TECHNICAL REPORT

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SOUTH-EASTERN TIBET AND HIMALAYA

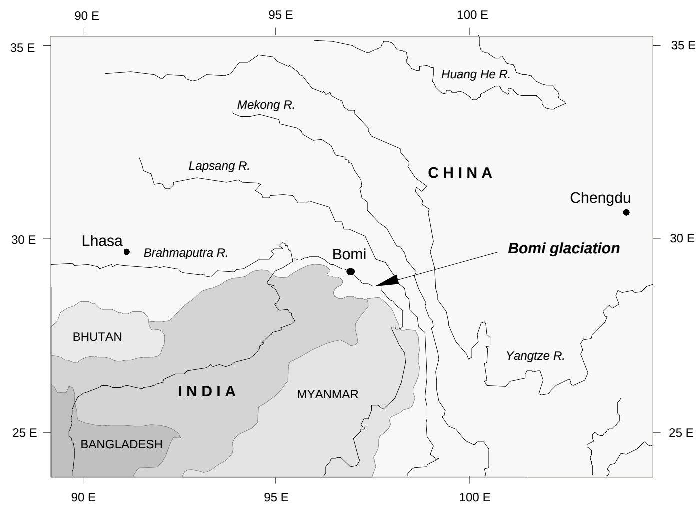

Figure 1. Map Bomi glacierized region and Zuoqiupu Glacier, South-Eastern Tibet-Himalayas.

Overview

The Bomi mountains are the largest glacier covered area (approximately 28,000 km^2) in the low latitudes of the Northern Hemisphere (29^{o}30'N; 97^{o}00'E) with the highest peaks over 7,700 m a.s.l. (Figure 1). The glacial accumulation areas elevated above 5,000 m where glacier's, ice thicknesses are greater than 300 m (*Aizen,1994*) are suitable for the recovery of ice core records. The location of this area between Tibetan and Himalayas mountain ranges, on the southeastern margin of the Tibetan Plateau provide an excellent opportunity to develop climatic records relating to the major circulation systems such as the tropical and subtropical monsoons, Tibetan high pressure system and the westerly jet stream. Furthermore, the Bomi region, as the montane barriers to southeastern air masses moving across the Tibetan Plateau, plays an important role in determining the climatic processes in the southern periphery of Asia. In addition, the Bomi glaciated area holds the greatest concentration of snow and ice in the low latitudes and constitute a source of fresh water shared by ten very populated countries. Bomi glaciers feed several major Asian rivers: Yangtze, Mekong, Hengduan, Brahmaputra, and play a very important role in the water cycle in this region. For example, glaciers of Gongga Shan (another glaciated area in south-eastern Tibet) tend to trap, accumulate,

Figure 2. Up and down through Tibet to Bomi glaciers. Our expedition truck is going forward. Photo by V. Aizen

and transfer about 0.24% atmospheric moisture from the external water cycle returning 0.30% of water per year to the Pacific and Indian oceans. The 0.06% of this external moisture is taken from accumulated glacial resources of this area (Aizen & Aizen*, 1997)*. In contrast to the relatively short-term records of the chemical composition of wet deposition provided by the National Atmospheric Deposition Program and Hydrological BenchMark data bases, glacier ice in low latitudes provides a much longer record of wet and dry deposition *(Naftz, et al., 1991).* A long-term record of atmospheric deposition in the inhabited Tibetan glacial area is desirable to evaluate the possible relationship between anthropogenic emissions and chemical composition of wet and dry deposition. Furthermore, there exists a network of hydro-meteorological stations that have been in operation for the past 40-50 years in the south-eastern Tibet and Himalaya that provide sufficient data for detailed climatological analyses as well as providing data that can be used to compare and calibrate ice core records.

Figure 3. Zuoqiupu Glacier, passage to snow-firn plateau, 5800 m a.s.l. Photo by V. Aizen

Field itinerary

Our first field reconnaissance in south-eastern Tibet-Himalaya started on September 24 from Chengdu the capital of Sichuan Province. Two 'Toyota' jeeps and one 6 ton truck (similar to 1944 Studebaker) loaded with expedition gears and food moved to Bomi through Luding, Kagding, Batang and Baxoi. Six days we traveled by unpaved alpine roads up and down from one pass to another ascending over 5,500 m elevation. On September 30 we finally arrived to Bomi village. The next day we established our base camp near Youlong Glacier, the biggest glacier (32 km long) in the Bomi glaciated area. After three days acclimating around base camp (4,500 m a.s.l.) and working on installing one of the 'Campbell' automatic weather stations,

Figure 4. Tibetan porters carrying ice-core in termo-insolated boxes, Zuoqiupu Glacier, 6100 m a.s.l. Photo by V. Aizen

we moved to the Zuoqiupu Glacier. The 15 yaks and 20 porters with expedition gears and food went ahead from base camp. The first day we ascended to 5,800 m a.s.l. and the following day installed the second 'Campbell' automatic weather station for annual meteorological measurements. After one day, Dr. Stanislav Nikitin, Daniel Joswiak and I took alpine ropes, ice-axes, ice screws, crampons, radio-telephone, and our personal backpacks and went to the glacier to scout best way trough the ice-fall. After several hours we crossed ice-fall, marked the crevasses with red colored wig-wags and screwed down five 80 m alpine ropes for our porters at the most dangerous spots. This day the first portion of our gear and food was transferred to our research site we found at 6,120 m a.s.l. on the upper part of the snow-firn plateau. The next day, Tibetan porters moved all our cargo to the advance camp. One week was spent on the plateau accomplishing our research goal, which included ice thickness radio-echo sounding measurements, collecting snow samples, digging snow pits and recovering a 14 m shallow firn core. After we finished our scheduled work we returned to base camp at 4,500 m and continued collecting stream samples and measuring ice thickness at the Zuoqiupu Glacier terminus area. The 14 m firn core and snow samples were transported down to base camp by our porters in thermo-insolated boxes. At base camp, all boxes were placed on the truck into four chest freezers powered by a mini-electric generator. On October 16 heavy snow forced us to retreat from the alpine area. Four days we then had to drive west to Lhasa along the Brahmaputra River tributaries. The east route was closed, winter had come to Tibet. The jeeps and truck returned to Lanzhou Institute via the Tibetan highway (5 days), we flew from Lhasa to Lanzhou, then to Seattle through Beijing. Firn core and snow samples were transported from Lanzhou to Seattle and the University of Idaho freezer.

Field results

Zuoqiupu Glacier radio-echo sounding measurements

Detailed radio-echo sounding measurements were completed at over 100 sites throughout at the accumulation area and glacier terminus in order to determine ice thickness (Figure 5). These measurements were accomplished using a light-weight ice-penetrating radar system (30^{o} direction of aerials, 700 MHz frequency, 10 Watt impulse, 50 NSC duration of impulse, -130 Decibel sensitivity of receiving signal, 1-2% error of measurement). Measured ice thickness range from 100 to 150 m, with a depth of 132 m at the shallow firn core site. Several intermediate horizons were apparent in the radio echo sounding reflections that may be associated

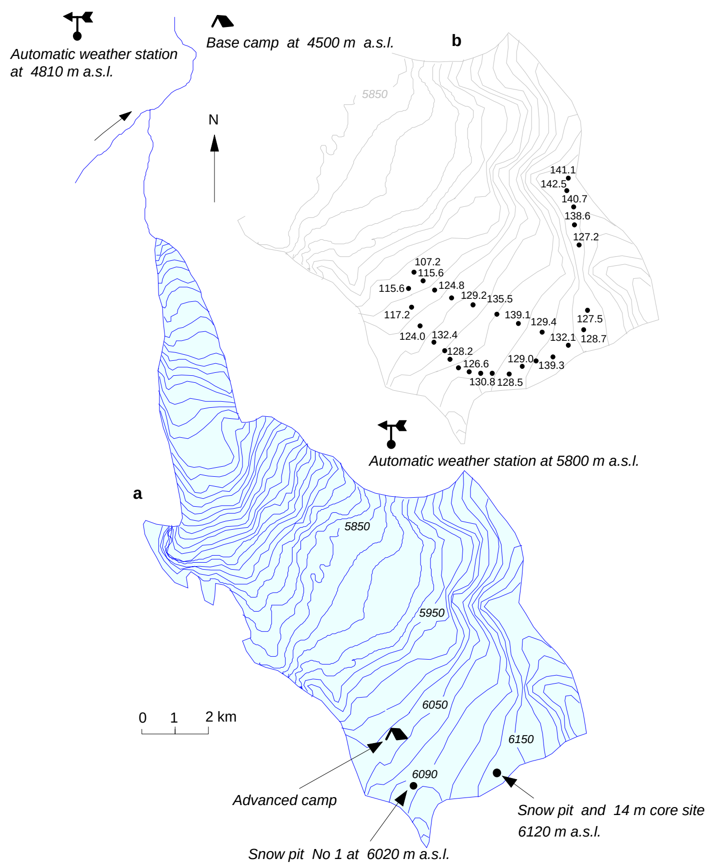

Figure 5. Zuoqiupu Glacier, automatic weather stations, snow pits, shallow core sites (a) and the glacier ice thickness measured by ice-penetrated radar (b).

with the presence of fine-grained sediment of eolian genesis. The radio-echo thickness measurements were surveyed using a GPS tool to coordinate each point of measurement. The recorded GPS measurements were converted from the World Geodetic System 1984 (WGS-84) to the topographic map system (*Hvostov, V.V., 1990*) using Helmet's parameters calibrated for Zuoqiupu glacier basin. The accuracy of GPS in an independent regime is about 20 m, the accuracy of our converted coordinates is about 3 m, quite high compared to the accuracy of the Chinese topographic map. The Helmet's transformation implements a conversion from one coordinate system (X,Y,Z) to another using seven parameters: - zero coordinates linear displacement (3 parameters), angle of orientation components (3 parameters), and the scaling coefficient (1 parameter). The orthogonal coordinates of the radio-echo sounding points which were not referenced by GPS were calculated by two methods: - linear interpolation, when points are located in longitudinal section between the points referenced by GPS, or through extrapolation by the angle of cross section profile when each point (control stake) is not more than 50 m from the previous point. The altitudes of radio-echo sounding points on the glacier surface were calculated using Digital Elevation Model (DEM). A Triangulated Irregular Network (TIN) has been developed for the glacier bedrock topography (187 triangles based on 119 echo records).

Figure 6. 'Mini-Felix' sun powered electro-mechanical drill. Drill barrel cleaning after each run. Zuoqiupu Glacier, 6,120 m a.s.l proposed deep drilling site. Photo by V. Aizen

Meteorological observations

Two 'Campbell Scientific' automatic weather stations were installed to record hourly measurements in the Zuoqiupu Glacier basin for one year. One station is near the terminus (4,800 m a.s.l.) and the other at the glacier equilibrium level (5,800 m a.s.l.) (Figure 7). Both stations were assembled to record air temperature, air humidity, wind speed and direction, barometric pressure, solar radiation (short and long waive) and the snow/rain amounts. The stations worked very well through the year 2002/2003. Data was successfully retrieved from the automatic weather stations in October 2003 by Daniel Joswiak, Arjhan Surazakov and Young Han. Using a laptop computer to connect to the CR10X datalogger on the automated weather stations, the hourly records were downloaded and the memory was cleared to allow for another year of recording.

Figure 7. 'Campbell Scientific' automatic weather station established at 5,800 m, 2 km northeast from proposed drilling site at Zuoqiupu Glacier snow-firn area. Photo by D. Joswiak

Shallow firn core and snow sampling

Figure 8. 'Mini-Felix' sun powered electro-mechanical drill. Zuoqiupu Glacier, 6,120 m a.s.l proposed deep drilling site. Photo by V. Aizen

During three weeks work in the Bomi glacial area, fresh snow and stream water samples were collected in pre-cleaned 200 ml plastic bottles and placed in chest freezers. Snow from six 3-3.5 m snow pits was collected every 5 cm deep, and detailed snow stratigraphy was described and recorded. Density samples were taken every 3-5 cm in snow pits using a 100 cm^3 stainless steel sampler and electronic balance. Temperature was measured by an electronic sensor each 10 cm. A firn core (14 m long and 7.5 cm in diameter) was extracted at an elevation of 6120 m, where the results of radio-echo sounding suggests an ice depth of about 132 m (Figure 5). The core was drilled from the bottom of the 3.0 cm snow pit (number 2) with a 'Mini-Felix' (Swiss made) solar powered electro-mechanical drill (Figure 6 and 8). The diameter, length and weight of each recovered core section were measured for density calculations. Firn-core sections, sealed in pre-cleaned polyethylene bags, were packed in insulated shipping containers and delivered to the University of Idaho freezer for further processing and analysis. Samples from firn core, snow pits, fresh snow, and streams were analyzed for ^{18}O, ^{2}H, major ions and trace elements. To prevent contamination, the outer portion of each core section was removed in a laminar flow clean bench using sterilized stainless blades.

Laboratory analyses

Core and snow samples from Zuoqiupu Glacier were melted at room temperature on a laminar flow horizontal clean bench at the U of I. Ultra-clean sample preparation techniques previously described by Kreutz and others (2000) were used to prepare liquid firn samples from the 10 cm sections.

Major ion analyses were performed at the U of I and WSU geochemical laboratories. Anions were determined using a Dionex AI-450 Ion Chromotograph, and cation concentrations were determined by inductively coupled plasma- atomic emission spectroscopy (ICP-AES) with an axial-view torch (Perkin Elmer Optima 3000 XL) in the Department of Geological Sciences at the University of Idaho. Heavy metals and REE concentrations were determined at the Washington State University ICP-MS laboratory using a ThermoFinnigan Element2 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). Calibration standards for each analysis were made from certified standard acquired from Aldrich Chemical Company and Fisher Scientific. Sets of three to five different concentrations of standards were used to establish calibration curves, with correlation coefficients better than 0.999. Blanks and standards of known concentrations were run periodically throughout the analyses as quality-control checks.

Stable isotope ($\delta\,^{18}O$) analysis was performed at the UofI Stable Isotope Laboratory using a Finnigan Delta plus isotope ratio mass spectrometer (IRMS) coupled with Finnigan's GasBench II. The GasBench injects from the headspace five times per vial, and we use the mean of the five CO_2 peaks. The GasBench flush-fills the headspace of each vial with ~3000 ppm CO_2 in helium for 4 minutes to turn over this gas volume completely. This CO_2 equilibrates with the oxygen in the water (0.5 mL) over 18 hours at 26^{o}C. After equilibration, the $\delta^{18}O$ of the CO_2 in this classical "headspace" experiment is almost the same as the water's value. The details of the actual fractionation during equilibration, such as a temperature-based coefficient of fractionation which indicates the amount that the CO_2 does not match the water's isotopic signature, are not needed since several vials of water of known isotopic composition are run along with each melted firn sample through the identical treatment principle, with the same adjustment applied to each sample within the batch.

Discussion

Located in South-Eastern Tibet, the Zuoqiupu Glacier area has extremely low values of anions (Figure 9) compared to other Asian sites (Tien Shan and Altai) associated with the greatest amounts of precipitation (Figure 10), close proximity to moisture sources (Indian Ocean), and location far from terrestrial dust inputs. The low SO_4^{2-} and NO^{3-} concentrations point to minimal effects from anthropogenic impact in the most recent record recovered from the shallow firn-core. The elevated Cl^- levels among other anions (Figure 9) is related to the close proximity to a marine moisture source. Small concentrations of Ca^{2+}, Mg^{2+}, K^+ and SO_4^{2-} are dominate in the fall and winter. Maximum concentrations of Na and Cl were observed in the spring and summer samples (Fig. 11), during monsoon periods of maximum precipitation.

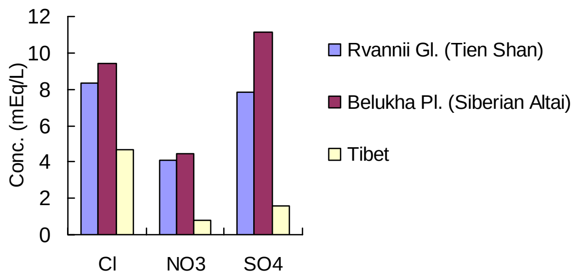

Figure 9. Anion concentration in snow at different Asian sites.

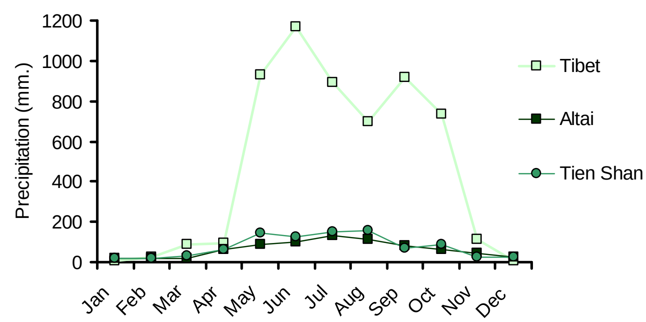

Figure 10. Mean monthly annual precipitation adjusted to the drill sites.

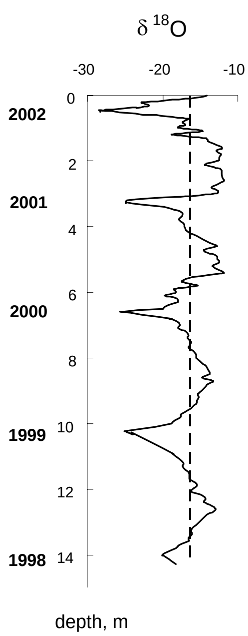

Figure 11. South-East Tibet 14 m shallow core (6120 m a.s.l.)

The firn-core recovered at Zuoqiupu Glacier shows well-preserved annual isotopic variation. The low annual range (8.8‰) (Figure 11) results from the warmer monsoon climatic conditions and short transport distance of source moisture. The mean and absolute (maximum and minimum) values are slightly lower than from Altai core, although moisture source transport distance is less.

The meteorological records from two automatic weather stations in the Zuoqiupu glacier basin were obtained in November 2003, after one year of recording. This data will be analyzed this year with other long-term meteorological and synoptic data we collected in China during our reconnaissance.

The GPS satellite grounded survey at the terminus of two glaciers in the Bomi area was accomplished in November 2003 and will required additional measurements in the Fall of 2004 in order to understand glacier-ice velocity and link GPS coordinated points with high resolution satellite images. The glaciers in the Bomi area have been retreating at extraordinary rates for the last 20-30 years and may disappear in the near future. The climate and glacier regimes in the Bomi area are absolutely unknown, even though they are one of the most interesting and important phenomena in the northern hemisphere tropics. We are the first geo-scientists visiting the Bomi region to study climate and glaciers, and our goal is to document glacier distribution and couple glacier surface and volume changes with ice-core paleo-climatic reconstructions. We are planning to accomplish our research goals in this region within the next few years.