Department of Geography
College of Mines and Earth Resources
P.O. Box 443025, University of Idaho
Moscow, ID 83844-3025

SCIENTIFIC AREA: **Earth Sciences (Global Change)**

PROJECT TITLE:

PALEOCLIMATIC and GLACIOLOGICAL RECONSTRUCTIONS in CENTRAL ASIA THROUGH COLLECTION and ANALYSIS of ICE CORES and INSTRUMENTAL DATA in the TIEN SHAN and ALTAI MOUNTAINS

PI: **Vladimir B. Aizen**
CONTACT: Tel: 208-885-5888, fax: 208-885-5724, e-mail: aizen@uidaho.edu

ANNUAL REPORT

DOE/INEEL Contract Number: BBWI 00000073 R10
Budget Period: 01/06/2001 to 31/12/2001

16 March, 2002

RESEARCH TEAM ‘ 2001:

Professor, Dr. **Vladimir Aizen**, glaciologist
Department of Geography, College of Mines and Earth Resources, P.O. Box 443025, University of Idaho
Moscow, ID 83844-3025, **U.S.A.**
Tel. (208) 885-5888, fax. (208) 885-5724
E-mail: aizen@uidaho.edu

Associate Researcher, Dr. **Elena Aizen**, climatologist
Department of Geography, College of Mines and Earth Resources, P.O. Box 443025, University of Idaho
Moscow, ID 83844-3025, **U.S.A.**
Tel. (208) 885-5888, fax. (208) 885-5724
E-mail: eaizen@uidaho.edu

Assistant Professor, Dr. **Karl Kreutz**, isotope-geochemist
Stable Isotope Laboratory, University of Maine, Institute for Quaternary and Climate Studies, 236 Sawyer Environmental Research Center, Orono
Maine 04469, **U.S.A.**
Tel. (207) 581-3011, fax. (207) 581-3490
E-mail: karl.kreutz@maine.edu

Dr. **DeWayne Cecil**, hydro-geologist
Water Resources Division, US Geological Survey
900 N. Skyline Drive, Suite ‘C’, Idaho Falls
Idaho 83402, **U.S.A.**
Tel. (208) 528-2611, fax.(208) 528-2605
E-mail: ldcecil@usgs.gov

Professor, Dr. **Stanislav Nikitin**, geophysicist
Glacio-Climatological Laboratory, Tomsk State University
36 Lenina Str., Tomsk 634050, **Russian Federation**
Tel. +7 (3822) 55-47-03, fax. +7 (3822) 41-58-92
E-mail: nikitin@ic.tsu.ru

Associate Professor, Dr. **Koji Fujita**, glaciologist
Division of Earth and Environmental Sciences
Nagoya University, Furo-cho, Chikusa-ku
Nagoya 464-8605, **Japan**
E-mail: bri@ihas.nagoya-u.ac.jp

Two undergraduate students from the Nagoya University (Yoshihiro Matsudo and Konichiro Matsuki), one PhD student from the Institute of Inorganic Chemistry, Russian Academy of Sciences at Novosibirsk (Stanislav Polesskiy), three graduate students from the Tomsk State University (Arjan Surazakov, Aleksei Lushnikov and Alexei Chebotarev) and one support personnel from Tomsk State University (Tatyana Prokopinskaya) were also involved in Altai field research.

Table of Contents:

1. PREFACE

The presented report composed from two parts: **Part I** is the field reconnaissance 2001 in Altai Mountains at South Siberia (Russia) and initial data analyses and **Part II** is the analytical research with snow and water samples, ice-core records, meteorological and synoptic data collected in Tien Shan deep ice-coring expedition 2000. Both these research were conducted under the Project Paleo-Environmental Record in Mid-Latitude Glacial Ice from the Northern Hemisphere: National Global Change Outgoing Program supported by the U.S. Department of Energy (DE-A107), the USA National Science Foundation NSF-ATM9905670 and the Ministry of Education, Culture, Sports, Science, and Technology fund of the Japanese Government. We are also expressing our acknowledgement to the Tomsk State University in support our field research in South Siberia the Russian Federation.

PART I. ALTAI RECONNAISSANSE

Overview

After successful deep ice-core expedition in central Tien Shan in summer 2000 we focused our field research to Altai mountains in South Siberia. In June 2001 **three years Agreement on collaborative research** in Altai has been signed between the University of Idaho, USGS Idaho Falls, Research Institute for Humanity and Nature, Nagoya University and Tomsk State University. Please see Appendix A. Investigations in Siberian Altai permits to expand our scope from Tibet, Himalayas, Tien Shan and Pamir to the area located at the northeastern edge of the Central Asia Mountain System. (**Fig. 1**) Altai forms a natural barrier to the northern and western air masses and therefore affords an opportunity to develop modern paleo-climate records relating to the westerly jet stream, the Siberian High and Pacific monsoon.

Fig. 1. Location of the research site

Altai alpine snow/ice accumulation areas are also appropriative for studying air pollution dynamics at the center of Eurasia, eastward from the major Former USSR air pollutants in Kazakhstan, South Siberia and Ural mountains. During the last century Altai became extremely contaminated region by heavy metal mining, metallurgy, nuclear test in Semipalatinsk polygon and Baikonur rocket site.

Our first field reconnaissance on the West Belukha snow/firn plateau at the central Altai (Fig. 2) was carried out in July 2001. Dispute of the large Altai mountains glaciation, the West Belukha Plateau (49°48’ N, 86°32’E, 4000-4100 m a.s.l.) is only one suitable snow accumulation site in Altai to recover ice-core paleo-climatic and environmental records that is not affected by melt water percolation.

Objective

Our main objective of the reconnaissance 2001 was to find an appropriate deep drilling site in Altai mountains by radio-echo sounding survey, to recover shallow ice-core and identify the annual snow accumulation rate, oxygen and deuterium isotopes, heavy metals, major ions, and radionuclide level distribution.

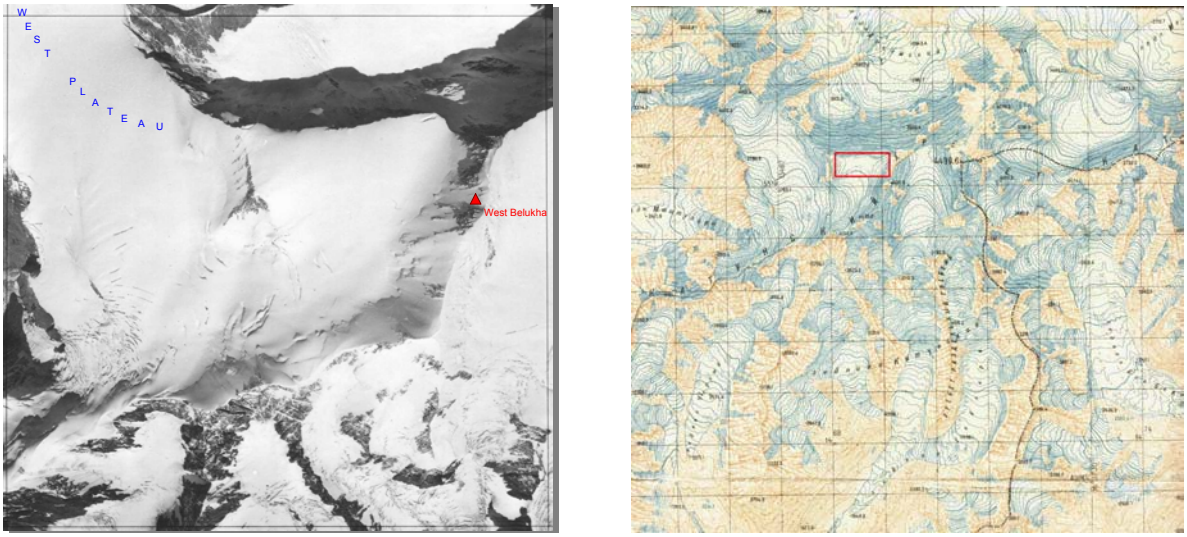


Fig. 2. Belukha Mt. Massif and Snow-Firn Plateau on the aerial photo and topographic map.

Field Measurements

During two weeks work at Belukha Snow-Firn Plateau, snow and firn samples were collected every 5 cm from four 2-m snow pits and a 22-m firn-ice core has been recovered by PICO Hand Auger on the West Belukha snow/firn plateau. Snow pit samples were obtained at altitudes from 4109 to 4115 m, and a firn-ice core was taken at 4115 m where the results of radio-echo sounding suggests about 200 m ice thickness (**Fig. 2**). Snow pit, precipitation, fresh snow, surface and groundwater samples were collected in pre-cleaned plastic bottles and allowed to melt at the field camps. Detailed physical statigraphy of ice core and snow pits were described. Samples from ice core, snow pit, fresh snow, precipitation, and surface and ground water were analyzed for $\delta^{18}O$, δD, major ions and heavy metals. To analyze the trace metal concentration sterile stainless blades were used to remove the outer, contaminated portion of the core, under a laminar flow hood. Samples from the ice core layer at 17.31-17.36 m were melted in pre-cleaned Teflon bottles and were shipped to laboratory analysis. Four automatic snow gauges were installed near proposed deep ice coring site for year around records.

Laboratory Analyses

Core processing at the National Polar Research Institute (Tokyo, **Japan**) was done in a dedicated cold room (temperature <-12ºC) using established techniques for ultra-clean sample preparation. Frozen 18 mΩ water blanks were sent through the entire system to assure that there was no contamination. Upon melting, an aliquot (10ml) of sample was removed and shipped to the **University of Maine** for oxygen and deuterium isotope ($\delta^{18}O$ and δD) analysis as well as snow pit, precipitation, fresh snow, and surface and groundwater samples. A VG-Fisons Sira Series II mass spectrometer fitted with dual inlets, triple collectors, and mated to an automated CO_2 equilibration dev-ice was used for analysis (precision ±0.05‰). Sample ratios were reported relative to standard mean ocean water (SMOW).

The samples were analyzed for trace metal concentration on a Finnigan ELEMENT ICP-MS instrument in the Institute of Inorganic Chemistry, Russian Academy of Sciences at Novosibirsk, Russia.

The statistical analysis of present meteorological conditions was based on long-term data from the meteorological stations (Akkem, 2050m; Kara-Turek, 3600m) located 15, and 30 km north, and northwest of the Belukha Glacier massif.

To describe large-scale atmospheric circulation patterns that can potentially influence climate of Western Siberia, we used different approaches: Zonal and Meridianal indices (ZACP, MACP), a description of atmospheric pressure distribution through North Atlantic Oscillation (NAO), Pacific-

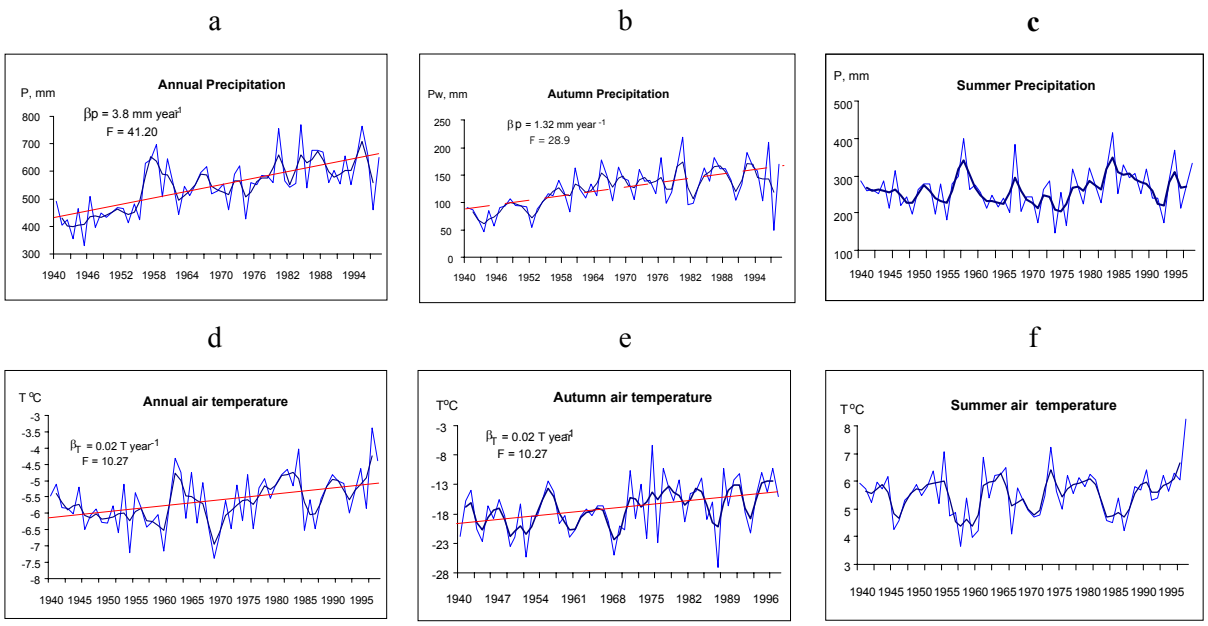
North American (PNA), Western Pacific Oscillation (WPO), and Northern Asian (NA) indices.

First results

Regional climates and large-scale atmospheric circulation patterns:

Precipitation: The Altai Mountains is situated under strong influence of the Siberian High, which decreases the quantity of winter precipitation with minimum in January (Fig. 3). Maximum precipitation is observed in summer. For the period from 1940 to 1998, a statistically significant increase in precipitation was detected and attributed mainly to reduction in autumn, spring and winter precipitation (**Fig. 3a, b**). Annual mean of precipitation has increased about 40% of total average and autumn mean has increased up to 44% of autumn average. We did not detect significant trends in summer precipitation regime for the past 58 years (**Fig. 3c**).

Fig. 3. Precipitation and air temperatures distribution over the 50 years period

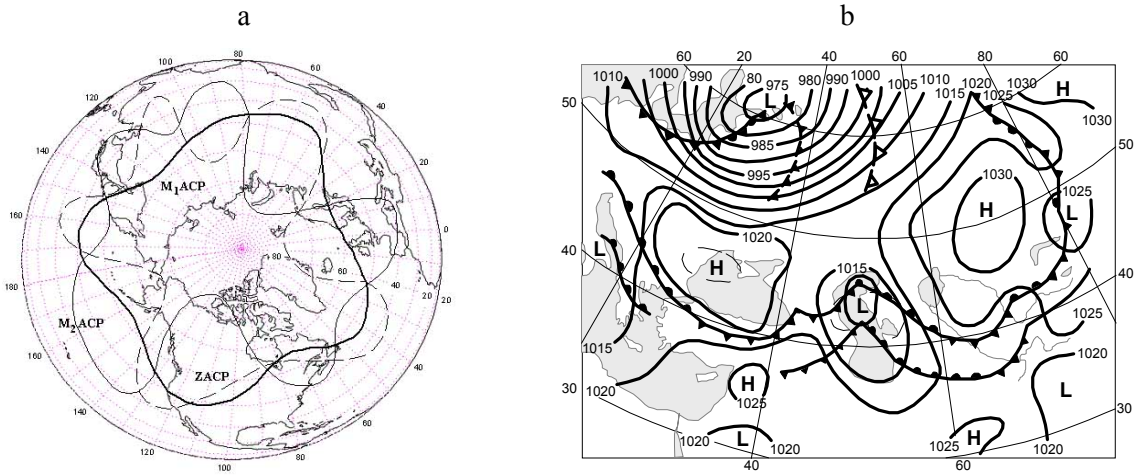


Air Temperature: The location of the Altai, in the center of the Earth's largest continent, results in a generally continental climate. The amplitudes in annual changes of air temperature reach up to 30°C (**Fig. 3d,e,f**). During the period 1940-1998, air temperatures did not decrease in any season, and mean annual air temperature rose by an average rate of 0.02°C per year (**Fig. 3d**) with increasing winter and autumn air temperatures (**Fig. 3e**). According to coefficients of determination, on average, 15% of interannual air temperature variability is described as a linear trend. Spring and summer air temperatures were not changed during the period from 1940 to 1998 (**Fig. 3f**).

Atmospheric circulation patterns: Development of meridianal pattern (M_1ACP) with shallow sub-polar lows, low pressure over Europe and location of Siberian High further east (**Fig.4a,b**) is favorable for annual and winter precipitation increase in the mountains of western Siberia (**Table 1**). The organization of the major long-wave when the M_1ACP are prevailing results in increasing frequency of western cyclones (**Fig. 4b**), which are most favorable for development of precipitation. The positive correlation between frequency of M_1ACP and annual/winter precipitation corresponds to our result of a positive trend of precipitation in mountains of western Siberia for the period from 1940 to 1998. According to *Subbotuna* (*1995*) using data during the period from 1961 to 1990, the M_1ACP was dominant (**Fig. 4a**) and resulted in increasing precipitation. High pressure over Eastern Europe and further west location of Siberian High during increasing frequency of M_2ACP (**Fig. 4b**)

decrease annual and summer precipitation (**Table 1**). The Altai is a region where winter precipitation is significantly inversely associated with zonal type of atmospheric circulation (**Table 1**).

Fig. 4. Development of meridianal pattern (M_1ACP) with low pressure over Europe (a) and location of Siberian High further east (b)



Western streams from Atlantic Ocean are the main source of precipitation in this continental mountain. The North Atlantic Oscillation has statistically significant inverse relationship over Altai (**Table 1**). A negative difference in anomalies of sea level pressure between the Azores and Iceland is favorable for precipitation development over western Siberia. During positive NAO phases, with increase over average air pressure gradient directed from near Azores to Iceland, the strong westerlies bring intensive precipitation to the limited northwestern region of Europe and decrease winter precipitation at mid-latitudes of continental Eurasia (*Aizen et al., 2001*).

Changes in anomalies of geopotential height at a large positive center located in the north Pacific and two negative centers in the Aleutian zone and near the Russia – China – Mongolia border (PNA) affect the regional annual precipitation regimes in Western Siberia (Table 1), which most probably occurred in spring autumn seasons.

We did not find any significant impact of West Pacific Oscillation, Northern Asian pattern on precipitation in western Siberia.

Table 1. Correlation coefficients between indices of ACP and annual, winter and summer precipitation in western Siberia. ΔZACP $\Delta M_{1,2}$ACP, ΔNAO are indices of zonality, meridionality and North-Atlantic Oscillation mode; EOFs(PNA), EOFs(WPO), EOFs(NA) are time coefficients (empirical orthogonal functions) of Pacific North Atlantic, West Pacific Oscillation and Northern Asian modes.

	ΔM_1ACP	ΔM_2ACP	ΔZACP	ΔNAO	EOF(PNA)	EOF(WPO)	EOF(NA)
annual	0.36*	-0.33*	0.21	-0.35*	0.53	0.06	0.05
winter	0.79*	0.20	-0.90*	-0.27*	-0.18	-0.09	-0.24
summer	0.11	-0.43*	0.23				

* is significant correlation at 10% level.

Snow pits stratigraphical analysis:

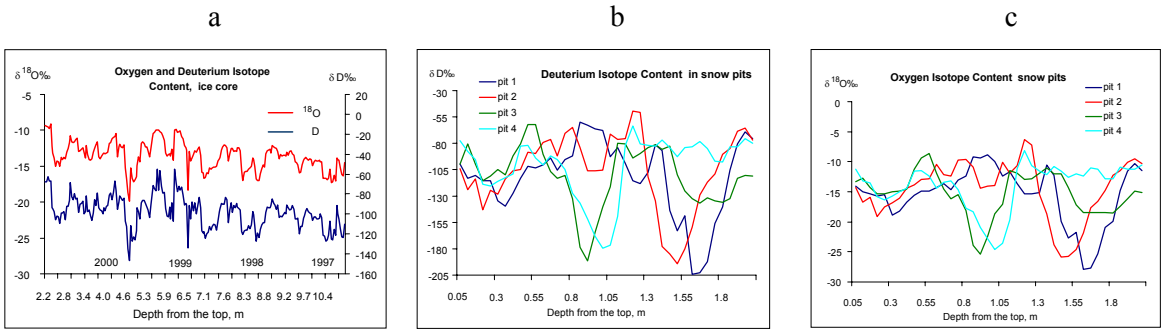
According to stratigraphic profiles of yearly deposition, the snow-firn strata in pits seem to have been formed during one accumulation period and seasonal accumulation at the drilling site was ranged from 250 to 300 см with density of 0.34 – 0.40 g cm^{-3}. Accumulation area seems to lie in the cold infiltration-recrystallization zone. The stratigraphic analysis of snow pits and ice core demonstrates the absence of melting. The data of isotopic composition were not redistributed through percolation.

Isotope analysis

(There have not been published any isotope data from Altai glaciers)**:**

Ice core (a half of ice core has been analyzed – about 11 m from the top): The average value of $\delta^{18}O$ was 13.6‰ in the ice core. The apparent variability in the $\delta^{18}O$ data with increasing depth throughout the ice core and snow pits reflects the annual cycles in precipitation $\delta^{18}O$ (**Figures 5**).

Fig. 5. Distribution ^{18}O and D in ice core (a) and snow pits (b, c)



Amplitude fluctuation is not significant (maximum range of 10.8 ‰ in the ice core, see **Table 2**) comparing to Tien Shan variability in oxygen isotope records (range = 29.6 ‰, *Kreutz, et al., 2001*). Given the regional distribution of annual air temperatures (**Fig. 3d**) with very significant annual variability, insignificant variations in composition of $\delta^{18}O$ could reflect snow brought by different air masses: for example western cyclones (MACP, NAO) during summer and PNA during autumn.

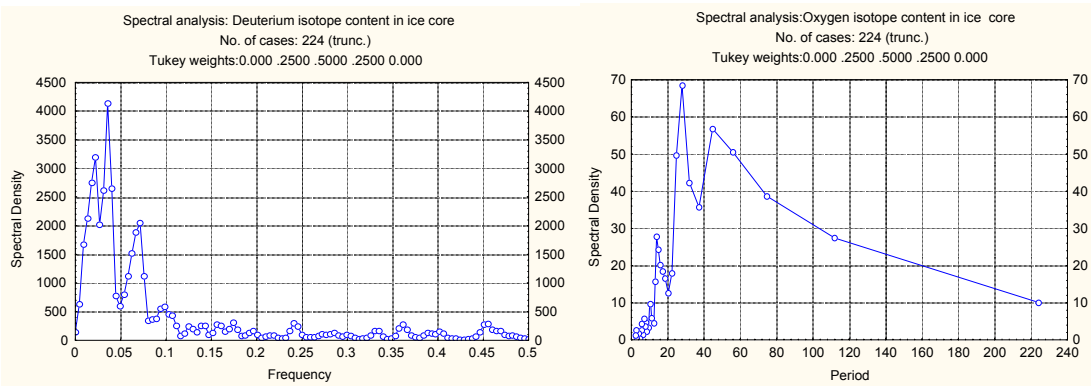
Table 2. Oxygen and deuterium isotope ratios in Altai snow pits, firn/ice core, fresh and old snow, precipitation, streams, river and lake. N is number of samples.

	Snow pit 1	Snow pit 2	snow pit 3	snow pit 4	ice core	fresh snow	old snow	precipi tation	streams	ground water	river	lake
N	40	40	40	40	480	3	6	28	11	5	10	5
$\delta^{18}O$												
Ave.	-15.5	-14.6	-15.3	-14.0	-13.6	-15.3	-23.7	-15.3	-14.5	-13.3	-15.0	-14.6
Max	-8.8	-6.3	-8.6	-8.1	-9.1	-14.9	-22.4	-6.1	-12.8	-13.1	-14.6	-14.3
Min	-27.9	-25.9	-25.4	-24.7	-19.9	-16.6	-25.3	-18.3	-15.7	-13.5	-15.4	-15.1
stdev	4.8	4.8	3.7	3.9	1.9		1.3	3.9	1.1	0.2	0.4	0.4
Δ	19.2	19.6	16.8	16.6	10.8	1.3	2.9	12.2	2.9	0.4	0.9	0.8
Tien Shan, Inylchek gl (*Aizen et al., 1996, Kreutz, et al., 2001*)				-15.0	-16.8							
Bogda Shan (*Wake, 1993*)				-15.1								
Glacier N.1 (*Wake, 1993*)				-16.4								
δD												
Ave.	-112.1	-105.8	-110.4	-101.7	-97.9	-101.9	-176.2	-114.3	-106.1	-98.0	-109.2	-105.5
Max	-59.9	-48.9	-61.9	-63.5	-55.1	-101.9	-161.7	-53.7	-89.4	-96.3	-102.7	-100.9
Min	-204.5	-194.3	-191.3	-179.6	-146.7	-115.6	-194.6	-140.8	-118.6	-101.0	-114.6	-109.4
stdev	35.9	36.4	28.8	29.1	15.6		11.5	25.7	8.6	1.8	4.1	3.5
Δ	144.6	145.4	129.4	116.1	91.6	13.7	32.9	87.1	29.3	4.7	11.9	8.4

Based on the meteorological data, we established a depth/age scale for the firn-ice core taking into account the annual amount of precipitation and annual minimum variability of air temperature**.** Taking into account that the air mass with lower temperatures is characterized by relatively light $\delta^{18}O$ isotopic ratios, we assume that the lowest $\delta^{18}O$ values (**Fig. 5a**) correspond to winters. The data on distribution of snow and firn-ice density in the core were taken from the measurements in snow pits, crevasses and firn-ice core on the Belukha glacier. Thus, $\delta^{18}O$ records from the 11 m of ice core presents about five years of accumulation (2001-1996) with 800 mm annual accumulation

and the rest half of core contents records from about other five years (1995 –1990). Double picks with relatively high $\delta^{18}O$ isotopic ratios observed during an annual period is a result of 1) summer maximum air temperature and 2) the second source of moisture during spring/autumn precipitation located closer than the first, which brings snow during summer.

Fig. 6. Special analysis: Frequency (a) and period (b) of Deiterium and Oxigen isotopes in ice core



To reveal major physical processes causing periodic rhythms in $\delta^{18}O$ ratios in the ice core, we used single series Fourier analysis (**Table 3**). The confidence interval for standardized spectral density of the white noise was determined according to the Kolmogorov-Smirnov criterion. The largest values of $\delta^{18}O$ and δD periodogram relate to the high-frequency part of spectra (**Fig. 6**). Up to 50% of variance in the $\delta^{18}O$ and δD is explained by variations with periods 28 and 44 records. The period of 44 in 224 records could be associated with a regular annual cycle in air temperature during precipitation and period of 28 records could be associated with second source of moisture to the Belukha glacier.

Table 3. Largest periodogram values of $\delta^{18}O$ and δD records in ice core.

Frequency	Period	Periodogram	Density	Frequency	Period	Periodogram	Density
		$\delta^{18}O$				δD	
0.022	44.8	98.46	54.37	0.036	28.0	6281.77	4133.33
0.036	28.0	94.31	62.96	0.022	44.8	5474.87	3193.97
0.013	74.7	52.05	39.22	0.071	14.0	3342.93	2046.23
0.040	24.9	49.95	47.89	0.013	74.7	2561.34	2132.24
0.071	14.0	45.55	26.21	0.063	16.0	2224.62	1519.01

Distribution of δD signal in ice core is absolutely in accordance with $\delta^{18}O$ distribution (r = 0.99), that proves data results reliability.

Snow pits fresh, and old snow, precipitation, streams, river and lakes

The average value of $\delta^{18}O$ was ranged from –15.5‰ to 14.0 ‰ in the snow. Similar $\delta^{18}O$ signals have been noted in snow pits from other locations on the Tien Shan, the near central Asian mountains (**Table 2**). The most light isotope ratio is observed in old snow (up to –25.3‰, Table 2), while the heaviest isotope ratio is observed in precipitation (-6.1‰). Amplitude fluctuation of isotope content in precipitation (Fig. 13) and snow pits is significant reached 19.6‰ (**Table 2**).

Trace metal concentration

High concentration of trace metal (**Table 4**) is associated with the western advection of the main air masses, which transport of air pollutants emitted especially from heavy metal mining and metallurgical used areas of East Kazakhstan and Southwest Siberia.

Table 4. The chemical element concentration (c, ppb) in ice core layer from 17.31-17.36 m depth. Δ is background.

	Zn	As	Se	Sr	Cd	Sn	Sb	Te	Hg	Tl	Pb	Bi	Th	U
C	6.1	0.04	0.33	0.89	0.03	0.04	0.01	0.002	0.01	0.001	0.95	0.005	0.002	0.001
Δ	0.11	0.04	0.28	0.10	0.003	0.015	0.0007	0.002	0.009	0.0001	0.042	0.0002	0.0002	0.0
c-Δ	6.0	0.002	0.05	0.78	0.02	0.025	0.009	0	0.001	0.00125	0.91	0.005	0.001	0.001

Findings

During the period 1940 to 1998, annual precipitation and air temperature increased with the increasing winter autumn air temperatures. We conclude that weakening continentality of climate occurred in Altai was caused by decreasing influence of Siberian High, i.e., its location more to east. Degradation of Altai glaciers was a result of these circulation changes causing an increase in autumn air temperatures, which decrease of the share of solid precipitation. Glacier degradation occurred despite an increase in autumn winter precipitation.

A suitable location for drilling was found and an exploratory 22 m firn/ice core at the selected site was obtained along with snow pit, fresh and old snow, precipitation, surface and ground water samples. Analyses on identification of possible melt and of seasonal layers in ice core occurred.

According to identification of annual layers in the cores, the mean annual snow accumulation for the period from 1997 to 2001 was found to be about 800 mm. Analysis of large-scale atmospheric patterns (NAO and PNA), oxygen and deuterium isotope content in ice core and snow pits assume two sources of moisture on the Altai mountains.

PART II. TIEN SHAN ANALYTICAL RESEARCH

Lab work statement, overview

The research described in **Part II** of this report was a of collaborative effort with the United States Geological Survey's (USGS) Global Environmental Research Program which began studying radionuclide deposition in mid-latitude glaciers in 1995. The first step in this research (**the expedition 2000 only**) **was funded jointly by NSF (ATM-**9905670**) and the Department of Energy (**this contract**). Please see our Annual Report 2000 (AR00).**

In contrast to the Tibetan/Himalayan existing ice core records, which have been recovered in regions dominated by monsoon circulation, the Tien Shan Mountains lie on the upwind side of Tibetan Plateau (**Fig. 7**) and act as the initial barrier in Central Asia to the westerly jet stream and Siberian High. In addition, Tien Shan records can be directly compared with ice core records available from the polar regions and can therefore expand our understanding of inter-hemispheric dynamics of past climate changes. The central Tien Shan glaciers are archived excellent nuclear tests records from China (Lobnor) and Former USSR (Semipalatinsk) test areas which help us to identify annual accumulation layers chronology through radionuclide analyses.

Fig. 7. Location of the Tien Shan ice-coring site.

After expedition 2000 two ice-cores recovered from the South Inylchek Glacier, central Tien Shan were transported to the freezers at University of New Hampshire (UNH) and Stable Isotope Laboratory the University of Maine (UM). The ice chips from upper 100 m of Core #1 collected in the field were shipped frozen directly to the Paul Scherrer Institute/ETH in Zurich and have been analyzed for ^{36}Cl during the spring 2001. In 2001 we continued glaciological and meteorological data analysis processing 17 m upper part of Core #1 for ^{18}O isotopes and major ions and ice chips from two 165 m firn/ice cores obtained in expedition 2000 in the accumulation zone of the South Inylchek Glacier, central Tien Shan mountains, Kyrgyzstan (**Figure 7, 8**). The additional information for analytical research we derived from field observations in expeditions 1998, 1999 that preceded deep ice-coring expedition in 2000 while we checked the characteristics of the proposed ice-core site (**see Annual Report 2000**) performing detailed meteorological, hydrological and glaciological measurements over a range of elevations (4900 - 5500m) in the Inilchek glacier basin, collected snow samples from five 2m

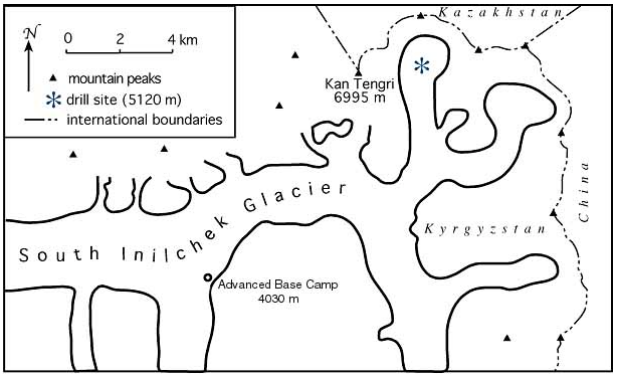


Fig. 8. Map of the Inilchek Glacier Basin with the location of the accumulation zone where the two 165 m ice cores were recovered during the 2000 field season.

snow pits and a shallow (14.5m) firn core for physical and chemical analysis to identify the temporal and spatial variations in snow chemistry and microparticle content, to determine the snow/ice density and visible stratigraphy of the accumulation layers, dirt layers, bubble content and textural changes from a possible snow melt, snow wind redistribution and recristalization process. The rich long-term meteorological and synoptic data collected during three field expeditions in Tien Shan is the basis for the deep ice-cores calibration on the physical links between the multi-parameter ice core record and a variety of meteorological variables. This data forms the current basis of our lab and analytical research in 2001.

Rvannyi Glacier Digital Elevation Modesl, glacier bedrock and glacier active layer topography

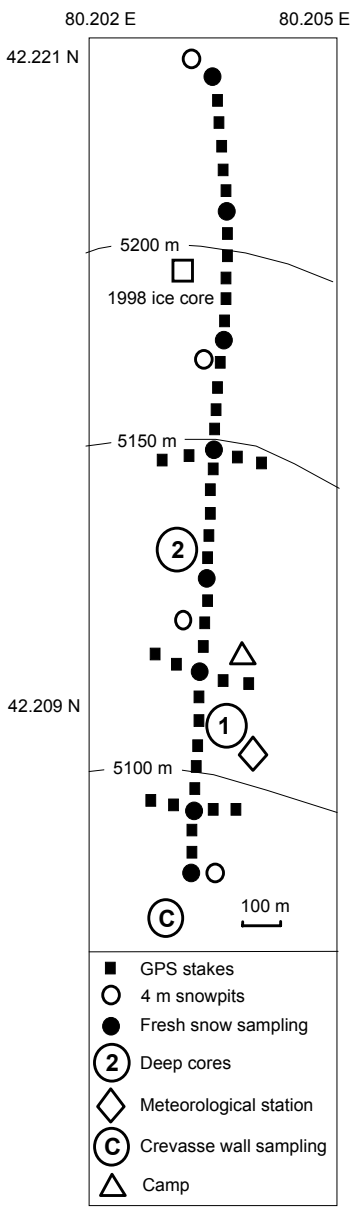


Fig. 10. Map of the accumulation zone of the Upper Inylchek Glacier with location of research activities

Detailed radio-echo sounding measurements were completed at over 150 sites on the glacier in order to determine ice thickness and basin morphology (**Fig. 9**). These measurements were accomplished using a light-weight ice-penetrating radar system (30° 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 109 to 302 m, with depths at the Borehole #1 and Borehole #2 being 285-300 m and

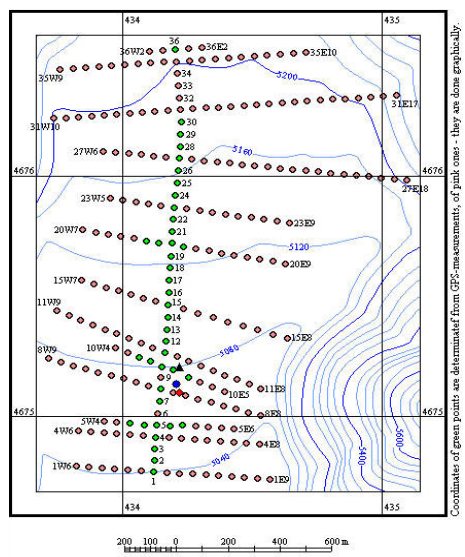


Fig. 9. Ice thickness measurement profiles. Coordinates of green points are fixed by GPS, the pink points determined graphically.

250-260 m, respectively. Ice thickness at the two core sites were also verified using a separate mono-pulse radio echo sounding system. The results indicate that the glacier bedrock does not have any major depressions, faults, or bends in an explicit form. Internally, the glacier has

several intermediate horizons which were apparent in the radio echo sounding reflections that could be associated with the presence of fine-grained sediment of eolian genesis. Water in a liquid form inside the glacier body is not apparent in any of the radio echo sounding data. This conclusion is supported by the absence of any liquid water in the boreholes during the ice core drilling efforts and borehole temperature measurements. Most of the radio-echo thickness measurements were surveyed using a GPS (**Fig. 9, 10).**

The Rvannyi Glacier digital elevation model (DEM) (**Fig. 11**) we developed using ArcInfo software application based on 1:100000 cm scale topographical map. DEM was developed with 50 m greed resolution. The glacier basin map electronic version was constructed in MapInfo format. The DEM calibration and control were accomplished using our field 2000 Geo-Position Satellite Survey (GPS) data together with mathematical algorithms and software applications

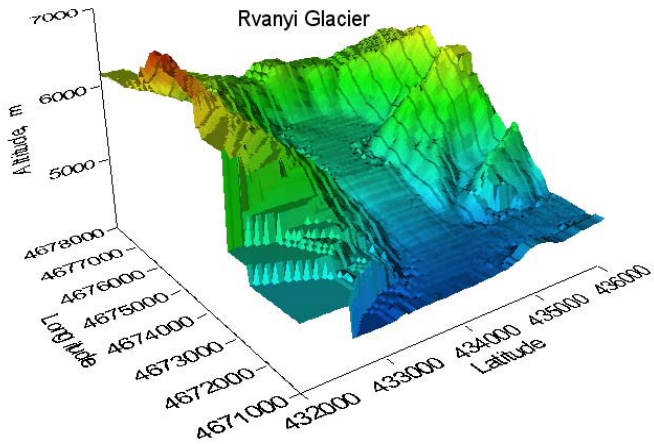


Fig. 11. Rvannyi Glacier Basin (DEM). Tien Shan, Central Asia.

Each glacier surface points recorded by GPS were converted from the World Geodetic System 1984 (WGS-84) to the topographic map system (*Hvostov, V.V., 1990*) using

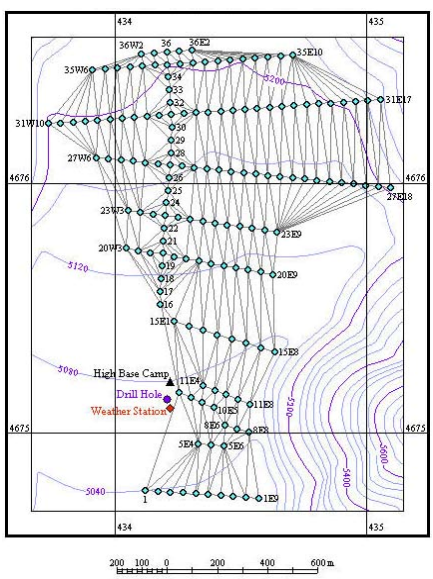


Fig. 12A. Triangles of Rvannyi Glacier bedrock reflection points.

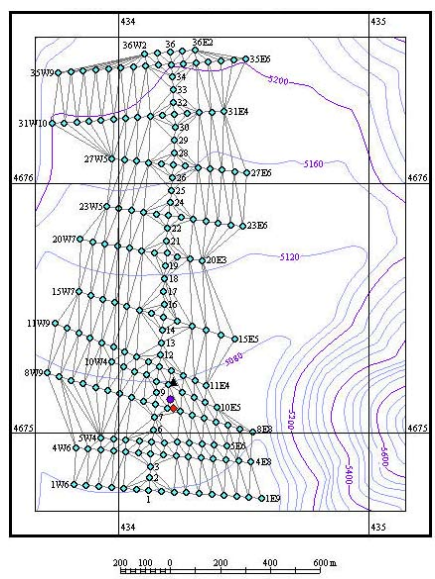


Fig. 12B. Triangles of Rvannyi Glacier active layer reflection points.

Helmet's parameters calibrated for the head of South Inilchek Glacier basin. The accuracy of converted coordinates is about 3 m, which is relatively little in compare with accuracy of the topographic map we used since the accuracy of GPS in an independent regime is about 20m. The Helmet's transformation is implicating a conversion from one system coordinates (X,Y,Z) to another using seven parameters: - zero coordinates linear displacement (3 parameters); angle of orientation components (3 parameters); the scaling coefficient (1 parameter). The orthogonal coordinates of the radio-echo sounding points that were not referenced by GPS calculated by two methods: - through the linear interpolation, when not referenced points are located in longitudinal section between the points referenced by GPS or through extrapolation by the angle of cross section profile, when we can assume that each next point (stake) has not more than 50 m distance from the previous point. The altitudes of radio-echo sounding points on the glacier surface were calculated by DEM. Two data sets were completed from 237 points of the glacier radio-echo sounding: one set is with bedrock echo signals and the second one with glacier active layer echo signals. Each data sets was processed separately but using the same mathematical algorithms. A Triangulated Irregular Network (TIN) has been developed for the glacier bedrock topography (267 triangles based on 149 echo records) and the glacier ice active layer (340 triangles based on 149 echo records) (**Fig. 12 A, B**).

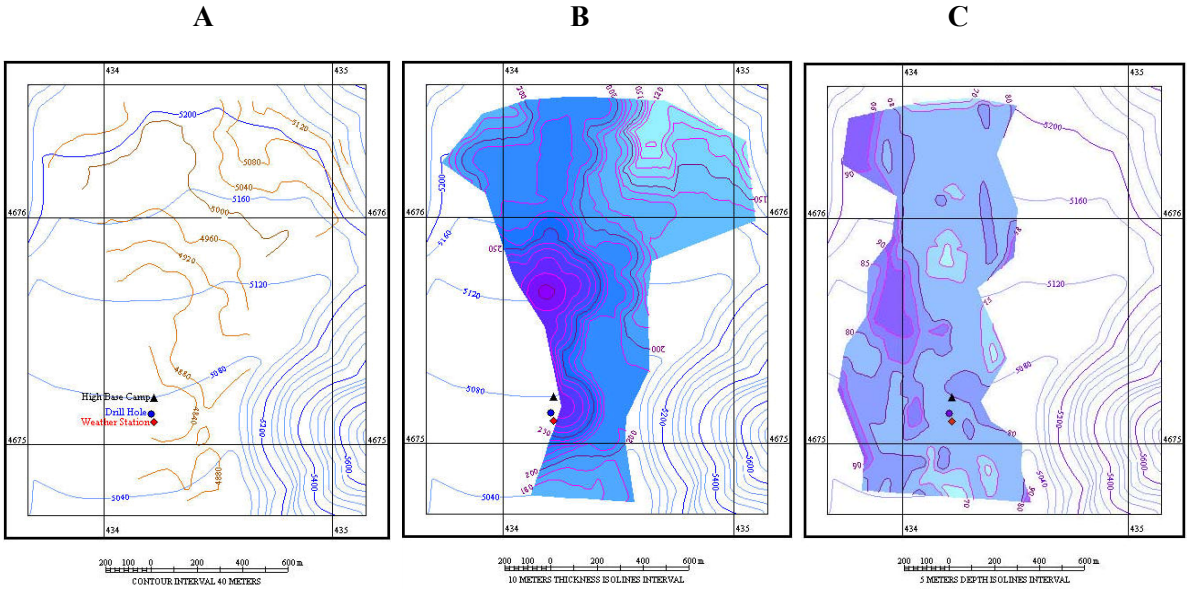


Fig. 13. Rvinnyi Glacier. Isolines of the glacier bedrock –A, Digital model of the bedrock topography – B, and deepness of the glacier active layer – C.

The radio-echo sounding instruments measuring glacier ice thickness usually have antenna with large angle of impulse, in our case 50 degree. Thus we may assume that the echo point is located on the surface of a sphere segment in a moment of sounding. To simulate the topography of the glacier bedrock we use a method of tangent to the sphere segments in polyhedron (*Kuzmichenok V.A., 1992*). According to this method for each triangle formed on echo signal coordinates we calculated a tangent plane and for each regular greed node, appurtenant to the triangle, the altitude of reflected surface was calculated by linear interpolation on the given plane. Note that in our calculations we are considering that only one tangent plane may exist. Accordingly, the digital models of

bedrock topography and the glacier ice active layer were developed based on this method (**Fig. 13 A,B,C**).

The isolines of glacier bedrock and deepness of the glacier active layer were calculated by linear interpolation based on developed digital elevation models.

First Radionuclide Analysis from ice chips Core #1

In the upper 80 m of Core #1, core chips from each drill run were collected for radionuclide analysis. The procedure consisted of bagging all chips produced from each run, weighing each bag, melting the chips, filtering through glass fiber (GF/F) filters, and sealing the filters in petri dishes for transport. Surface snow and core chips from the maximum depth achieved (167 m) were also collected via the same procedure to assess blank levels and matrix effects. The filters were shipped to the University of Maine (UM), where they were analyzed for the particle reactive elements of Pu, Np, and Cs. Gamma spectrometry has been conducted using a HpGe planar detector for Cs analysis, and a Finnegan Element high-resolution ICP-MS for the Pu and Np analysis.

To date, two filters have been analyzed (qualitatively) for Cs. The first sample, from a depth of 12.19 – 13.20m, had detectable Cs levels. The second sample, from a depth of 37.29 – 38.19m, had no detectable Cs. Quantitative Cs measurements, as well as Pu and Np isotopic measurements, will be made on the entire suite of filter samples to provide complete time-series records once funding from NSF is secured. The benefits of these data are twofold. First, a well-constrained depth/age relationship for ice cores from the Inilchek glacier can be constructed with a combination of radiogenic isotopes, cosmogenic isotopes, major ions, and stratigraphy. Second, the combination of an accurate chronology and Pu and Np measurements will allow a more complete characterization of fallout contamination to the region. In addition to collecting the drill chips from the upper 80 m, scrapings from the upper 100 m of Core 1 that was processed in the field were collected for analyses of the radionuclides ^{10}Be, ^{36}Cl, ^{129}I and ^{137}Cs. These samples were allocated to the Global Environmental Research Program in order to develop a detailed record of radionuclide deposition preserved in the ice. The ice core samples were shipped frozen to the Paul Scherrer Institute (ETH) in Zurich and have been processed by accelerator mass spectrometry (AMS). The radionuclide records will be used to:

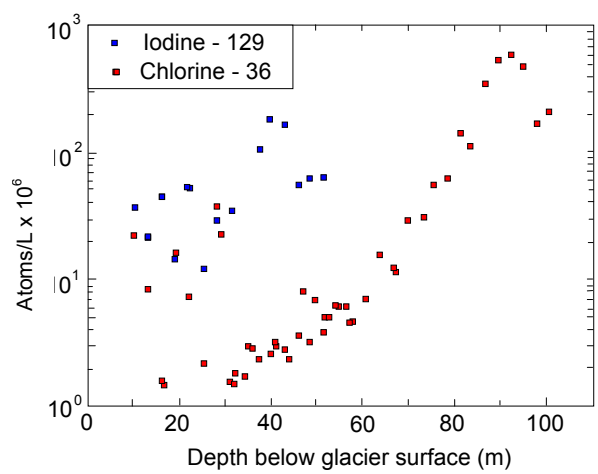


Fig. 14. Preliminary chlorine-36 and iodine-129 profiles from the ice core number 1, Inilchek Glacier, Kyrgyzstan. Weapons-tests concentrations of chlorine-36 are preserved at a depth of greater than 92 m, indicating a larger than expected accumulation rate at this site.

- Establish a time marker of fallout events from the atmospheric nuclear weapons tests in the 1950s-60s.
- Reconstruct the fallout distribution of ^{36}Cl at mid latitudes globally in conjunction with our measurements at other mid-latitude sites, most notably the Upper Fremont Glacier in Wyoming, USA (*Cecil and others, 1999*).
- Evaluation of ice accumulation rates at the South Inilchek Glacier.

- Establishment of the ice-core chronology in combination with stable isotopic and major trace element data.
- Reconstruction of the anthropogenic increase of ^{129}I in Central Asia for comparison to this record at the Upper Fremont Glacier.

For the radionuclides ^{36}Cl and ^{129}I, the first 100 m we analyzed with a resolution of 1 m per sample using AMS. This corresponded to about sub annual time resolution and extended back into the pre-nuclear weapons tests era. In parallel to the AMS analyses, the samples were measured with gamma spectrometry to develop a record of ^{137}Cs fallout that peaked in 1953 and 1963. Since a relatively large number of radionuclides are being measured, a complex chemical sample preparation protocol is being followed. We initially tested the chemical separation protocol with a set of samples before analyzing all samples. Twenty samples were prepared and measured in the first stage of the analysis for ^{36}Cl and ^{129}I. Starting at a core depth of 10 m, the samples were taken from every third meter. Preparation and analyses was completed successfully, and additional samples are now being analyzed. Preliminary results from these glacial samples show the ^{36}Cl weapons-tests peak was preserved at a depth of 92 m below the surface of the glacier (**Fig. 15**), indicating a larger than expected accumulation rate at the site of the South Inilchek Glacier. This larger accumulation rate will provide a record with a higher resolution than expected. In addition to ^{36}Cl and ^{129}I, ^{137}Cs measurements of the samples are in progress.

Rvannyi Glacier. Crevasse Wall Ice Samples, Oxigen isotope analysis

Seventy five snow samples at 20 cm sample intervals were collected from a 15 m section of a crevasse wall at 5050 m the lower end of South Inilchek Basin during August, 2000 (**Fig. 10**). In addition to collecting samples, the stratigraphy of the wall was described in detail (**see AR00**). A north oriented wall of the ice crevasse was cleaned up to 0.5m deep, 1m wide along the entire 15m depth. Mountaineering equipment was used to secure the scientists working in the crevasse. Snow and ice samples were collected each 10 cm for stable isotope and radionuclide analyses (not yet performed). At the depth of 11.5 m we discovered an almost 3 m thick avalanche deposit that we estimate occurred during 1991 or 1992. Dense firn/ice cobbles with diameters of 8 to 10 cm diameters were clearly apparent in the fine-grained firn layer. In the 1998, 14 m core in the upper part of the firn plateau we did not find any traces of this massive avalanche deposit (**see AR00**). However, in Ice Core #1, and to a lesser extent in Ice Core #2, we did find evidence of this deposit. In the entire 165 m of the ice cores, this was the only section where we identified avalanche debris. We therefore expect that this avalanche deposit was the result of a unique event that caused the hanging glaciers on the east wall of Kan Tengri to fall to the accumulation zone of the glacier where we recovered the ice cores. The avalanche deposit noted in Core #1 was clearly visible below 10 m in the crevasse wall. The stable isotope data from snow samples above 10 m depth in the crevasse wall display clear annual

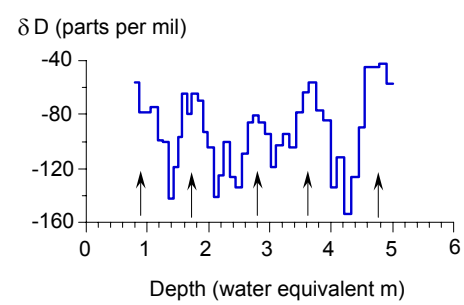


Fig. 15. Oxygen isotope profiles from the upper 10 m (5 m WE) of samples collected from a crevasse wall. Summer layers are identified with arrows

cycles (**Fig. 15).** We are continuing to investigate the possible cause of this event, included analysis of large earthquakes in central Tien Shan from Kyrgyzstan and Chinese seismological stations in the late 1980's and early 1990's.

Seasonal signals in the Inilchek glaciochemical records

Reconstruction of climatic and environmental variability based on signals preserved in ice cores relies upon the development of accurate depth/age scales. For records of centennial-scale length, a combination of two methods are commonly used: 1) annual layer counting, using isotopic, soluble ion, other chemical time-series, and/or physical stratigraphy (*e.g., Taylor et al., 1992; Meese et al., 1997*); and 2) identification of known, absolute reference horizons such as local, regional, or global volcanic events (*e.g. Zielinski et al., 1997*), or fallout products from nuclear testing beginning in the 1950s (*e.g., Clausen and Hammer, 1988; Cecil and Vogt, 1996*).

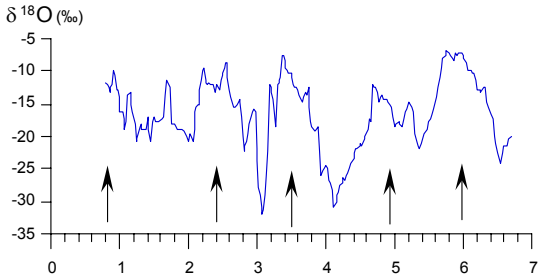


Fig. 16A. Oxygen isotope and selected major ion profiles from the upper 18.7 m (10.5 m water equivalent) of Core 1 recovered from the South Inilchek Basin during the summer of 2000 with the avalanche debris layer identified (4.90 to 8.79 WED).

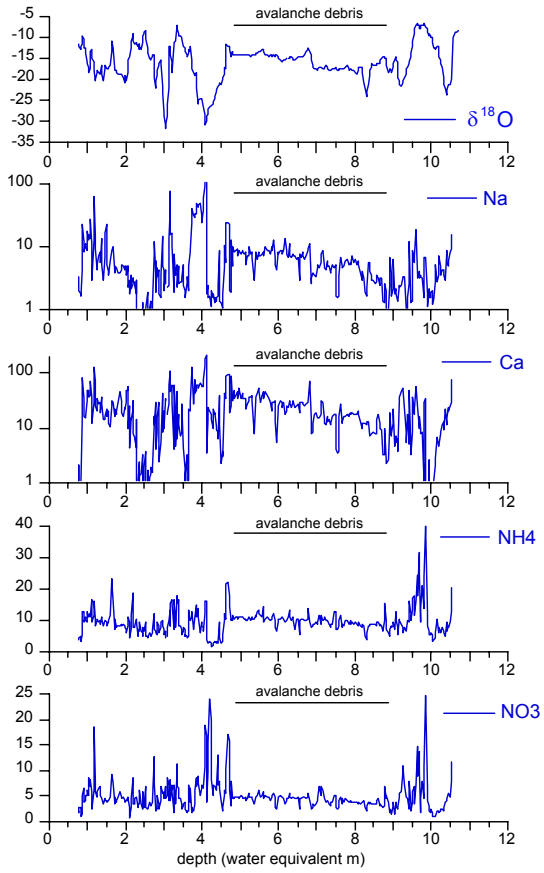


Fig. 16B. Oxygen isotope from Core 1 recovered in during the summer of 2000 with the avalanche deposit removed. Summer layers are identified by the arrows.

From the two 165 m ice cores were recovered during 2000, isotope and soluble ion analyses have been completed to a depth of 18.17 m in Core #1. As we mentioned in the previous paragraph, there is a unique layer in Core #1 that extends from 9.87 to 15.15 m real depth (4.90 – 8.79 m WED) that has a mottled appearance (dense firn/ice cobbles with diameters of 8 to 10 cm diameters supported in a fine grained firn matrix), and scattered small pebbles. This layer was also evident in the physical stratigraphy in Core #2. The layer in Core 1 contains relatively uniform isotope values and major ion concentrations (**Fig. 16A,B**). We interpret the interval from 4.90 – 8.79 m WED as avalanche debris originating from the fall of a hanging glacier on eastern wall of Kan Tengri. This slope is now essentially bare, stripped of its glacier cover. Sections with this mottled appearance or pebbles are not observed elsewhere in Core #1 or Core #2. We are therefore confident that the avalanche debris layer from 4.90 – 8.79 m WED is a unique event in the depositional history of the South Inilchek Glacier and has not been repeated over the length of record in the 165 m core. In order to calculate snow accumulation rates without the influence of this unique avalanche deposit, we have removed accumulation represented by this 3.89 m WE layer (**Fig. 16B**).

As in the 1998 firn core, annual isotope signals are clear in the corrected Core 1 record, and yield a mean annual accumulation rate estimate of 1.50 m WE from 1996 to 2000. Isotope data from the 1998 core, 2000 Core #1, and the crevasse wall all display variable peak values for the summer layers, indicating that meltwater percolation has not smoothed or otherwise significantly modified the record.

The upper 100 m of 2000 Core # 1 was scraped in the field in a custom built science trench and placed in pre-cleaned polyethylene containers for shipment to UNH. The shavings were collected for radionuclide analysis at the Paul Sherrer Institute/ETH in Zurich, Switzerland (*Cecil and Synal, pers. comm., 2001*). Analysis of ^{36}Cl via accelerator mass spectrometry (AMS) at ETH has been completed for approximately one-third of the samples. The record shows a distinct peak from 75.2 to 76.0 m WED (**Fig. 17**). The height of nuclear weapons testing, and hence production of ^{36}Cl, occurred during 1955-1958 (*Bentley et al., 1986*). We assign the peak in the Tien Shan ^{36}Cl record at 75. 6 m WE to the year 1956. Subtracting the 3.89 m WE. avalanche debris gives us 71.7 m WE accumulation over 44 years, equivalent to a mean annual accumulation rate of 1.63 m WE. The accumulation rate estimate based solely on the ^{36}Cl marker horizon (1.63 m WE) is consistent with estimates from annual layer counting in the 1998 core (1.46 m WE) and 2000 Core #1 (1.50 m WE), lending support to our interpretation of the annual chemical cycles.

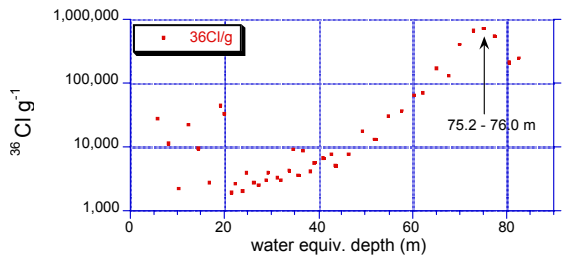


Fig. 17. Chlorine-36 profile from Tien Shan 2000 – core 1 (data from Synal and Cecil, pers. comm., 2001). The maximum Cl-36 occurs from 75.2 to 76.0 m water equivalent depth.

Collection of meteorological data for the Tien Shan deep ice-cores analysis

Table 5 provides a list of long-term meteorological data in the Tien Shan that we have collected over the past two years for the outgoing ice-core paleoclimatic research project. Data from these stations (**Fig. 18, 19**) we are using to calibrate the ice core records and form a basis for our paleoclimatic reconstruction. All data produced as part of this project will be made publicly available as specified under NSF data sharing agreements. Specifically, all meteorological and hydrological data will be incorporated into the Central Asia Data Base: (mines.uidaho.edu/~aizen/aizen.html). Ice core chemical data will be available on individual laboratory websites (www.ume.maine.edu/iceage/sil; and www.ccrc.sr.unh.edu) after publication, and also archived at the National Snow and Ice Data Center and the World Data Center for Paleoclimatology.

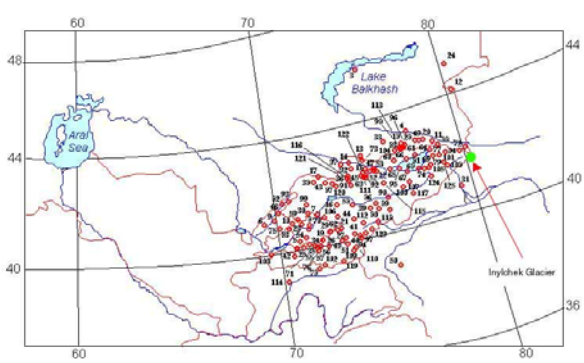


Fig. 18. Scheme-map the Tien Shan meteorological stations with over 50 to 150 years records.

Our initial data analysis revealed strong relationships between climatic variables (*Aizen et al., 1997a, Aizen et*

al., in press). The periods showing similar trends can be reconciled by analyzing the macro- and synoptic-scale climatic anomalies governing atmospheric circulation. For

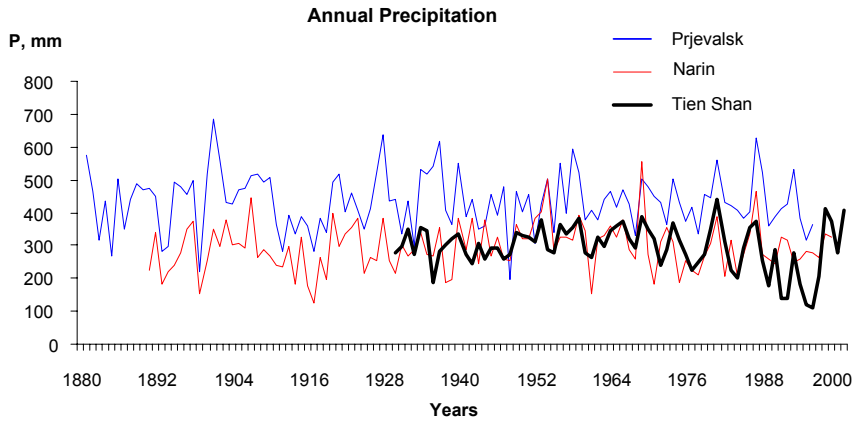


Fig. 19. Long-term annual precipitation in central Tien Shan research area according to Prjevalsk, Narin and Tien Shan stations

example, there exists statistically significant inverse correlation between regional precipitation and indices of zonality over the mid-latitudes of Asia. An organization of the major long-wave pattern and a particular distribution of depressions and anticyclones at the surface characterize each type of the zonal and meridional macro processes (*Barry and Perry, 1973; Aizen et al., 2001*). The development of meridional patterns is favorable for an increase in winter precipitation in the mountains and plains of the Central Asia and Western Siberia. However, a shift in the location of the Siberian High to the east favors precipitation development; while a shift to the west results in a decrease of annual

Table 5. A sample of representative to the central Tien Shan meteorological data that has already been collected and digitized.

Station	Elevation (m)	lat Start	lat End	long Start	long End	Temperature		Precipitation		Resolution
S. Balkhash	410	46 23	75 10	1897	1999	1897	1991	monthly
Ili	452	43 52	77 12	1904	1999	1904	1999	monthly
Chilik	606	43 36	78 15	1933	1999	1933	1999	monthly
Alma Ata	848	43 15	76 55	1891	2000	1891	2000	monthly
Turgene	900	43 22	77 36	1936	1999	1936	1999	monthly
Talgar	1015	43 16	77 12	1899	1999	1899	1999	monthly
Aksu	1104	41 13	80 15	1958	1999	1958	1999	monthly
Issik	1290	42 22	77 28	1917	1999	1917	1999	monthly
Kashi	1291	39 31	75 45	1958	1999	1958	1999	monthly
Baitik	1579	42 40	74 30	1913	2000	1913	2000	daily
Tup	1620	42 44	78 13	1926	1991	1926	1991	monthly
Cholpon Ata	1645	42 10	77 31	1928	2000	1928	2000	monthly
Tamga	1690	42 10	77 31	1937	1991	1937	1991	monthly
Prjevalsk	1716	42 26	78 26	1881	1996	1881	1996	monthly
Teplokluchenka	1890	42 29	78 31	1870	2000	1870	2000	monthly

Atbashi	2025	41 40	75 49	1927	1991	1927	1991	monthly
Narin	2039	41 26	76 00	1890	1999	1890	1999	monthly
Djergalan	2400	42 37	79 02	1948	1991	1948	1991	monthly
B. Kizilsu	2555	42 14	78 10	1948	1999	1948	1999	monthly
Koilu	2800	42 07	79 03	1950	1991	1950	1991	monthly
Dolon	3040	41 50	75 46	1950	1991	1950	1991	monthly
Aksai	3135	42 07	76 49	1952	1991	1952	1991	monthly
Chatir Kul	3540	40 36	75 20	1940	1991	1940	1991	monthly
Tien Shan	3614	42 27	78 14	1930	2001	1930	2001	daily
Chon Ashu	4050	42 27	79 08	1961	1994	1961	1994	monthly

precipitation. Low pressure over Europe (**Fig. 20A**) is favorable for increasing the frequency of synoptic processes associated with precipitation (*Aizen et al., in press*). High pressure over Eastern Europe (**Fig. 20B**) blocks this type of atmospheric activity and may be conducive to the development of synoptic processes originating on the southwestern periphery of the Siberian High, which are not favorable for precipitation development (*Aizen et al., in press*). Further analysis of this data will illuminate the relationships between global air temperature, the location and intensity of Siberian High, the strength of the westerly jet stream and regional precipitation over Tien Shan.

In order to document the atmospheric circulation conditions that result in precipitation in the central Tien Shan, we defined six types of synoptic processes that are associated with precipitation (*Aizen et al., in press*). The main synoptic processes which transport moisture to the central Tien Shan is characterized by the influx of air masses from the west, while western cyclones and N-NW air advection results in less precipitation. Western derived air masses are formed over the Atlantic Ocean and subsequently transferred at middle latitudes over the Mediterranean, Caspian, and Black Seas at high altitudes, while the moisture in the western cyclones originates over the Caspian, Black, and

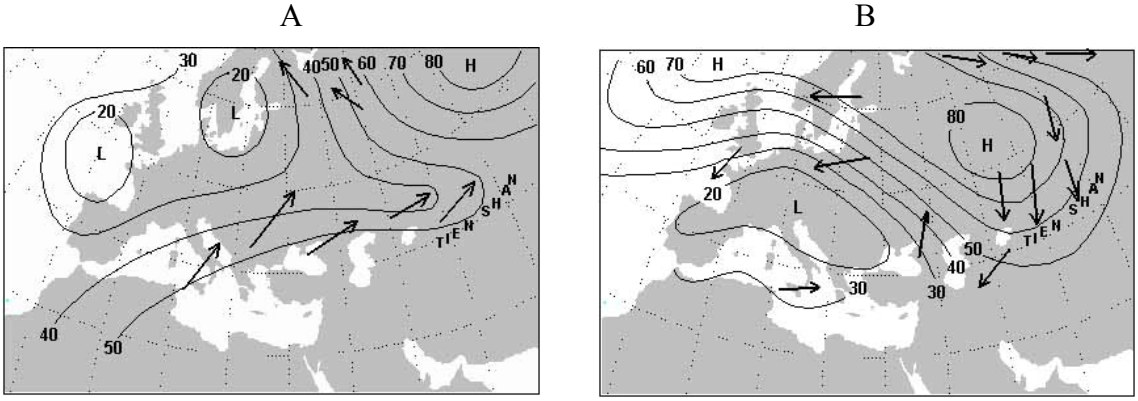


Fig. 20A,B. Synoptic situation during abnormally wet (A) and dry (B) summer seasons at the central Tien Shan. Numbers represent the frequency of anticyclonic circulation patterns. Arrows represents the directions of the prevailing wind. **H** identifies the center of maximum frequency of anticyclone circulation patterns while **L** represents the center of maximum frequency of cyclonic circulation patterns.

Mediterranean seas and is transferred to Middle Asia at low altitudes and latitudes. The synoptic processes associated with northern cold advection, large-amplitude stationary waves, weak-mobile cyclones, S, S-E, S-W periphery of Siberian High, summer thermal

depressions, and high-pressure systems with small barometric gradients are not favorable for the development of precipitation.

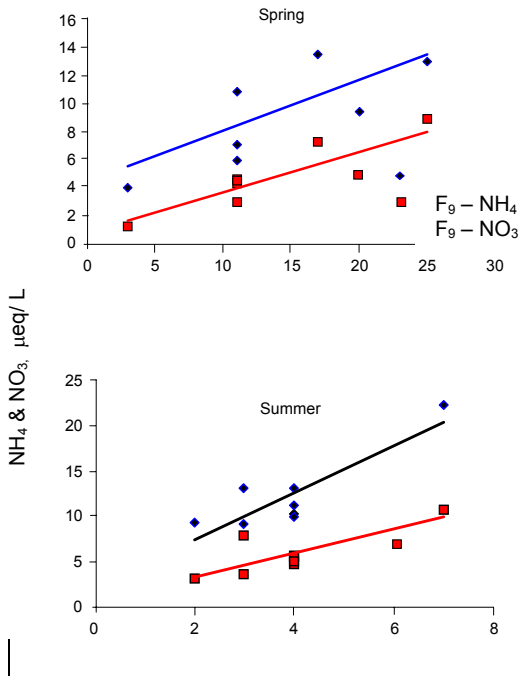


Fig. 21. Association between frequency of synoptic processes with position of southeastern

We compared observational data on the frequency of synoptic processes, air temperature, and precipitation over the Central Tien Shan to annual and seasonal records of snow accumulation, stable isotope content, and major ion concentrations from a 14.4-m firn core collected in the accumulation zone (5100m) of the Inylchek Glacier. The snow accumulation measured in the shallow firn core compares well with annual precipitation measured at the Central Tien Shan meteorological station located adjacent to the Inylchek glacier (*Aizen et al, in press; Kreutz et al., in press*). There exists a linear relationship between seasonal maximum air temperature and the least negative seasonal $\delta^{18}O$ in accumulated precipitation originating from the same moisture source. During the influx of western air masses, which originated over the Atlantic Ocean, Mediterranean Sea and Black Seas, the more negative values of $\delta^{18}O$ were observed than during other synoptic processes, which transported moisture from a closer source. During spring, an increase in the frequency of synoptic processes along the southeastern and southern periphery of Siberian High over the central Tien Shan are associated with an increased content of NH_4^+ and NO_3^- ions (r = 0.82, **Fig. 21**). In autumn, NO_3^- concentrations are associated with weak-mobile cyclones formed over the northern Kazakhstan, and NH_4^+ concentrations are associated with northwestern advection, which originates over south Urals. During summer, the main synoptic process associated with major ion concentrations is the large thermal depression which serves to transport dust from the Kara Kum and Kizil Kum deserts to Tien Shan. More detailed information on these analyses is available at the CADB web site.

References

Aizen, V.B, E.M. Aizen, K.J. Kreutz, D.L. Cecil, C.P. Wake. Association between atmospheric circulation patterns and ice core records from a snow-firn field on the Inylchek Glacier, central Tien Shan Mountains, Asia, *J. Geophys. Res*., in press.

Aizen, E.M., V.B. Aizen, J.M. Melack, T. Nakamura, T. Ohta. Precipitation and Atmospheric Circulation Patterns at Mid-Latitudes of Asia, *International Journal of Climatology* 21, 535-556, 2001.

Aizen, V.B., E.M. Aizen. Estimation of glacial runoff to the Tarim River, central Tien Shan. Proceedings of International Symposium "WaterHead'98", Merano, ITALY, *IAHS Publ. No 248,* 191-199, 1998.

Aizen, V.B., and E.M. Aizen. Hydrological cycles on north and south peripheries in mountain-glacial basins of central Asia. *Hydrological Processes,* 11, 451-469. 1997b.

Aizen, V.B., E.M. Aizen, J.M. Melack, and J. Dozier. Climate and hydrologic changes in the Tien Shan, central Asia. *J. Climate*, 10, 218-229, 1997.

Aizen, V.B., E.M. Aizen, J. Dozier, J.M. Melack, D.D. Sexton, V. Nesterov. Glacial regime of the highest Tien Shan mountain, Pobeda-Khan Tengry massif. *J. Glaciol.* 43, 1997a.

Aizen, V.B., E.M. Aizen, and J.M. Melack. Snow distribution and melt in central Tien Shan, Susamir Valley. *J. Arctic and Alpine Research,* 29, 403-413, 1997c.

Aizen, V. B., E. M. Aizen, J. Melack. Statistical Models in Simulation of Snow and Glacier Runoff in Central Asian Alpine Watersheds. Proceedings, *Prudhoe Bay, Fairbanks*, *Alaska. Eleventh International Symposium and Workshop, August 18-22,* pp.19-38, 1997d.

Aizen, V.B., E.M. Aizen, J.M. Melack, and T. Martmaa. Isotopic measurements of precipitation on central Asian glaciers. (Southeastern Tibet, northern Himalayas, central Tien Shan). *J. Geophys. Res*., **101**, 9185-9196, 1996.

Aizen, V.B., E.M. Aizen, V.N. Nesterov and D.D. Sexton. A study of glacial runoff regime in central Tien Shan during 1989-1990. *J. Glaciology and Geocryolog*y, **3**, Lanhzou, 442-459, 1993a

Barry, R.G. and A.H. Perry, 1973. Synoptic Climatology, Methods and Applications. Harper & Row Publishers, London, Beccles and Colchester, 555 p.

Bentley, H.W., F.W. Phillips and S.N. Davis, in *Handbook of Environmental Isotopes, Vol. 2*, P. Fritz and J-C. Fontes, Elsevier (eds.), New York, 422-480, 1986.

Cecil and Synal, pers. comm., 2001(Abstract)

Cecil, L.D., Green, J.R., Naftz, D.L., Synal, H-A., Kreutz, K.J., Aizen, V.B., Wake, C.C., and Frape, S.K., Cosmogenic isotopes in mid-latitudes glacial environments in the Northern Hemisphere, indicators of global fallout and the effects of meltwater elution on the isotopic record, *Conference Compendium, 8th International Conference on Accelerator Mass Spectrometry, Vienna, Austria*, p. 189-190, 1999.

Cecil, L.D., and S. Vogt. Bomb-produced chlorine-36 flux calculated from mid-latitude glacial ice of North America *Radiocarbon,* **38**(1): 14-15, 1996.

Clausen, H.B. and C.U. Hammer, The Laki and Tambora Eruptions as revealed in Greenland ice cores from 11 locations. Annal. Glaciol. 10, 16-22, 1988.

Dolgushin, L.D. and G.B. Osipova. *Glaciers*, Moscow, Misl Publishing, 447. (Russ.),1989.

Dunphy, P. P. and J. E. Dibb. Cs-137 gamma-rays from fallout detected at Summit, Greenland. J. Glaciol., 40, 87-92, 1994.

Hvostov, V.V., Ed. Book: The Earth Parameters 1990, Geoizdat, Moscow, 36p., (Russ.), 1986,

Kang, S., C.P. Wake, D. Qin, P.A. Mayewski and T. Yao. Monsoon and dust signals recorded in Dasuopo glacier, Tibetan Plateau. *J. Glaciol.* 46, 222-226, 2000.

Kattelmann, R., K. Elder, J.M. Melack, E.M. Aizen and V.B. Aizen, Initial survey of snow chemistry in the Tien Shan of Kirgyzstan and Kazakhstan. *IAHS Publ.,* 228, 318-321, 1995

Kreutz, K.J., V.B. Aizen, L.D. Cecil, and C.P. Wake. Oxygen isotopic and soluble ionic composition of precipitation recorded in a shallow firn core, Inilchek Glacier (central Tien Shan), *Journal of Glaciology*, in press.

Kreutz, K.J., and E.R. Sholkovitz, Major element, rare earth element, and sulfur isotopic composition of a high-elevation firn core: Sources and transport of mineral dust in Central Asia, *Geochemistry, Geophysics, Geosystems (G^3)*, **1**, paper 2000GC000082, 2000.

Kuzmichenok V.A., et ell., Ice thickness and bedrock topography of the Abramov Glacier based on low-frequency radio-echo sounding. Materiali Glaciologicheskih Issledovanii, Moscow, V. 75, pp.63-68 (Russ.), 1992.

Mayewski, P.A., W.B. Lyons, N.Ahmad, G. Smith, and M. Pourchet. Interpretation of the chemical and physical time-series retrieved from Sentik Glacier, Ladakh Himalaya, India. *J. Glaciol.* **30**, 66-76. 1984.

Meese, D.A., A.J. Gow, R.B. Alley, G.A. Zielinski. P.M. Grootes, M. Ram. K.C. Taylor, P. A. Mayewski and J.F. Bolzan, The Greenland Ice Sheet Project 2 depth-age scale: Methods and results. J. Geophys. Res. 102, 26,411-26,424, 1997.

Taylor, K., R. Alley, J. Fiacco, P. Grootes, G.Lamorey, P. Mayewski and M.J. Spencer. Ice core dating chemistry by direct-current electrical conductivity. *J. Glaciology,* **38,** 325-332. 1992.

Thompson, L.G., T. Yao, E. Mosley-Thompson, M. E. Davis, K. A. Henderson, and P.-N. Lin. A High-Resolution Millennial Record of the South Asian Monsoon from Himalayan Ice Cores. *Science* **289***,* 1916-1919, 2000.

Thompson, L.G. and eight others, Tropical Climate Instability: The last glacial cycle froma Qinghai-Tibetan ice core. *Science* 276, 1821-1825. 1997.

Thompson, L.G., E. Mosley-Thompson, M.E.Davis, P.N.Lin, J.Dai and J. Bolzan. A 1000 year ice core climate record from the Guliya Ice Cap, China: its relationship to global climate variability. *Annals of Glaciology*, **21**, 175-181. 1995.

Thompson, L.G., E. Mosley-Thompson, M.E.Davis, J. Bolzan, J. Dai, T.Yao, N. Gundestrup, X. Wu, L. Klein, and Z. Xie. Holocene-Late Pleistocene climatic ice core records from Qinghai-Tibetan Plateau. *Science,* **246**, 474-477. 1989.

Wake, C., and P.A. Mayewski. The spatial variation of Asian dust and marine aerosol contributions to glaciochemical signals in central Asia, in *International Symposium on Snow and Glacier Hydrology, Kathmandu, Nepal*, IAHS Pub. No. 218, 385-402. 1993.

Wake, C.P., P.A., Mayewski, Z.Xie, P.Wang, and Z.Li. Regional variation of monsoon and desert dust signals recorded in Asian glaciers. *Geophys. Res. Lett.* **20**, 1411-1414, 1993.

Zielinski,G.A., P.A.Mayewski, L.D. Meeker, S.I.Whitlow, M.S. Twickler. A 110,000 -yr record of explosive volcanism from the GISP2 (Greenland) Ice core. Quaternary Reseach, 45, 109-118, 1996.

FINDINGS

The findings of our project research activities are summarized in five compressed abstracts presented on the International Glaciological Symposium on Ice Cores and Climate, in Kangerlussuaq, Greenland, on August 19-23, 2001 by the team.

An approach for interpretation of ice-core paleo-climatic records from the central Tien Shan based on complex of isotopes/major ions composition and long-term meteorological/synoptic data

The method of evaluation and interpretation of the Tien Shan ice cores has been developed on base of multiple source analyses. Using standard simple and multiple regression, and factor analysis, the ice core data IS compared with meteorological data on a seasonal and annual variability (e.g., temperature, precipitation) and indices of atmospheric circulation patterns (frequency of the main synoptic processes; ZACP, M1,2ACP, NOA, WPO, PNA etc.). The soluble ionic content of precipitation reflects different moisture sources and areas over moisture was transported. Hence, precipitation chemistry is closely linked to synoptic processed and compared with the frequency of fourteen synoptic processes using correlation analysis. Simultaneously, we analyzed the information on dust storms (e.g., their origination, trace and frequency and intensity). According to our first results, the soluble major ion content of snow deposited in the Tien Shan clearly reflects changes in the prevailing atmospheric patterns in the central Tien Shan. The meteorological and synoptic time series analysis allows development of the multi-regression model for paleoclimatic reconstruction. These results provide valuable input for the simulation of glacier mass exchange and glacier dynamics. For example, the cycles of atmospheric circulation patterns with year peak energies may be taken into account in long-term probabilistic model of glacier mass balance evaluation.

Precipitation and atmospheric circulation patterns in Central Asia

The coupling between large-scale atmospheric patterns and modifications of regional precipitation regimes at seasonal and annual time scales in different terrain of mid-latitudes of Asia including western Siberia, Tien Shan and Pamir mountains, and plains of Central Asia were found based on data from 35 hydro-climatic stations with 100 year records. For the past 100 years, a positive trend in precipitation was revealed in western Siberia, and northern regions of Tien Shan. We suggest that during the last century, impacts of the western jet stream increased in the northern regions of Tien Shan. During the years with Zonal pattern predominance, negative deviations in annual, seasonal and monthly maximum amount of precipitation occurred everywhere in Central Asia, and western Siberia. Development of both meridional patterns is favorable for winter precipitation increase in the mountains and plains of Central Asia and Western Siberia. Location of Siberian High further east during the prevalence of M_1ACP is most favorable for annual precipitation increase in the mountains and plains of middle Asia. During dominant development of zonal atmospheric pattern with essentially rapid movements of small-amplitude waves from the

west to east decreasing the annual and seasonal precipitation observed over the most regions in continental.

North Atlantic Oscillation and West Pacific Oscillation indices have inverse associations with average amount of precipitation in western Siberia and in mountains and plains of Central Asia. We did not find significant impact of Pacific-North American or Northern Asian patterns on precipitation in Central Asia. Our results suggest that NAO and WPO are potentially useful prognostic tools for precipitation over mid-latitudinal Asia.

Chlorine-36 and Iodine-129 in ice cores collected from Inilchek, Nangpai Gosum, and Upper Fremont Glaciers

Measurements for radioactive chlorine-36 (^{36}Cl) and iodine-129 (^{129}I) have been conducted on ice cores collected from these three glaciers. These analyses were performed by accelerator mass spectrometry at Purdue University's PRIME Laboratory, U.S.A. and the Paul Scherrer Institute, Switzerland. The ^{36}Cl profiles from the ice cores reflect ambient concentrations, the rise and fall of nuclear-weapons tests input, and modern anthropogenic input from nuclear facilities and nuclear accidents around the world. Although the ^{36}Cl concentrations vary considerably between the two glacial sites being studied due to local or regional effects, the shapes of the profiles are similar. A preliminary ^{129}I profile from the Inilchek Glacier ice core shows the rise and fall of anthropogenic ^{129}I produced during the nuclear-weapons testing era. An ^{129}I profile of the Upper Fremont Glacier ice core is expected to show large ^{129}I releases from the U.S. Department of Energy's Hanford Site, U.S.A. This information is being used to refine the ice-core chronology and to perform dose reconstruction to human population due to these atmospheric releases.

Spatial and seasonal variability of major ion snow chemistry in the central Tien Shan

To improve the understanding of modern atmospheric processes and hence the interpretation of past climate variability in the Tien Shan, we examine here stable isotope ($\delta^{18}O$ and δD) data from precipitation (rain and fresh snow) and snowpit samples collected during several field expeditions (1989, 1990, 1992, 1998, 1999, and 2000) in the Tien Shan. Overall, sampling sites range in elevation from 1620 m to 5250 m, and span a distance of over 60 km, allowing regional-scale processes to be investigated. Surrounding the drillsite, several (8) snowpits and 10 fresh snow events have been sampled, and thus local-scale variability can also be addressed. Mean $\delta^{18}O$ values from multi-year snowpits in the drillsite basin display little spatial or elevational variability, suggesting that precipitation processes are not strongly affected by adiabatic temperature changes within limited (150 m) elevation gradients. Moreover, significant wind redistribution of snowfall is likely not a factor. Fresh snow samples collected from individual events within the basin display little (<1 ‰) spatial and elevational variability. Fresh snow samples collected from individual events both in the drill site basin (5100 – 5250 m) and lower in the valley (4100 m) also have $\delta^{18}O$ values that are identical (within the sampling error). It therefore appears that processes at the precipitation cloud base layer may be controlling snow $\delta^{18}O$.

Spatial and seasonal variability of major ion snow chemistry in the Central Tien Shan

As part of an ice core drilling program in the central Tien Shan during the summer of 2000, we collected over 600 samples from seven separate fresh snowfall events and from four snowpits over a range of elevations (5000 to 5300 m) to investigate the spatial and temporal variability of major ion snow chemistry in the accumulation zone of the Inylchek glacier. The major ion concentrations in the fresh snow samples show much larger variability between events compared to changes in concentration with elevation, indicating a minimal influence of elevation on the major ion content of precipitation over the range of elevations sampled. The changes in precipitation chemistry between events will be compared with synoptic weather patterns to determine the source of major ions in summer time snowfall in the central Tien Shan. Mean major ion concentrations from the four snowpits show no statistical differences. The major ion profiles from the 4 m snowpits display considerable seasonal variability that is similar in all four pits. These results indicate that the major

ion content of precipitation falling in the accumulation zone of the Inylchek Glacier is not significantly affected by the surface elevation between 5000 and 5300 m, but rather by the source regions for the precipitation and the major ions, and/or changes in atmospheric circulation. The variability in the long-term ice core glaciochemical time-series should therefore provide a record related to changes in the climate system.

Copies of these papers are available online at: www.mines.uidaho.edu/~aizen/aizen.html

Journal Publications

Aizen, E., V.Aizen, J.M. Melack, T. Nakamura, and T. Ohta, "Precipitation and Atmospheric Circulation Patterns at Mid-Latitudes of Asia", International Journal of Climatology, p. 535, vol. 21, (2001). Published

Aizen, V., E. Aizen, E.M. Aizen, K.J. Kreutz, J. A. Melack, L.D. Cecil, "Association between atmospheric circulation patterns and shallow firn core records from the South Inilchek Glacier, Tien Shan Mountains central Asia", Journal of Geophysical Research, p. , vol. , (2002). Accepted

Kreutz, K., V. Aizen, D. Cecil, and C. Wake, "Oxygen isotopic and soluble ionic composition of precipitation recorded in a shallow firn core, Inilchek Glacier", Journal of Glaciology, p. , vol. , (2002). Accepted

Aizen V. B., E.M. Aizen, K. J. Kreutz, L.D. Cecil, C.P. Wake, "An approach for interpretation of ice-core paleo-climatic records from the central Tien Shan based on complex of isotopes/major ions composition and long-term meteorological/synoptic data", Annals of Glaciology, p. , vol. , (2002). Accepted

Cecil, D., H. Synal, K. Kreutz, J. Green, K. Wake and V. Aizen. "Cl-36 and I-129 in Ice Cores Collected from Inilchek, Nangpai Gosum, and Upper Fremont Glaciers", Annals of Glaciology, p. , vol. , (2002). Accepted

Kreutz, K., V. Aizen, C. Wake, D, Cecil, "Ice core records of Late Holocene climate variability in the Tien Shan mountains, Central Asia", Proceedings: Institute for Quaternary and Climate Studies 9th Annual Agassiz Symposium, Orono, p. 34, vol. , (2001). Published

Kreutz, K.J., C. Wake, V. Aizen, D. Cecil, "Spatial and altitudinal variability of precipitation isotopes in the Central Tien Shan mountains", Annals of Glaciology: Symposium on Ice Cores and Climate, International Glaciological Society, Kangerlussuaq, Greenland, August 19-23, p. , vol. , (2002). Accepted

Training and Development

At the University of California, Santa Barbara, Dr. Vladimir Aizen and Dr. Elena Aizen have used project developed materials in general graduate and undergraduate courses. During 2000/2001 we were participating at the National and International Conferences and Seminars presenting our results. Dr. Aizen had five invited lectures: at the Geographisches Institut, ETH, Zurich (SWITZERLAND); at the University of Alaska, Fairbanks; at Martin Lockheed National Laboratory (ENEEL), Idaho Falls; at the USGS Headquarter, the International Glaciological Symposium, Greenland, where he presented the results of current research and new proposed research development. Drs. Elena and Vladimir Aizens also presented their results at San Francisco AGU Fall Meeting in 2000 and 2001.

Outreach Activities

Dr. Aizen gave two lectures on Alpine Climatology and Hydrology in the Kyrgyz-Russian Slavonic University, Bishkek during his 2000 field trip to Tien Shan and one lecture on Alpine climatology in Tomsk State University, Russia in November 2001 when he visited the University.

From the Fall 2001, since Dr. Vladimir Aizen and Dr. Elena Aizen moved to new positions at the University of Idaho they have begun to develop a new Global Change Research/Educational Outreach Program at the University of Idaho to strengthen the UofI graduate and post-graduate program. From November 2001 Drs. Aizen are opened the UofI Seminar Series: "Alpine Climatology and Hydrology" with emphasis on climatic, glaciological and environmental monitoring at Mid-Latitudes of the Northern and South Hemispheres, and particularly in North West of America and central Asia.

Product Type: Data Base; Software; DEM.

Product Description

Central Asia Data Base at www.uidaho.edu/~aizen/aizen.html: Long-term data on synoptic, meteorological, hydrological, glaciological, topographic and geochemistry with focus on data collection from the Central Tien Shan high elevated statitions, Kyrgyzstan.

Sharing Information

All data produced as part of this project will be made publicly available as specified under NSF data sharing agreements after publication, and also archived at the National Snow and Ice Data Center and the World Data Center for Paleoclimatology. The ice-core chemical and isotopic data will be available on the UNH and UM personal webstes: (www.ume.maine.edu/iceage/sil; and www.ccrc.sr.unh.edu).

Product Description

A computer software application for the Tien Shan ice-core paleo-climatic records calibration and simulation in IDL format.

Sharing Information

This software will be used for further ice-core analysis and interpretation among the active research members.

Product Description

The South Inilchek accumulation zone Digital Elevation Model (DEM) with 50 m grids resolution developed based on 1:25000 scale topographic maps, the GPS field measurements and data of the glacier ice-thickness received from radio-echo sounding survey in 2000 expedition.

Sharing Information

The Inilchek DEM will be used for ice-flow dynamics simulation among the working team members and will be available CADB after publication.

CONTRIBUTIONS

Contributions within Discipline

Specific contributions to advancing scientific knowledge that will be derived from this research include:

- extracting and evaluating the synoptic/climate signals stored in the Tien Shan ice core glaciochemical time-series and investigating interannual to decadal-scale climate variability in Central Asia;

- evaluating the interannual to decadal-scale variability in aridity and atmospheric dust loading over the past 100-200 years;

- assessing pollutant deposition in the Tien Shan;

- determine the traces of anthropogenic pollutants and their impact on the glacier water resources of Central Asia;

- in conjunction with our USGS colleagues, determining the radionuclide fallout flux in Central Asia.

The results of our research will be used in undergraduate and graduate courses at UI, UM and UNH, and will be disseminated to the general public via outreach programs at all three institutions. In addition, the graduate students are trained as part of this research, and several undergraduate students are also involved in the research at all three institutions. Our research is a collaborative effort that involving the University of Idaho (UIdaho), the University of New Hampshire (UNH), the University of Maine (UMaine), and the US Geological Survey (USGS),the University of California at Santa Barbara, Paul Scherrer Technological Institute (ETH) in Zurich, Tomsk State University in Russia and Kyrgyz-Russian Slavonic University in Bishkek, Kyrgyzstan. The glaciochemical records will be compared with meteorological data from the robust station network in the former Soviet Central Asian Republics including several high elevation stations in the Tien Shan in order to determine the extent to which the ice core record can be used to develop paleoclimate and paleo-environmental records in the region.

Contributions to Other Disciplines

The Tien Shan holds the greatest concentration of snow and ice in the low-mid latitudes and constitute a vital sources of water supply for large population of Kyrgyzstan, Tajikistan, Kazakhstan, Uzbekistan, Turkmenistan, Afghanistan and Xinziang where population reached up ton 100,000,000 people at the end of 1990s. The complexity of the problems associated with management of our present and future environment has led to the need of water where huge population is settling. For example, the well-known drying of Central Asia in the 20th century has captured a large share of the attention afforded to environmental problems in the Aralo-Caspian basin. Since that the produced results on estimation of long-term water resources and environmental changes of Central Asia is extremely useful in economics, agriculture and engineering of irrigation systems in completion of natural and human ecosystems. Findings in our research is the foundation of complicated mathematical models integrating the laboratory investigations, remote sensing, observations of human interactions, and processes, along with a knowledge of the physical, biological, economic and social dimensions.

Paleoclimatic records from this region are relatively rare, but critical for improving our understanding of climate change in the interior of continental Eurasia. For example, global circulation models predict that in a world warmed by human derived greenhouse gases, the greatest impacts will occur in continental interiors, with substantial warming in both summer and winter in Central Asia (IPCC, 2001). The development of a global network of high resolution paleoclimatic records is also a central theme of the International Geosphere-Biosphere Program (IGBP) - Past Global Changes (PAGES) - Pole-Equator-Pole (PEP) paleoclimatic initiative, which seeks to link regional paleoclimatic records on a north-south transect from the Arctic, through the temperate and tropical regions, to Antarctica (PAGES, 1995). In addition, one of the main scientific objectives of the IGBP-PAGES sponsored Himalayan Interdisciplinary Paleoclimate Project is to expand the geographic coverage of high resolution paleoclimate records in the highlands of Central Asia in order to better document climate change in the region and thereby identify processes and forcing factors that contribute to this variability. The research outlined in this proposal will also contribute

to the World Climate Research Program (e.g., World Glacier Monitoring Service; WMO), and to the Climate Variability and Predictability Research Effort (CLIVAR) by developing valuable paleoclimatic records of the westerly jet stream and changes in the moisture budgets in the continental mountains of Central Asia. The results of this research can also be applied in improving our understanding of physical processes associated with the transfer of heat, moisture and momentum across the land/atmosphere interface that is directed by Global Energy and Water Cycle Experiment (GEWEX).

Contributions to Human Resource Development

Based on extensive synoptic, meteorological, hydrological, glaciological and isotope/geochemistry long term data our innovative coupled method of ice-core calibration and interpretation was used to develop educational materials for the graduate and post-graduate students at the University of California Santa Barbara and the University of Idaho. Developed results provide opportunity for the further research by following tasks:

(i) further improvement of the developed physical-mathematical simulation with applying of nonlinear response functions for the global climate model;

(ii) develop a method of paleo-climatic reconstruction using both synoptic-meteorological and isotope geochemical data obtained from high elevation ice-cores;

(iii) improve our knowledge in glacier physics and glacier dynamics for educational purposes;

(iv) monitoring the long-term changes of solute content in snow/ice/water chemistry and stable isotopes, including radionuclides to develop water resources control system, water treatment and remediation technology;

(v) estimate an air temperature and precipitation dynamics during long period of time (hundred to thousands of years) that can be used in regional and global climate and water cycle models.

Contributions to Resources for Research and Education

Based on the project fund we have extended the automatic weather stations resources in our group purchasing a new 'Grant Instruments' Automatic Weather station, additional sensors and supplies, which we use in our current research and the educational program. The advanced IDL PC based computer applications we are using in our research and educational program. Courses that benefited from new hardware and software are:

Environmental Hydrology (Geog. 112), Water Quality (Geog. 162), Advanced Hydrologic Models (Geog. 246) and Water Resources Systems (Geog. 208), all taught at UCSB. Climate and Water Resources Changes (Geog. 505), Alpine Hydrology (Geog. 518) and Climate Modeling (Geog. 581) at the University of Idaho.

APPENDIX "A"

COLLABORATIVE RESEARCH PROJECT (2001-2003)

RECONSTRUCTION of PALEOCLIMATIC and ENVIRONMENTAL CHANGES in CENTRAL ASIA THROUGH
COLLECTION and ANALYSIS of ICE CORES and INSTRUMENTAL DATA in the Altai Mountains, RUSSIA

This project proposal, for the joint scientific investigations between researchers from the University of Idaho (UI), Research Institute for Humanity and Nature (RIHN), Nagoya University (NU), Tomsk State University (TSU), and the U.S. Geological Survey (USGS), involves glaciological and climatological research questions addressed by these Institutions in their on-going research programs. The three-year project outlined in this proposal will increase the understanding of present and past climatic regimes, glacier-water resources and related processes in the North periphery mountain system located in Central Asia, as well as variations as a result of the global climate and environmental changes in this region.

The agreement will be begin in June 2001 and go through December 2003 involving various numbers of scientists depending on the program each year. During the first year, fieldwork and data analysis will be conducted and is explained below in further detail. The specific program for 2002 and 2003 will be determined in the future based on initial results from the field reconnaissance in 2001.

PROBLEM STATEMENT: There is very little knowledge regarding the long-term (about 1000-5000 years) changes in climate and water resources in continental high-mountains and the variability of atmospheric circulation patterns at mid-low latitudes of Central Asia forcing us to find alternative sources of information. Fortunately, the accumulation zones of high elevation, mid-low latitude glaciers provide a high resolution of natural archives that can be used to document changes in atmospheric circulation, temperature, precipitation, biogenic and forest fire activity, and anthropogenic impacts.

RESEARCH OBJECTIVES/SIGNIFICANCE: Our main objective is to identify and quantify the various sources of moisture which nourish glaciers in the Altai Mountains and determine the response of climate in this unique region to global-scale climate fluctuations over the past thousand years. This study would indicate the relationship between large-scale climatic change patterns and modifications of water resources in continental, mid-latitudinal, alpine areas. The research goals consist of (1) development of high resolution, multi-parameter, paleoclimatic and environmental change records over the past thousand years through the chemical and physical analysis of ice cores recovered from high elevation glaciers in the Altai; and (2) investigation of the synoptic, climatology, and quantification of moisture, which is found in the Altai glaciers, allows us to estimate the sources, timing, extent and distribution of precipitation and glacial resources in the Altai. A regional array of high resolution, multi-parameter ice core records developed from temperate and tropical regions of the globe also can be used to document regional climate and environmental change in the mid-latitudes, which are home to the vast majority of the Earth's human population. In addition, these records can be directly compared with ice core records available from the Polar Regions to expand our understanding of inter-hemispheric dynamics of past climate and environmental changes.

STUDY AREA: The mountains on the northeastern periphery of Central Asia are an excellent location for studying moisture transport from the Atlantic Ocean, Pacific Ocean, and the atmospheric circulation patterns (i.e. western jet streams and Siberian High). The Altai Mountains form the second mountain block in Asia that the western jet stream encounters after crossing the Ural Mountains in these latitudes. These glaciers, with high elevations provide several accumulation zones (>4000m) with ice thickness greater than 150 m that are suitable for the recovery and development of ice core records extending back greater than 1000 years. In addition, these glacier basins provide an ideal platform for the collection of modern observational data (e.g., meteorological, water flux, etc.) at elevations for which very little data currently exists in the World. Our main study will occur on the Belikha Glacier in Altai.

METHODS: Our scientific approach will be two fold. First, we plan to collect and analyze the high- resolution, long-term meteorological and hydrological records from the Altai Mountains. Secondly, we will develop paleo-climatic records of atmospheric circulation, temperature, and precipitation through the physical/chemical analysis of two ice-cores retrieved from bedrock of the Belukha Glacier massif accumulation zone. The fieldwork in the region will include determination of the major meteorological parameters at several different altitudes in the glacier basins. Applying these two approaches we will simulate changes for the past 1000 to 5000 years in atmospheric circulation patterns including links between variations in the Pacific monsoon activity and Siberian High, and the highest, western jet stream. We will determine the probability of periodic and nonperiodic changes from one climatic state of atmospheric circulation pattern to another predicting the future climate based on extrapolation of reconstructed variability. The duration of the proposed research is three years. This proposal is aimed at filling in a substantial knowledge gap in global change processes as it relates to our understanding of climate and environmental change and their effects on water resources in Central Asia. The proposed research will rely on an extensive a hydrometeorological data set, both in terms of its temporal and spatial coverage. In addition this research will produce one of the most complete, long-term, hydrometeorological and paleo-data sets for continental glacier basins to be made available to the World global change research community.

A central theme of the International Geosphere-Biosphere Program (IGBP) - Past Global Changes (PAGES) - Pole-Equator-Pole (PEP) paleoclimatic initiative is the development of a global network of high-resolution paleoclimatic records. Through the temperate and tropical regions, these programs seek to link regional paleoclimatic records on a north-south transect from the Arctic to Antarctica (PAGES, 1995). In addition, one of the main scientific objectives of the IGBP-PAGES sponsored Himalayan Interdisciplinary Paleoclimate Project is to expand the geographic coverage of high resolution paleoclimate records in the highlands of Central Asia to provide better documentation of climate change in the region, while identifying processes and forcing factors that contribute to this variability (PAGES, 1996). The research outline in this proposal will contribute to the World Climate Research Program (e.g., World Glacier Monitoring Service: WMO - WCRP; WMO, 1988), and to the Climate Variability and Predictability Research Effort (CLIVAR) by developing valuable paleoclimatic records of the westerly jet stream and changes in the moisture budgets in the continental mountains of Central Asia. The results of this research can improve our understanding of physical processes associated with the transfer of heat, moisture and momentum across the land/atmosphere interface, directed by Global Energy and Water Cycle Experiment (GEWEX). The collection and analysis of ice cores and meteorological data from the Altai is a collaborative research project that involves not only the researchers from the Institutions signing this agreement but also involves researchers from the University of Maine (UM, U.S.A.), the National Institute of Polar Research (NIPR, Japan) and the Paul Scherrer Institute (PSI, Switzerland).

The field logistics of helicopter support, availability of guides, ground transportation, cooks, food supply, safety of all personnel, permission for work in the Altai, and ice core/sample transportation will be organized by the team of the Tomsk State University using the project

fund. The Tomsk State University has many years of experience in glaciological, hydro-meteorological field, and stationary research in Altai, particularly in the Belukha Glacier area since 1956. The leader of this project (Dr. V. Aizen, the UI) has directed over twenty field research expeditions in the mountains of Central Asia and is very experienced in working at high elevation glacier basins, which should benefit our research aim. In summer 2000, the research team lead by Dr. Aizen, and three other project PIs Drs. Cecil, Kreutz and Wake, completed a three-year field program in central Tien Shan (Kyrgyzstan) with deep ice-coring on the South Inilchek Glacier. Two frozen ice-cores (165 and 167m) and snow/ice samples were delivered to the U.S.A. and Switzerland for further analyses and interpretation. The Altai ice-coring and paleo-climatic project is a continuation of the Program, "The Paleoenvironmental Record in Mid-Latitude Glacial Ice from the Northern Hemisphere", which is sponsored by the U.S. Department of Energy, the U.S. National Science Foundation and the U.S. Geological Survey.

FIELD AND LABORATORY PROGRAM

OUTLINE OF COOPERATIVE RESEARCH PROGRAM: During 2001 and 2002 we are planning one field reconnaissance each year, and in 2003, one deep ice-coring expedition in the Altai.

The reconnaissance of 2001, on the Altai glaciers, has three main purposes. First we will perform a preliminary survey of the drill site, which includes a radio-echo sounding survey of the entire upper accumulation zone to determine ice thickness and bedrock topography to help identify the best location for recovering a deep ice core. We will also collect a shallow core (15m) and samples from several snow pits over a range of elevations in the accumulation zone for chemical and isotopic analyses and the snow pack physical stratigraphy. Second, we will gather information on the local logistics specifically helicopter support, availability of guides, ground transportation, and renting freezer facilities. Third we will set up an automatic weather station near the vicinity of the drill site. The Altai reconnaissance of 2002 will consist of a two-three week expedition. During this time we will maintain the automatic weather station, collect field and long-term observational data from the region, and snow sampling at a proposed drilling site. During the expedition of 2003, we will continue our field work for the glacier-climatic monitoring. Within one month, we will collect data and recover several 20 to 50 m shallow ice cores along with two deep ice-cores (150-300 m) for isotopic, physical, and geochemical analyses.

ICE CORE DRILLING AND SAMPLING: The 150 m to 300 m firn/ice cores will be recovered using the 'Eclipse' ice drill that was specifically designed for drilling ice in remote alpine regions. This drill has already been tested to a depth of 160m in the St. Elias Range (Canadian Arctic) during the summer 1997 and central Tien Shan during the summer of 2000. The Eclipse drill is a derivative of the Danish tipping tower intermediate-depth ice coring drill which is a proven design, capable of drilling dry holes up to 350m while producing good quality ice core. The entire 'Eclipse' drill weighs 200kg and can be broken down into 7 or 8 pieces (each weighing less than 30 kg) for transport. The drill recovers core 8.2 cm in diameter and can be powered by photovoltaic cells and/or a generator. One 'deep' core will be processed on site. The second and the third cores will be shipped frozen in insulated shipping containers from the glacier to the freezers at the National Ice Core Laboratory (NICL) in Denver and the National Institute of Polar Research (NIPR) in Tokyo for archiving and further analysis.

METEOROLOGICAL, GLACIOLOGICAL, HYDROLOGICAL MEASUREMENTS: We will carry out the field glaciological measurements and meteorological observations at two points, the timberline and in the accumulation zone. In addition to these measurements, we will set up 10 to 20 electronic snow-measurement sticks to record accumulation during the year. For the meteorological observations, we will use automatic Mini-Met stations [GRANT Instruments (Cambridge) Ltd.] and Campbell Scientific instruments. These instruments record the total radiation balance, air temperature, wind speed, wind direction, atmospheric pressure and

temperature in borehole. The glaciological observations will include measurements of ablation, accumulation, and snow-firn-ice stratigraphy in the pits and ice cores. The meteorological records taken during the expeditions and year-round measurements by automatic stations in the accumulation zone, will be linked with stationary observations at base stations and with long-term data. The methods of field glaciological measurements and calculations of glacier mass balance have been described in our previous studies (Aizen and Aizen et al., 1989, 1993, 1995, 1996, 1997, 2001).

LABORATORY ANALYSES: In order to develop synchronous multi-variate records, the major ion and isotopic analyses will be performed on aliquots taken from a single melted ice-core sample. All measured constituents for each sample will represent approximately the same age. The University of Maine, the University of Idaho and the National Institute of Polar Research have the sampling and analytical facilities necessary to develop detailed, highly resolved, multi-variate glaciochemical records from snow and ice. Concentrations of major anions and cations will be determined using a "Dionex (tm)" Model 2010 ion chromatograph with auto sampler located in the GRG laboratory at the University of Maine, the University of Idaho, and the National Institute of Polar Research. Ten percent of the samples will be replicates to estimate laboratory precision of the analyses. There should be four thousand samples from each ice core, which will take approximately six months to analyze.

Stable isotope analyses will be directed by Dr. Karl Kreutz at the University of Maine. The remarkable advances in Accelerator Mass Spectrometry (AMS) which make possible the measurement of microgram samples of modern carbon suggest that annual layer time resolution will be possible with carbonaceous particles extracted from mid-latitude glaciers such as the Altai glaciers. The AMS work will be undertaken at the Paul Scherrer Institute (PSI) in Zurich, Switzerland. All AMS target preparation and analyses will be performed on melted ice-core samples. Target preparation will performed in a Class 100 clean room at the PSI. Microparticle and biochemical analyses will be performed at the National Institute of Polar Research in Tokyo.

PLAN OF THE RECONNAISSANCE TRIP. The following is the itinerary for 2001 and 2002 in transporting personnel, supplies, and equipment from home institutions in the United States and in Japan to the glacier basin for all field seasons. We will fly from the USA to Japan then to Novosibirsk in Russia via Seoul, South Korea. A bus will transport the personnel, equipment and food from Novosibirsk to Gorno-Altaisk and then continue on to the Base Camp at Akkem Meteorological Station by helicopter. From the Base Camp, reconnaissance flights by helicopter will be made to potential firm fields points for selecting an appropriate ice-core drilling site. All personnel and cargo will be transported by helicopter to the proposed drilling. At the ice-core drilling site, we will work for 5-6 days extracting shallow ice-cores and, snow samples and then establishing all the necessary equipment for year round observations in the automatic regime. When the work is completed, all of the ice core and frozen samples will be packed into Insulated Shipping Containers with freezer packs to ensure that they stay frozen during shipment. Our equipment, snow samples, and ice core will be transported from the drilling site to Gorno-Altaisk by helicopter. In Gorno-Altaisk, the ice core and snow samples will be transported to a freezer truck for direct shipment to Novosibirsk. In Novosibirsk, the samples and ice cores will immediately be placed in a freezer for at least 48 hours, which then will be air freighted directly to USA and Japan via Seoul. The personnel and the equipment will be transported to Novosibirsk by bus. The detailed itinerary will be prepared each year separately.

AGREEMENT

Between Researchers from the University of Idaho (UI), the Research Institute for Humanity and Nature (RIHN), Nagoya University (NU), the Tomsk State University (TSU), and the U.S. Geological Survey

The following points are agreed to by all participants.

Field research will be carried out by members of all research teams from UI/RIHN/NU/USGS and TSU. The American/Japanese team in 2001 will be composed of 6 scientists and the University of Tomsk team will have 1 scientist and 3 students.

UI/RIHN/NU/USGS will provide all necessary scientific instrumentation and camping equipment during the field research of 2001 (July). The major equipment: (a) automatic meteo-station (UI); (b) snow measurements sensors with data loggers (NU); (c) 15 m fiberglass PICO auger (NU); (d) GPS receivers (NU); (e) insulated ice shipping containers and sample bottles (UI/USGS); (f) camping gear - tents, portable transceivers, alpine gear, medications, etc. (UI/RIHN/NU/USGS).

All data collected in the field will be prepared and organized into a database and all data will be available to all of the researchers involved in this campaign. This data will include, but is not limited to, current and archival meteorological, hydrological, glaciological, hydrochemical, and isotopic data. All data will be available to the International research community upon publication of initial results and appropriate data will be available through Internet web sites at each participating Institution. Preparation, analysis and summary of data will be carried out by scientists from the UI, RIHN/NU, USGS and TSU teams. Scientists involved in the project will prepare co-authored reports and manuscripts for presentation and publication.

This agreement between researchers from UI, RIHN, NU, USGS and TSU is based on major financial and equipment contributions from the UI/RIHN/NU/USGS for expedition preparation, data collection, research and analysis during their fieldwork and at the Institutions. Expenses for 2001 will involve 3 scientists from USA, 1 scientist and 2 students from Japan, 1 scientist and 3 students from Russia. The 2001, 2002 and 2003 expenses also include the transportation of scientists and shipment of cargo from USA and Japan to Altai and back. Other expenses would be for the fieldwork, data collection, data analysis, and the publications. Presumably each expedition cost will be shared equally according to the quantity of participants or the funding ability.

UI/RIHN/NU/USGS will share financial or field equipment support for 1 scientist and 3 students from TSU in 2001. The expenses covered will include transportation, basic living expenses, during the trip, and $30 per day per diem, while on the expedition (July 2001). UI/RIHN/NU/USGS will provide some expenses for field and scientific equipment that is not available in Russia (*to be determined*). In addition, they will cover expenses (*by report*) that are relevant to the organization of the expedition such as paper work and official trips during the expedition preparation.

TSU scientists and their institution will assist in the official preparation of this expedition. They will stay in contact with governmental authorities regarding the visas. In addition they will get permission to participate in scientific research, snow/ice core and samples exportation from Russia to USA and Japan for scientific analysis, and automatic meteo-stations installation in Altai through the years 2001/2003. TSU will realize assistance on expedition preparation since start to finish under collaboration with governmental authorities and other organizations (*based on our agreement*).

This agreement is for a period of three years and implies continued scientific cooperation and consultation in future, possible scientific exchange between researchers from the University of Idaho, the Research Institute for Humanity and Nature, the Nagoya University, the Tomsk State University and the U.S. Geological Survey with continued financial support from the US Department of Energy, the Ministry of Education, Culture, Sports, Science, and Technology (Japanese Government), and the U.S. National Science Foundation. This agreement begins from June 2001 and extends through 2003.

Dr. Vladimir Aizen
Principal Investigator of the Project
Professor, College of Mines and Earth Resources
P.O. Box 443025, University of Idaho,
Moscow, Idaho 83844-3025, USA

Dr. Masyoshi Nakawo
Co-Principal Investigator
Professor, Research Institute for Humanity and Nature
Oiwake-cho, Kitashirakawa, Sakyo-ku
Kyoto 606-8224, Japan

Dr. Koji Fujita
Co-Principal Investigator
Associate Professor, Nagoya University
Furo-cho, Chikusa-ku
Nagoya 464-8605, Japan

Dr. L. DeWayne Cecil
Co-Principal Investigator
Hydrogeologist, Water Resources Division
900 N. Skyline Dr.,U.S. Geological Survey, Idaho Falls
Idaho 83402, USA

Dr. Peter Okishev
Co-Principal Investigator
Head, Professor, Glacio-Climatological Laboratory
36 Lenina Str., Tomsk State University, Tomsk 634050
Russia

Dr. Stanislav Nikitin
Co-Principal Investigator
Senior Scientist, Glacio-Climatological Laboratory
36 Lenina Str., Tomsk State University, Tomsk 634050
Russia

APPENDIX "B"

AGREEMENT ON COLLABORATIVE RESEARCH

University of Idaho (UofI)
College of Mines & Earth Resources
P.O. Box 443025 Moscow
Idaho 83844-3025, U.S.A.
E-mail: aizen@uidaho.edu

Lanzhou, Cold & Arid Regions
Environment and Engineering
Research Institute (LCAREERI),
Chinese Academy of Sciences
People Republic of China
260 West Donggang Road,
Lanzhou 730000, P.R. of CHINA
E-mail: liusy@ns.lzb.ac.cn

LONG-TERM DYNAMIC OF SOUTHERN MONSOONS AND HYDRO-CLIMATOLOGICAL REGIME OF THE SOUTHEASTERN TIBETAN ALPINE BASINS

This document is a preliminary Agreement in developing the Collaborative Research Project between the University of Idaho (UofI), and the Lanzhou Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, (LCAREERI – the People Republic of China, Principal Institution). The General 3-4 years long-term Project-Agreement on joint investigation of the Climate and Water Resources Changes in South-East Asia between UofI and LCAREERI can be signed after the first research expedition in Southeastern Tibet (Bomi glaciation) in spring or autumn 2002 and upon receiving financial support from the sponsored Agencies of the USA and China for 3-4 years field and analytical research in this area.

Objectives of the Agreement

1.1 Organization and achievement of three joint glacio-climatic environmental monitoring expeditions to Southeastern Tibet glaciation area (Bomi)
1.2 Investigation of the climatic changes and monsoon dynamics in the South and South-East Asia based on hydro-meteorological and synoptic data from the Tibetan Mountains over the last 50 years and three-four year all year around hydro-meteorological and glaciological monitoring in Bomi glaciation area with automatic weather stations
1.3 Study the glaciers and snow cover existence climatic regime glaciers mass balance and runoff dynamics during the last 50 to 100 years in tropical monsoon region
1.4 Study precipitation, snow, ice and water geochemistry, isotopic and trace metal dynamics in the region during last 50 to 100 years
1.5 Development Land-Surface-Atmosphere Model Interaction in South Asia Tibet Monsoon Area emphasizes on recent climatic and environmental changes in the region

The UofI first 2002 expedition scope

The purpose of this expedition is to explore the conditions in which the current glaciation at low tropical latitudes of Asia exists. During one-month expedition we will establish a glacio-metorological and hydrological monitoring network in the alpine area, and begin to document recent climatic and environmental changes. The first exploration will be based on meteorological, glaciological and hydrological observations in Bomi glaciation area, collection of long-term data from nearby hydro-meteorological stations, high-resolution shallow ice/firn core records, snow and water samples and tree-ring chronology records. The collected data and samples will be processed in field and at the UofI and LCAREERI laboratories through the physical, isotope, geo-chemical and radionuclide analysis. Tree-ring analysis, glacier mass balance calculation, data statistical control and analysis and mathematical simulation will occur. With growing numbers of precisely collected environmental data in Asia we will begin to examine the climatic appearance of regional to global synoptic-scale atmospheric phenomena like the ENSO and the tropical and sub-tropical monsoon and changes in glaciers mass balance and water resources.

Our particular interest focuses on glaciers of southeastern Tibet (the Bomi region) for several reasons.

1) The existence of widespread glaciation in a tropical-monsoon belt.
2) The location of the proposed research area on the southeastern margin of the Tibetan Plateau that provides an opportunity to collect information relating to the tropical monsoons and Tibetan High.
3) To study unique Tibetan glaciers that hold the greatest concentration of snow and ice in the low latitudes and constitute a source of fresh water shared by ten heavily populated neighboring countries, the glaciers that can cause the flood disasters in certain climatic and environmental changes.
4) Decadal records of atmospheric deposition in inhabited areas of the Tibetan Plateau are desirable to evaluate the possible relation between anthropogenic emissions and chemical composition of snow/ice depositions.

The main goal of this expedition is a preliminary survey of the Bomi glaciation area to develop new glacio-climatic and glacio-environmental monitoring program. The proposed 3-4-week field research will include:

1. Establishment of local logistics (road conditions, ground transportation, porters, guides, food, cooks, local medical and rescue groups);
2. Establishment of glacial-climatic and hydrological monitoring net-work in research area. Two-three automatic weather stations at different altitudes will be assembled for the hourly year around measurements (air temperature, precipitation, duration and intensity of solar radiance, atmospheric pressure, wind speed and wind direction, snow/glacier ablation and water runoff;
3. Radio-echo sounding and GPS survey of the glaciers to determine present glaciers ice thickness and the glacier surface parameters;
4. Rain and fresh snow events occurring during the field season over a range of elevations at ablation and accumulation zones, several shallow firn-ice cores and snow pits will be sampled to recover climatic records through physical, geo-chemical, oxygen 18 and deuterium isotopic and radio-nuclide analysis. Local

spatial variations in snow, firn, ice chemistry will allow us to assess the variations in source of precipitation, micro particle content changes with elevation and to calibrate the oxygen 18 isotope-temperature relationship through comparison with meteorological and synoptic data;

5. Collection of the annual tree ring records will give us information about long-term climatic trend in Bomi glaciated area. The Sabina tree samples will be used for denro-analyses as far as this tree provides the longest records (*Liu Guang et al., 1995*).
6. Collection of meteorological and synoptic data (mean daily and monthly values), from the region of investigation extending back 40-50 years for further data analysis comparison and calibration, and development of an algorithm for remote sensing glaciological monitoring over the research area using new high quality SAR-data.

The results of the preliminary studies will be submitted in special reports and publications in appropriate journals. All results of scientific investigations will be the ownership of UofI and LCAREERI collaborators.

Obligations

A. The **UofI** will provide major scientific instrumentation for field research and the cost of camping equipment and supplies during the expeditions according to the Year 2002 budget and scientific schedule. Specifics of the instrumentation and camping equipment are following:

a) Two automatic weather stations and supplies in addition to the other one we shipped to LCAREERI in 2001 for year around climatic and hydrological monitoring (one station will be installed at high accumulation snow-firn area and the other one will be used for field monitoring and return to U.S.A. every year
b) Portable shallow solar-powered mechanical auger to collect 20 to 30 m firn-ice cores for geochemical, isotopic and trace metal analysis (equipment will be return to U.S.A. every year)
c) U.S.A. team will be shared shallow ice-core with LCAREERI 50 by 50 after we will recover them
d) Portable radio echo-sounding instruments for the measurements of ice/firn thickness (return to U.S.A. every year)
e) Snow and firn sampling and field processing kit and clean plastic bottles to collect and transport samples (return to U.S.A. every year)
f) GPS equipment to measure glacier ice velocity and the glacier terminus dynamic (return to U.S.A. every year)
g) Dendro-drills and dendro-containers kit to collect dendro-cores (return to U.S.A. every year)
h) Insulated firn/ice shipping containers (return to U.S.A. every year).
i) UofI will invite two Chinese scientists participated in our collaborative research to the University of Idaho for two weeks a year to joint laboratory research and the field results discussion or (and) will invite one post-graduate student for the period of our research in Tibet (4 years) to complete his PhD thesis upon we will get an additional fund and stipend for the student.

B. The **LCAREERI** will provide the following during the agreement and expeditions in year 2002 and through year 2004

a) Provide and direct qualified, communicative and responsible collaborators that are the specialists in climatology, glaciology, and isotop-geochemistry and will be able to work at altitudes over 4000-6000 m
b) Assist in collection existing synoptical, meteorological, hydrological and other necessary data and information for the Project fulfilling an initial statistic data control and analysis
c) Implement and solve all formal acquiescence (at the Government level of the People Republic of China) associated with obtaining permission for:

- the fulfillment of the scientific investigations at the Tibet territory
- permission for installation automatic weather stations, GPS and Satellite Phone use in field
- permission to transport snow, ice and water samples and dendro-cores from Tibet, through China to U.S.A. in 2002-2004.

This preliminary Agreement begins from the time of signing by both collaborators. <u>This agreement is in effect upon new general agreement will be signed but no late than December 31, 2004.</u> The agreement will be extended in details **EACH** year if both parties agree to continue this research.

The Preliminary-Agreement and field budget has been signed:

From the University of Idaho
Leader of the Project
Prof., Dr. Vladimir B. Aizen

From the Lanzhou Cold and Arid Regions Environmental Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, 730000, P.R. China
Director, Prof. Dr. Yao Tandong

Lanzhou (China), Moscow Idaho (U.S.A.)

March, 2002