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Holocene Climate Change as Recorded in Mongolian Lake Sediments

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ABSTRACT

Mongolia, a land-locked country in Central Asia, is located in the region of the highest degree of seasonal contrast on Earth.

This paper presents sedimentologic and geomorphic data used to infer Holocene climate change in North-Central Mongolia. Correlation of data show that the climate was cold and dry before 10500 years BP. The post glacial warming occurred from 10500 to 8700 yr BP. The climate was characterized by becoming warmer and dry from 7300 to 6090 radiocarbon years. Between 6100 and 5500 years ago, conditions were hyper arid. Increased effective moisture balance but still arid conditions prevailed between 5500 and 3900 years ago. Since 3900 years ago, generally more humid conditions prevailed and originated varved sediment accumulation. Between about 2300 to 1300 years ago, greater than present day effective moisture balance. Since 1200 years ago climate was cooler and since 600 years ago becoming warmer.

Keywords : paleoclimate; Holocene; lacustrine; sediments; warm; cold; lake core; radiocarbon age

Introduction

An urgent problem at the present is to identify the reasons for climatic changes, and to forecast the future climate. In other words, to predict oscillations of climate in the future, we need to know the regularities and nature of fluctuations in the past.

Lake-watershed systems have the potential to yield important insights into past climatic conditions for a variety of reasons. In particular, lakes with a deep central basin are likely to contain continuous sedimentary geologic records. As climate changes, ecosystem boundaries shift, and new vegetation, soil conditions, and lake levels are established at the site. These changes in turn influence the type of sediment that is accumulated in the lakes. This study included rock magnetism, palynology, geochemistry, diatoms, biogenic silica and detailed lithostratigraphy to provide insight into orbital and internal forcing mechanism of the Asian Monsoon. A wide variety of samples, including lacustrine cores, soil and plants were collected from the lake basin and watershed of lakes. The lake depressions of Khangai and Khubsugul region vary in size, depth, landscape and structural features, but have the same origin. The Khangai and Khubsugul region is characterized by a considerable recent tectonic activity. It is a zone of strong earthquakes and numerous young faults with hot and cold springs.

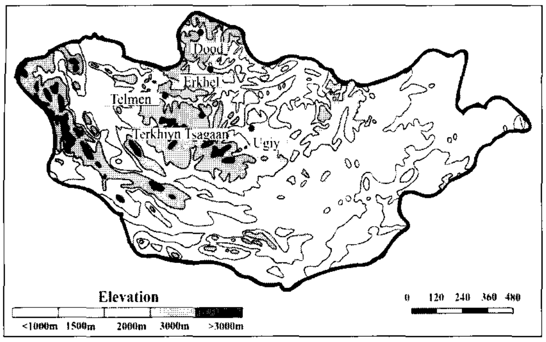

Fig. 1. Location map of paleoclimatic study in Mongolia

Basalt volcanism manifested itself in connection with a new stage of tectonic

activity in Khangai and Khubsugul area, deformation of the system of the depressions. They are filled with Neogene-Quaternary sediments.

During the summers 1998 and 1999 we collected numerous samples from the catchments and lake basin of Telmen, Dood, Erkhel, Terhiyn-Tsagaan, Ugiy and Khubsugul(Fig. 1).

The result of this study indicates that bottom sediments accumulation in small lakes of Mongolia records paleoclimatic and environmental changes.

In this paper, we present new data about lake bottom sediment investigations carried out by American-Mongolian joint project of Interdisciplinary Paleoclimatic Studies of Late Quaternary Lacustrine Systems in lakes of Mongolia in 1998-1999. During the summers of 1998 and 1999 we collected numerous samples from the catchments and basins of Telmen, Dood, Erkhel, Terkhiyn-Tsagaan, Ugiy, Khubsugul and Gun/1998, 2003/lakes. Followings are the lake systems:

Dood Nuur is a fresh water lake. At Lake Dood Nuur was recovered, 5.43 m long sediment core from 14.39 m water depth. It provided an important set of climate proxies, spanning most of Holocene, from which an interdisciplinary paleoclimate was made.

Erkhel Nuur is a salty lake that displays great changes in lake level over time. Past lake high stand terraces were surveyed, sampled and lake cores show pronounced lithology changes resulting from geochemical changes as the water volume.

Telmen Nuur is slightly salty and shows pronounced lake level changes that surveyed and sampled. We recovered 3.28 m sediment core from 24.54 m water depth. This core allowed for highresolution study of rapid climate changes in Mongolia during the latest Holocene.

Terhiyn Tsagaan Nuur is a fresh water lake. The lake core provided a detailed record of paleolimnology change from shallow, intermediate and deep water.

Ugiy Nuur is a fresh water lake. In the deep-water basin, a 3.66 m sediment core was obtained from 13.36 m water depth.

The Lake Khubsugul is located in the Northern Mongolia is the deepest(262 m) and largest(136 km by 37 km) fresh water lake. Maximum thickness of its sediment is 550 m determined by gravity measurements.

This paper makes an attempt to reconstruct the paleoclimate and paleoenvironmental change of the lake Terhiyn-Tsagaan from sedimentary sequences.

The Lake Terhiyn-Tsagaan is located in the Central Mongolia(48°10'N, 99°45'E), fresh water lake formed when a river became dammed by a lava flow about 8 Ka BP; therefore it has a rapid water renewal rate. The average water depth is 12 m with a maximum depth 18 m. The modern lake is 16 km long, between 1.8 km and 7.0 km wide.

Materials and Methods

During the summer of 1998 and 1999 we collected numerous samples from the lake basin(Fig. 2). Sediment core LT98C9 (48°10.245'N; 99°45.518'E) was obtained in water depth of 11m but closer to the outflow from the lake. Length of core sample LT98C9 is 400 cm. There were measured physic parameters including magnetic susceptibility, natural remnant of magnetization, gamma-ray attenuation and X-ray for whole cores. Then

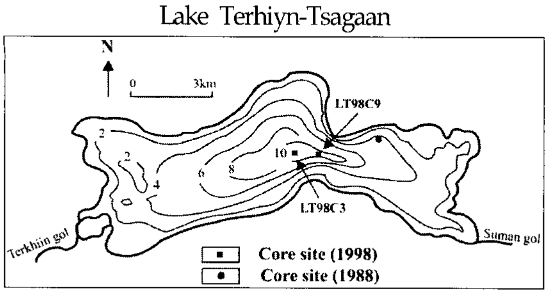

Fig. 2. Lake Terhiyn-Tsagaan bathymetry map(depth in meters) with core sample locations shown. Core sites discussed in text are labeled.

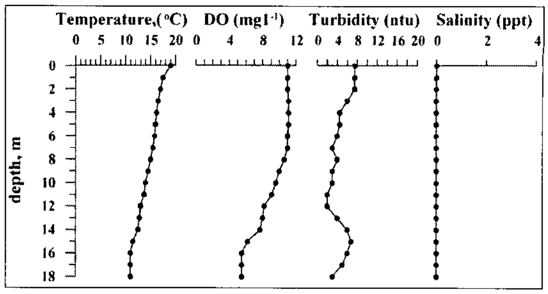

Fig. 3. Physical limnology profiles of the lake Terhiyn-Tsagaan at locations water depth of 18m

the core was split, scanned for digital color, photographed, described and sampled in 1 cm intervals for variety of analytical measurements.

Vertical profiles of physical limnology parameters (temperature, conductivity, dissolved oxygen(DO), turbidity, and pH) of all lakes were measured using a Horiba water meter(Fig. 3).

We conduct an interdisciplinary set of analyses on core samples including: detailed lithostratigraphy, rock-magnetic, $CaCO_3$-content, X-ray mineralogy, diatom, ostracode, TOC, $\delta^{13}C$, C/N, smear slide, loss-on-ignition (LOI)(water content, organic content, wet and dry bulk density) measurements(Fig. 4). Lithostratigraphy of the sediment cores is based upon a variety of sediment parameters, including: whole-core logging on a Geotek core logger(wet bulk density, magnetic susceptibility) and X-ray imaging: description of sediment texture, color, composition and structure and digital color scanning of split cores.

Sediment wet and dry bulk density (WBD, DBD respectively) as well as water content were measured by weight LOI of a $1cm^3$ sample after heating at 100°C for 12h(Dean, 1974). The organic content was determined by weight loss after heating at 550°C for 2h. Organic carbon content was determined by multiplication of organics LOI by coefficient 0.432.

A total of 105 samples of the cores were analyzed on CHN Carlo-Erba Elemental Analyzer. The number of isotopic analyses performed was also 105 samples correspondingly. The organic carbon contents and isotopic compositions are distinctly different in cores and reflect different limnic conditions.

Low frequency magnetic susceptibility(0.43 kHz) of the core samples was measured on the 5cc subsamples with a Bartington Instruments loop sensor operating at a peak AF field of $8\mu T$. The magnetic susceptibility has been reported as volume specific susceptibility (K) in dimension less 10^{-3} SI units and also as mass specific susceptibility (X) in 10^{-6} m^3 kg^{-1}. The natural remnant magnetization(declination, inclination, intensity) was measured using a 2-G single sample cryogenic magnetometer. Anhysteric remnant magnetization(ARM) was induced in the samples with a Schonstedt GSD-1 demagnetizer operating at a peak AF field of 0.1 mT and measured on a SCT cryogenic magnetometer. Saturation isothermal remnant magnetization (SIRM) was induced in the samples by an electromagnet using a field of 1.2 T and measured on the cryogenic magnetometer.

Diatoms were processed from core LT98C9 using the method of Patrick and Reimer (1966). A minimum 300 diatoms were identified and counted unless a sample contained few or no diatom remains.

Smear slide analyses of 760 samples was performed in other to quantity lithologic composition and mineral grain size. X-ray analyses for clay minerals were per

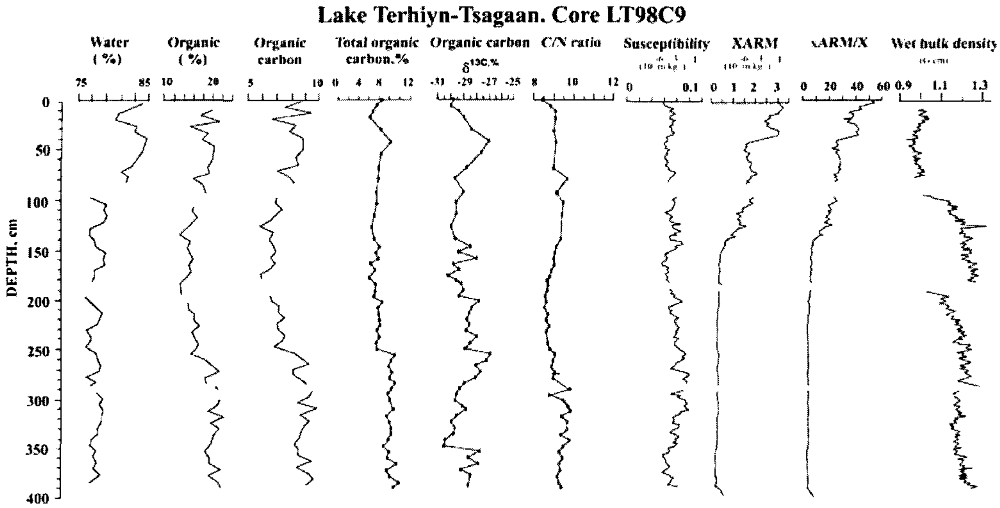

Fig. 4. Core LT98C9 of Lake Terhiyn-Tsagaan, obtained in 11.0m of water (see Fig. 2). Additional sedimentary property profiles of core LT98C9 are shown: water (%), organic (%), organic carbon (%), total organic acrbon δ^{13}(%), organic carbon C(%), C/N ratio, magnetic susceptibility, XARM, xARM/X, wet bulk density

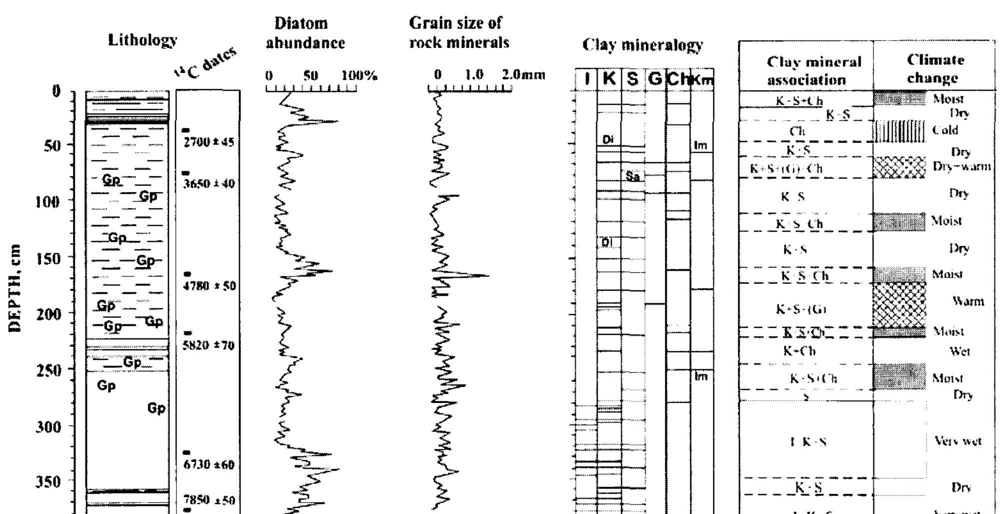

Fig. 5. Sedimentary profiles for core LT98C9 (see Fig. 2). Lithology column is based on a composite section constructed core LT98C9 and selected diatoms, grain size, clay mineralogy, relationship between clay mineral association and climate change, AMS radiocarbon ages.

formed on 380 samples using Japanese RINT-2200 diffractometer at the Central Geological Laboratory, Mongolia(Fig. 6).

The cores obtained from other lake bottoms were analyzed by similar methods to the core LT98C9.

AMS radiocarbon dates were obtained from the

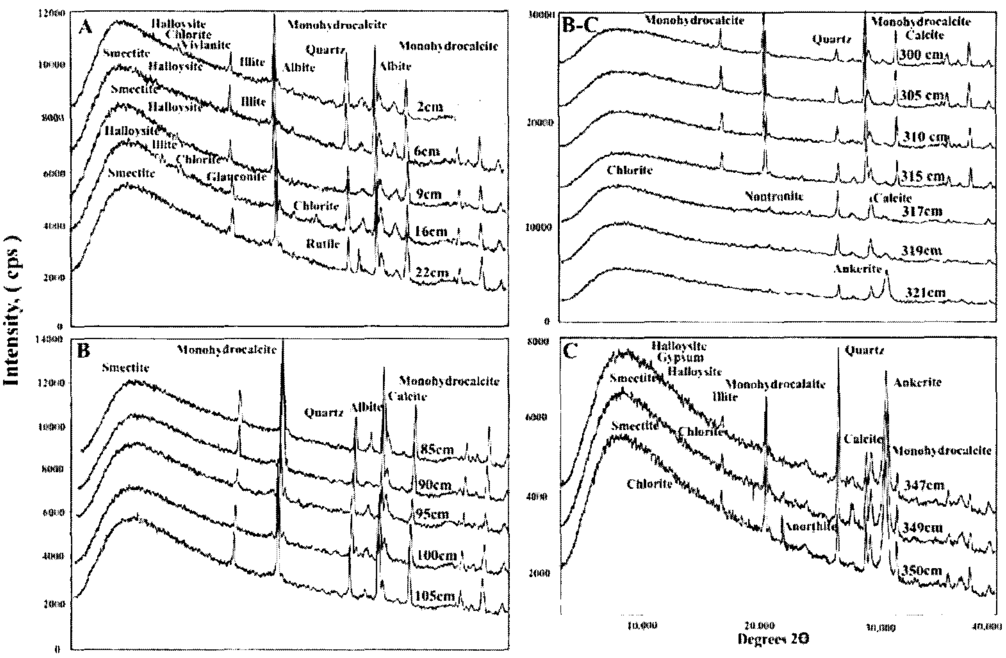

Fig. 6. Examples of X-ray diagrams in monohydrocalcite (A), monohydrocalcite (A), monohydrocalcite calcite (B) and calcite-ankerite (C) organic mud from core TN99C1+C4 of Lake Telmen

humic acid fraction of bulk sediment and pollen concentrates of lacustrine sediment and determined by the Center of Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory using analyses radiocarbon C^{14} isotope.

Results and Discussion

There's activating study of paleoclimatic changes, rhythms related to Late Quaternary. The study's opportune on contents of lake bottom sediments located in various regions of Mongolia. Especially description of climatic change records in Holocene is getting very important. This abstract presents following joint study based upon detailed study of clay minerals of lacustrine sediments and results are compared to other study and detailed the paleoclimatic changes have been recorded during Holocene.

There were accessed some uninterrupted records of climatic changes during Upper Pleistocene-Holocene, as result of drilling carried out to mountain regions in Khangai and Khubsugul in frame of MongolianAmerican joint project labeled "High Resolution, Interdisciplinary Paleoclimatic Studies of Late Quaternary Lacustrine Systems in Mongolia".

Lacustrine sediment of Baikal Lake containing diatom, sand and biogenic silica is presented as well-known mark of paleoclimatic change.

Interbedding of diatomic mud and terrigenic clay is reflecting climatic changes of cold and warm periods. Climate change's expressed on periodic variability of sedimentary contents in Mongolian Lakes. Climatic change's represented by lacustrine sediment clay association, biogenic silica and terrigenic pelite.

The clay association consisted of illite, smectite; chlorite, kaolin and tosudite that contained in lacustrine sediments of Mongolia have been studied by numerous researchers of Mongolian-American joint project. There were occurred differences in clay minerals of muddy clay and diatom clay recovered in cores of lakes Telmen,

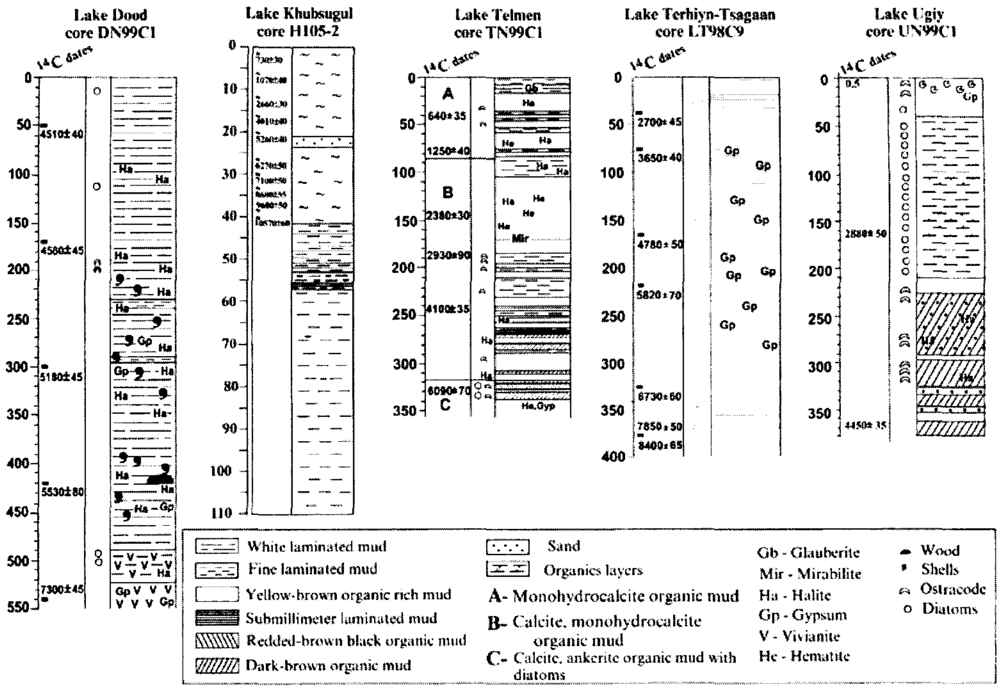

Fig. 7. Correlation of lithological sections of lake cores of Khangai-Khubsugul region.

Terhiyn Tsagaan, Ugiy, Khubsugul, Dood, Erkhel and there have been observed obvious correlation between association of clay minerals and contents of diatom.

By study of the authors, there were observed following clay minerals in core: illite, smectite, illite-smactite, chlorite-smectite, kaolin and tosudite, which have formed various beds that located in various intervals of lacustrine sediments of Mongolian lakes.

Clay association dominated by smectite, illite-smectite, chlorite-smectite(tosudite) and kaolin is related to warm period of climatic change. In other word, chemical weathering of the clay minerals is increasing in rising temperature.

Association of clay minerals formed in cold period consists of illite, illite-smectite and chlorite. There was compiled, section of lacustrine sediments climatic change curve in column for total length of lake sediment core of Mongolian Lakes, that based on determination of clay association. Then comparison between above columns using data of age determination on base of carbon isotope-C^{14}, defined on study of organics distinguished from lake bottom core. The climate change curve compiled on clay association has been related to data collected on diatom. These facts, collected on study of the clay association formed in cold and warm periods can describe characteristics of environment change related to current time intervals; therefore clay association study can be used as paleoclimate change indicator for study of Late Quaternary lacustrine systems, Mongolia.

The X-ray analysis made on samples indicates the contents of clay association consist of illite-smectite, illite, chlorite, smectite, chlorite-smectite and kaolin (Fig. 6). The terrigenic minerals are presented by quartz, plagioclase, kali-feldspar and amphibole.

Correlation of lithological sections, radiocarbon ages and clay association of Khangai-Khubsugul Region that compiled on results of lacustrine sediment studies of Mongolian lake systems in Late Quaternary is shown in figure 7.

The warm and cold periods are distinguished by expected clay association ratio of core LT98C9 on figure 5.

Following clay minerals as illite, illite-smectite and chlorite-smectite with kaolin are formed in warm period. They are all formed by weathering processes of environments.

Clay association studied on lacustrine sediment cores and contents of clay, especially smectite, are directly related to climatic change condition, which has effected on weathering processes.

The smectite beds observed in illite-smectite and chlorite-smectite are indicating the favorable conditions for weathering, which is defined by temperatures and climate humidity.

Qualitative estimation made on kali-feldspar and plagioclase observed in sediments and ratio of terrigenous mineral allow evaluating the degree of chemical weathering in different periods. Therefore the results of joint project execution carried out on clay association and terrigenous part of lacustrine sediment can be useful for paleoclimate change.

Completed study of diatoms and clay mineral assemblages from bottom sediments allows reconstructing the climatic conditions. Each of these investigations provides information on changes of some parameters of environment only, while their combined analyses suggest mutual control and most reliable paleoenvironmental reconstruction. Most complete data obtained from the Khangai and Khubsugul regions. It is possible here to draw general trend of climatic changes, position of climatic belts and their migration in time. The general trend of warm periods during the Holocene is interrupted by periods of cooling between 6100-5500 years ago, for example, disappearing of *Cyclotella bodanica* and forming smectite bed (Figs. 6 and 7).

This paper presents sedimentologic and geomorphic data used to infer Holocene climate change in North-Central Mongolia. Correlation of data show that the climate was cold and dry before 10500 years BP. The post glacial warming occurred from 10500 to 8700 yr BP. The climate was characterized by becoming warmer and dry from 7300 to 6090 radiocarbon years. Between 6100 and 5500 years ago, conditions were hyper arid. Increased effective moisture balance but still arid conditions prevailed between 5500 and 3900 years ago. Since 3900 years ago, generally more humid conditions prevailed and originated varved sediment accumulation. Between about 2300 to 1300 years ago, greater than present day effective moisture balance. Since 1200 years ago climate was cooler and since 600 years ago becoming warmer.

Furthermore, it would be necessary to realize Khubsugul drilling project, aiming to correlate between particular sections that have been compiled on irregular studies of Cenozoic sediments and also for purpose to conduct interregional correlation bottom sediment sections of Lakes Baikal, Russia, Biwa, Japan and other lakes of Asia to compile their paleoclimatic features.

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