefficient being 0.54. Sodium is weathered from the sodic plagioclase of Rohtang Gneisses. Similarly, significant correlation between potassium and sulphate is also observed.

Concentration of dissolved silica (2.2 mg/l) in the meltwater (average temp. 2.6°C) fits to the Meyback classification, based on temperature versus and sediment concentration of the melt water. This suggests that the temperature of the glacier basin controls dissolved silica content. But according to Collins, (1979) glacial meltwater should always be treated as variable in chemical composition.

The suspended sediment concentration is found to be low in early hours, then it rises upto mid-noon followed by a fall, which is indicative of dilution affect. The dominating clay minerals are illite followed by chloride. Low concentration of alumina in sediments is found and it is suggested that there may be mobilisation taking place, precipitating alumina

subglacially.   But still its doubtful, as the field

check could not be done.   But the XRD analysis says

that the absence of gibbsite.   The coarse   sand size,

poor sorting, coarsely skewed and leptokurtic in

nature of bed sediment are observed.

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