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HYDRO-GEOCHEMISTRY OF KAFNI GLACIER MELTWATERS, PINDAR VALLEY, KUMAON HIMALAYAS, UTTAR PRADESH

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CERTIFICATE

The research work embodied in this dissertation entitled **"HYDRO-GEOCHEMISTRY OF KAFNI GLACIER MELTWATERS, PINDAR VALLEY, KUMAON HIMALAYAS, UTTAR 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.

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LIST OF TABLES

LIST OF FIGURES

CONTENTS

CHAPTER 3

METHODOLOGY

CHAPTER 4

RESULT AND DISCUSSION

CHAPTER I

INTRODUCTION

Himalayas, the abode of eternal snow, are the largest store house of snow and glaciers outside the polar regions. The Himalayan rivers are unique because all the major Indian rivers are fed by them and thus the Himalayan rivers are perennial. The significance of Himalayan glaciers is that they influence the climatic condition and comprise 75 percent of the fresh water resources of India. According to Vohra (1992) glaciers in Indian Himalayas cover an area of 38,039 km^2, broadly divided into three river basins - Indus, Ganga and Brahmaputra. The Indus basin has the largest number of glaciers (3538), followed by Ganga (1020), and Brahmaputra (662).

Glaciers are moving mass of ice, instead of rivers of water there are rivers of ice, called glaciers which operate as the main geomorphic agent (Davis, 1961). Longwell and Flint (1961) defined a glacier as a body of ice, consisting mainly of recrystallised snow flowing on a land surface. In simple terms a glacier may be defined as a large natural accumulation of ice with a downward or outward movement from the snow field under the influence of gravity. And the branch of science which deals with the study of glaciers is known as glaciology. At present it has been estimated that approximately 10 percent of the land surface and 7 percent of the oceans are covered by glacier ice.

Research and investigations on hydrogeochemical studies of Himalayan glacier is still in its infancy. With the increasing exploitation of water for irrigation and power, there will be an increasing demand for more detailed scientific information on glacier drainage for an optimum utilisation of water resources and the management of the environmental regeneration in this unique high altitude environment.

Glaciers are also very powerful agents of erosion. They erode the bed rock of their valley and the valley sides, the effects of which can be seen in the form of moraines as glaciers retreat. Apart from physical erosion glaciers are good agents of chemical erosion. Geochemical studies of meltwaters of glaciers near their snout indicate that glaciers are good agents of chemical erosion which indicates active chemical weathering at low temperature which is of great interest (Reynolds, et al. 1972). The silicate minerals reacts rapidly with water at near freezing temperature. The H+ ions needed for acid hydrolysis of minerals comes from high dissolution of atmospheric CO_2 and the release of bicarbonate cations and dissolved silica in melt waters is due to acid hydrolysis of minerals (Raiswell, 1984).

The factors that control the volume of the suspended sediments in the meltwater are the competency and the capacity of the stream and availability of suitable size fractions which can be carried in suspension. Low temperature of meltwater leads to an increase in the viscosity of water which reduces the falling velocity of sediments under suspension. This increases effective contact surface area of sediment with the meltwater and there by promotes chemical weathering. Partial dissolution of the suspended sediments may contribute to the solute concentration (Collins, 1979). For the assessment of the role of meltwater in subglacial environment, the solute and suspended load in the melt water near the snout of the glacier can be investigated. The solute load of a stream draining from a glacierised catchment reflects the chemical, lithological and climatological environment of the area concerned.

Diurnal variations in discharge, total suspended matter and total dissolved solids are of great interest. It is generally observed that increased discharge cause an increase in the concentration of suspended matter and dilution of dissolved salts. Chemical studies of stream and mineralogical studies of sediments offer an insight into the provenance of the glacier basin .

Kafni glacier, Pindar valley, in Kumaon hills of Almora district of Uttar Pradesh, which serves as a catchment for the Kafni river was selected to study the glacial hydrochemical processes.

OBJECTIVES :

The objectives of the present work are to study :

1. Hydrochemistry of the meltwaters draining from Kafni glacier.
2. The process and controls of chemical weathering in the glaciated region .
3. Source of major ions in the melt water.
4. Mineralogy of bed and suspended sediment in the light of their provenance area and to assess the influence of basin characteristics on the mineralogy of the sediments.

LITERATURE REVIEW

The increasing demands of modern society on the environment have necessitated a fuller understanding of the hydrological cycle. The hydrological cycle is an important contribution to the near surface chemical processes. 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 the earth's fresh water reserve, approximately 80% is in the form 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 such as easing the glacier movement- both by creep and basal sliding (Duval,1979).

The role of hydrogeochemistry in glacial environment is important as it controls erosion and sedimentation. The flow of meltwater causes significant erosion (both chemical and mechanical) under great pressure and high velocity.

Studies on chemical weathering are based on the sampling of the meltwaters and discharge measurements near the snout of glaciers. The most important studies in these fields have been carried out by Rainwater and Guy (1961), Keller and

Reesman (1963), Lorrain and Souchez (1972), Collins (1978,79,83), Lemmens and Roger (1978), Hasnain et al, (1989). The studies have been based on the factors influencing chemical weathering and the processes involved.

1.1. **Previous works on Himalayan glaciers:**

Mountain glaciers occupy an area of 14.9 million sq. km. which is 10% of the worlds land area. Out of this over 50,000 sq. km. of the areas is covered by Himalayan glaciers. There are 22 major river systems originating from these Himalayan glaciers having their mountain catchment area of over 10 million sq. km. (Bahadur, 1987), Table 1.1.

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 (Bahadur, 1987). This is due to snow melting and glacial drainage.

Studies on other aspects of Himalayan glaciers like survey of glaciers, (Walker and Pascoe, 1906), morphological studies, geological and mineralogical aspects have been studied since few decades back. However the hydrochemical works on meltwater draining from glacierised basins has been started only in 1986-1987 by Hasnain and others. Working on Chhota Shigri glacier, Lahul valley, Hasnain et al.(1989) report that at low

TABLE 1.1

Principal Glacier Red River Systems of Himalaya

Sl. No.	Name of River	Major River System	Mountain Area (km^2)	Glacier Area (km^2)	Percentage glaciation
1.	HINDUS	INDUS	268,642	8790	3.3
2.	JHELUM		33,670	170	5.0
3.	CHENAB		27,195	2944	10.0
4.	RAVI		8,029	1295	2.7
5.	SUTLEJ		47,915	1295	2.7
6.	BEAS		14,504	638	4.4
7.	JUMNA	GANGA	11,655	125	1.1
8.	GANGA		23,051	2312	10.0
9.	RAMGANGA		6,734	3	0.04
10.	KALI		16,317	997	6.01
11.	KARNALI		53,354	1543	2.9
12.	GADAK		37,814	1845	4.9
13.	KOSI		61,901	1218	2.1
14.	TISTA	BRAHMAPUTRA	12,432	495	4.0
15.	RAKKAD		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	2.0
	TOTAL		1,001,294	25724	2.6

flows the meltwaters are highly enriched in solute concentration and at high flows with low solute content.

1.2. **Sediment and chemical load in the meltwaters:**

According to Collins (1979), the source of solute in meltwaters is controlled by inputs from lithological and atmospheric influences. Gorham (1961) says, snow is not efficient to remove materials from atmosphere. Lithogenic inputs are the main source of solute and suspended load in the meltwaters. Both dissolved and suspended load in the glacial meltwater are the byproduct of chemical denudation. However, in alpine environment the atmospheric CO_2 plays a vital role in supplying hydrogen ions to the meltwaters. The atmospheric CO_2 dissolves in the water and produces bicarbonate which reacts with silicate minerals to release bicarbonate, cations, dissolved silica and clay minerals (Raiswell, 1984). The chemical composition of the material transported in solution in the fresh water systems is generally made up of just four major components (HCO^-_3, SO^{-2}_4, Ca^{+2} and SiO_2), which constitutes about 80% of the total dissolved load and among these four, calcium and bicarbonate represent the dominant cation and anion respectively in most freshwater systems (Meybeck, 1981), (Table 1.2). Calcium and bicarbonate are the dominant ions where rock weathering is the major mechanism controlling solute content and when total ion contribution typically ranges in between 50 to 1000 mg l^{-1} (Gibbs,1970).

In Alpine environment, the streams carry much higher suspended load with them because of low temperature and the high viscosity of the meltwater. The amount of suspended sediments in glacial meltwaters are controlled by the character of the rock eroded, glacial abrasion and glacial melting (Keller and Reesman, 1963).

Table 1.2 Major water types associated with world riverwater (Meybeck, 1981)

Cations	Anions	Percentage of global sample
$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	$HCO^{-}_{3} > Cl^{-} > SO^{2-}_{4}$	33.1
	$HCO^{-}_{3} > SO^{2-}_{4} > Cl^{-}$	2.5
	$SO^{2-}_{4} > HCO^{-}_{3} > Cl^{-}$	1.0
$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	$HCO^{-}_{3} > SO^{2-}_{4} > Cl^{-}$	46.7
	$HCO^{-}_{3} > Cl^{-} > SO^{2-}_{4}$	15.0
$Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$	$HCO^{-}_{3} > Cl^{-} > SO^{2-}_{4}$	1.4
	$SO^{2-}_{4} > Cl^{-} > HCO^{-}_{3}$	0.1
	$Cl^{-} > HCO^{-}_{3} > SO^{2-}_{4}$	0.1

1.3 Factors controlling chemical weathering in the glacial environment:

Gorham (1961), described climate, geology, topography, biota and time as principal environmental factors which interact to determine the concentration and composition of atmospheric precipitation, soil solutions and surface water bodies. The factors which control the world surface water chemistry are atmospheric precipitation, rock dominance, and the evaporation-crystallisation processes (Gibbs, 1970). Relief, vegetation, and composition of material in the basin are second order factors (Gibbs, 1970). In the 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). Gorham (1961), Lorrain and Souchez (1972), and Lemmens and Roger (1978) say the Ion exchange and sorption mechanisms as factors in the transport of major cations by water. The concentration of hydrogen ions in the water plays an important role in the chemical weathering of primary minerals (Lemmens and Roger, 1978; Raiswell, 1984). In the absence of dissolved organic matter in the glacial environment, the chemical factors which influence the chemical weathering are- water composition, water flow rate and rock mineralogy (Raiswell,1984). The natural factors controlling suspended load of rivers are relief of the basin, area, amount of discharge, geology of the drainage basin and climate (Milliman, 1980). The hydraulic factors responsible for the pronounced variations in the concentration and discharge of the sediments in the melt water are-very high stream velocity, marked discharge variation (both seasonal and diurnal) and increased water viscosity due to low temperature (Drewry, 1986).

1.3.1 **Ion exchange and sorption :**

Ion exchange and sorption mechanisms have been studied by Gorham (1961), Lemmens and Roger (1978), as contributing factor to the dissolved load. Lemmens and Roger (1978) have concluded from their work on an alpine glacier that cation exchange appears to be an essential mechanism of water solute enrichment in the subglacial and frontal zone of alpine glaciers and in their proglacial areas. The most important reactions as demonstrated by Lemmens and Roger (1978) in meltwater involves monovalent and divalent cations : Na^{+}-->Ca^{2+}, Na^{+}-->Mg^{2+}, K^{+}--> Ca^{2+}, K^{+}-->Mg^{2+}. Ion exchange also causes rapid increase in the concentration of sodium and potassium in the frontal zone of glaciers. The concentration shows very little variation in the downstream due to the decrease in the rate of diffusion as a result of the diminishing gradient between the Guoy layer and concentration of cations in the water (Fig.1.1).

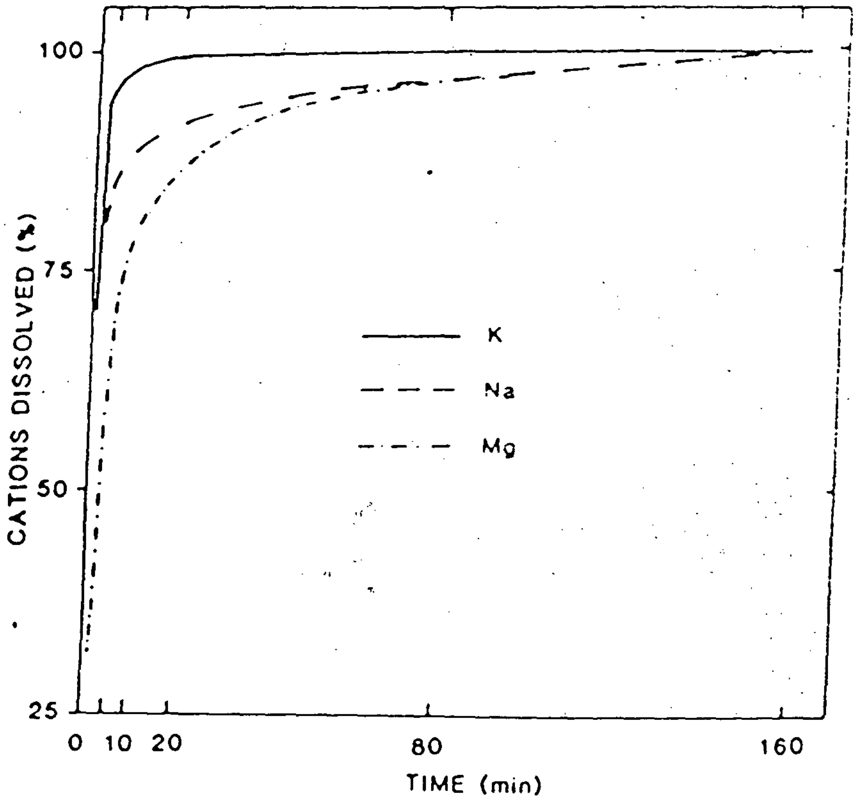

Figure 1.1 Experimental determinations of the rapid chemical enrichment of glacial meltwaters after contact with fine-grained till materials (from Lemmens and Roger, 1978).

Sorption mechanism in the glacial environment was studied in detail by Lorrain and Souchez (1972). According to them the sorbed cations are originally exchangeable cations held on morainic particles. These particles with their sorbed cations are carried away in suspension by glacial meltwaters. Because of the very dilute character of the meltwaters, desorption occurs due to the law of mass action before these particles reach the morainic deposits. The amount of cations sorbed on the suspended matter is more important than that held on the bed sediments because of increase in effective contact area of the sediment in suspension.

1.3.2. **Suspended sediment :**

The grinding action of glaciers produce very fine sediments. These fine materials are carried away in suspension by the turbulent waters emerging from the snout of the glacier. The fineness of suspended load increases their effective surface of contact with the meltwater and this promotes chemical actions between them. Partial dissolution of the suspended sediment may contribute to the solute concentration (Collins, 1979).

1.3.3 **Relief :**

Relief as a controlling factor in influencing the supply of major ions to waters has been recognised by Gorham

(1961) and Gibbs(1967). The turbulence in the hilly streams is responsible for exposing fresh rock surface, thereby promoting enhanced chemical weathering. Water velocity, which depends on relief, was described as major controlling factor by Raiswell (1984). He explained that as many silicate and aluminosilicates have equibrilium constants of similar magnitude, only a small increase in the concentration of aqueous products (and decrease in H^+) are needed to approach the equilibrium and stabilises solid phases. At high flows, fresh supply of hydrogen ions and flushing out of dissolved solids prevents the water from reaching equilibrium. Thus, it is assumed that increased flushing rates cause increased rates of mineral dissolution.

1.3.4 **Geology :**

Influence of geology on water chemistry was carried out by Gorham (1961), Gibbs (1967), Collins (1979) and Meybeck (1983). The chemical composition of streams and rivers depends on the terrain over which they flow. Meybeck(1981) presented average value of total dissolved solids and their constituents for waters flowing over different rock types, namely, sedimentary rocks ,volcanic rocks, plutonic and highly metamorphosed rocks (Table 1.3). Na^+ and Cl^- concentrations were attributed by him to the dominance of oceanic influences. Also, that dissolved load is influenced by rock mineralogy, as the minerals weather at different rates. Low variations in the concentrations of potassium and silica was attributed by him to silicate weathering.

Table 1.3 : Influence of rock types on the average composition of world river-waters (Meybeck, 1981)

Constituents	Average concentraion (ppm) Plutonic and highly metamorphic rocks	Volcanic rocks	Sedimentary rocks
SiO_2	1.5x	3.5x	x
Ca^{2+}	4	8	30
Mg^{2+}	1.0	3	8
K^+	1.0	1.5	1.0
Na^+	Oceanic influence dominant		
Cl^-	Oceanic influence dominant		
$SO^{2-}{}_4$	2	6	25
$HCO^-{}_3$	15	45	100

x = Average SiO_2 content of water from rivers draining sedimentary rocks at a given temperature.

CHAPTER II

AREA OF STUDY

The mighty Himalayas, which is the store house of numerous small and large valley glaciers, is stretching for about 2,414 km between the Indus in the west and Brahmaputra in the east with an average snow line of 4500 m. The glaciation in the Himalayas started during the ice age in the pleistocene period.

2.1 **Location and Description:**

Kafni glacier is situated 24 km north-east of Khati village($30^{0}07'$N: $79^{0}55'$E), on the left side of Pindar valley under mount Nandakote in the greater himalayan ranges and lies in the Almora district of Uttar pradesh. It is a transverse valley glacier emerges from Nandakote peak(6860 m), the glacier snout of which lies at an elevation of 3800 meters.

The route Almora-Bageswar-Song (by bus)-Loharket-Dakuri-Khati- Dwali-Bayali-Kafni (by trekking) provides accessibility to the area (Fig.2.1).

2.2 **Climate:**

The climate in the region is characterised by cold-temperate to polar. The winter extends from october to march. The

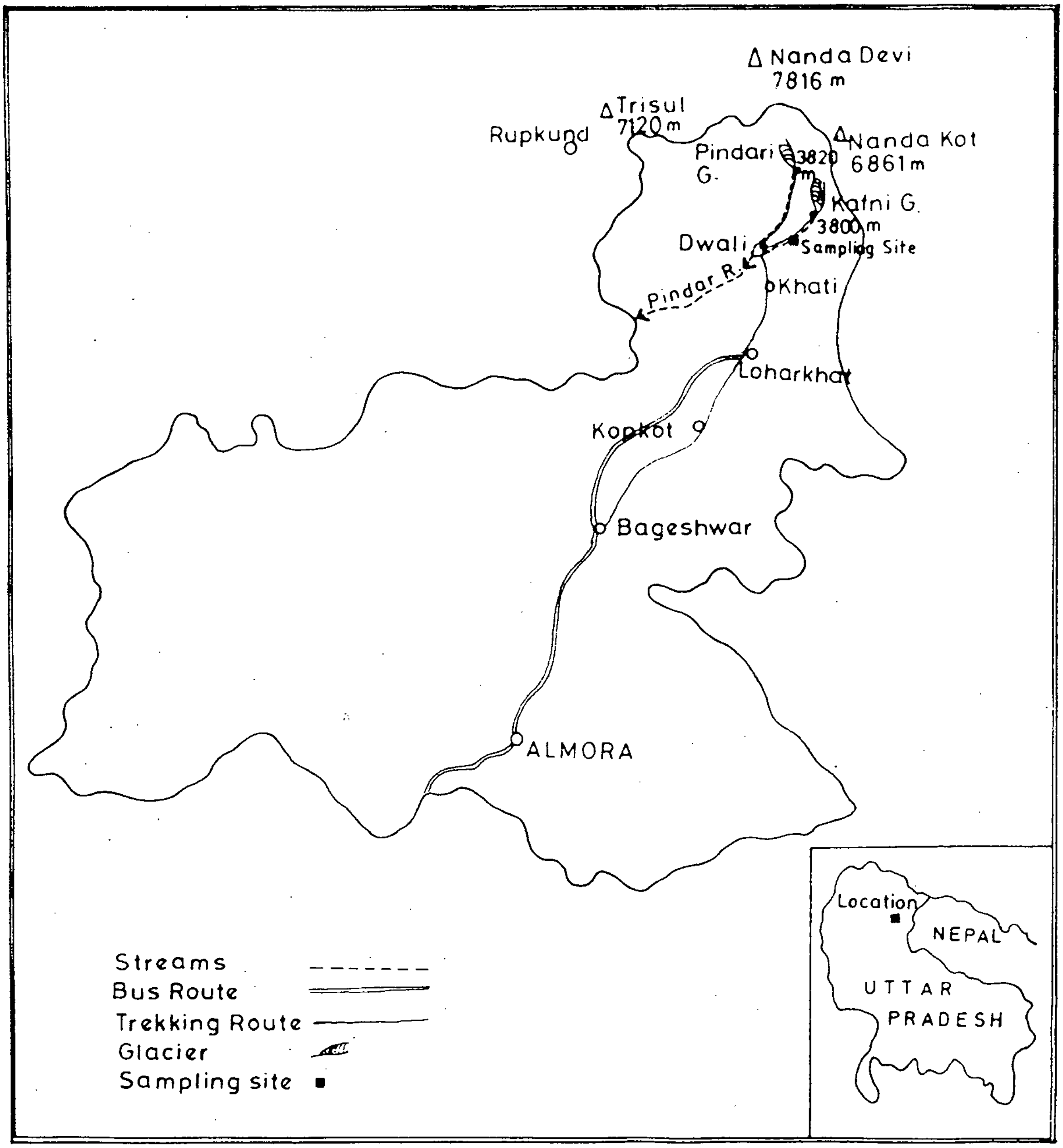

Fig. 2.1. LOCATION MAP OF THE AREA
(based on survey of India :GARHWAL & KUMAON HILLS of U.P.)
(Not to the scale)

temperature in the winter season is below freezing point, where as the maximum temperature in summer is around 20^{0}C. The south - west monsoon, the cyclones and the local thunder storms bring precipitation in the area. Nearly 80% of the total precipitation can be attributed to the south west monsoon, while 15% is associated with cyclones and 5% with local thunderstorms. The winter precipitation, associated with cyclones, is in the form of snow fall.

2.3 **Geomorphology:**

High mountain ranges and the deep narrow river valleys are the two major topographic features in this area. In the evolution of the geomorphic features of the area, the combined action of both glacial and fluvial processes have played a vital role. So the geomorphology of the region can be studied under two processes, i.e. 1. Glacial land forms. 2. Fluvial land forms.

2.3.1 **Glacial land forms:**

Glacial land forms can be divided in to active and inactive zones. Active zone land forms are in contact with glacier where as inactive land forms are no longer in contact with the glacier due to glacial retreat.

2.3.2 **Features in active zone:**

The geomorphic features in active glacial zone are 1. Snout, 2. crevasses, 3. moraines, and 4. Glacial till.

1. **Snout :**

The snout is an outlet in the form of ice cave from where maximum ablation of ice of glacier takes place in the form of melt water.

2. **Crevasses:**

These are cracks developed on the glacier surface, formed in the accumulation zone of glacier.

3. **Moraines:**

These are depositional features generally consist of unstratified material in the glaciated zone. The different kinds of moraines in this region are 1. end moraines, 2. lateral-moraines and 3. ablation moraines . The prominent moraines in Kafni glacier are lateral moraines. The ablation moraines consists of angular to subangular boulders of surrounding rock types.

4. **Glacial till:**

These are mass of broken rock fragments, mostly angular to subangular and of many different sizes and composition, laid down by the glacier.

2.3.3 Features in inactive zone:

The geomorphic features in the inactive zone are no more in contact with glacier ice due to glacial retreat. The important features in this zone are: 1. Terminal moraine. 2. Ground moraine.

2.3.4 Fluvial landforms:

The prominent fluvial landforms in this area are alluvial cones and alluvial fans, which are present at the base of the hanging valley. Besides these, several glacial drift deposits i.e., wind blown detritus, crevasses filling and glacio-fluvial deposits occur in the area.

2.4 Geology:

This region belongs to the Greater Himalayan ranges of Vaikrita Group of Pre-Cambrian age and are made up almost wholly of high grade metamorphics, (Greisbach, 1891, 1893; Heim and Gansser, 1939; Valdiya, 1979) which is further divisible into four formations (Valdiya, 1973; Valdiya and Goel, 1983),(Table 2.1), Fig. 2.2.

2.4.1. Joshimath Formation:

This formation is constituted of psammitic- kyanitic-sillimanite- garnet-bearing two mica gneisses and schists, with

Table 2.1:Lithostratigraphy of Greater Himalayas in Pindar Valley (After Valdiya, 1973 and Valdiya and Goel,1983)

		Pindari-Kafni Area	
Age	Group	Formation	Member
PRECAMBRIAN	VAIKRITA GROUP	Budhi Schist	Biotite-prophyroblastic -calc schists; marble
		Pindari Formation	Psammitic schists, Gneisses,inter banded calc silicate rocks; amphibole calc-gneisses.
		Pandukeswar Formation	Pandukeswar quartzite, Schists, Leptynite.
		Joshimath Formation	Kyanite-sillimanite garnet-mica gneisses

........M.C. Vaikrita thrust........

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GEOLOGICAL MAP OF THE AREA

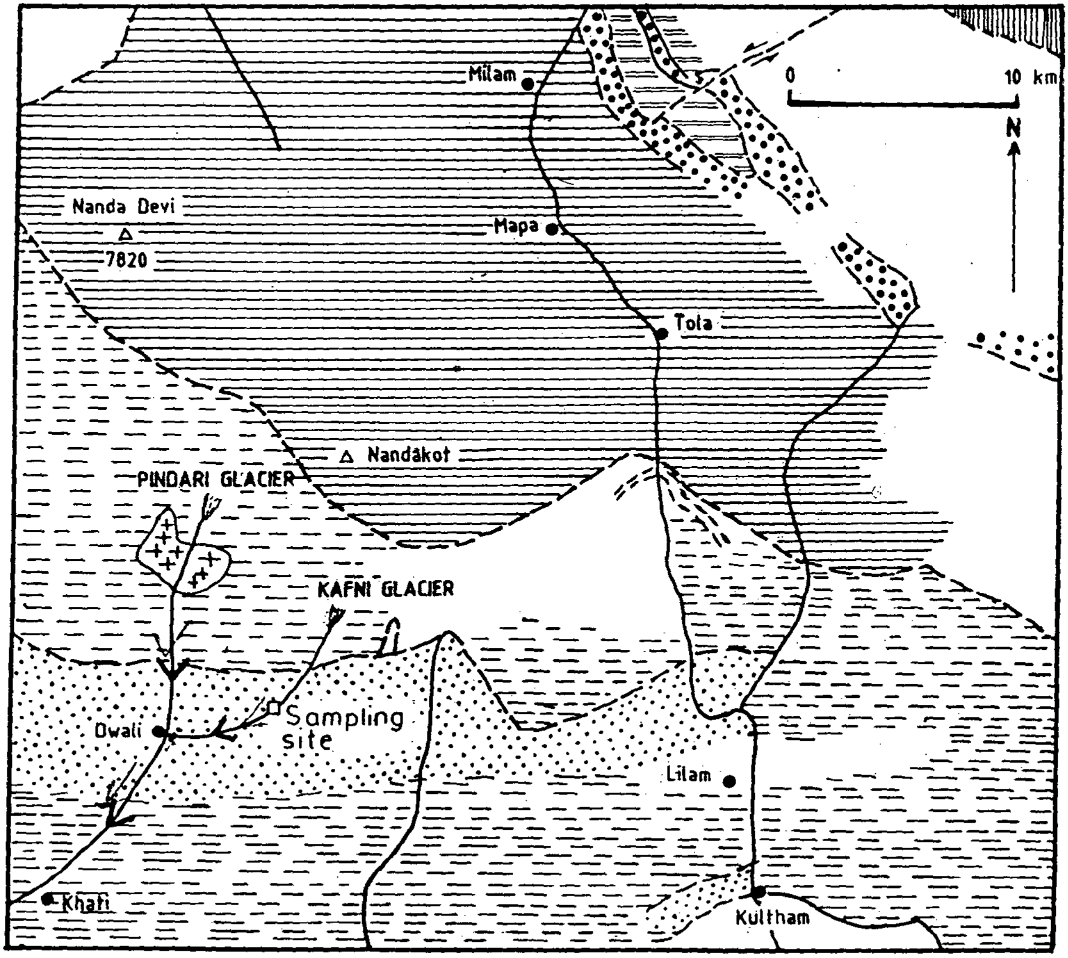

Fig. 2.2

LEGEND

- ▥ 1. Variegated Silurian-Yong Limestone
- ▤ 2. Garbyang Fm
- ⁘ 3. Ralam Fm
- ☰ 4. Martoli Fm
- ◠ 5. Budhi Schist Pindri Fm
- ░ 6. Padukeshwar Quartzite
- ╌ 7. Joshimath gneisses and schists
- ⇄ 8. Inverted fold axis
- + 9 Mid-Tertiary pegmatite and granite

(Redrawn after Heim and Gansser, 1939; Valdiya 1979; and Sinha 1986).

very subordinate lenses of micaceous quartzite and calc-silicate rocks, intruded by the Mid-Tertiary batholiths of granite and dykes and veins of tourmaline-rich adamellite and pegmatite, Fig 2.2.

2.4.2 **Pandukeswar Formation:**

This formation consists of garnet-kyanite bearing biotite-muscovite rich quartzite with subordinate schists and rare leptynites.

2.4.3 **Pindari formation:**

This formation is made up of sillimanite rich kyanite-garnet bearing psammitic schists and gneisses interbedded with calc-silicate rocks and amphibolite bearing calc-gneisses.

2.4.4 **Budhi schist formation:**

It is the uppermost unit with an assemblage of biotite-porphyroblastic-calc schists and marble.

The mineral assemblages of the Vaikrita group indicate their development at temperatures as high as 600^0C to 650^0C and pressure of about or above 5 kilobars(Valdiya and Goel, 1983.).

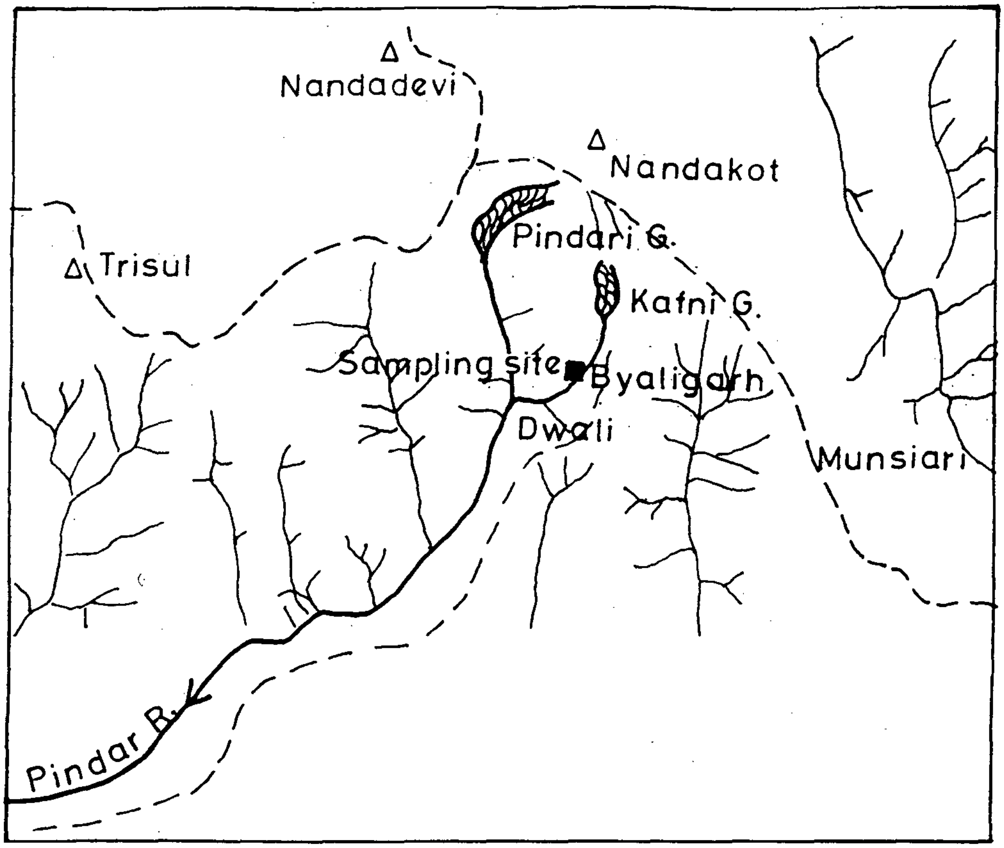

Fig. 2.3 Drainage Pattern of the area.
(not to the scale)

2.5 **Surface drainage:**

The Kafni river originating from Kafni glacier joins the Pindar river (originating from Pindari glacier), at Dwali, Fig.2.3. The Pindar joins the Alaknanda, a tributary of river Ganga, at Karnaprayag.

2.6 **Vegetation and human interference:**

The Kafni area does not possess any permanent vegetation, as it is covered by snow for a longer period. Anyhow, during summer, after the snow melting few grasses and small flowering plants grow along the lower ridges.

After the Dwali village, the upper part of the valley are free from human interference, except for a few shepherds who move into the valley during October- September to feed their sheep.

CHAPTER III

METHODOLOGY

3.1 FIELD METHODS

Meltwater samples of Kafni glacier were collected in polyethylene bottles seven times a day (630, 830, 1030, 1230, 1430, 1630,1830) to broadly cover diurnal variations during the sampling period. The samples were collected during the period from 14-10-1991 to 19-10-1991.,taking great care to avoid contamination. Electrical conductivity (EC) of the water samples was measured in the field using a hand held Pentax EC meter. Sediment samples were collected in polyethylene bags at a few locations for their analysis in the laboratory.

3.2 LABORATORY METHODS

The water and sediment samples were later analysed in the laboratory following prevalent techniques in chemical analysis. A brief description of the methods followed is given below.

3.3 Water Analysis:

3.3.1 pH:

pH of the samples were measured in the laboratory using C-425 pH- conductivity meter. While measuring the pH of water samples, the electrodes were immersed for at least ten hours in 0.1 N KCl, in order to make the electrodes stable. After rinsing the electrode with distilled water it was immersed in a buffer solution of pH 6.87 (25^{0}C) and the cal. knob was adjusted, again when the electrode was immersed in a buffer of 4.01 pH, slope knob was adjusted. After the calibration of the instrument, pH of the samples were recorded to get the accurate results.The samples were stirred well during measurement to provide homogeneity.

3.3.2 **Electrical Conductivity:**

Electrical conductivity was measured using Consort C 425 Conductometer. Consort C 425 provides measurement of EC by a cell consisting of two Platinum electrodes, to which an alternating potential is applied. The corresponding current is proportional to conductivity of the ionic solution in which the cell is dipped. For EC measurement, the instrument was calibrated and set for 0.01 KCl standard. The conductivity was measured in uS cm^{-1} for water samples.

3.3.3 **Bicarbonate:**

Bicarbonate was determined in the laboratory by following the potentiometric titration method. In this method no indicator was used, instead the pH of the samples as well as that of the standard solutions were maintained at 4.5 to signify the end points, by adding HCl(0.005N). A graph was plotted for standards against the amount of HCl consumed and from the graph the amount of bicarbonate in the samples was calculated.

3.3.4 **Chloride:**

Chloride in the laboratory was determined by following the potentiometric titration method. Standards of various concentrations (1 to 5 ppm) were prepared. 25 ml. of each standard and water samples were titrated against 0.003N Silver nitrate solution. The end point of the reaction is the appearance of pink colour. Concentration of chloride in samples was determined from the graph plotted for standards against amounts of Silver nitrate consumed.

3.3.5 **Sulphate:**

Sulphate ion concentration was measured by turbidimetric method. The method is based on the principle that SO^{-2}_4 is precipitated in an acetic medium with Barium chloride, so as to form Barium sulphate crystals of uniform size. Light absorbance of $BaSO_4$ suspension is measured by a photometer and the concentration is determined by comparison of the reading with standard curve.

100 ml. of standard solution and sample were measured in a volumetric flask and 20 ml. of buffer solution (prepared by

dissolving 30 gm. of $MgCl_2 .6H_2O$, 5 gm. of $CH_3COOH.3H_2O$, 1 gm. of KNO_3 and 0.111 gm. of Na_2SO_4 and 20 ml. of Acetic acid (99%) in 500 ml. of distilled water and then the total volume made upto 1000 ml). was added and mixed with the help of magnetic stirrer. While stirring a spoonful of $BaCl_2$ crystals were added. This was stirred for sixty seconds with constant speed. After the stirring period, solution was poured into the absorbance cell of the photometer and turbidity was measured at 5±0.5.

Sulphate ion concentration was estimated by comparing reading with calibration curve prepared by carrying sulphate standard through the entire procedure. Reliability of the calibration curve was checked by running a standard with every three or four samples.

3.3.6 **Dissolved silica :**

The dissolved silica content was determined by the Molybdo-silicate method. Standard solutions of different concentrations ranging from 0.1 to 7 ppm were prepared by dissolving Na_2SiO_3. 20 ml of each standard and sample were pipetted out into a 20 ml volumetric flask and 10 ml of ammonium molybdate solution and 15 ml of reducing agent were added and mixed well. Ammonium molybdate solution was prepared by dissolving 2 gm of ammonium molybdate in 10 ml of concentrated HCl and the whole volume is made upto 100 ml by adding distilled water. Reducing agent was prepared by mixing 100 ml of metol sulphite. Solution was prepared by dissolving 5 gm of metol in 210 ml by distilled water, 3 gms of Sodium sulphite was added and the volume made to 250 ml by adding distilled water. The samples were stirred properly and kept for three hours to complete the reaction. The optical density was measured for standard and water samples at 814 nm using GBC 911 UV/VIS spectrophotometer.

3.3.7 **Calcium, magnesium, sodium and potassium:**

The analysis of cations were carried out on GBC 906 Atomic Absorption Spectrophotometer. Calcium and magnesium were analysed in the absorption mode, sodium and potassium in emission mode. The instrument was calibrated using different chemical standards.

3.4 **SEDIMENT ANALYSIS (MINERALOGY OF SEDIMENTS)**

Prior to sediment analysis, the bed sediments (not representative) and suspended sediments were made free of organic material by treatment with 35% hydrogen peroxide solution after the sediment had been wetted and buffered with sodium acetate. The sediments were weighed before and after treatment, the weight loss was taken to be the total amount of organic matter present in the sediments. The organic matter freed sediment were used for mineralogical studies. Before this, the organic freed bed sediments were sieved by GSMW standard sieve and sediments of size less then 256 u were collected.

3.4.1 **Mineralogy :**

The bulk mineralogy of suspended sediments and bed sediments (size <256 um) were prepared by drop on slide technique (Gibbs-1967a) and run on Phillips X-ray diffractometer using Cu-K radiation and Ni filter. Scan speed 5^{0}minute^{-1}, step sampling 0.1 ^{0}, voltage/current 30 KV 30 mA and intensity 4×10^{2} were maintained. Methods of Carroll (1970) were used in identifying the minerals.

CHAPTER IV

RESULTS AND DISCUSSIONS

Chemical analysis of the Kafni meltwater, along with the mineralogy of the bed (size < 256 um) and suspended sediments were carried out in the laboratory following standard procedure described in the previous chapter. The results obtained are tabulated in the tables 4.1, 4.2 and 4.3. Table 4.2 shows the range of the different parameters observed in the sampling sites. On the basis of result obtained, the character of meltwater and mineralogy of the sediments are discussed below.

4.1 pH :

The pH of the meltwater during the sampling period ranged from 7 to 7.6 and the average pH for the meltwaters was around 7.2. The neutral to slightly alkaline pH may be due to metamorphic formations which constitute the bed rock of the glacier catchment. According to Meybeck (1981) dissolved load in water draining from the igneous or metamorphic rocks is less than in water flowing over the sedimentary rocks (Table 1.3).

4.2 ELECTRICAL CONDUCTIVITY :

Electrical conductivity is a measure of the dissolved solids and is dependent on the anionic strength of the solution. An increase in the solute content increases the ionic strength

Table 4.1 Chemical Characterstics of Meltwater

				Anions*				Cations*			
Sample No.	Time (hrs.)	pH	E.C. (umhoS)	HCO_3^-	Cl^-	SO_4^{--}	H_4SiO_4*	Ca^{++}	Mg^{++}	Na^+	K^+
Meltwater samples											
1	630	7.61	116.00	45.05	2.51	5.39	3.95	16.50	2.83	1.62	1.59
2	830	7.45	110.00	44.05	2.42	4.84	2.39	16.08	2.66	1.60	1.56
3	1030	7.39	90.00	40.06	2.37	5.29	1.80	14.05	2.32	0.91	1.57
4	1230	7.26	82.00	34.07	2.27	2.68	1.31	12.52	2.52	0.85	1.11
5	1430	7.35	83.00	32.08	2.13	3.93	2.19	13.02	2.65	0.93	1.11
6	1630	7.41	85.00	33.08	2.22	2.80	2.40	13.24	2.91	1.02	1.29
7	1830	7.56	95.00	41.06	2.32	3.71	2.44	15.08	2.98	1.55	1.41
8	630	7.39	114.00	45.55	2.22	5.24	2.57	16.63	2.38	1.40	1.59
9	830	7.32	107.00	44.05	2.18	5.11	2.19	16.62	2.47	1.34	1.58
10	1030	7.29	98.00	33.08	2.13	4.39	1.70	15.49	2.53	1.11	1.50
11	1230	7.11	83.30	30.09	2.08	3.14	1.44	13.29	2.79	0.84	1.05
12	1430	7.19	85.10	31.08	2.20	2.35	2.52	13.41	2.27	1.01	1.07
13	1630	7.20	85.20	33.08	2.22	4.39	2.53	13.58	2.43	1.18	1.24
14	1830	7.22	90.00	38.07	2.27	5.56	2.53	14.01	2.50	1.26	1.40
15	630	7.30	85.00	34.07	2.27	4.61	3.26	13.30	2.72	1.18	1.28
16	830	7.26	84.00	33.08	2.22	3.93	2.65	13.07	2.49	1.16	1.11
17	1030	7.17	84.00	32.07	2.22	3.82	2.94	12.93	2.34	1.16	1.10
18	1230	7.11	83.00	30.08	2.13	4.16	2.89	12.92	2.32	1.01	1.09
19	1430	7.24	84.00	32.19	2.18	4.05	3.39	12.95	2.69	1.18	1.09
20	1630	7.25	85.00	34.07	2.22	4.16	2.41	13.05	2.73	1.21	1.11
21	1830	7.32	87.00	35.07	2.27	3.48	2.53	13.45	3.30	1.40	1.14
22	630	7.23	88.80	34.67	2.22	2.12	2.50	14.33	2.58	1.07	1.17
23	830	7.17	86.70	31.08	2.22	3.16	2.53	14.23	2.40	1.07	1.11
24	1030	7.05	86.60	31.58	2.13	3.25	2.59	14.23	2.22	1.02	1.05
25	1230	7.01	86.10	30.08	1.98	2.43	2.51	13.23	1.81	0.86	1.02
26	1430	7.01	86.20	30.58	2.08	2.24	2.56	13.50	2.01	0.95	1.03
27	1630	7.11	87.60	32.58	2.27	3.71	3.03	13.58	2.30	0.99	1.09
28	1830	7.13	87.60	32.58	2.27	3.37	3.58	14.33	2.34	1.05	1.11
29	630	7.15	86.90	31.58	2.18	3.93	3.58	13.62	2.42	1.13	1.17
30	830	7.07	86.20	30.58	2.18	3.59	2.83	13.48	2.26	1.00	1.16
31	1030	7.09	86.50	30.08	2.13	2.69	2.81	12.78	2.06	0.91	1.09
32	1230	7.06	86.40	29.58	2.08	1.33	2.44	11.81	2.03	0.91	1.01
33	1430	7.11	85.10	30.58	2.13	2.01	2.81	12.84	2.17	0.91	1.08
34	1630	7.12	87.20	31.50	2.20	2.92	3.28	13.12	2.26	1.08	1.08
35	1830	7.23	90.00	33.08	2.20	2.35	3.71	13.25	2.30	1.28	1.03
36	630	7.36	91.60	33.04	2.27	4.27	3.42	13.92	2.46	1.65	1.57
37	830	7.22	87.60	31.58	2.22	3.82	2.57	13.83	2.37	1.40	1.15
38	1030	7.18	87.40	30.58	2.22	3.71	2.52	13.55	2.03	1.25	1.07
39	1230	7.11	86.20	30.08	2.13	3.25	2.26	13.12	1.95	0.84	1.05
40	1430	7.16	85.40	30.58	2.13	4.05	2.52	13.23	2.12	1.05	1.06
41	1630	7.20	86.70	30.58	2.20	4.27	2.81	13.49	2.48	1.08	1.07

* values in ppm.

Table: 4.2. Range of ionic concentration in meltwaters.
(concentration in ppm).

	Meltwater	**Average**
pH	7.01-7.61	7.22
EC (uS cm^{-1})	82-116	89.22
HCO_3	29.58-45.05	33.69
Cl^-	1.98-2.51	2.2
SO_4^{-2}	2.80-5.56	3.60
H_4SiO_4	1.31-3.95	2.65
Ca^{2+}	16.50-11.81	13.77
Mg^{2+}	1.81-2.83	2.42
Na^+	0.84-1.62	1.13
K^+	1.01-1.59	1.20

leading to a concomitant rise in electrical conductivity. During the observation period the minimum and maximum values of conductivity observed are 82 us cm^{-1} and 116 us cm^{-1} respectively.

The ionic strength of the solution is given by :

$$1/2\ m_i\ z_i^2 \ldots\ldots\ldots\ldots\text{Eq.(1)}$$

(where m_i is the concentration of the i^{th} ion in moles per litre and Z_i is the valency of i^{th} ion).

From the Eq.(1) it can be observed that an increase in the dissolved solids causes a proportional increase in electrical conductivity. The ratio of total dissolved solids to electrical conductivity is generally accepted as 0.7 (Davis and Deweist, 1962). For Kafni meltwater, however the ratio is around 0.68 (Fig. 4.1). As indicated by Meybeck (1981), lithology plays an important part in contributing to the dissolved loads in the meltwater (Table 1.3).

Diurnal variation in electrical conductivity were observed throughout the sampling period. Fig 4.2 and 4.2.1 show the diurnal variations in electrical conductivity observed during the sampling period. Rainwater and Guy (1961) and Collins (1979) put forward a two component subdivision of total flow to explain the nature of diurnal variations in glacierised catchments. According to them, this phenomena occurs due to variable dilution

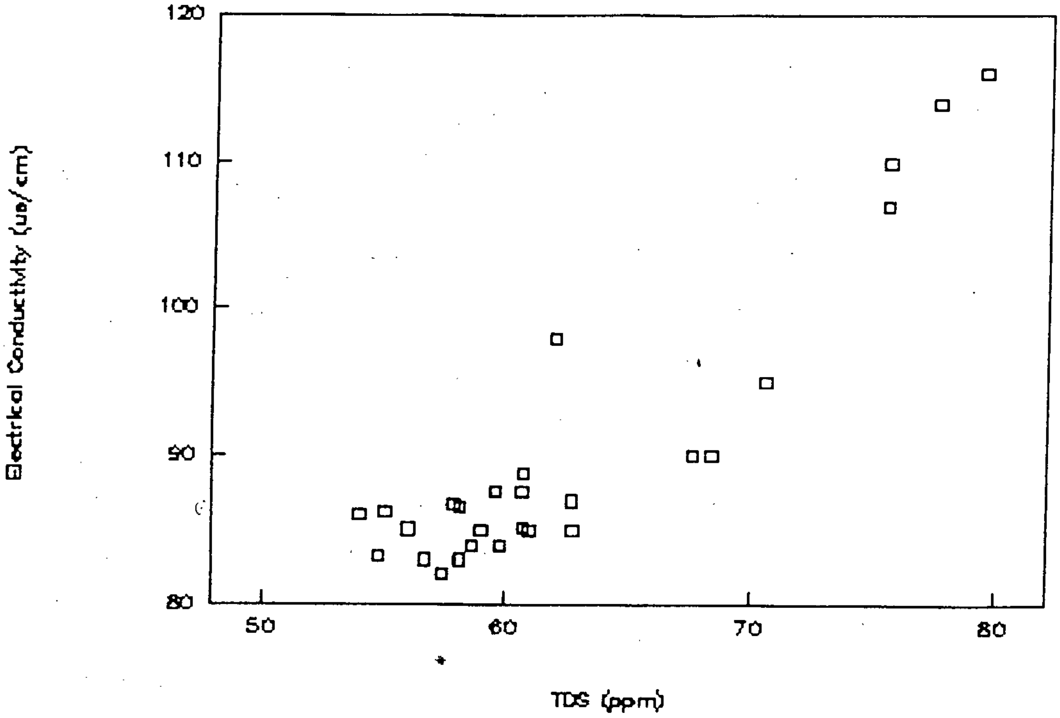

Fig4.1Electrical Conductivity vs TDS

of water coming from the ground environment, which undergoes chemical change while passing slowly through the ice-sediment-rock interface and basal sediments, and by water running off rapidly through englacial channels without undergoing much change. In the forenoon with the supply of solar energy, ablation starts and produces more englacial water which causes an increase in discharge and a corresponding decrease in electrical conductivity due to dilution (Fig. 4.2 and 4.2.1). Slowing down of the ablation in the late afternoon causes an increase in electrical conductivity.

4.3 **DISSOLVED LOAD :**

In catchments comprising predominantly of glacier ice and almost bare rocks, solutes are derived from two main sources i.e. atmospheric and lithospheric. Both the quantity and quality of precipitation may vary seasonally and topographically. As the water passes through the catchment it drains through a range of lithological environments, between each of which there are differences in rate and mechanism of solute release (Collins, 1979).

The dissolved load of the stream draining from the catchment reflects the mixing of waters of different compositions from different environments in varying proportions. Fig.4.2A shows the average concentration and standard deviation of major

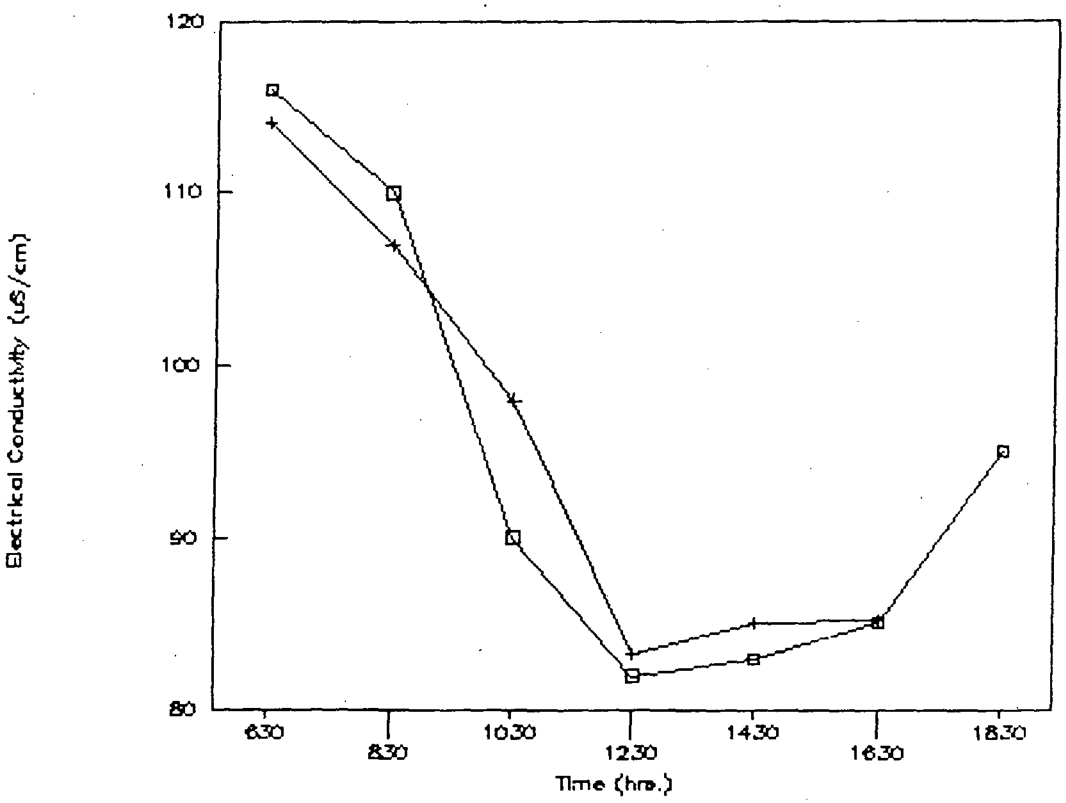

Fig. 4.2: Diurnal variations in electrical conductivity

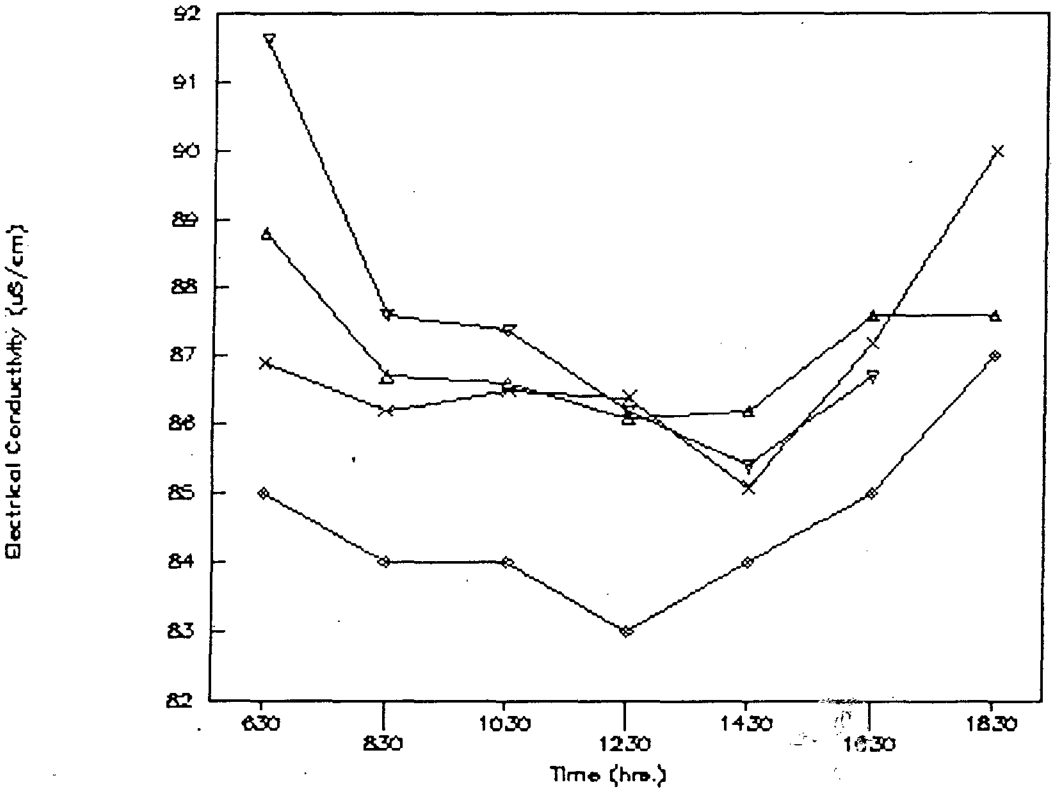

Fig. 4.2.1 : Diurnal variations in electrical conductivity

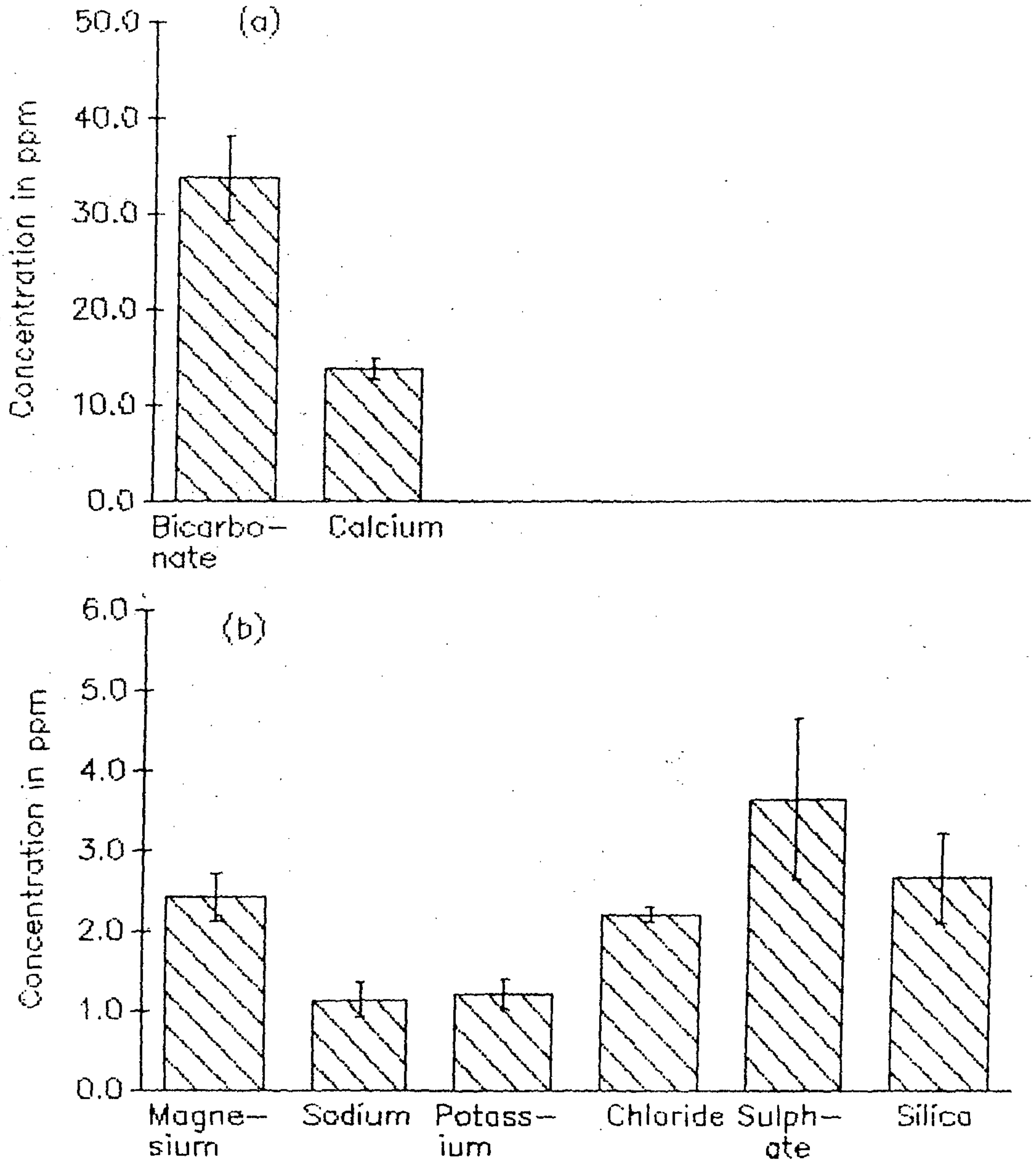

Fig. 4.2A Figure showing average concentration and standard deviation of major dissolved components in meltwater.

dissolved components of Kafni meltwaters throughout the sampling period.

4.3.1 **Total cations :**

Average chemical composition of the Kafni meltwater shows 74.37 % calcium out of total cations, followed by magnesium 13.09 %. Sodium and potassium show approximately equal percentages where the values are 6.1 % and 6.4 % respectively. The range of percentage of cations tabulated by Collins (1979) suggests that calcium is the dominant cation in melt waters except those at Baffin island, where the dominant cation, Na^+ is preferentially supplied from the bedrock. Calcium is the dominant cation, approximately 88 % of the total meltwaters and often comprises more than 70 % of the total cation equivalents (Raiswell, 1984). The cationic composition of Kafni meltwater also shows that calcium is the dominant cation followed by magnesium (Table 4.1). This table shows the changing proportion of cations during the observation period. The changing proportions of cations suggest that the Kafni meltwater may be from several subglacial routes along each of which the water comes in contact with morainic material of different composition.

4.3.2 **Total anions :**

Bicarbonate forms the dominant anion ranging from 76.05 to 84.48 % and averaging around 79.8 %of the total anionic content. Bicarbonate is followed by sulphate and chloride ranging from 3.75 % to 11.47 % and 3.99 % to 5.87 % and constitute 8.55 % and 5.28 % of total anions respectively. This indicates that the water is of $HCO_3^- > SO_4^- > Cl^-$ type of Meybeck (1981). Available data on meltwater chemistry shows that half of the meltwaters are bicarbonate dominant whereas the other half are dominated by sulphate (Raiswell,1984).

4.3.3 **Bicarbonate, Calcium, Magnesium :**

Bicarbonate constitute an average of 33.69 ppm in the meltwater draining from the glacier. The range of bicarbonate concentration is from 29.58 to 45.05 ppm during the sampling period. Calcium and magnesium in the meltwater together constitute 87.46 % of the total cation. The minimum and maximum concentrations observed for calcium and magnesium are 11.8 to 16.5 ppm and 1.81 to 2.83 ppm respectively. Diurnal variations are observed for these ions throughout the sampling period (Fig.4.3, 4.4, 4.5). A definite trend can be traced for calcium and bicarbonate (Fig. 4.3 and Fig. 4.4), but no specific trend is found in the case of magnesium (Fig. 4.5). Concentrations of both calcium and bicarbonate show a decrease with an increase in discharge with the start of ablation in the forenoon. The concentration rises again in the late afternoon as the discharge starts declining.

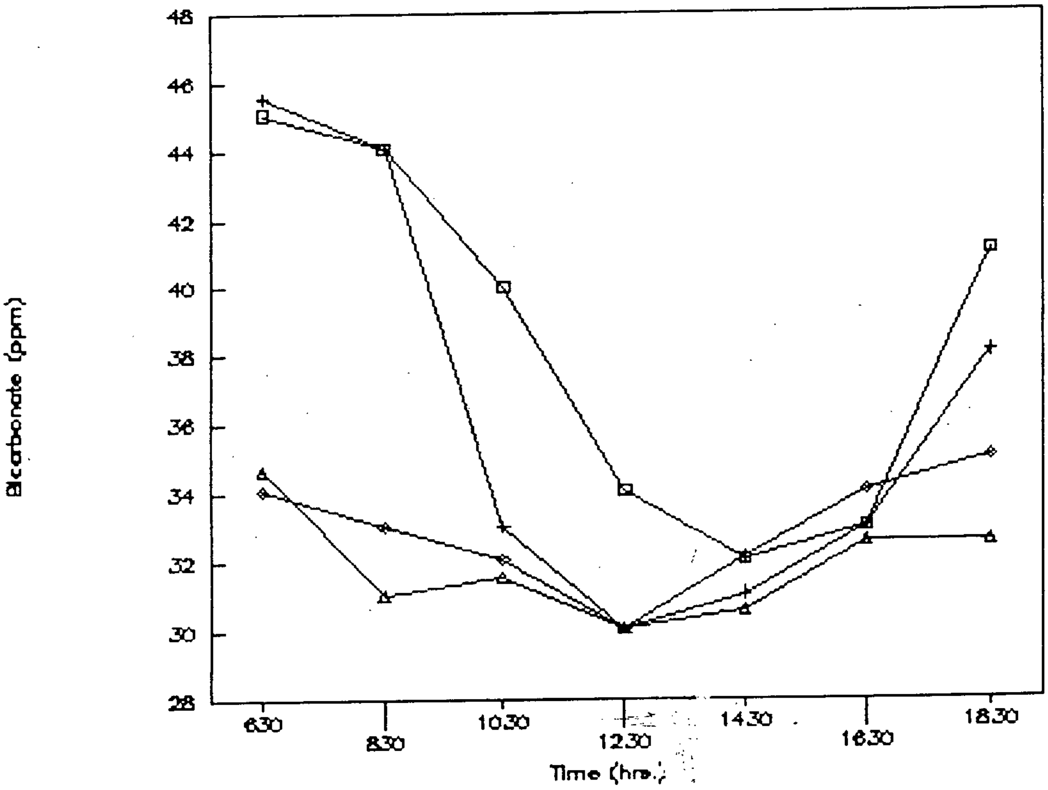

Fig. 4.3

: Diurnal variations in bicarbonate concentrations

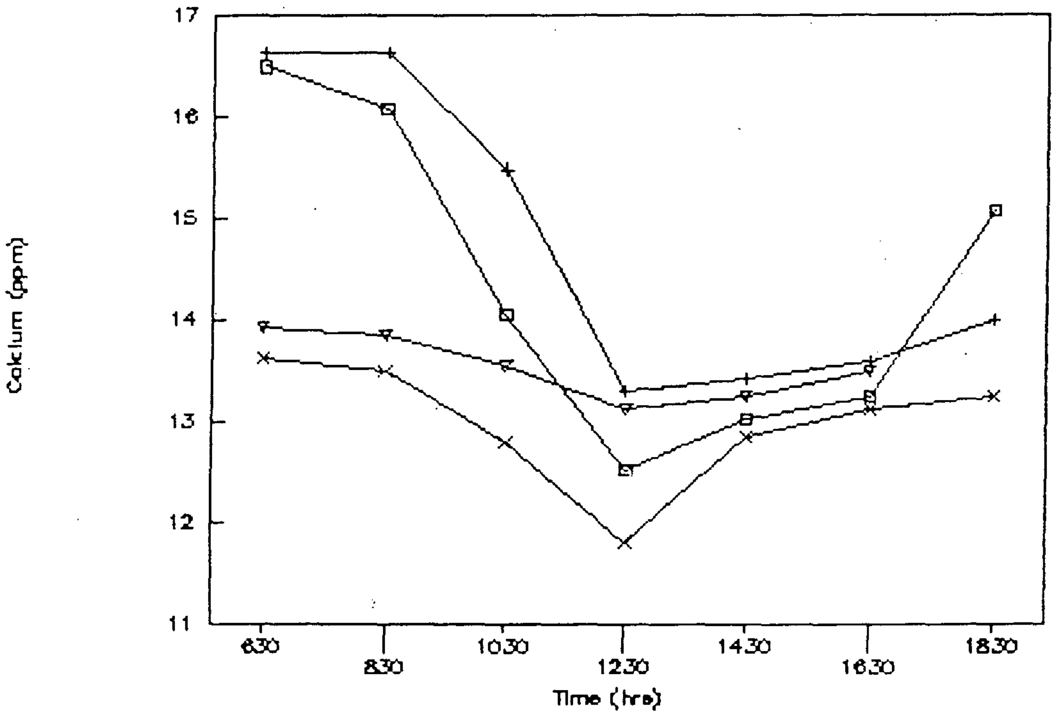

Fig. 4.4 : Diurnal variations in calcium concentrations

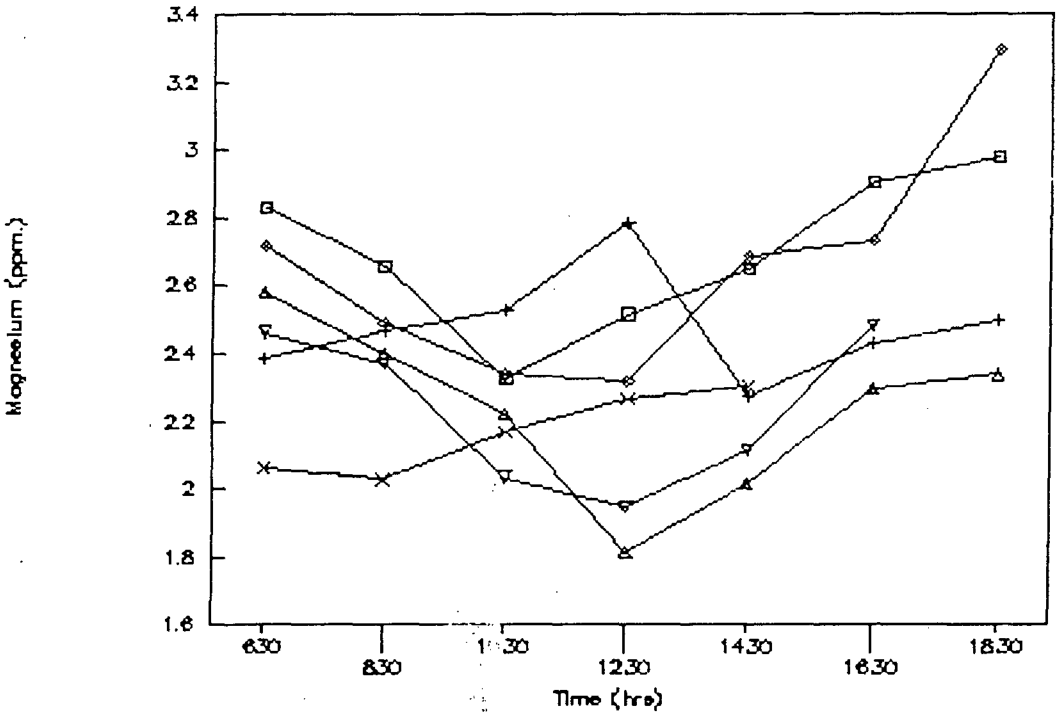

Fig. 4.5 : Diurnal variations in magnesium concentrations

The single most important process in the chemical weathering of rocks is acid hydrolysis. The source of bicarbonate in water is dissolution of carbon dioxide. The organic material in the soil zone of the glaciarised catchment is negligible to contribute CO_2 to water. So the main source of dissolved carbon dioxide in the water is from the atmosphere. The dissolved carbon dioxide produces bicarbonate and releases hydrogen ions required for the acid hydrolysis to the water.

$$CO_2 + H_2O = H_2CO_3^- \ldots\ldots\ldots\ldots\ldots \text{Eq.}(2)$$

$$H_2CO_3 = H^+ + HCO_3^- \ldots\ldots\ldots\ldots \text{Eq.}(3)$$

In Eq.(2) dissolved carbon dioxide reacts with the water to form carbonic acid. This weak carbonic acid dissociates itself to produce hydrogen and bicarbonate ions (Eq. 3). Bicarbonate may again split in to hydrogen and bicarbonate ions at pH values higher than 10.3 (Raymahashay, 1986). However this reaction is not important as the pH observed range from 7 to 7.6 for Kafni meltwater. Bicarbonate concentration in the meltwater is derived either from primary carbonates as well as calcareous cements or from silicates (Raymahashay, 1986).

4.3.3.1 **Carbonate weathering :**

Carbonate minerals like calcite and dolomite are acted upon by carbonic acid and release bicarbonate and cations to the water.

$CaCO_3 + H_2CO_3 = Ca^{2+} + 2HCO_3^-$....Eq.(4)

$CaMg(CO_3)_2 + H_2CO_3 = Ca^{2+} + Mg^{2+} + 4HCO_3$..Eq.(5)

If the carbonate involved in the reaction is calcite then according to the Eq.(4), Ca^{2+} and HCO_3^- will be released in 1:2 proportion. If dolomite is involved then calcium, magnesium and bicarbonate will be released in 1:1:4 proportions (Eq. 5).The values for calcium (mean 13.77 ppm) when plotted against bicarbonate (mean 33.69) show 1:2.44 relationship (Fig. 4.6). This suggests a common source for both calcite and bicarbonate and calcite may be the dominant carbonate involved in this region.

The $Ca^{2+}+Mg^{2+}$ / HCO_3^- serves as an index of carbonate weathering (Fig. 4.7). This suggests the carbonate weathering in this region. The calc-schist which are associated with marble bands of Budhi-schist formation may be the possible source for carbonate.

4.3.3.2 **Silicate weathering:**

The carbonic acid in glacial melt water, produced by the dissolution of CO_2, reacts with cation rich primary minerals, releases alkali and alkaline earths, silica, bicarbonate and some iron and aluminium to the solution. Stallard and Edmond (1987) suggest that the quantification of silicate rock weathering is more difficult than for carbonate weathering because of the

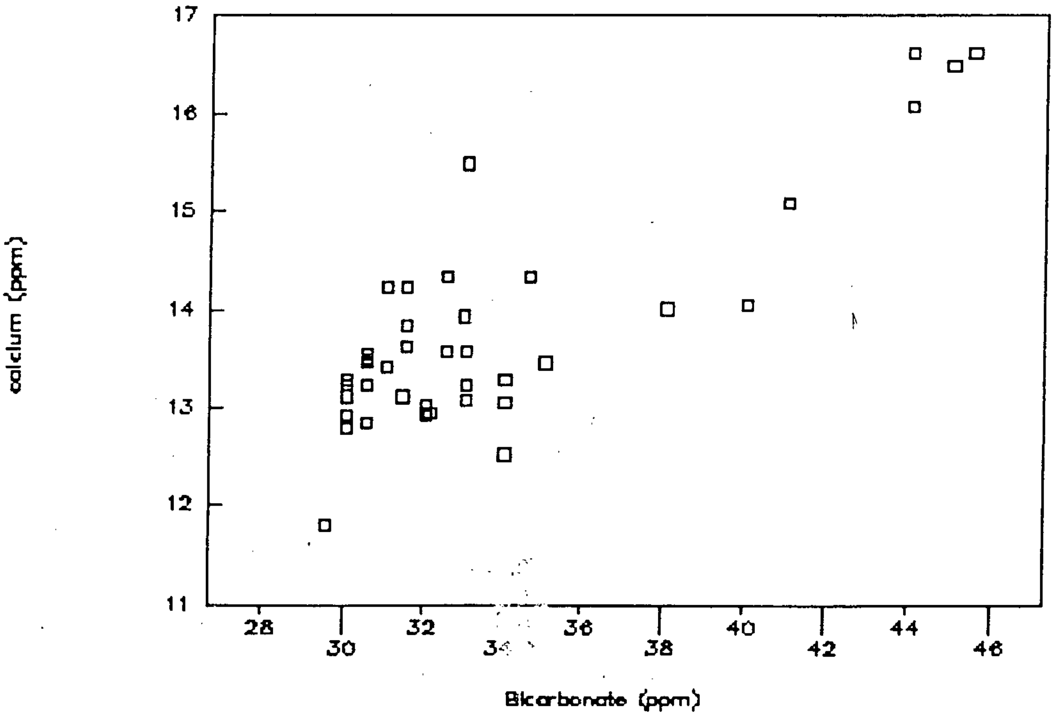

Fig.4.6 Calcium vs Bicarbonate

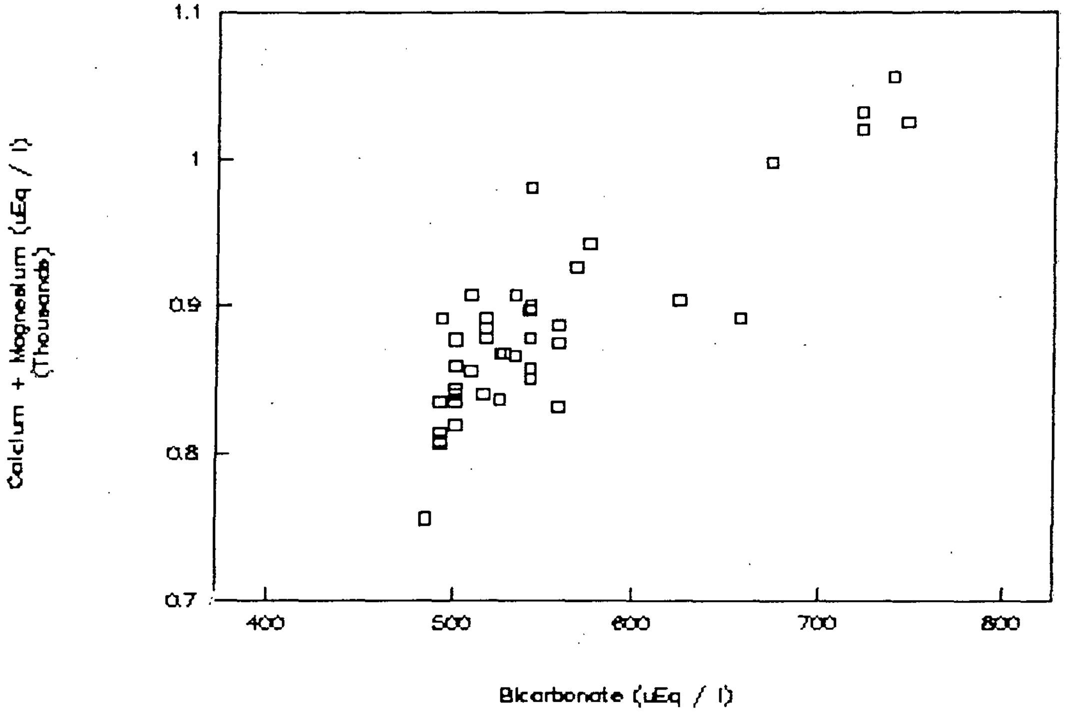

Fig. 4.7 : $(Ca^{2+} + Mg^{2+})$ / HCO_3

variety of solid phases generated by incongruent reactions. However, a reaction for weathering of silicate rocks with carbonic acid can be written as:

(Na,K,Ca,Mg)silicate + H_2CO_3 = Silica + Na + K + Ca +Mg + Kaolinite + HCO_3^-(Eq.6)

The quantities of cations and anions released in solution during the above reaction are dominated by the proton source, composition of the parent rock and solid products of the chemical weathering. However, distinctly different weathering reactions can generate similar solution composition. The relative proportions of Ca^{2+} and HCO_3^- released during the weathering of calcium silicate (anorthite) is the same as that resulting from calcite dissolution (Sarin et al., 1989). Therefore, water chemistry alone cannot identify the source of major ions. Additional information on the geology of the of the area and mineralogy of the suspended phases and sediments help to constrain the source minerals and weathering reactions.

Ca^{2+}+Mg^{2+}/TZ^+ = 0.9 can be used as an index for silicate weathering (Sarin et al.,1989). The Ca^{2+}+Mg^{2+}/TZ^+ ratio for the Kafni glacial meltwaters (0.91) suggests that silicate weathering is the prominent weathering process taking place in this region (Fig. 4.8).

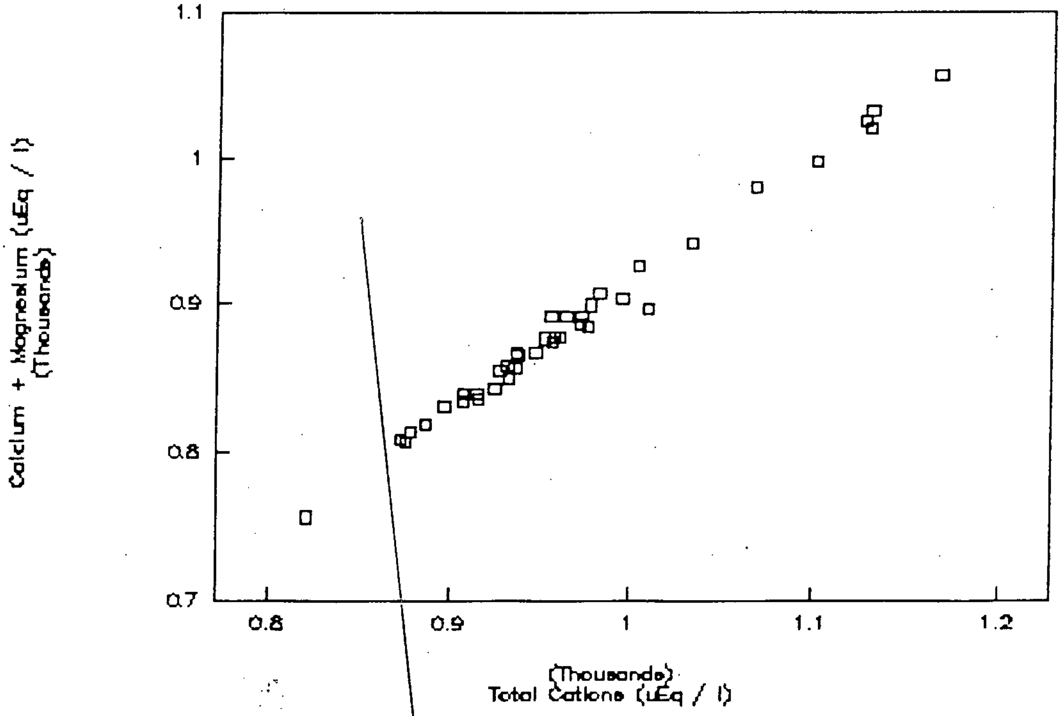

Fig. 4.8 : $(Ca^{2+} + Mg^{2+})$ / TZ^{+}

4.3.4 Sodium and Potassium:

The concentrations of Na^+ and K^+ in the meltwaters range from 0.84 ppm to 1.62 ppm and 1.01 to 1.59 respectively. Sodium and Potassium together constitute about 12.5 % of the total cations. They show similar concentrations such as Na^+ (6.1 %) and K^+ (6.4 %) respectively. Their low concentration may be because of their relative immobility. Fig. 9 and 10 suggest diurnal variations but no definite trend could be interpreted. There is no definite relation between Na^+ and K^+ with other major ions. This suggests that the the processes involved in the formation of sodium and potassium are different from that of calcium and magnesium.

Sodium shows an average concentration of 1.13 ppm. Sodium as cyclic salts in waters close to oceans also contain appreciable inputs from the atmosphere. Sodium in the meltwater is assumed to be a result of lithogenic input as the meltwater is far from the oceans to have appreciable input of sodium from the atmosphere.

The ionic concentration of potassium ranges from 1.01 ppm to 1.59 ppm and averages around 1.2 ppm in the meltwater. These alkalis in the meltwater, from lithogenic input with negligible input from the atmosphere,suggest the origin of these alkalis are due to the chemical weathering of both soda and potash feldspar.

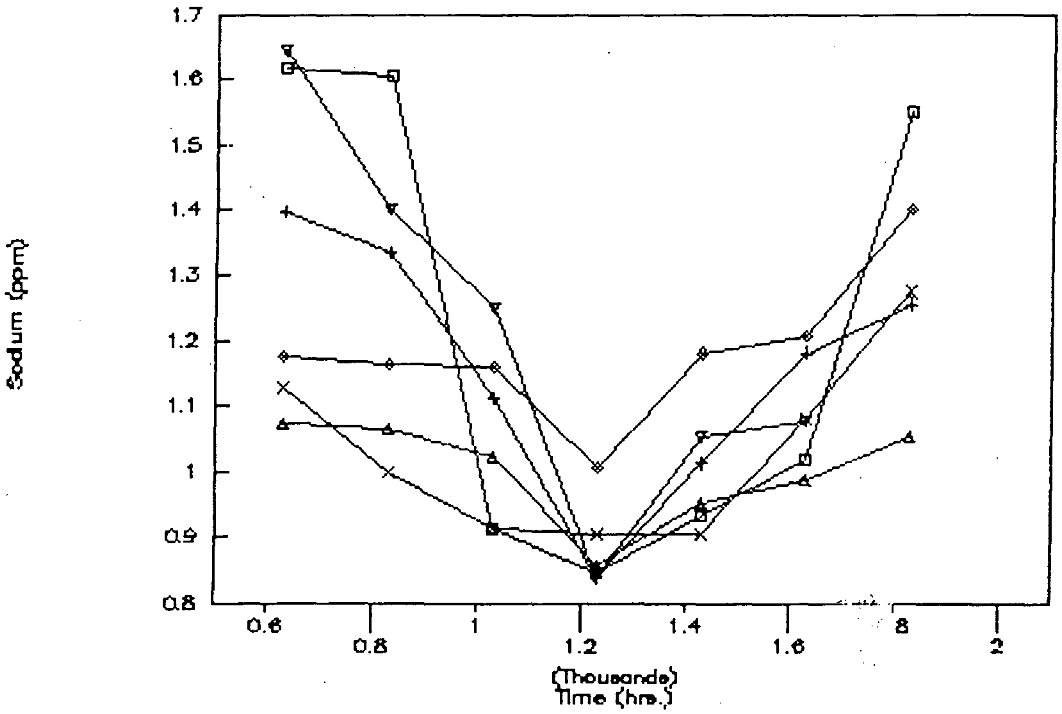

Fig. 4.9 : Diurnal variations in sodium concentrations

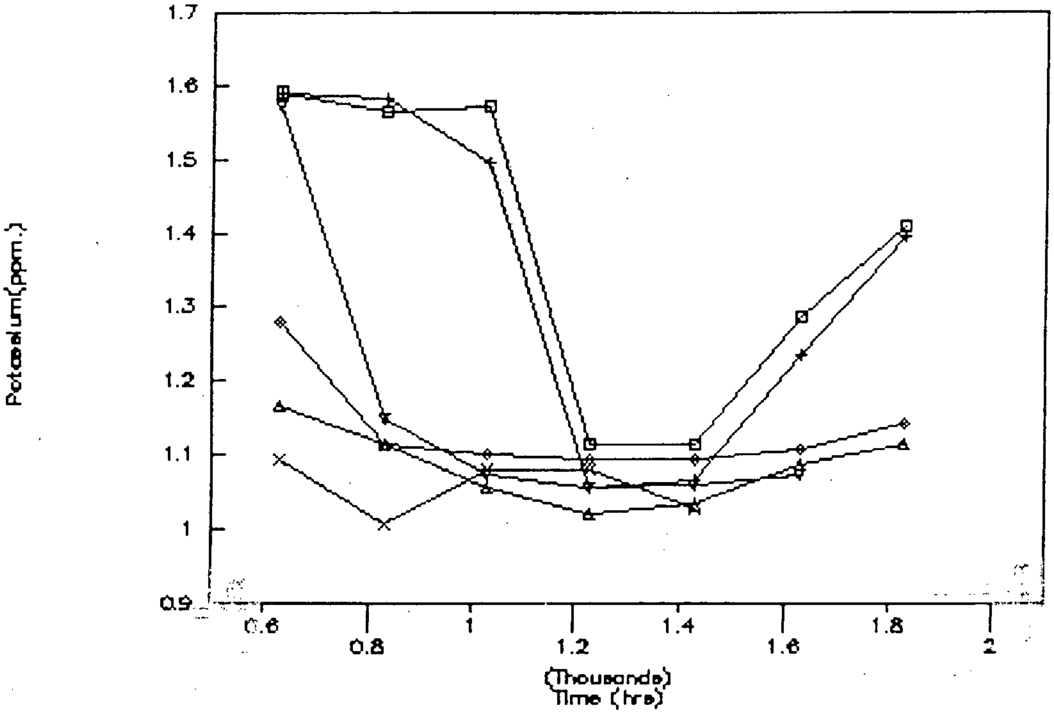

Fig. 4.10 : Diurnal variations in potassium concentrations

4.3.4 **Sulphate and Chloride:**

Sulphate and chloride together constitute around 13.63 % of the total anions. The concentration of sulphate in the meltwater ranges from 2.8 ppm to 5.56 ppm and averaging around 3.64 ppm. Chloride concentration in the meltwater ranges from 1.98 ppm to 2.51 ppm with an average of 2.2 ppm through out the sampling period.

The diurnal variation for Cl^- and SO_4^{2-} concentrations are observed through out the sampling period (Fig. 4.11 and 4.12). A definite trend could be traced for both the ions. Concentrations of both sulphate and chloride show a decrease with the an increase in discharge with the start of ablation in the forenoon. The concentration rises again in the late afternoon as the discharge starts declining.

Chloride in the meltwater is assumed to be mainly derived from oceanic sources. The atmospheric fallout contributes most of the chloride in freshwater. Walling and Web (1986) have discussed about the influence of certain factors like altitude and proximity to the oceanic source, on chloride concentration. Sulphate in the meltwater might have come from anthropogenic sources.

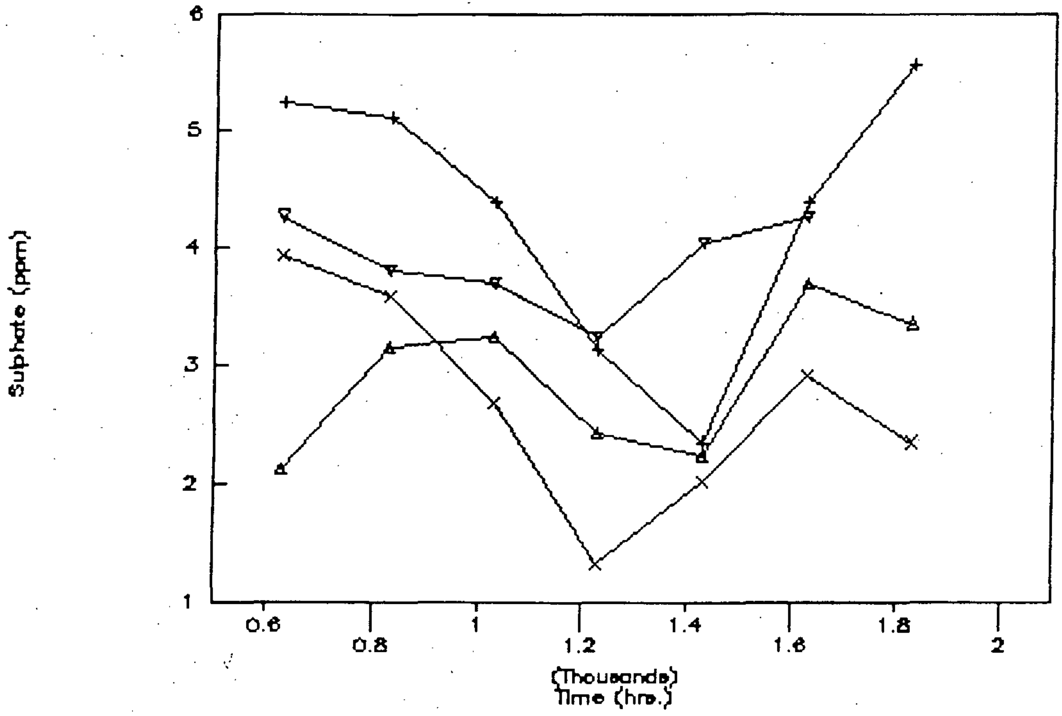

Fig. 4.11 : Diurnal variations in sulphate concentrations

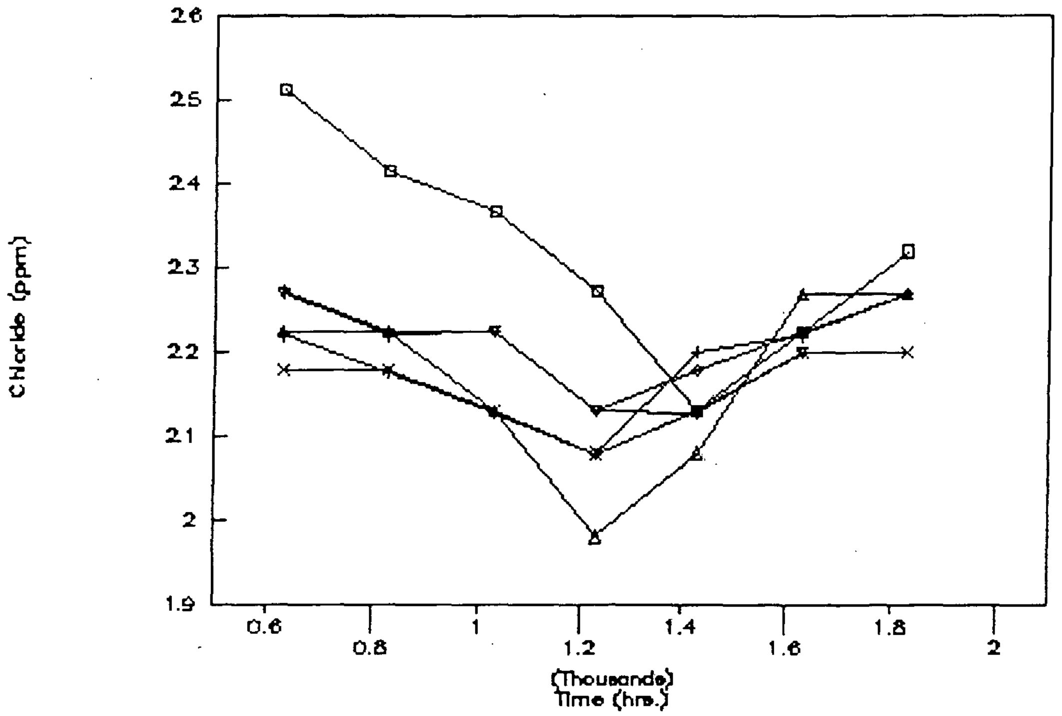

Fig. 4.12 : Diurnal variations in chloride concentrations

4.3.5 Dissolved silica:

During the sampling period the concentration of dissolved silica ranges from 1.31 ppm to 3.95 and averaging around 2.65 ppm. The low concentration of silica in the meltwaters results from the inactiveness of silica in the chemical reactions. However, silica in the meltwaters is due to silicate weathering. Fig. 4.13 shows the diurnal variation in silica concentration in the meltwater during the sampling period.

4.4 SUSPENDED LOAD:

The amount of suspended load in the meltwater varies as a function of the competency of the stream and availability of suitable size fractions. The range of suspended sediment concentration during the sampling period varies from 1.8 mg l^{-} to 198 mg l^{-}. Fig. 4.14 shows the diurnal variation in the suspended sediment concentration throughout the sampling period.

The source of sediment is due to the grinding action of the glaciers which results in the pulverization of the rock debris into very fine particulate materials. These fine sediments are carried away in suspension by the turbulent waters which emerges from the snout of the glacier. The higher competency and capacity of the glacial streams result in the transport of a major amount of load in suspension. Fig. 4.14 indicates that sediment concentration increases with increase in discharge.

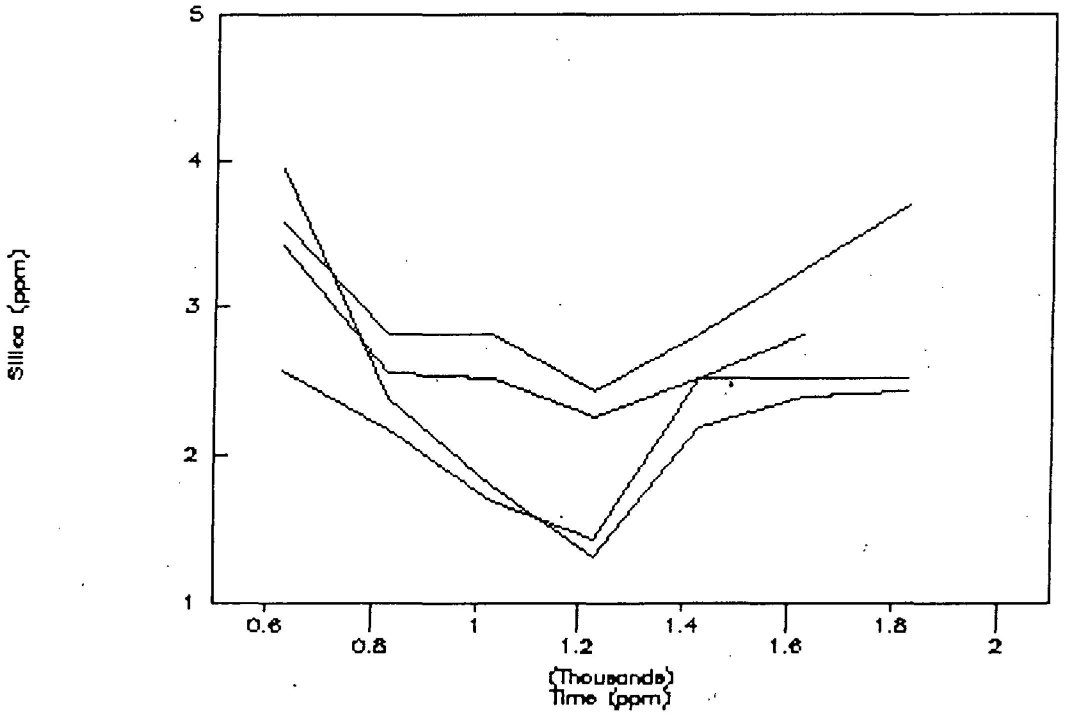

Fig. 4.13 : Diurnal variations in silica concentrations

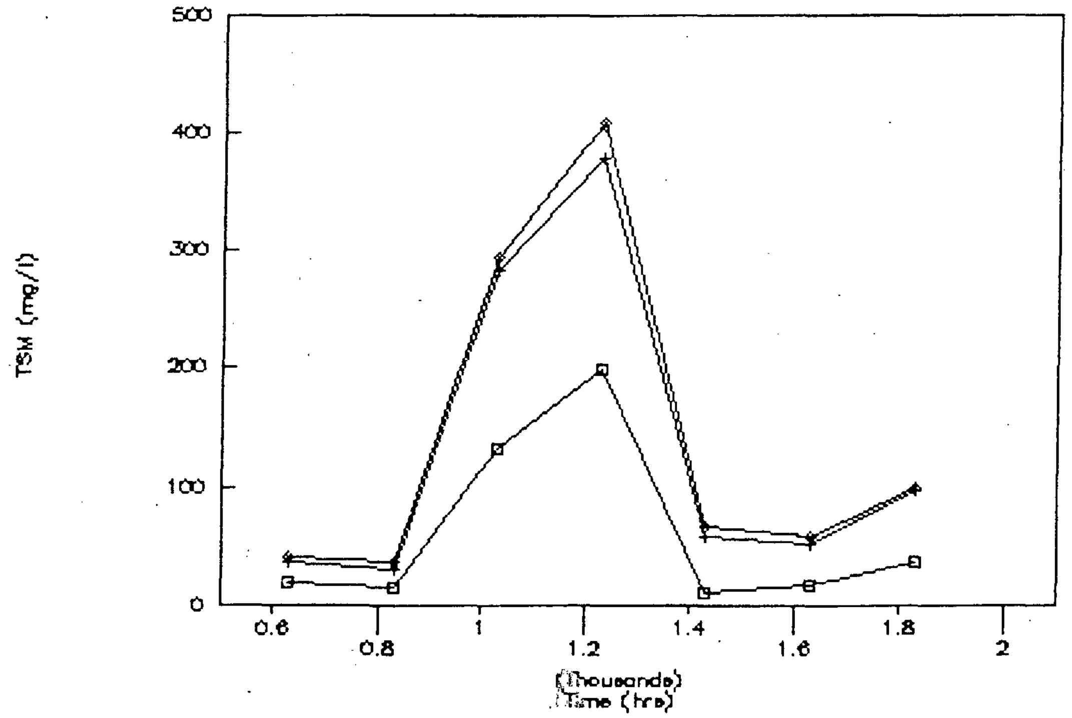

Fig. 4.14 : Diurnal variations in TSM

4.4.1 **TSM/TDS :**

The ratio of suspended load to chemical load gives an idea about the importance of physical and chemical weathering processes. Fig. 4.15 shows the importance of diurnal variations in physical and chemical weathering in the area. The sediment load is increasing along with the decrease of dissolved load in the afternoon. During higher discharge, dissolved load in water gets diluted because of the addition of more and more water from the englacial channels, whereas at the same time the suspended load increases because of more supply of sediment by erosion.

4.5 **Mineralogy of suspended and bed sediment :**

Mineralogy of suspended and bed sediment (size<256 um) was determined by X-ray diffractogram. Five samples each of suspended and bed sediments (size < 256 um) were analysed by XRD. Table 4.3 shows the percentage of various minerals found in suspended and bed sediment. Among the primary minerals quartz is the dominant mineral followed by feldspar and muscovite respectively (Table 4.3). Illite is the dominant clay mineral followed by kaolinite.

Depending on the rate of weathering of common igneous minerals Goldich (1938) suggested weatherability series is similar to that of Bowen's reaction series in igneous petrology. Among the primary minerals observed in the sediment, feldspar and

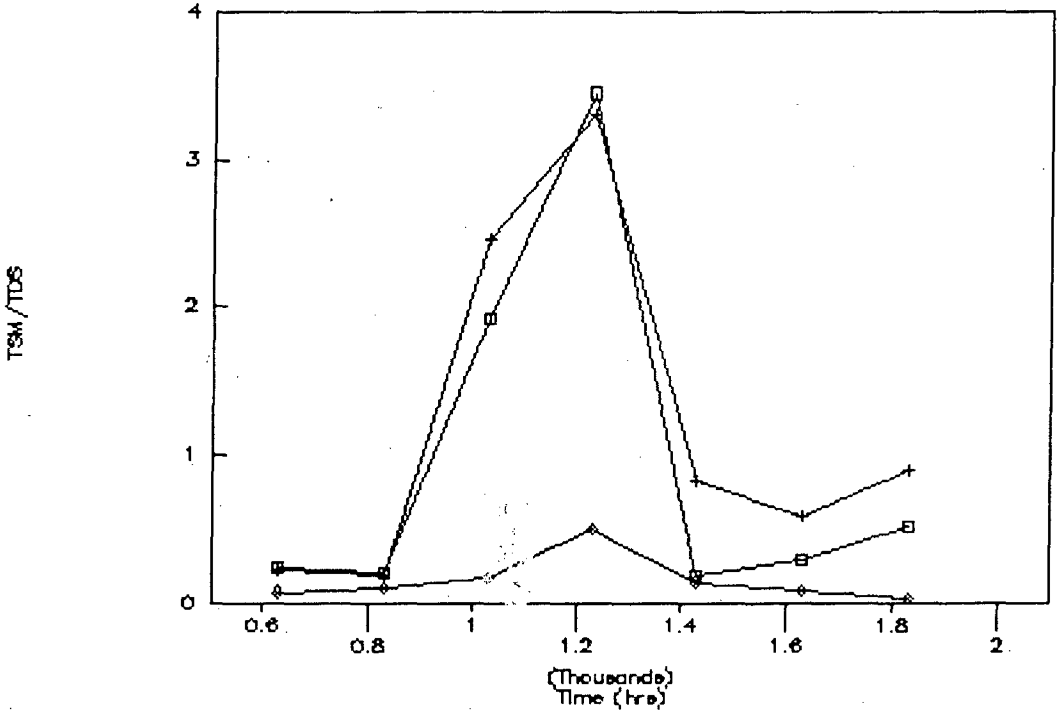

Fig. 4.15 : Diurnal variations in TSM / TDS

Table 4.3 **:Mineralogy of Suspended and Bed sediments (size<256um) (%age):**

Sample	Quartz	Feldspar	Muscovite	Illite	Kaolinite
Suspended Sediments					
1	40.5	23.8	1.5	24.8	9.4
2	38.4	24.5	3.2	25.6	8.3
3	44.7	17.2	2.8	23.2	12.1
4	43.4	15.3	3.4	28.4	9.5
5	42.2	19.4	2.3	29.6	6.5
Bed Sediment					
1	44.9	31.5	4.1	15.4	4.3
2	42.5	32.6	3.8	16.0	5.1
3	51.9	28.5	2.5	12.9	4.2
4	39.7	35.1	3.6	14.3	7.3
5	40.0	36.5	4.2	13.8	5.5

muscovite are rapidly weatherable whereas quartz is more resistant to weathering. The weathering of feldspar and muscovite produces clay minerals. With the intensity of weathering, the quartz component increases among the primary minerals and the weathering of other minerals results in the increase of clay content (Table 4.3).

The clay mineral composition in sediments shows that illite is the dominant clay mineral (73.7%), followed by kaolinite (26.24%). Illite in the sediments represent the degradation of mica.

The suspended sediments are mainly composed of quartz illite, feldspar, kaolinite and muscovite (in order of abundance). The high values of illite in the suspended sediment suggests the active chemical weathering in the region. The presence of feldspar in significance amounts (19.84 %) suggests the immaturity of the sediments.

The bed sediments are mainly composed of quartz followed by feldspar, illite, kaolinite and muscovite respectively. The high proportion of feldspars (32.84%) also suggests the immaturity of the sediments from the glacier and the abundance of recent sediments.

SUMMARY

Glacier meltwaters were collected from the Kafni glacier and analysed in the laboratory to study their chemical characteristics. Sediments were also collected from the region to know their mineral characteristics. During the course of study the following facts were observed.

1. There is a marked diurnal variation in the chemical composition of the meltwaters during high flow and low flows. Magnesium, sodium and potassium do not show any specific trend. Except these ions, others show diurnal variation with a specific trend. Ionic concentrations are higher in the forenoon and evening and show a decrease in the afternoon. This dilution has been explained by the dilution of these ions due to an increase in discharge following ablation in the afternoon.

2. Calcium accounts for almost 74.37 % of the total cations followed by magnesium (13.09 %). Calcium and magnesium together constitute 87.46 % of the total cations. Sodium (6.1%) and potassium (6.4%) constitute the rest of the major cations.

3. Bicarbonate is the major anion constituting 79.8 % of the total anion content followed by sulphate and chloride.

4. Both silicate and carbonate weathering occur in this region.

5. The study of mineralogy of the bed and suspended sediments reveals that illite is the dominant clay mineral in comparison to kaolinite. Quartz, feldspar, illite, kaolinite and muscovite are the major minerals. The high proportion of feldspars in both, bed and suspended sediment indicates the immaturity of the sediments.

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