CHAPTER I

INTRODUCTION

At various periods of geological history huge mantles of ice have covered large areas of the temperate regions, which are well preserved by the various deposits of different geological formations from Precambrian to more recent Pleistocene. Among Indian geological formations, oldest recorded glacial activity is shown by the scratched pebbles of the Kaldurga conglomerate of Dharwar age. Permo-Carboniferous glaciation is evidenced by Talchir Boulder Bed of Orissa, Tanakki Boulder Bed (Kashmir and Hazara), Mandhali Boulder Bed (Garhawal Himalayas), Blaini Boulder Bed (Simla) and Bap and Pokharan Boulder Bed of Rajasthan. Late in Pleistocene, some 20,000 years back whole of Northern Asia, Northern Europe, nearly half of North America, much of Patagonia, Greenland and Antarctica were covered by thick mantle of ice and snow. In India, during Pleistocene glaciation, glaciers are thought to have covered the Extra-Peninsular part, but in the Peninsular part the climate was rather cold. In Himalayas, the Karewa Formation (Kashmir) of Plio-Pleistocene age is indicative of such global continental glaciation.

The Himalayas, world's mightiest mountain system are the largest store-house of snow and glaciers outside the polar
regions. These mountain glaciers being first studied in Alps are also called Alpine glaciers. Almost 38,039 square km or 20% of the Indian Himalayas is ice-clad by 5,250 glaciers whereas only 2.2% in Alps is snow covered. The Himalayan glaciers occur at a much greater altitude than mountain glacier elsewhere. Characteristically, Himalayan glaciers are valley glaciers, occupying pre-existing valleys, fed by snow fields situated high up beyond the valleys.

The valley glaciers are important because of their proximity to human inhabitations and their melting contribute to water in river. They also influence the climatic conditions of the region. The significance of Himalayan glaciers has to be fully realised as they influence climatic fluctuations of the Indian sub-continent as well as comprising of 75% of the fresh water resources of India.

Studies on glaciers and glaciation especially with reference to Himalayan glaciers date back to a century and more. However, these studies were dealt mainly with the physical aspects of glaciers and glaciation. Glaciochemical studies on glaciers are a relatively recent phenomena. Glaciochemical studies of the meltwater which issue from the base of glaciers indicate that glaciers are equally good agents of chemical erosion. Evidently the low average temperature generally associated with an active glacier do not inhibit chemical
weathering reactions. Moreover, waters at near freezing
temperature are capable of reacting fairly rapidly with the
silicate minerals (Reynolds et al., 1972). High dissolution of
atmospheric CO₂ in these cold water supplies the H⁺ ions needed
for the acid hydrolysis of minerals which result in the release
of bicarbonate, cations and dissolved silica in the meltwaters
(Raiswell, 1984).

Grinding action of glaciers produces fine fractions of
sediments which can be carried in suspension. The concentration
of suspended sediments in the meltwater depends on the competency
and capacity of the stream and the availability of suitable size
fraction of sediments which can be carried in suspension. The
high velocity, turbulent meltwater streams also erodes the
morainic materials and carries the huge quantities of sediments in
suspension.

Diurnal variations in discharge, total suspended matter
and total dissolved solids are also of considerable interest. Observations indicate that generally the concentration of
suspended matter increases with increase in discharge accompanied
by dilution of dissolved salts. Textural, mineralogical and
chemical studies of stream and moraine sediments offer an insight
into the provenance of the glacier basin.
The present study has undertaken chemical weathering in the glacial environment. The Bhagnyu glacier in Chamoli district of Uttar Pradesh, which serves as a catchment for Alkapuri stream was selected for carrying out the present study.

Objectives of the present work:

The objectives of the present work is to study:

1. the glacio-chemistry of the meltwater draining from the Bhagnyu glacier,
2. the process and controls of the chemical weathering in the basin,
3. source of major ions in the meltwaters,
4. mineralogy of the bed sediments (size < 256 um) in the light of their provenance area and to assess the influence of basin characteristics on the mineralogy of the sediments.

GLACIO - FLUVIAL PROCESSES

Literature Review

Studies pertaining to chemical weathering in the temperate glacial environments date back to the early sixties. Most of these studies were based on sampling of meltwater and discharge measurements near the snout of glaciers. (Rainwater and Guy (1961), Keller and Reesman (1963), Lorrain and Souchez (1961), Collins (1978, 79, 83), Lemmens and Roger (1978), Raiswell (1984),
Hasnain et al (1989)]. Attention has been paid to the study of factors influencing chemical weathering and the processes involved. Diurnal variation in discharge and its effect on dissolved and suspended load of meltwater has been studied. Raiswell (1984) attempted to evolve chemical models for the study of solute load in meltwater.

1.1 **Source of dissolved constituents in meltwaters**:

The Alpine environment does not encourage the appreciable growth of biota due to the extreme climate, which limits the source of solutes in meltwaters to lithogenic and atmospheric (Collins, 1979). As snow is less efficient in removing materials from atmosphere (Gorham, 1961), the constituents of dissolved load in meltwaters are derived from lithogenic sources. Both dissolved and suspended load in the glacial meltwater are the byproduct of chemical denudation. Regarding the chemical composition of material transported in solution Meybeck says that 80% of the dissolved load in the fresh water system is generally made up of just four components (HCO$_3^-$, SO$_4^{2-}$, Ca$^{2+}$ and SiO$_2$) with a number of lesser constituents. The lithogenic input to the meltwaters is due to the weathering processes which involve solution, oxidation or reduction, the action of hydrogen ions and complex ion formation (Keller, 1975).

The CO$_2$ derived from atmosphere, dissolves in water and produces H$_2$CO$_3$, which is a source of H$^+$ in water. Cations,
dissolved silica, bicarbonates and clay minerals are also released by the reaction of \( \text{H}_2\text{CO}_3 \) with silicate minerals (Raiswell, 1984). Carbonation reaction proceeds more vigorously in colder regions because of increased solubility of \( \text{CO}_2 \) in cold waters.

1.2 **Factors controlling the chemical weathering in glacial environment**

There are diverse opinion regarding the factors which control the water compositions. Gorham (1961) and Gibbs (1967) described climate, geology, topography, biota and time as principal environmental factors which interact to determine the concentration and composition of atmospheric precipitation, soil solution and surface water bodies. R.J. Gibbs (1970) proposed atmospheric precipitation, rock dominance and the evapo-crystallization processes as major factors controlling the composition of dissolved salts of meltwaters. Other factors which play minor role within the zones dominated by the three major factors are relief, vegetation and composition of material in the basin, also called second order factors (Gibbs, 1970). Other mechanisms which control the supply of ions to the meltwater have also been studied by several workers. Ion exchange and sorption mechanisms as factors in the transport of major cations were described by Gorham (1961), Lorrain and Souchez (1972), and Lemmens and Roger (1978).
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, three chemical factors - water composition, water flow rate and rock mineralogy influence the chemical weathering to a greater extent (Raiswell, 1984). Diurnal variation in discharge and dissolved and suspended load were given due attention by all, whoever worked on the meltwater chemistry.

1.2.1 **Topography** : It plays as a controlling factor which influence the supply of major ions to waters, as shown by the study of Gorham (1961) and Gibbs (1967). While studying environmental factors which influence the water chemistry of the Amazon, Gibbs (1967) found that 12% mountainous area in the Andes supplies 86% of the total dissolved load. The turbulent waters in the hilly regions exposes fresh rock surface and promotes weathering. Water velocity, controlled by relief was described as an important factor by Raiswell (1984). Raiswell stated that as many silicate and aluminosilicates have equilibrium constants of similar magnitude, only a small increase in the concentration of aqueous products (and decrease in $H^+$) are required to reach equilibrium and stabilize solid phases. If the flow rate is high, fresh supply of $H^+$ and flushing out of dissolved solids prevent the water reaching equilibrium. So, it is generally assumed that
increased flushing rates may increase the rate of mineral dissolution.

1.2.2 Geology: Geology of the area also controls the water composition as studied by Gorham (1961); Collins (1979); and Meybeck (1983). Quoting Clarke (1924), Gorham explained that the local geological variation affects the composition of river water greatly, especially near their sources. If the rivers are large, these variations are evened out by the intermixing of tributaries, which tend to produce an average composition, which may be called that of a normal water. Average values of total dissolved solids and their constituents for waters flowing over different rock types, namely, plutonic, volcanic and sedimentary rocks was presented by Meybeck (1983) (Table 1.1). Sodium and chloride concentration were attributed by him to the dominance of oceanic influences. Also that dissolved load is influenced by rock mineralogy as the minerals suffer weathering at different rates. Low variation in the concentration of potassium and silica was attributed by him to silicate weathering. Raiswell (1984), pointed out that the sulphide minerals breakdown at exceedingly rapid rates in oxygenated surface environments and carbonate minerals weather more rapidly than silicates and aluminosilicates.

1.2.3 Suspended sediments: Very fine sediments are produced by grinding action of glaciers. This fine material is carried away
by the relatively cold turbulent meltwaters emerging out of glaciers (glacial milk). Low temperature of meltwater results into the increase of viscosity of water which reduces the falling velocity of sediments under suspension. This increases effective

Table 1.1: Influence of rock types on the average composition of world river-waters (Meybeck, 1981)

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Average concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plutonic and highly metamorphic rocks</td>
</tr>
<tr>
<td>SiO₂</td>
<td>1.5x</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>4</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>1.0</td>
</tr>
<tr>
<td>K⁺</td>
<td>1.0</td>
</tr>
<tr>
<td>Na⁺</td>
<td>Oceanic influence dominant</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>Oceanic influence dominant</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>2</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>15</td>
</tr>
</tbody>
</table>

x = Average SiO₂ content of water from rivers draining sedimentary rocks at a given temperature.
contact surface area of sediment with the meltwater and thereby promotes chemical weathering. Partial dissolution of the suspended sediment may contribute to the solute concentration (Collins, 1979).

1.2.4 **Ion exchange and sorption**: Gorham (1961), Lemmens and Roger (1978) have studied the mechanism of ion exchange and sorption, as contributing to the dissolved load. Lemmens and Roger (1978) from their work on an Alpine glacier have concluded 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. In ion exchange, the hydrogen ions in water will be exchanged with cations in the Guoy layer of suspended and bed sediments. The hydrological conditions in these regions favour ion exchange in two ways—by an increase in the surface area and in the time of contact between water and morainic material (Lemmens and Roger, 1978). Ion exchange also causes rapid increase in the concentration of sodium and potassium in the frontal zone of the glaciers. The concentration shows very little variation downstream due to decrease in the rate of diffusion as a result of the diminishing gradient between the Guoy layer and the concentration of cations in water (Fig. 1.1).

While Gorham’s (1961) study was confined to lake bottom mud, Lorrain and Souchez (1972) studied in the sorption mechanism
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).
in glacial environment. According to them, the sorbed cations are originally the exchangeable cations held on morainic particles which are carried away in suspension by subglacial meltwater with their sorbed cations. Due to 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 sorbed cations on suspended sediment is more important than that held on bed sediment because of increase in effective contact area of the sediment in suspension.

1.2.5 **Diurnal variation in discharge**: Diurnal variations in discharge and composition of meltwater has been observed by a number of authors. Rainwater and Guy (1961), and Collins (1979) proposed a two component subdivision of total flow, first, being water passing through the subglacial channel having ground environment and the second water running off rapidly through englacial channels, without undergoing chemical change, diurnal variation in the concentration of total dissolved solids in meltwaters results from the variable dilution of stable discharge from the ground environment by surface meltwaters.

According to Collins (1979), every forenoon with the starting of ablation, a steep increase in discharge and corresponding decrease in electrical conductivity was measured. Following peak discharge in the late afternoon, conductivity
Fig 1.2 Inverse relationship between solute concentration (as electrical conductivity) and discharge (After Collins, 1979).
rises as discharge decrease, both at a relatively slow rate. Collins (1979) plotted electrical conductivity against discharge at Gornera glacier (Fig.1.2). He found an inverse relationship between the two components. The solute-discharge relationship shows trapezoidal distribution. Side AB represents the lowest observed conductivity which occurs independent of discharge at higher flows, and which is determined by the solute content of ice and snow meltwaters from the glacier surface at times when there is minimal subglacial outflow. The maximum observed solute concentration is located by point D, which ideally is the concentration which would be measured in interstitial waters of basal moraine. Side CD indicates lowest discharge with varying proportion of surface run-off and basal outflow. When further surface contributions inhibit the basal outflow, solute content is decreased (CB), as discharge rises. The upper limit of the distribution (AD) are located by daily maximum conductivities.

1.2.6 Distance from the snout: There is very little variation in the chemical composition of meltwater from the frontal part glaciers to further downstream. Reynolds (1972) compared the waters flowing out of scree cones at the base of Le Conte mountain with the Cascade river water 8.3 mile downstream from the outflow of South Cascade lake. He observed that essential character of waters was fixed by the time they leave the alpine watershed and little further change occurs during miles of
transit downstream. After passing over 30 m on morainic material in the frontal zone of glacier, the dilute superglacial water does not alter much (for Na and K) even after one kilometer (Lemmens and Roger, 1978).

1.3 Composition of world fresh waters:

Calcium and bicarbonate represent the dominant cation and anion in the meltwaters. According to Meybeck (1981), more

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

<table>
<thead>
<tr>
<th>Cations</th>
<th>Anions</th>
<th>Percentage of global sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca²⁺&gt;Na⁺&gt;Mg²⁺&gt;K⁺</td>
<td>HCO₃⁻ &gt; Cl⁻ &gt; SO₄²⁻</td>
<td>33.1</td>
</tr>
<tr>
<td></td>
<td>HCO₃⁻ &gt; SO₄²⁻ &gt; Cl⁻</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>SO₄²⁻ &gt; HCO₃⁻ &gt; Cl⁻</td>
<td>1.0</td>
</tr>
<tr>
<td>Ca²⁺&gt;Mg²⁺&gt;Na⁺&gt;K⁺</td>
<td>HCO₃⁻ &gt; SO₄²⁻ &gt; Cl⁻</td>
<td>46.7</td>
</tr>
<tr>
<td></td>
<td>HCO₃⁻ &gt; Cl⁻ &gt; SO₄²⁻</td>
<td>15.0</td>
</tr>
<tr>
<td>Na⁺&gt;Ca²⁺&gt;Mg²⁺&gt;K⁺</td>
<td>HCO₃⁻ &gt; Cl⁻ &gt; SO₄²⁻</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>SO₄²⁻ &gt; Cl⁻ &gt; HCO₃⁻</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Cl⁻ &gt; HCO₃⁻ &gt; SO₄²⁻</td>
<td>0.1</td>
</tr>
</tbody>
</table>

15
than 97% of world water run off is this type. (Table 1.2). Calcium and bicarbonate are the dominant ions where rock weathering is the major mechanism controlling solute content and when total ion concentration typically ranged between 50 and 1000 gm l⁻¹ (Gibbs, 1970). Calcium is the dominant cation in approximately 88% of the meltwaters and often comprises more than 70% of the total cation equivalents. Among the anions, bicarbonate and sulfate dominate half the analyses each and Cl⁻ is almost invariably low (Raiswell, 1984).