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GLACIOCHEMICAL INVESTIGATIONS AS A TOOL FOR DETERMINING THE SPATIAL AND SEASONAL VARIATION OF SNOW ACCUMULATION IN THE CENTRAL KARAKORAM, NORTHERN PAKISTAN

by

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ABSTRACT

Between 70 and 80% of the total annual run-off from the Upper Indus Basin originates from heavy snowfall and glacierized basins at elevations greater than 3500 m a.s.l. However, very little is known concerning the mountainous headwaters of the Indus. This is especially true with respect to the amount of snowfall in the major source area, the high Karakoram. Recent studies of high-altitude alpine glaciers indicate that geochemical dating techniques can accurately and confidently identify seasonal and annual stratigraphy within snow pits and ice cores, and thus can be used to determine the seasonal and annual rate of snow accumulation. In addition, chemical records can usually be employed to determine sources of precipitation. Six snow pits, each 5–10 m deep, were investigated in the accumulation zones of the Biafo and Khurdopin Glacier basins. Both accumulation zones are characterized by broad, open basins separated by steep, narrow ridges in which direct precipitation is the dominant form of nourishment. Seasonal stratigraphy is delineated through an analysis of the seasonal variation in the chemical and physical characteristics of the snow-pack. Annual snow accumulation in the Biafo Glacier basin ranges from 0.9 to 1.9 m water equivalent; maximum accumulation occurs in the elevation band 4900–5400 m a.s.l. Roughly one-third of this snow accumulation occurs during the summer.

INTRODUCTION

Pakistan depends heavily upon the waters of the Upper Indus Basin (UIB) for power generation, irrigation, and water supply. Between 70 and 80% of the total annual run-off from the UIB originates from heavy snowfall and glacierized basins at elevations greater than 3500 m a.s.l. Glacier basins are concentrated along the northern edge of the watershed, especially in the Karakoram Himalaya, and this mountain range contains approximately 15 000 km^2 of perennial snow and ice (Mercer, 1975). The major role which the Karakoram plays in the hydrology of the UIB draws attention to the snow and ice conditions in this mountain range.

Little is known concerning the mountainous headwaters of the Indus. A concerted research effort concentrating on the glacial hydrology of the UIB was begun in 1985, as part of the Snow and Ice Hydrology Project. The work presented in this paper is concerned with estimating precipitation inputs into the region. Most of the precipitation in the Karakoram Range occurs at elevations greater than 3500 m (Hewitt, 1986). It is this precipitation, in the form of snow, that creates the only large moisture surplus for the region. However, precipitation records for the UIB come from weather stations which lie well below 3500 m, mostly in semi-arid and valley locations. The stations are in the main towns of the region, and subject to the topoclimatic effects of valley wind systems (Butz and Hewitt, 1986).

Accumulation zones of high-elevation alpine glaciers often contain well-preserved records of snowfall and provide an opportunity for retrieving climatic data. Recent studies on high-altitude alpine glaciers indicate that a variety of geochemical dating techniques can accurately and confidently delineate summer and winter layers within snow pits and snow/ice cores (Ambach and others, 1976; Jouzel and others, 1977; Oescheger and others, 1978; Oerter and others, 1982; Lyons and Mayewski, 1983; Holdsworth and others, 1984; Mayewski and others, 1984; Thompson and others, 1986; Yamada, 1987). A paleo-climatic record can be developed through an analysis of the chemical and physical characteristics of snow pits and ice cores. Identification of the seasonal variation of stable and radioactive isotopes, major ions, and microparticles has enabled researchers confidently to delineate seasonal snow-pack stratigraphy and to determine the rate of seasonal and annual snow accumulation. In addition, chemical records can usually be employed to determine the source of precipitation.

The basis of the snow-accumulation research in the Karakoram described in this paper is to employ glacio-chemical dating techniques to examine the spatial and seasonal variations in accumulation. This is accomplished by developing a snow-pit sampling network covering a wide range of geographic locations within the Biafo Glacier basin, such a network type being essential for picking out altitudinal and lateral variations in snow accumulation.

Two previous studies have measured the rate of snow accumulation in the UIB. The Batura Glacier Investigation Group (1979) recorded a net winter accumulation of 1.03 m water equivalent (w.e.) at 4840 m on Batura Glacier (36°40′ N, 74°23′ W). A stratigraphic analysis of ice layers in two different crevasse walls at 5000 m revealed an apparent net annual accumulation rate ranging from 1.03 to 1.25 m w.e. over the previous 5 years. Mayewski and others (1984) recovered a 16.6 m core from Sentik Glacier (33°598′ N, 75°57′ W) in the Ladakh Himalaya at an elevation of 4908 m. Core chronology was established by correlating a strong peak in the total β-activity time-series profile with the increased atmospheric concentration of total activity and β-activity following the 1963 series of thermonuclear weapons testing, as well as by seasonal signatures for selected chemical species and for deuterium. The results indicated an average net accumulation of 0.62 m w.e. from 1963 to 1980.

REGIONAL SETTING

Climatic controls

Climate in the Karakoram is dominated by the influx of westerly air mases (Hewitt, 1968; Barry and Chorley, 1982). Throughout the winter the sub-tropical westerly jetstream steers cyclonic depressions toward the Karakoram

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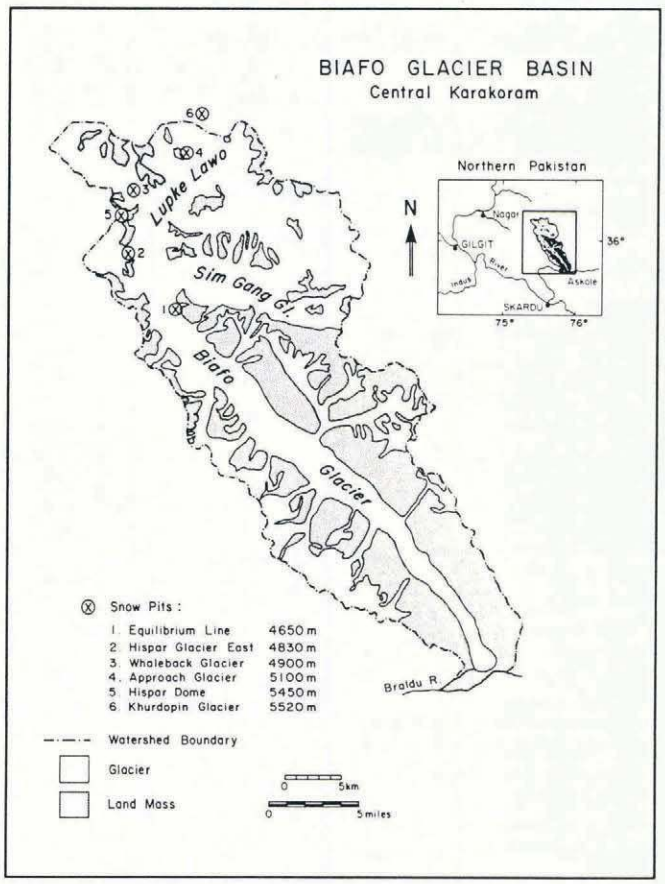

Fig. 1. The Biafo Glacier basin, central Karakoram.

and northern India. These lows penetrate across the Middle East from the Mediterranean Sea and the Atlantic Ocean. During the winter the jetstream is split into two distinct branches, one passing to the north and the other to the south of the Tibetan Plateau. In May and June the jetstream slowly weakens, and by mid-June is altogether diverted to the north of the plateau. While the regional airstream continues to be influenced by the westerlies, temporary destruction of the Tibetan anticyclone can result in the incursion of monsoonal air masses from the Indian Ocean into the Karakoram, resulting in heavy precipitation. We know from our own experience that significant amounts of snowfall can occur in the northern parts of the basin during the summer. Snowfall during late summer 1985 and 1986 exemplified the influx of monsoonal air masses.

Study location: the Biafo Glacier basin

Biafo Glacier descends south-west from the main crest of the Greater Karakoram in the central part of the range. The glacier itself is a large valley glacier about 59 km long, the basin has an area of 852 km^2, of which 64% is covered by perennial snow and ice. A map of the Biafo Glacier basin, after Mott (1950), appears in Figure 1. The firn line in 1985 and 1986 lay at approximately 4650 m on Biafo Glacier (close to the location of the equilibrium-line snow pit illustrated in Figure 1). The glacier flows from a broad, gently sloping accumulation zone consisting of two large accumulation basins, Sim Gang Glacier to the west, and Lukpe Lawo to the north (Fig. 1). These basins are separated by steep, narrow ridges which occupy a small percentage of the area in the accumulation zone. The majority of precipitation falls on to the broad, relatively flat regions of the accumulation zone. Direct precipitation is the predominant form of nourishment. In this regard, Biafo Glacier appears to be exceptional amongst the valley glaciers in the central Karakoram. Thus, due to the minimal influence of avalanches on overall accumulation rates, the basin provides an ideal location for determining the rate of snow accumulation.

Khurdopin Glacier flows northward from the main crest of the Greater Karakoram. The glacier is approximately 47 km long. In general, basin morphology is similar to that of Biafo Glacier, although it is smaller.

METHODOLOGY

During the summer of 1986 we collected data from six snow pits, each 5–10 m deep (Table I), excavated in the accumulation zone of the Biafo Glacier and Khurdopin Glacier basins. All of the snow-pit locations were far from the influence of avalanches and experienced little or no heavy winds. There was no evidence of surface sastrugi nor of well-rounded snow grains on the surface, and wind conditions at all snow-pit locations were usually very calm. Fresh snow samples were also collected throughout the summer, and a 12 m record of snow accumulation, dating back to 1983, was obtained from the Hispar Dome site. The results and interpretation of these experimental data appears elsewhere (Wake, 1987).

Snow-pack stratigraphy was interpreted from measurements of density, hardness, color, crystal size, and shape, and the position of ice layers and debris bands. Snow samples were collected over an integrated section with a 1.5×10^{-2} m vertical. Extreme care was exercised at all times during sample collection to ensure that samples were uncontaminated. A clean suit combined with an over-the-shoulder hood, particle mask, and plastic gloves, was worn by the sample collector. Samples were collected in pre-cleaned, 1.25×10^{-1} m^3 polypropylene containers with wide mouths and polyethylene caps. Following melting, the samples were transferred into two pre-cleaned linear polyethylene (LPE) scintillation vials each of 2×10^{-2} m^3 volume. In addition to the collection of samples described above, 3×10^{-2} m samples were collected from the wall of the snow pit at the Hispar Dome site. These samples were melted and transferred into 5×10^{-1} m^3 LPE containers for total β-activity analysis.

LABORATORY WORK

Anions (Cl^-, SO_4^{2-} and NO_3^-) were analyzed using a Dionex model 2010 ion chromatograph with an AS-4 column with 0.0021 M $NaHCO_3$/0.0017 M Na_2CO_3 eluent and a computer-driven autosampler. Na^+ was analyzed using a Perkin Elmer model 2280 atomic absorption spectrometer equipped with a Model 400 furnace. Both the anion and cation analyses were completed using the facilities of the Glacier Research Group at the University of New Hampshire. The oxygen-isotope analyses were done by the Geophysical Isotope Laboratory at the University of Copenhagen using gas-source mass spectrometry. A summary of the mean chemical content of the snow-pack at each sample location appears in Table I. Low minimum ion concentrations, especially for Na^+ and Cl^-, demonstrate that field sampling and subsequent analytical procedures have not introduced significant levels of contamination. Analyses of sample blanks indicate that sample contamination during sample transfer and subsequent transport was negligible. Forty samples from the Hispar Dome snow pit were also analyzed for microparticle concentrations in 15 different size ranges, using a Coulter Counter TA III, by the Byrd Polar Research Center at Ohio State University. The total β-activity of samples recovered from the Hispar Dome site was measured at the University of New Hampshire using a Canberra model 2404 αβγ counter with a 12 h counting period, on 47 mm Whatman SA-1 cation filters through which 5×10^{-2} m^3 samples had twice been gravity filtered.

POST-DEPOSITIONAL ALTERATION

The percentage of ice layers and lenses in each annual accumulation layer, expressed as annual melt per cent (AMP) ranged from 5 to 7% for the higher-elevation sites at 5450–5520 m, and from 7 to 13% for the lower-elevation snow pits at 4650–5100 m, indicating that melting events do occur. Herron and others (1981) found AMP values ranging from 3 to 8%, excluding extreme melting events, in a deep core recovered from southern Greenland. Interpretation of glaciochemical data recovered from snow pits in which there has been melting, such as in the Karakoram, relies upon the conclusion that the redistribution of ions due to melt-water percolation is limited to the uppermost stratigraphic layers and is significantly less than seasonal

TABLE I. SUMMARY OF SNOW PITS INVESTIGATED IN THE CENTRAL KARAKORAM, SUMMER 1986

	Biafo Glacier basin					
	Equilibrium line	Hispar Glacier E.	Whaleback Glacier	Approach Glacier	Hispar Dome	Kurdopin Glacier
Elevation (m)	4650	4830	4900	5100	5450	5520
Aspect	SW	E	SE	E	–	W
Depth (m)	2.3	4.8	4.5	4.8	5.0	10.0
No. of samples	16	33	20	40	41	73
Density*	415	470	490	535	450	470
$\delta^{18}O$	−14.0	−14.5	−18.1	−17.2	−13.0	−16.2
$Na^+ : Cl^-$	0.41	0.65	–	0.51	0.46	0.56
Na^+†	17	33	9	16	13	37
Cl^-†	40	50	–	19	28	50
NO_3^-†	218	224	–	96	154	167
SO_4^{2-}†	143	121	–	47	82	128

* Mean values for each snow pit in kg/m^3.
† Mean values for each snow pit in $\mu g/kg$.

accumulation. This conclusion is derived from two separate lines of evidence:

First, snow-pack temperature is below freezing slightly beneath the air–snow interface. Upon encountering a below-freezing layer, melt water percolating down through the snow-pack spreads out laterally and freezes, forming ice layers and lenses. The ice layers thus formed can then act as a barrier to further melt-water percolation. The presence of ice layers at between 20 and 60 cm (one-tenth to one-third of annual snow depth) in all of the snow pits analyzed delineates the maximum depth to which melt water percolates. The AMP values indicate that more melt water is generated at the lower-elevation sites. Therefore, confidence in the above-stated conclusion increases with increasing elevation of the sample site.

Secondly, the chemical profiles from a snow-pack in which there had been significant melt-water percolation would display $\delta^{18}O$ and ion time-series profiles that appeared washed out and show weak, if any, seasonal variation (Mayewski and others, 1981). The $\delta^{18}O$ and ion time-series profiles from all of the sample sites show distinct seasonal variations, and thus do not appear to have been affected significantly by melt-water percolation (Fig. 2A and B).

SNOW-PIT DATA

A summary of the chemical and physical data for each snow pit appears in Table I. The time-series profiles of the chemical components ($\delta^{18}O$, sodium, chloride, sulfate, nitrate ions, and total β-activity) and of the physical properties (microparticle concentrations, the stratigraphic position of the ice, and visible dirt layers) for the high-elevation sites (5450 and 5520 m) appear in Figure 2.

Oxygen isotopes

The oxygen-isotope record is considered to be the single most useful profile, as it consistently displays a regular pattern of seasonal variations. Winter precipitation is characterized by a relative depletion in the heavy isotope, which results in an increasingly negative $\delta^{18}O$ value, summer precipitation is characterized by a relative increase in the heavy isotope content, which results in a less negative $\delta^{18}O$ value (Dansgaard and others, 1973). Distinct changes in the oxygen-isotope profiles were used as reference horizons to define summer and winter strata in all of the snow pits.

Sodium and chloride ions

Variations in Na^+ and Cl^- concentrations with depth are closely related, correlation coefficients for each snowpit are respectively 0.92, 0.61, 0.73, 0.71, and 0.81 at the 0.001 significance level. The mean $Na^+ : Cl^-$ ratio for all samples from the Karakoram is 0.54, very close to the ratio for

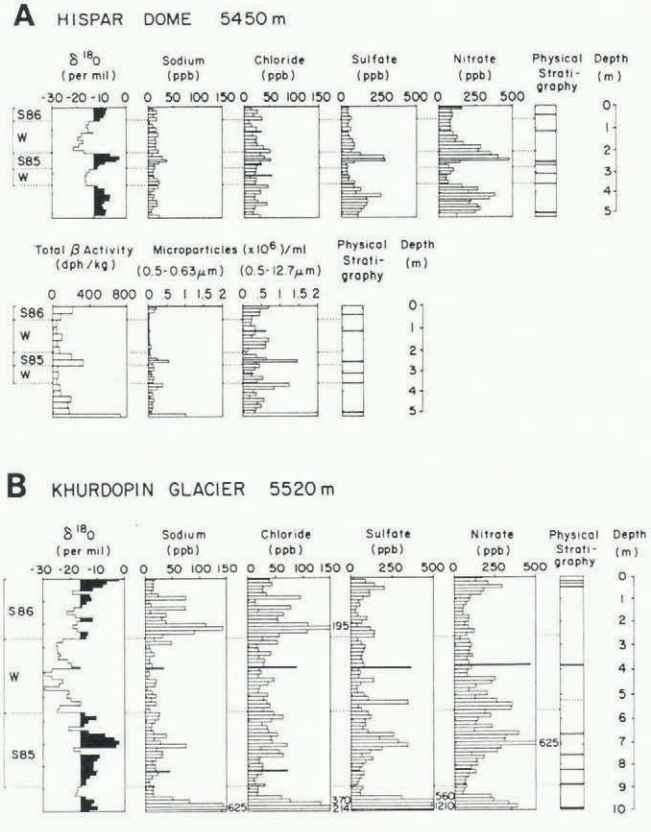

Fig. 2. $\delta^{18}O$ and ion time-series profiles for Hispar Dome (A) and Khurdopin Glacier (B).

sea-water which is 0.56. This strongly suggests a marine source for most of the Na^+ and Cl^- within the central Karakoram snow-pack. The Na^+ and Cl^- time series from Khurdopin Glacier (Fig. 2) show strong seasonal variations, with peaks in the profiles corresponding to less negative summer $\delta^{18}O$ values. The Na^+ and Cl^- profiles from Hispar Dome (Fig. 2) display weaker seasonal variations, although the higher values also correspond to summer deposition. Interpretations by Mayewski and others (1984) suggest that the high concentrations of Na^+ and Cl^- observed in the time-series profiles from a core recovered in the Ladakh Himalaya are due to moisture derived from the Arabian Sea. The increased levels of these ions observed in the time-series profiles from the Karakoram coincide with summer strata, and also most probably reflect the influx of moisture from the Arabian Sea. Winter layers, as defined by the ^{18}O profile, are characterized by relatively low values

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TABLE II. COMPARISON OF CHEMICAL CONTENT IN SNOW FROM THE KARAKORAM AND LADAKH HIMALAYA

	Biafo Glacier Karakoram	Sentik Glacier Ladakh Himalaya†
Na^+*	24	72
Cl^-*	38	104
$Na^+ : Cl^-$	0.54	0.70
NO_3^-*	178	62

*Mean values for all samples collected, in μg/kg.
†Lyons and Mayewski (1983) and Mayewski and others (1984).

for Na^+ and Cl^-. Low winter concentrations are attributed to westerly marine sources more distant than the Arabian Sea, most probably the Atlantic Ocean or the Mediterranean Sea. Mean concentrations of Na^+ and Cl^- from the central Karakoram are three to four times lower than those measured in the Ladakh Himalaya (Table II). This difference suggests that westerly derived moisture, with its lower Na^+ and Cl^- content, has a greater influence on precipitation in the Karakoram than in the Ladakh Himalaya.

Sulfate and nitrate ions

It is apparent in the time-series profiles from the high-elevation sites (Fig. 2) that SO_4^{2-} and NO_3^- concentrations display strong seasonal variation; high concentrations correspond to mid- to late-summer strata. Several studies have identified specific sources of sulfate ions in Greenland snow (Herron, 1982; Mayewksi and others, 1986). Sea-salt-associated SO_4^{2-} (Blanchard, 1983) and biogenic SO_4^{2-} originating from the oceans (Bonsang and others, 1980) represents less than 15% of total SO_4^{2-} in snow from the Karakoram. The random nature of volcanic events cannot account for the observed seasonal variations in the concentration record. India is the closest source of anthropogenically produced SO_4^{2-} and these excess ions could be transported into the Karakoram during the summer at the same time as moisture derived from the Arabian Sea is drawn into the region. Terrestrial biogenic emissions are a source of both excess SO_4^{2-} and excess NO_3^-, and are therefore discussed together below. A variety of different sources for NO_3^- and NO_2^- ions in the Ladakh Himalaya has been reviewed by Lyons and Mayewski (1983). Seasonally controlled biological emissions in the Karakoram could account for the observed seasonal variation in the SO_4^{2-} and NO_3^- profiles. Both sulfur and nitrogen are injected into the atmosphere by biological emissions, primarily from plant exudates (Lawson and Winchester, 1979; Stallard and Edmond, 1981). Nitrogen gases are also readily liberated from the soil during the warm season (Yaalon, 1964). The extensive use of natural fertilizer during the summer is a potential seasonal source of nitrate. In addition locally derived pollution, predominantly from biomass combustion, is a potential source of both SO_4^{2-} and NO_3^-. The mean concentration of the samples from the Karakoram is almost three times the mean combined NO_2^-/NO_3^- concentration of the Sentik Glacier core samples (Table II).

Total β-activity

The total β-activity profile from Hispar Dome (Fig. 2) also displays strong peaks within summer deposits. Spring precipitation is characterized by high values of total β-activity (Ambach and others, 1976). Ablation horizons act as adsorption filters and are characterized by concentrated β-active deposits, even during periods of low atmospheric fall-out (Prantl and others, 1973; Ambach and others, 1976). The strong summer peaks in the total β-activity profile from the Hispar Dome site support this model.

Microparticles

The small (0.5–0.63 μm) and total (0.5–12.7 μm) microparticle profiles from the Hispar Dome site display seasonal variations similar to those already described, with typically sharp peaks occurring in the summer horizons. Seasonal variations in the total microparticle profile correlate well with variations in the total β-activity profile, suggesting that microparticles could be acting as adsorption filters for radionuclides. Unfortunately, the record is too short for the development of concrete conclusions at this time.

Physical stratigraphy

In the four low-elevation snow pits (4650–5100 m) the end of the 1985 summer season is clearly identified by a horizon containing visible dirt adjacent to an ice layer. Visible dirt layers occur nowhere else in the profiles. This is a strong indication that physical characteristics of the snow-pack at elevations ranging from 4650 to 5100 m can be good stratigraphic indicators for the most recent year of snow accumulation. This increases confidence in the results of the two snow pits investigated in 1985 (Young and others, 1986).

SPATIAL VARIATION OF SNOW ACCUMULATION

Distinct changes in the $\delta^{18}O$ profile are used as reference horizons to define summer and winter strata in all of the snow pits. Seasonal cycles that are not clear from the $\delta^{18}O$ profile can be clarified through an analysis of profiles of the major ions, total β-activity, and microparticles. The seasonal snow-accumulation data, in metres of water equivalent, for the 1985–86 accumulation year appear in Table III, and these results provide the basis for the interpretation of the altitudinal and lateral variation of snow accumulation within the central Karakoram.

TABLE III. ALTITUDINAL VARIATION OF SNOW ACCUMULATION IN THE BIAFO GLACIER BASIN, 1985–86

Site	Elevation	Net annual accumulation	Net summer accumulation
	(m)	(m w.e.)	(%)
Equilibrium line	4650	0.90	–
Hispar Glacier E.	4830	1.07	31
Whaleback Glacier	4900	1.79	49
Approach Glacier	5100	1.88	35
Hispar Dome	5450	1.20	27

Altitude variation of snow accumulation

The study sites within the Biafo Glacier basin can be separated into three distinct groups which represent three elevation bands (Table III). Maximum accumulation in the Biafo Glacier basin occurs in the elevation band from 4900 m up to at least 5100 m. This band may extend as high as 5400 m a.s.l.; unfortunately, no data were collected at these elevations. Many sources, including Flohn (1974), Barry (1981), and Price (1981), have identified an increase in the amount of precipitation with altitude in temperate and sub-tropical mountain ranges throughout the world, and this phenomenon is apparent in the Karakoram. However, a second very important process, involving change in the pattern of snow deposition due to the action of the wind, must also be considered.

The zone of maximum accumulation from 4900 m to 5400 m coincides perfectly with the broad, open areas in the accumulation zone of Biafo Glacier, which accounts for the bulk of glacier cover in the basin. The strong relationship between snow accumulation and basin morphology suggests that a part of the snow accumulation in the elevation range from 4900 to 5400 m is due to the redistribution of snow by strong winds, both during precipitation and following deposition. This is most likely to be a function of strong winds at high altitude, especially those accelerating over peaks and ridges keeping snow in suspension, while the relatively sheltered, deeper air column over the broad, flat areas of the accumulation zone acts to

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trap snow. Morphologically, the accumulation zone of Khurdopin Glacier is much like Lukpe Lawo, but on a smaller scale and at a higher elevation. Data from the Khurdopon Glacier snow pit at 5520 m indicate an annual rate of snow accumulation of 2.31 m w.e. within the broad flat areas of the accumulation zone.

Lateral variation of snow accumulation

The data presented in Table III suggest that accumulation for any given elevation band within the broad, flat areas in the accumulation zone of Biafo Glacier is relatively uniform. Moreover, this is also a good indication that within any elevation band the snow-pit locations chosen may be considered to provide a representative sample for the whole basin, in the sense that none seems subject to major disturbances by wind or avalanches. So long as samples of net annual accumulation can be obtained which measure or predict average basin accumulation by elevation, we can ultimately determine large-scale overall variations in accumulation, as opposed to small-scale local variations.

With this stratified view of snow accumulation in the accumulation zone of the Biafo Glacier basin, a crude estimate of the moisture input during the 1985–86 accumulation year can be calculated (Table IV). Snow-pit data exist for three of the seven elevation bands, and these three elevation bands represent 75% of the glacier-covered area in the accumulation zone. Moisture input into the glacierized part of the accumulation zone of Biafo Glacier is estimated to be of the order of 0.5 km^3 of water, representing an annual yield of 1.35 m w.e. (note that these figures do not include estimates of snow falling below the equilibrium line). This is almost three times as large as the annual yield of 0.50 m w.e. which flows past the Besham Qila gauging station (Pipes and Quick, 1987) about 40 km up-stream from the Tarbela reservoir. Accepting the relatively crude method of estimation, these results are promising and provide us with a rough framework from which we can begin to quantify the various components of the hydrological system in the Biafo Glacier basin. Possession of such a framework represents a crucial step towards a better understanding of snow and ice hydrology in the UIB.

TABLE IV. ESTIMATE OF MOISTURE INPUT IN THE GLACIERIZED PART OF THE ACCUMULATION ZONE IN THE BIAFO GLACIER BASIN, 1985–86

Elevation band	Area (km^2)	Net annual accumulation (m w.e.)	$\times 10^6$ m^3 water
4650–4877*	63.0	1.0	84
4877–5181*	109.5	1.9	208
5181–5486*	99.2	1.9	188
5486–5791	61.8	1.2 (?)	74
5791–6096	27.6	1.2 (?)	33
6096–6401	8.6	1.2 (?)	10
6401–6706	1.3	1.2 (?)	2
Totals	371.0		599

*Elevation bands for which snow-accumulation data exist.

CONCLUSIONS

Net annual accumulation has been determined at six different sites in the central Karakoram through an analysis of the chemical and physical characteristics of the snow-pack. The results demonstrate that glaciochemical investigations are a precise and efficient method by which to determine net seasonal snow accumulation in the Karakoram. Especially importantly in regions for which little data exist, this technique makes possible the production of snow accumulation and chemical records for use in both climatic and hydrological investigations. In addition, the chemical records provide valuable data concerning sources of moisture.

The results shown in Tables III and IV provide information about a number of different aspects of snow accumulation in the central Karakoram. Within the Biafo Glacier basin, maximum accumulation occurs in the elevation band from 4900 to 5400 m a.s.l. and this zone probably extends as high as 5500 m a.s.l. in the Khurdopin Glacier basin. The altitudinal variation of snow accumulation within the central Karakoram is best explained by an increase in precipitation with elevation combined with the redistribution of snow by strong winds. Snow redistribution by the wind probably results in an overcatch situation within the broad, protected areas of the accumulation zone. The elevation over which winds redistribute snow is dependent upon the area–altitude relationships of the glacier basin.

For any given band, accumulation of the broad flat parts of the accumulation zone in the Biafo Glacier basin is relatively uniform. This is a good indication that the locations chosen for the snow pits within the basin are representative of the basin in general. Moisture input in the accumulation zone of Biafo Glacier for the 1985–86 season was estimated to be 0.5 km^3. As this figure does not include snow falling below the equilibrium line, it does not represent total moisture input to the whole basin. Annual yield for moisture input into the accumulation zone of the Biafo Glacier basin was equivalent to 1.35 m w.e.

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