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ARTICLE

Lithology and the content of some major elements in the sediments of Buir Lake, East Mongolia

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Abstract: The freshwater Buir Lake in Khalkh Gol soum, Dornod aimag, is located (47° 51′ 47″ N, 117° 51′ 29″ E) on the border of Mongolia and Inner Mongolia, China. The northwest and northeast part of the lake is swampy, and is flat in the rest part. This research paper reveals the lithology and some major elements content (SiO2, Al2O3, TiO2, Fe2O3, MgO, K2O, Na2O, MnO and P2O5) of the core sediments and their distribution along the depth and the Chemical Index of Alteration (CIA), which will be a significant factor in restoring environmental change. According to the data of analysis of major elements of Buir Lake sediments, the concentration of SiO_2 ranges from 42.92 to 58.29%; Al_2O_3 = 9.25-12.83%; Fe_2O_3 = 3.66-4.79%; TiO_2 = 0.46-0.62%; MnO = 0.08-0.13%; CaO = 5.73-11.56%; MgO = 1.34-1.81%; Na_2O = 0.72-1.50%; K_2O = 1.58-2.31%; and P2O5 = 0.14-0.26% respectively. The chemical index of alteration is basically the same as the distribution of SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MgO, K_2O and Na_2O in the sediments of the lake, but their content at 32.5 cm interval of the core sharply decreases and also increases. This is perhaps due to global climate change. The content and distribution patterns of water-soluble elements, such as CaO, MnO, and P_2O_5, are negatively correlated with the chemical index of alteration. These lead to conclude that major elements of Buir Lake sediment and Chemical Index of Alteration are closely related to climatic changes in eastern Mongolia pertaining to the Upper Pleistocene and the Holocene epochs.

Keywords: *Buir Lake; major elements; Chemical Index of Alteration (CIA); climatic change;*

INTRODUCTION

Mongolia is situated in the arid and semi-arid parts of the Central Asian plateau. It has a sharp continental climate, it is far from the seas and oceans, and it is sensitive to global climate change, an ideal subject for paleo-climate and environmental research. Mongolia is located in the northern edge of the Asian monsoon system, as well as in the intertidal zone of the southern edge of the Siberian continent, where the Atlantic air flows from the west [28]. In recent years, the study of continental lakes has been intensified.

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For example, five drill cores, with a maximum length of 600 m, were drilled from Lake Baikal in the period from 1993 to 1999, which are approximately 8-12 million years old [3; 4; 5; 41; 15; 18; 53; 7].

In 2001, the Institute of Geology of the Mongolian Academy of Sciences and the Institute of Limnology and Geochemistry of the Russian Academy of Sciences carried out a comprehensive research project on Lake Khuvsgul in north Mongolia. In 2003 we had the Khuvsgul Drilling project with Japan, Russia and Korea. In the course of the life of the project since 2003 and 2009, we drilled five times on Lake Khuvsgul. The longest cores were 53 m and 82 m respectively. Study was conducted on lithology, geochemistry, organic geochemistry, mineralogy, element content, diatom and age models of the short cores. The results of paleo-magnetic analyses for long core determined the age model in relation to environmental changes. Studies have shown that 53 m and 82 m cores are almost 1 million and 1.07 million years old respectively [9; 19; 51; 33; 34; 35; 41; 42; 1; 16].

The project has been expanding since 2007. The Institute of Geology has been studying the sediments of the paleolake in the Darkhad basin. In 2010, scientists from Japan, Korea, Russia and Mongolia participated in an International Project “Darkhad Drilling" and successfully drilled 3 cores in the northern part of the Darkhad basin. The lithological structure of the lake sediments and the content of some trace elements in the drill core were determined by ICP-MS and the content and distribution patterns of the elements were determined [25; 26; 11; 17; 37; 38]. Also Dood Nuur [8; 40; 31], Telmen [10; 40], Achit [46; 39], Uvs [29; 12; 13; 24; 30], Khyargas [36], Tolbo, Khoton [44; 48; 49], Ugii Lake [55], Gün Lake [58], Erkhel [21], Böön Tsagaan Nuur, Adagiin Tsagaan Nuur [27; 17], Olgoy Lake [56], Orog Lake [57;27], Terkhiin Tsagaan Lake [23] and many scientists have been studying the lakes in the western and central parts of Mongolia and such coming up with innovative results.

Research field

Buir Lake is located in the Khalkh Gol soum, Dornod aimag, and is a freshwater lake (47° 51′ 47″ N, 117° 51′ 29″ E) on the Mongolian-Chinese Inner Mongolian border. On the southern shore of the lake there is a 3-5-meter-high sand dam formed by tidal waves, in the middle of which there is a small lake, which is connected to the main lake. The Khalkha River flows into Buir Lake and the tributary Orshuun River flows into it. The water level of lake Buir depends on its fluctuations and the amount of precipitation flowing into the tributary. Excess water will be fed through Lake Orshuun to Lake Hulun. Lake Buir is one of the lakes in the country, the water of which is highly fresh. The lake water is classified as *hydrocarbonate-chloride* due to the predominance of ions, such as *hydrocarbonate*, *chloride*, *sodium*, and *calcium*. Buir Lake is of tectonic origin, but itcan be classified as a steppe lake due to its coastal features. It is the fifth largest lake in the country with a length of 40 km from northeast to southwest, a width of 21 km, a coastline 118 km long, a catchment area of 20,200 square kilometers and an area of 615 square kilometers [50].

The average depth of the lake is 6 meters, and the deepest part reaches 16 meters. Lake Buir is 583 meters above sea level. Buir, one of the largest fish lakes in Mongolia, is a beautiful place with many willows and waterfowl nesting. The fish of Buir Lake have been used since the 19th century. In 1930, a Mongolian fishing ground has been established on the southeastern shore of the lake. From the beginning, it was expanded into a state-owned fishing factory and caught 6.5 kg of fish from every one hectare. The lake has an annual catch of 300 tons of fish and 199 species of migratory birds. Lake Buir is listed as an annex to the Ramsar Convention on Wetlands of International Importance, especially in the habitat of waterfowl, in 2004 [22], as there are more than 20,000 waterfowl in the area.

The pH of Buir Lake water is 8.4, while the salinity of its water is 248 mg/l. [According to the survey of Dornod aimag's information HMRC on September 19, 2018].

Figure 1. Space aerial view of Buir Lake and sampling location, Eastern Mongolia (N47°49′ 23.7′′; E117° 46′54.0′′)

Mongolia's freshwater lakes include Lake Khuvsgul, Upper White Lake, Hoton, Khurgan, Dayan, Tolbo, Tal and Duroo. Also Bayan Lake, Terkhiin Tsagaan Lake and Sharga Lake fall into this category. The oligotrophic lakes in this group are deep and have fresh water. Mesotrophic or nutrient-rich lakes are located in low-lying areas, including Buir Lake, Ugii Lake, Khar Us, Dalai, Khar Lake, and Achit Lake.

The purpose of this study is to investigate the composition of some major elements of the core Buir-2019 and to find new information on the climatic and environmental history around Buir Lake.

In recent years, many studies have been conducted on lakes in mainland China and Inner Mongolia Autonomous Region of China near Lake Buir. Satellite surveys were conducted in the 1970s and 2000s using Landsat maps to estimate changes in lakes in the Mongolian plateau and related factors. Studies have shown that the Mongolian highlands have been affected by the shrinkage of lakes and pasture degradation over the past few decades, causing lakes to dry up rapidly [43]. The number of lakes with a surface area of >1 km^2 decreased from 785 in the late 1980s to 577 in 2010. This decline has been evident in Inner Mongolia since the late 1990s, with the number of lakes >10 km2 decreasing by as much as 30%. Statistical analysis shows that precipitation in Mongolia has a major impact on lake water and its sedimentation, and mining has become a factor in pastureland and climate change. In addition to climate change, the use of high groundwater and groundwater resources, and the increase in mining activities, continue to bring down the water level of lakes, shrink lakes, and thus have a negative impact on the environment.

Climatic conditions in the lake region are extreme, with air temperatures varying between -25°C in January and +20°C in July. Total annual precipitation does not exceed 200 mm. These arid to semi-arid conditions only permit the growth of sparse vegetation, including dwarf trees in the valleys, with larger trees interspersed sporadically.

MATERIALS AND METHODS

In March 2019, drill core of Lake Buir were taken by gravity method using a special drilling instrument. The sampling was drilled using polyethylene pipe. The length of the core was 67 cm; the depth of the lake was 9.5 m at geographical coordinates of N47° 49′ 23.7′′; E117° 46′ 54.0′′ (Figure 1). After taking a picture of the drill core, we cut it in to two parts lengthwise and made a lithological description.

After the lithological description, the core was sub-sampled at 2 cm intervals for major element analysis and samples were dried in the oven for two to more than 10 hours at the Institute of Geology at laboratory petrography of the Mongolian Academy of Sciences, after which they were sent for analysis.

Geochemical analysis of 34 samples was performed at the Swiss-funded SGS Laboratory in Mongolia using X-ray fluorescence (XRF) instruments on major elements such as SiO_2, Al_2O_3, TiO_2, Fe_2O_3, K_2O, Na_2O, P_2O_5, MgO and CaO using standard procedure (https://www.sgs.mn). Dry sediment samples were powdered in an agate mortar and samples of 1.5 g were mixed with lithium tetroborate ($Li_2B_4O_7$) of 6 g in an agate mortar. The mixture was placed in a platinum (Pt) crucible, and heated to 1100^{0}C for 10 min into glass beads. After that the crucible was cooled to room temperature and the mixture became a transparent round disc. The precision of XRF analysis ranges from 0 to 1% for major elements. The Rb, Ni, Cu, Th, Zn, Cr, rare elements, such as Co, Pb and Sr and rare earth elements were determined by ICP-MS at SGS Laboratory in Mongolia and the results were processed. Powdered samples (50 mg) were digested with mixed HNO3+HF acid in steel-bomb coated Teflon beakers for 2 days in order to assure complete solution of the refractory minerals. An internal standard solution, containing the single element Rh, was used to monitor signal drift. The accuracy was checked by running sediment standards SG and ST. Analytical precision was generally better than 5%. The Chemical Index of Alteration (CIA) was used in order to elucidate the sediment accumulation condition and weathering processes of the catchments area.

RESULTS AND DISCUSSION

The analytical results of the major and trace elements are shown in (Table 1). Also shown are the range and the mean contents of the elements, as well as CIA values of the two lithological groups. Areas around Buir Lake are intruded by numerous Mesozoic rare metal granite plutons and is overlapped by Upper Jurassic to Jurassic non-marine volcanic and sedimentary rocks [6].

Studies have been conducted on the origin and stratification of the sediments along the shores of Lake Buir [20], and they have shown that the sedimentary environment is composed of lakes and soils, with ages ranging from the Upper Pleistocene to the Holocene Period.

According to visual description, the sediment of the core Buir-2019 consists of 2 main lithological units from bottom to the top (Figure 2).

Sediment Unit 1 (Unit 1; 67-54 cm) is a dark grey dense silty clay (7.5Y/2) layer.

Sediment Unit 2 (Unit 2; 54-0cm) is dark olive gray (7.5Y/3) watery clay silt.

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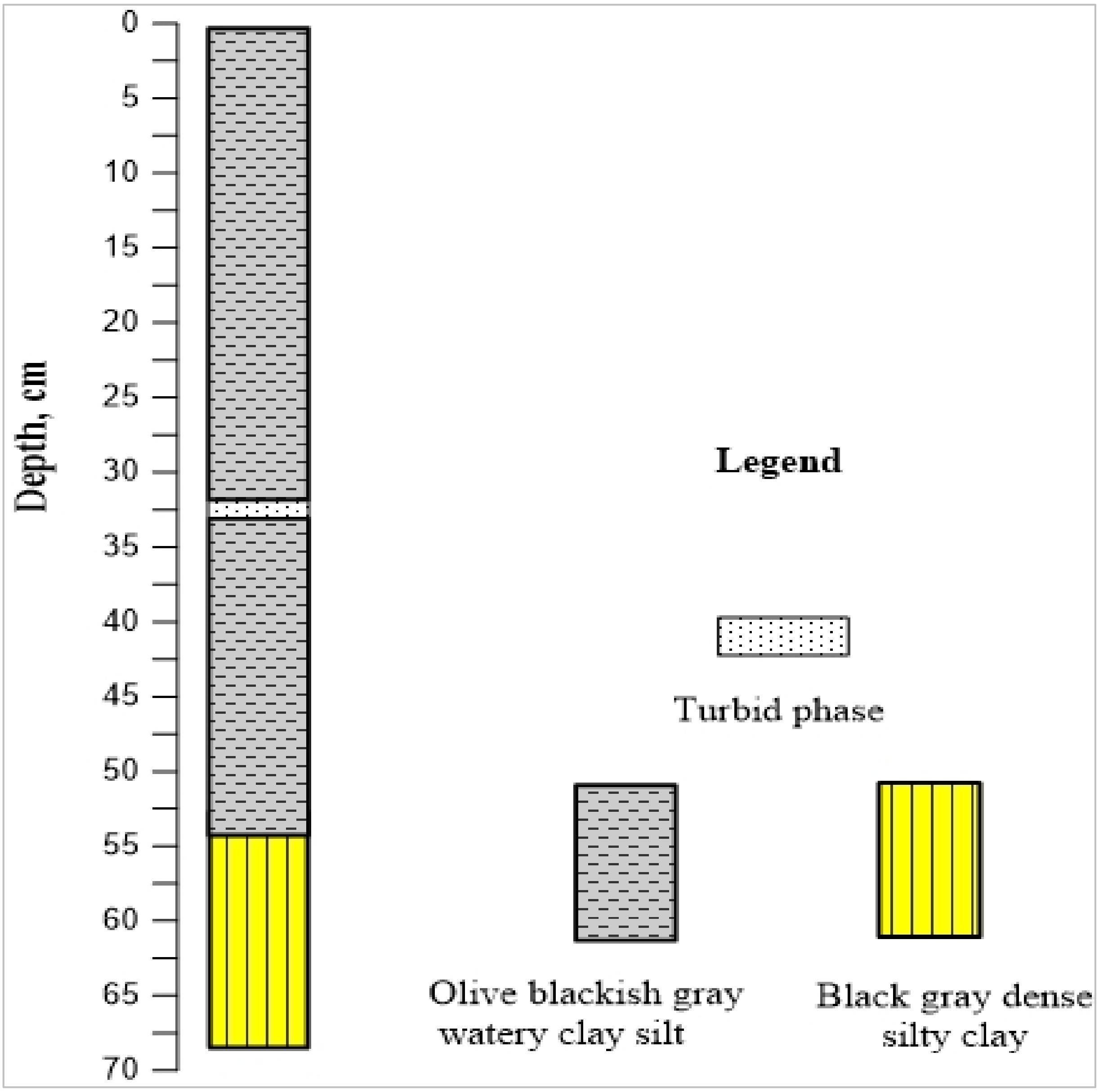

Figure 2. The lithology of the sediment of Buir Lake

Major element contents of the core sediments and their distribution

This study determined the concentration of major elements of SiO_2; Al_2O_3; Fe_2O_3; TiO_2, MnO, CaO, MgO, Na_2O; K_2O, P_2O_5 and Chemical Index of Alteration (CIA) in 34 samples from Buir Lake sediment. The concentration of elements and their distribution are shown in Fig. 3. Some elements are positively correlated to the CIA. The concentration of SiO_2 ranges from 42.92 to 58.29%. The concentrations of Al_2O_3, Fe_2O_3, TiO_2, MnO, CaO, MgO, Na_2O, K_2O, and P_2O_5 range from 9.25 to 12.83%; 3.66 to 4.79%; 0.46 to 0.62%; 0.08 to 0.13%; 5.73 to 11.56%; 1.34 to 1.81%; 0.72 to 1.50%; 1.58 to 2.31%; and 0.14 to 0.26% respectively. The Buir-19 core was divided into two units based on the lithology and distribution of contents of major elements of the core (Figure 3).

Unit 1. This interval of the core includes the accumulation of sediments between 67 and 54 cm (from bottom to top). The content of SiO_2, CaO, Na_2O, K_2O decreased in the dark grey dense silty clay in the lower part of the core, while the concentration of Al_2O_3, Fe_2O_3, TiO_2, P_2O_5 and MgO has many variations. The Chemical Index of Alteration (CIA) has also decreased (Figure 3).

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Table 1. Analytical results of the major elements of Buir Lake (wt %)

Depth, cm	Al_2O_3	CaO	Fe_2O_3	K_2O	MnO	MgO	Na_2O	P_2O_5	SiO_2	TiO_2	CIA
0-2	9.25	11.56	3.66	1.58	0.13	1.34	0.72	0.26	42.92	0.46	40.02
2-4	10.47	10.1	3.98	1.77	0.11	1.45	0.82	0.22	45.35	0.51	45.18
4-6	10.99	8.85	4.1	1.84	0.11	1.42	0.78	0.22	47.19	0.54	48.93
6-8	11.13	8.4	4.1	1.88	0.1	1.48	0.84	0.2	47.6	0.55	50.02
8-10	11.63	7.47	4.21	1.97	0.1	1.48	0.89	0.2	49.43	0.58	52.96
10-12	12.14	7.47	4.34	2.1	0.1	1.52	1.09	0.19	51	0.61	53.24
12-14	12.11	7.37	4.32	2.09	0.09	1.52	1.01	0.18	50.44	0.6	53.63
14-16	12.22	7.45	4.33	2.09	0.09	1.52	1.08	0.18	50.46	0.61	53.5
16-18	12.17	7.53	4.31	2.09	0.09	1.63	1.08	0.18	50.4	0.6	53.21
18-20	12.22	7.42	4.24	2.11	0.09	1.6	1.12	0.17	50.33	0.6	53.43
20-22	12.22	7.34	4.25	2.1	0.09	1.57	1.08	0.17	50.53	0.6	53.73
22-24	12.44	7.28	4.2	2.17	0.09	1.58	1.23	0.17	51.91	0.61	53.81
24-26	12.65	6.82	4.25	2.29	0.08	1.57	1.31	0.16	53.26	0.62	54.83
26-28	12.75	6.69	4.28	2.24	0.08	1.61	1.28	0.16	53.24	0.61	55.53
28-30	12.55	6.49	4.19	2.21	0.08	1.6	1.19	0.15	53.53	0.6	55.92
30-32	11.37	5.73	3.76	2.21	0.08	1.42	1.11	0.14	58.29	0.53	55.68
32-34	12.33	7.08	4.27	2.2	0.08	1.69	1.17	0.18	52.1	0.59	54.12
34-36	12.83	6.98	4.34	2.28	0.09	1.68	1.28	0.17	52.34	0.61	54.89
36-38	12.73	7.81	4.39	2.19	0.09	1.79	1.12	0.18	50.6	0.62	53.38
38-40	12.5	7.89	4.41	2.21	0.09	1.81	1.18	0.17	50.19	0.61	52.56
40-42	12.39	7.71	4.43	2.21	0.1	1.74	1.26	0.19	50.22	0.61	52.56
42-44	12.17	7.34	4.12	2.31	0.09	1.62	1.5	0.17	51.51	0.6	52.18
44-46	12.17	7.36	4.12	2.31	0.09	1.64	1.5	0.17	51.45	0.6	52.14
46-48	12.08	7.67	4.07	2.3	0.09	1.68	1.44	0.17	51.24	0.59	51.42
48-50	12.01	7.64	4.14	2.26	0.1	1.69	1.43	0.18	50.72	0.6	51.46
50-52	11.98	7.43	4.2	2.22	0.1	1.72	1.38	0.18	49.93	0.58	52.06
52-54	11.83	6.78	4.11	2.23	0.1	1.62	1.22	0.16	51.7	0.55	53.84
54-56	11.72	6.78	4.13	2.26	0.09	1.6	1.09	0.21	52.77	0.55	53.64
56-58	11.6	6.61	4.14	2.23	0.09	1.59	1.03	0.19	53.63	0.53	54.02
58-60	12.64	7.08	4.79	2.11	0.09	1.77	0.91	0.16	48.88	0.6	55.58
60-62	12.62	6.6	4.67	2.1	0.08	1.81	0.97	0.15	47.43	0.59	56.62
62-64	12.63	6.57	4.66	2.08	0.09	1.78	0.88	0.16	47.85	0.59	56.99
64-66	12.23	7.9	4.59	2.07	0.08	1.69	0.94	0.15	47.66	0.58	52.85

Unit 2. Sediment 54-0 cm is clay silt and can be divided into 3 subunits based on lithology and their element distribution. These include:

2–1 subunit of 54–32.5 cm
2–2 subunit of 32.5–22 cm
2–3 subunit of 22-0 cm

At the intervals of 67-54 cm, there is a high fluctuation of the elements and increased concentration of oxides, such as Al_2O_3, TiO_2, Fe_2O_3, MgO, while the concentration of SiO_2, MnO, Na_2O, CaO and K_2O decreased. In the 2-1 subunit, the concentration of most oxides, such as SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, and K_2O were stable, while oxides, such as MnO, Na_2O, and MgO fluctuated significantly (Figure 3). In subunit 2-2, the CIA value reached a maximum of 56.99. Subunits 2-2 of the sediment coincided with a 32 cm turbid phase, which may have been a natural phenomenon. The contents of SiO_2, CaO, K_2O, TiO_2 and MnO of all oxides, as well as the distribution at depth, changed dramatically

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(Figures 3, 4). Turbidity usually occurs in areas such as river deltas where sediments accumulate. There is also an increase in CIA value in arid regions. Stratigraphic changes in the chemical composition of lake sediments have been widely used for paleoenvironmental reconstructions [2; 47]. However, some element ratios have different environmental significance across different lakes. The Rb/ K_2O and Na_2O/K_2O K_2O/Al_2O_3 ratios have been interpreted in chemical weathering intensity in the catchment areas [14]. Thus, the key factors and mechanisms governing the chemical compositions of sediments differ among sediment records.

Distribution of SiO_2

The concentration of SiO_2 in subunit 2-2 at an interval of 35-32 cm sharply increases from 52.34 to 58.29%. The value of CIA is also extremely high, 56 - in this subunit. Increases in the concentration of SiO_2 and high values of CIA may have coincided with a sudden turbidity process of climate change (Figure 3).

Distribution of CaO and MgO

Concentrations of CaO and MgO vary from 5.73 to 11.56%; and from 1.34 to 1.81% respectively (Figure 3). The distribution of CaO and MgO, relevant to the depth of the core of Buir Lake, is inverse between themselves. But in Khyargas and Achit lakes the distribution of calcium and magnesium oxide was positively correlated [36; 39] between themselves. Calcium oxide content increased by 10-0 cm in sediments, while magnesium oxide content decreased sharply in this interval. In addition, the content of magnesium oxide in the subunits of 2-1 and 2-2 of the core appears to increase and decrease with the depth of the fluctuating distribution pattern. In subunit 2-3 of Buir Lake sediment, or in the upper part of the core, the calcium content increased, while the magnesium content decreased.

Distribution of Na_2O and K_2O

Sodium oxide content in lake sediments varies between 0.72 and 1.50% and potassium oxide content between 1.58 and 2.31%. Their distribution is positively correlated with each other (Figure 3). In addition, the results showed that the content of potassium and sodium oxides is positively correlated with the silica content.

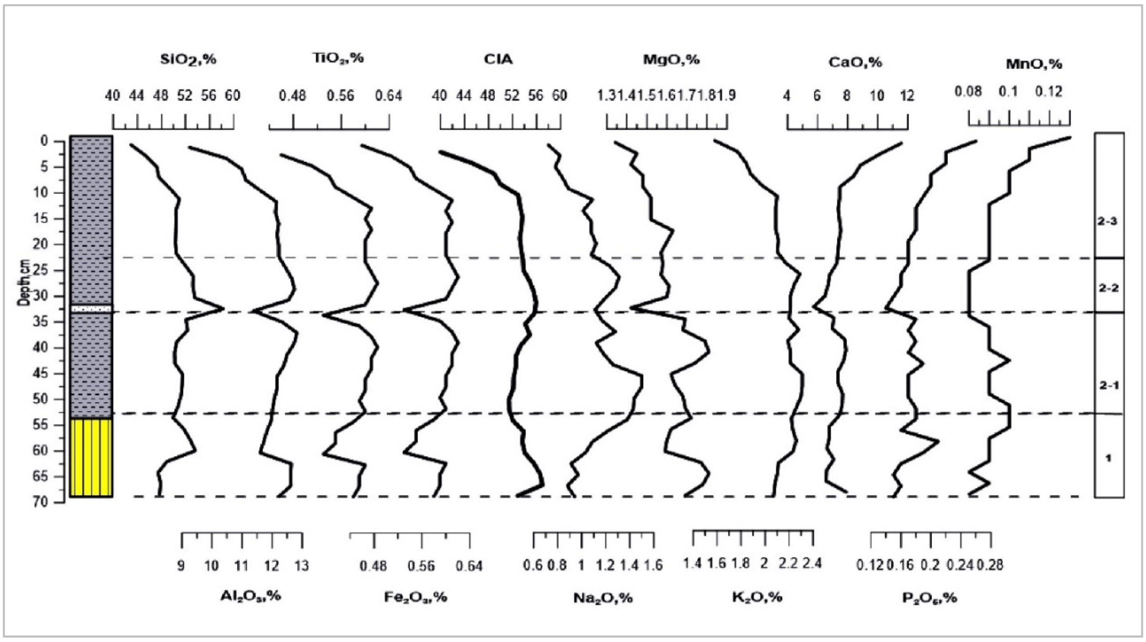

Figure 3. Vertical distribution of major oxide concentrations (wt %) of Buir-19 in core sediments and CIA

Distribution of alumina and iron oxides (Al_2O_3, Fe_2O_3)

The content of alumina and iron oxides in the sediments of Lake Buir is generally positive ($r = 0.68$-0.74, $p < 0.04$) and their concentration varies from 9.25 to12.83%; and ranges from 3.66 to 4.79%. The concentration of alumina and iron oxides sharply increase and decrease in the 2-2 subunit and unit 1 of the core (Fig. 3). But these oxides are stable in the 2-1 subunit.

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Aluminum and sodium oxides are associated with weathering processes of the sediments.

Distribution of MnO

The concentration of MnO in the sediments of Buir Lake varies from 0.08 to 0.13%. There is an extremely high fluctuation of concentration, especially from units 1 to 2-1 subunit and 2-3 units at intervals of 2 cm and its content is high with a value of 0.13%. The distribution curve of manganese oxide has the same appearance as that of calcium oxide.

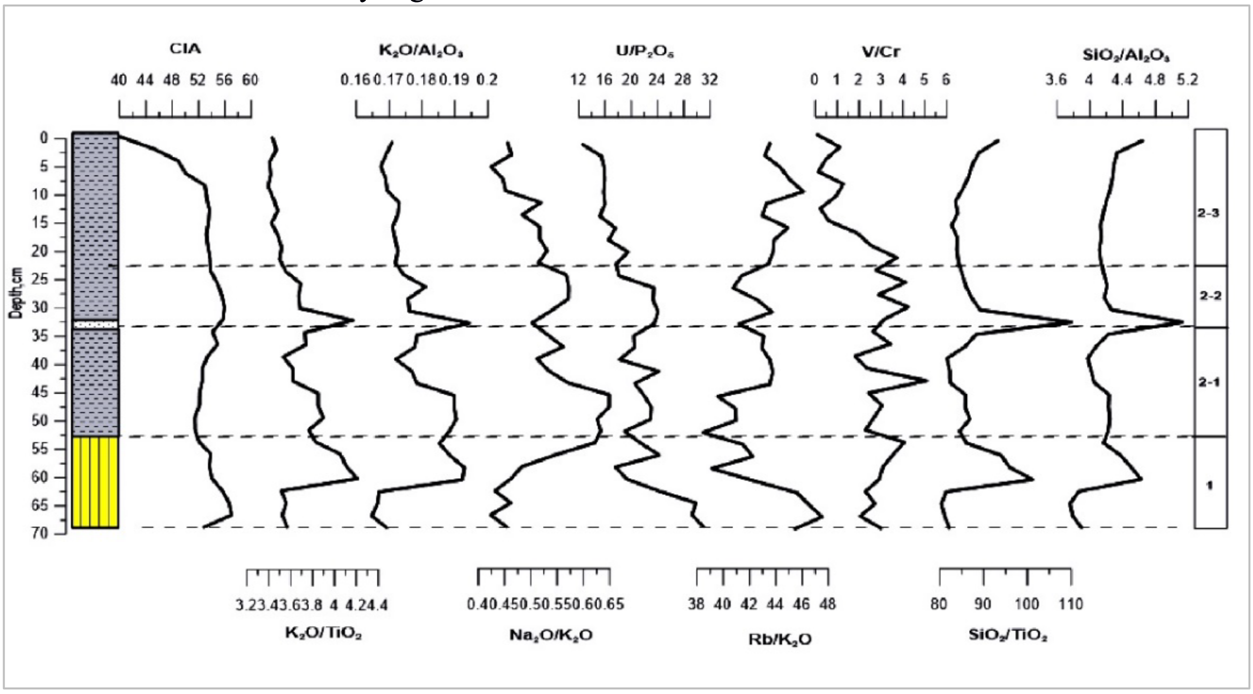

Figure 4. Vertical distribution of major element oxide ratios and CIA of Buir-19 in core sediments

Distribution of TiO_2

The titanium content of the Buir Lake sediments varies between 0.46 and 0.62%. The titanium content is similar to aluminum and iron oxide distribution, which fluctuate sharply, increasing and decreasing during the first and second 2-2 subunit of the core.

Chemical Index of Alteration (CIA)

The chemical index of alteration (CIA) values of sediments could reflect the intensity of chemical weathering and could be associated to climate conditions. Generally, low CIA values indicate a cold-arid climatic condition with a near absence of chemical alteration [32]. CIA was calculated using the following equation [32].

$$CIA=[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]\times 100$$

CIA has been widely used as a quantitative indicator for estimating the degree of silicate weathering [45].

In Buir Lake sediments, CIA (Figure 3) ranges from 40.02 to 56.99, and the average is 52.84. Additionally, different major element oxide ratios of K_2O/Al_2O_3 and K_2O/TiO_2 SiO_2/Al_2O_3, SiO_2/TiO_2 were used in order to elucidate the sediment accumulation condition and weathering processes of the catchment areas of Buir Lake.

Studies in the eastern part of Mongolia are limited, even though the areas are crucial for environmental studies into the arid and semi-arid dry region. The chemical index of alteration (CIA) was determined based on the ratio of sedimentary oxides in the core of Lake Buir. The average chemical index of alteration is 52.84, the lowest value is 40.02 and the maximum value is 56.99. The average CIA of Lake Buir is generally low, indicating that the source sedimentary rock has little effect on the chemical index of alteration, which is normally observed in semi-arid or arid climates. On the other hand, considering the distribution of the main oxides of the lake sediments, the increase in the alumina, titanium and iron oxides in the unit 2 (except for intervals of 32 cm) indicates that the climate is warmer and drier.

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Different levels of weathering of sedimentary rocks are the products of decomposition and dissolution of source rocks that are subject to chemical changes. Stable minerals such as zircon, chromite, and ilmenite are the least volatile in nature, while olivine, pyroxene, and feldspar are the most susceptible. Changes in the latter group of minerals lead to the formation of various mineral phases, such as iron oxides, hydroxides, and clay minerals. The survival of these minerals depends on the intensity of chemical weathering associated with climatic conditions. During the hydrolysis of aluminum silicates, one of their weathered products is almost always in clay minerals, with some of the original aluminum and silicon remaining. The alkaline elements Ca, Mg, K, and Na, which are released during hydrolysis, are highly soluble, and a small part of them remains with the converted product. From the above discussion, it can be seen that as the intensity of chemical weathering increases, the content of mobile elements decreases and immobile elements, such as Al and Ti increase. For this reason, [32] the chemical index of alteration has been calculated.

CIA values vary for different rock types and mineral compositions, for example, 30-45 in basalt and 45-55 in granite and granodiorite [32]. Al_2O_3 and TiO_2 are usually less mobile elements.

In the subunit 2-2, the concentration of silicon oxide has increased and other chemical composition have relatively unstable fluctuations, while magnesium, sodium, and potassium oxides have decreased, while the concentration of aluminum, titanium, iron, calcium, and manganese increased, indicating significant climate change. It is also equivalent to an increase in the chemical index of alteration, a key yardstick of chemical weathering (Figure 3).

The amount of precipitation, which is a component of the climatic system, is determined by the amount of titanium oxide in the sediment [44]. Titanium is relatively stable during diagenesis, and the higher its content, the greater the amount of debris transported by the river. For example, Figure 3 shows the maximum values of the material transported in the subunit 2-1 and 2-3 of the sediment. However, the intensity of river flow is directly related to the amount of precipitation. Therefore, it can be considered that the flow and energy of the rivers flowing into Buir Lake and the source of air precipitation, which is its source, increased in the 1st unit and in the 2-2 subunit, between the transition from 1 to 2-1 subunit. The change in air temperature is determined by the CIA, the chemical index of alteration. The intensity of the transformation process in the basin is determined by the fluctuation of the CIA values, determined along the sedimentary depth of Buir Lake.

Al_2O_3 and TiO_2 are normally used as normalizing elements on the assumption that these are among the least mobile elements. Figure 4 shows the ratios of K_2O/Al_2O_3 and K_2O/TiO_2 SiO_2/Al_2O_3, SiO_2/TiO_2.

Also shown are other ratios of particular interest in following the fate of elements that are normally closely associated in primary rocks (Figure 4).

These ratios of K_2O/Al_2O_3 and K_2O/TiO_2 also SiO_2/Al_2O_3 and SiO_2/TiO_2 show obvious negative correlation with CIA value. On the other hand, the decrease in 2-2 subunit K_2O/TiO_2 ratio and ratio of K_2O/Al_2O_3 indicate that what remained of K_2O in the weathered product is totally associated with the Al bearing minerals (K feldspar and clay minerals). The decreasing P_2O_5 content with increasing CIA value can be explained as being due to the predominantly arid conditions of the weathering sites.

As well as the intensity of the transformation process in the basin is determined by the CIA. On the other hand, units 1 and 2 were usually characterized by arid climates; it is correlated to the Upper Pleistocene and to the Holocene Periods.

Pollen-assemblage data from a sediment core from Khulun Lake in North East Inner Mongolia [54] describe the changes in the vegetation and climate of the East Asian monsoon margin during the Holocene Period. Dry steppe dominated the lake basin from ca. 11,000 to 8000 cal yr BP, suggesting a warm and dry climate. Grasses and birch forests expanded 8000 to 6400 cal yr BP, implying a remarkable increase in the monsoon precipitation. From 6400 to 4400 cal yr BP, the climate became colder and drier. *Chenopodiaceae* dominated the interval from 4400 to 3350 cal yr BP, marking extremely dry conditions. *Artemisia* recovered 3350–2050 cal yr BP, denoting an amelioration of climatic conditions. Both temperature and precipitation decreased 2050 to 1000 cal yr BP as indicated by decreased *Artemisia* and the development of pine forests. During the last 1000 years, human activities might have had a significant influence on the environment of the lake region. Authors suggest that the East Asian summer monsoon did not become intense until 8000 cal yr BP due to the existence of remnant ice sheets in the Northern Hemisphere. Changes in the monsoon precipitation on millennial to centennial scales could be related to ocean–atmosphere interactions in the tropical Pacific.

A huge abundance of diatom frustules and *chrysophyte* cysts in Lake Baikal suggests that the Holocene climatic optimum occurred in this interior part of Asia during the early-middle sub boreal period, 4500–2500 yr BP [19].

Sedimentological and palynological data from Lake Telmen, north-central Mongolia, suggest a sequence of arid conditions from ca. 7000 to 4500 cal yr BP and humid conditions since ca. 4500 cal yr BP [40; 10]. In Gun Lake, the highest contents of organic matter in the core sediments at depths of 450 to 130 cm were interpreted to represent the most humid conditions during the period of approximately 5600 to 2500 yr BP [58]. The discrepancy between the paleoclimatic records from Khulun Lake and the lakes in the mid-high latitude continental interior implies that Holocene climatic changes might have occurred asynchronously in the monsoon and non-monsoon regions.

The lakes in central and western Mongolia are different from the lakes in the eastern parts, which are situated in middle latitudes, which may be due to the East Asian monsoon climate change.

In future, through detailed geochronological records of the lake sediments, the paleoclimate changes in eastern Mongolia are planned to be reviewed.

CONCLUSIONS

The present study explored the major element concentration by the depth and their distribution in the sediments of Buir Lake. Based on the analyzes, the following conclusions can be drawn, which may be associated with the regional climatic changes.

1. The Upper Pleistocene silty clay at the intervals of 67-54 cm, is characterized by high fluctuation of the elements and increased concentration of oxides, such as Al_2O_3, TiO_2, Fe_2O_3, MgO, while the concentration of SiO_2, MnO, Na_2O, CaO and K_2O decreased.

2. The Holocene clay silt as shown in the 2-1 subunit, the concentration of most oxides, such as SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, and K_2O were stable, while such oxides as MnO, Na_2O, and MgO fluctuated significantly. In subunit 2-2, the CIA value reached a maximum of 56.99. Subunit 2-2 of the sediment coincided with a 32 cm turbid phase, which may have been a natural phenomenon. The contents of SiO_2, CaO, K_2O, TiO_2 and MnO of all oxides, as well as the distribution at depth, changed dramatically. Turbidity usually occurs in areas such as river deltas where sediments accumulate. There is also an increase in CIA values.

3. The low values of the chemical index of alteration (CIA) indicate to the low degree of chemical weathering in catchment areas during the Holocene Period. Moreover, the average chemical index of alteration is 52.84 which supports the above conclusion. This is normally observed in semi-arid or arid climates.

4. The degree of chemical weathering as expressed by the chemical index of alteration CIA values across the vertical section of the sediments of Buir Lake indicated that there was no obvious overall change in the climate during the period of deposition of the lake. However, slight fluctuation may have occurred during this period.

5. Major element concentration data, especially content of SiO_2, Na_2O, CaO, and K_2O, is the most important indicator of sediment accumulation conditions in the Upper

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Pleistocene and Holocene Periods in the Buir region. Additionally, the values of some major element oxide ratios such as K_2O/Al_2O_3 and K_2O/TiO_2 SiO_2/Al_2O_3 , SiO_2/TiO_2 and CIA are good reflections of paleoenvironmental changes.

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REFERENCES

1. An, C.-B., Chen, F.-H. and Barton, L. (2008) Holocene environmental changes in Mongolia: a review: Global and Planetary Changes, 63 (4), 283-289. DOI: 10.1016/j.gloplacha.2008.03.007.
2. An, F., Lai, Z., Liu, X., Fan, Q., & Wei, H. (2018). Abnormal Rb/Sr ratio in lacustrine sediments of Qaidam Basin, NE Qinghai–Tibetan Plateau: A significant role of aeolian dust input. Quaternary International, 469, 44– 57. Doi.org/10.1016/j.quaint.2016.12.050.
3. Baikal Drilling Project Members (2000) Paleoclimatic record in the late Cenozoic sediments of Lake Baikal (600 m deep-drilling data). Russ Geol Geophys 41:3–32. Google Scholar
4. Baikal Drilling Project Members (2001) The new BDP-98 600-m drill core from Lake Baikal: a key late Cenozoic sedimentary section in continental Asia. Quat Int 80–81:19–36 Google Scholar
5. BDP-99 Baikal Drilling Project Members (2005) A new Quaternary record of regional tectonic, sedimentation and paleoclimate changes from drill core BDP-99 at Posolskaya Bank, Lake Baikal:Quaternary International 136, pp. 105-121 DOI.org/10.1016/j.quaint.2004.11.012
6. Badarch, G., Cunningham, W. D. and Windley, B. F., 2002, A new terrane subdivision for Mongolia: Implications for the Phanerozoic crustal growth of central Asia: Journal of Asian Earth Science, v. 20, pp. 87–100. DOI:10.1016/S1367-9120(02)00017-2
7. Bezrukova, E.V., Abzaeva, A.A., Letunov, P.P., Kulagina, N.V., Vershinin, K.E., Belov, A.V., Orlova, L.A., Danko, L.V., Krapivina, S.M., 2005. Post-glacial history of Siberian spruce (Picea obovata) in the lake Baikal area and the significance of this species as a paleo-environmental indicator. Quat. Int. 136, pp. 47–57. DOI.org/10.1016/j.quaint.2004.11.007.
8. Dorofeyuk, N.I. and Tarasov, P.E. (1998) Vegetation and lake levels in Northern Mongolia in the last 12,500 years as indicated by data of pollen and diatom analyses: Stratigraphy and Geological Correlation, 6, pp. 70-83. (in Russian)
9. Fedotov A.P., Chebykin E.P., Semenov M.Yu., Vorobyova S.S., Osipov E.Yu., Golobokova L.P., Pogodaeva T.V., Zheleznyakova T.O., Grachev M.A. Tömörkhüü D., Oyünchimeg Ts., Narantsetseg Ts., Tömörtogoo O., Dolgikh P.T., Arsenyuk M. I., M. De Batist. Changes in the volume and salinity of Lake Khubsugul (Mongolia) in response to global climate changes in the upper Pleistocene and the Holocene // Palaeogeography, Palaeoclimatology, Palaeoecology. – 2004. – V. 209. – pp. 245-257. DOI:10.1016/j.palaeo.2003.12.022.
10. Fowell, S.J., Hansen, B., Peck, J.A., Khosbayar, P. and Ganbold, E. (2003) Mid to late Holocene climate evolution of the Lake Telmen basin, north central Mongolia, based on palynological data: Quaternary Research, 59, pp. 353-363. DOI:10.1016/S0033-5894(02)00020-0.
11. Gillespie A.R., Burke R.M., Komatsu G., Bayasgalan A., (2008). Late Pleistocene glaciers in Darhad Basin, northern Mongolia. Quaternary Research, 69 (2), pp.169-187. DOI : 10.1016/j.yqres.2008.01.001.
12. Grunert, J., Lehmkuhl, F. and Walther, M. (2000) Paleoclimatic evolution of the Uvs Nuur basin and adjacent areas (Western Mongolia): Quaternary International, 65/66, pp. 171-191. DOI:10.1016/S1040-6182(99)00043-9
13. Grunert, J.; Klein, M.; Stumböck, M. & Dasch, D. (1999): Bodenentwicklung auf Altdünen im Uvs Nuur Becken. - Die Erde 1999/2: pp. 97-115.
14. Heymann, C., Nelle, O., Doerfler, W., Zagana, H., Nowaczyk, N., Xue, J., &

Unkel, I. (2013). Late glacial to mid-Holocene palaeoclimate development of Southern Greece inferred from the sediment sequence of Lake Stymphalia (NE-Peloponnese). Quaternary International, 302, pp. 42– 60. Doi.org/10.1016/j.quaint.2013.02.014

15. Kashiwaya K., Ochiai S., Sakai, H., Kawai, T (2001). Orbit related long-term cycles revealed in a 12-Myr continental record from Lake Baikal. Nature 410:71-74 DOI.org/10.1038/35065057.
16. Kashiwaya, K., Ochiai, S., Sumino, G., Tsukamoto T., Szyniszewska, A., Yamamoto, M., Sakaguchi, A., Hasebe, N., Sakai, H., Watanabe, T. and Kawai, T. (2010) Climato-hydrological fluctuations printed in long lacustrine records in Lake Khuvsgul, Mongolia: Quaternary International 219, pp. 178-187. DOI.org/10.1016/j.quaint.2010.02.007.
17. Komatsu, G., Brantingham, P.J., Olsen, J.W. and Baker, V.R. (2001) Paleoshoreline geomorphology of Böön Tsagaan Nuur, Tsagaan Nuur and Orog Nuur: The Valley of Lakes, Mongolia: Geomorphology 39, pp. 83-98. DOI:10.1016/S0169-555X(00)00095-7.
18. Kuzmin, M I., Vladimir V. Yarmolyuk V.V., Karabanov E.B., Kawai T. 2003. Paleoclimate Records from the Lake Baikal Sediments and Lava Formations of the South Baikal Volcanic Area. In book: Long Continental Records from Lake Baikal (pp. 23-41) , DOI:10.1007/978-4-431-67859-5_2
19. Karabanov, E., Williams, D., Kuzmin, M., Sideleva, V., Khursevich, G., Prokopenko, A., Solotchina, E., Tkachenko, L, Fedenya, S., Kerber, E., Gvozdkov, A., Khlustov, O., Bezrukova, E., Letunova, P., Krapivina, S. 2004. Ecological collapse of Lake Baikal and Lake Hovsgol ecosystems during the Last Glacial and consequences for aquatic species biodiversity. Palaeogeography, Palaeoclimatology, Palaeoecology 209: pp. 227-243. (E) DOI.org/10.1016/j.paleo.2004.02.017
20. Badamgarav D., Tüvshinjargal B., Narantsetseg Ts., Idermönkh T. 2008. Mongolian Academy of Sciences. Institute of Geology and Mineral Resources. Transaction No 18, p 145-155, Ulaanbaatar, (in Mongolian).
21. Khosbayar P., Ariunbileg S., Peck J., Narantsetseg Ts. 2001. The lithology and clay minerals of Lake Erkhel. MU SHUTIS, Geology, N 4. pp. 147 -151.
22. [mn.wikipedia.org ›wiki› Buir_nuur].
23. Khosbayar P., Ariunbileg S., Sainzaya E., Narantsetseg Ts.1999. The mineralogical contents and paleoclimate change of bottom sediments of Terkhiin Tsagaan Lake. Institute of Geology and Mineral Resources of MAS. No. 13, pp. 90-93.
24. Krengel, M. (2000): Discourse on history of vegetation and climate in Mongolia - palynological report of sediment core Bayan Nuur I (NW-Mongolia). 2000: State and Dynamics of Geosciences and Human Geography of Mongolia. - Extended Abstracts of the International Symposium Mongolia 2000. - Berliner Geowiss. Abh. Reihe A, 205: pp. 80-84.; Berlin.
25. Krivonogov S.K., Sheinkman V.S. and Mistruykov A.A. (2005) Stages in the development of the Darkhad dammed lake (Northern Mongolia) during the Late Pleistocene and Holocene: Quaternary International, 136, pp. 83-94. DOI.org/10.1016/j.quaint.2004.11.010.
26. Krivonogov S.K., S. Yi., Kashiwaya K., Kim J.C., Narantsetseg T., Oyünchimeg T., Safonova I.Y., Kazansky A.Y., Sitnikova T., Kim J.Y. and Hasebe N. (2012) Solved and unsolved problems of sedimentation, glaciation and paleolakes of the Darhad Basin, Northern Mongolia: Quaternary Science Reviews, 56, pp. 142-163. DOI.org/10.1016/j.quascirev.2012.08.013.
27. Lehmkuhl, F, J. Grunert, D.Hülle,O.Batkhishig,G.Stauch. Paleolakes in the Gobi region of southern Mongolia. Quat. Sci. Rev.,179 (2018), pp.1-23, DOI.org/ 10.1016/j.quascirev.2017.10.035.
28. Lydolph, P.E., 977. Climates of the Soviet Union. In: Landsberg, H.E. (Ed.), World Survey of Climatology 7. Elsevier Publishing Company, Amsterdam, pp. 1-443.
29. Naumann, S. (1999): Spät- und postglaziale Landschaftsentwicklung im Bayan Nuur Becken (Nordwestmongolei). - Die Erde 130 (2): pp. 151-172.
30. Naumann, S. & Walther, M. (2000): Mid-Holocene Lake-Level Fluctuations of Bayan Nuur (NW Mongolia). - Marburger

Vol. 62 No 01 (241) 2022
DOI: https://doi.org/10.5564/pmas.v62i01.2084

Geographische Arbeiten 135: pp. 15-25; Marburg.

31. Narantsetseg, Ts., Krivonogov, S.K., Oyünchimeg, Ts., Uugantsetseg, B., Bur, G.S., Tömörkhüü, D. and Dolgorsüren, Kh. (2013) Late Glacial to Middle Holocene climate and environmental changes as recorded in Lake Dood sediments, Darhad Basin, northern Mongolia: Quaternary International, 311, pp. 12-24. DOI:10.1016/j.quaint.2013.08.043
32. Nesbitt, H.W.and Young, G.M. (1984) Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations: Geochim Cosmochim Acta, 54, pp. 1523- 1534.
33. Oyünchimeg, Ts. Tömörkhüü, D. and Narantsetseg, Ts. (2003) The sedimentation condition and climate change of Khuvsgul basin using by chemical methods: Institute of Geology and Mineral Resources of MAS. No14, p135-147
34. Oyünchimeg, Ts., Chebykin, E.P., Tömörkhüü, D., and Narantsetseg, Ts. 2006. Application of mass spectrometry with inductively coupled plasma to determine the elemental composition of bottom sediments of Lake Khuvsgul. Institute of Geology and Mineral Resources of MAS. No16, pp. 144-148.
35. Oyünchimeg, Ts., Chebykin, E.P., High-performance technique on the base of ICP-MS for obtaining high-resolution records of climate-sensitive elements in bottom sediments of Lake Hovsgol (Mongolia) // Chemistry for Sustainable Development – 2009. – V. 17. – № 1., pp. 95-108. UDC 543.51:552.527(161.100.50
36. Oyünchimeg, Ts., Ariunbileg, S., Narantsetseg, Ts., Dolgorsüren, Kh. and Krivonogov, S.K. (2013). Lithology of Khyargas Nuur and petrochemical features: Khaiguulchin, 48, pp. 132-140.
37. Oyünchimeg, Ts., Krivonogov, S “Biogeochemical characterization of Darkhad Depression sedimentary environment and climate features” Proceedings of the Mongolian Academy of Sciences.V 52. 2012. №2 (202) pp. 5-14.
38. Oyünchimeg, Ts., Narantsetseg, Ts., Tömörkhüü, D., Dolgorsüren Kh. 2014. The results of the study of some microelements in the Darkhad drilling sample determined by ICP-MS instrument. “Khaiguulchin “. 2014. № 50. pp. 149-158.
39. Oyünchimeg Ts and Narantsetseg Ts. 2020. The Lithology and Inorganic Geochemistry from Achit Lake Sediments as an Indicator of Paleoclimatic Change, Western Mongolia Transactions, Japanese Geomorphological Union 41-3, pp. 249-259 (2020)
40. Peck, J.A., Khosbayar, P., Fowell, S.J., Pearce, R.B., Ariunbileg, S., Hansen, B. and Soninkhishig, N. (2002) Mid to Late Holocene climate change in north central Mongolia as recorded in the sediments of Lake Telmen: Palaeogeography Palaeoclimatology Palaeoecology, 183, pp. 35-153. DOI:10.1016/S0031-0182(01)00465-5
41. Prokopenko, A.A., Khursevich, G.K., Bezrukova, E.V., Kuzmin, M.I., Boes, X., Williams, D.F., Fedenya, S.A., Kulagina, N.V., Letunova, P.P. and Abzaeva, A.A. (2007) Paleoenvironmental proxy records from Lake Hovsgol, Mongolia, and a synthesis of Holocene climate change in the Lake Baikal watershed: Quaternary Research, 68, pp. 2-17. DOI.org/10.1016/j.yqres.2007.03.008
42. Prokopenko, A.A., Khursevich, G.K., Kuzmin, M.I., and Kawai, T. (2009) Productivity cycles in Lake Khuvsgul, NW Mongolia, during the last 1Ma and the age model of the HDP-04 drill core: Quaternary. Intnternational., 205, pp. 111-125. Doi.org/10.1016/j.quaint.2009.02.030
43. Shengli Tao, Jingyun Fang, Xia Zhao, Shuqing Zhao, Haihua Shen, Huifeng Hu, Zhiyao Tang. 2015. Rapid loss of lakes on the Mongolian Plateau. DOI.org/10.1073/PNAS.1411748112
44. Rudaya, N., Tarasov, P., Dorofeyuk, N., Solovieva, N., Kalugin, I., Andreev, A., Daryin, A., Diekmann, B., Riedel, F., Tserendash, N. and Wagner, M. (2009) Holocene environments and climate in the Mongolian Altai reconstructed from the Hoton-Nur pollen and diatom records: a step towards better understanding climate dynamics in Central Asia: Quaternary Science Reviews, 28, pp. 540-554. DOI.org/10.1016/j.quascirev.2008.10.013
45. Ruxton, B.P. 1968. Measures of the degree of chemical weathering of rocks: Journal of Geology, 76, No. 5, pp. 518-527. DOI.org/10.1086/627357

46. Sun, A., Feng, Z., Ran, M. and Zhang, C. (2013) Pollen-recorded bioclimatic variations of the last ∼ 22,600 years retrieved from Achit Nuur core in the western Mongolian Plateau: Quaternary International, 311, pp. 36-43. DOI.org/10.1016/j.quaint.2013.07.002
47. Sun, Q., Wang, S., Zhou, J., Chen, Z., Shen, J., Xie, X., Wu, F., & Chen, P. (2010). Sediment geochemistry of Lake Daihai, north-central China: Implications for catchment weathering and climate change during the Holocene. Journal of Paleolimnology, 43(1), pp. 75– 87. Doi.org/10.1007/s10933-009-9315-x
48. Tarasov, P., Dorofeyuk, N. and Metl'tseva, E. (2000) Holocene vegetation and climate changes in Hoton Nur basin, northwest Mongolia: Boreas, 29, pp. 117-126. DOI.org/10.1111/j.1502-3885.2000.tb01205.x
49. Tarasov, P.E., Dorofeyuk, N.I., Meteltzeva E.I. Holocene vegetation and climate changes in Hoton-Nur basin, northwest Mongolia Boreas,29 (3) (2000), pp.117-126. DOI.org /10.1111/j.1502-3885.2000.tb00978.x
50. Tserensodnom, J. (2000) Catalog of Mongolian lakes: Shuvuun Saaral, Ulaanbaatar, 116-117. (in Mongolian).
51. Tömörkhüü, D., Chebykin, E.P., Fedotov, A.P., Oyünchimeg, Ts., Borobyova, S.S and Narantsetseg, Ts. 2003a. Lake Hovsgol's sediment geochemistry. Abstract volume of "Baik-sed-2", International workshop on sedimentary processes in large Lakes, 17-18 January 2003, Gent, Belgium, p. 56.
52. Walther M. Paleo-Environmental Changes in the Uvs Nuur basin (Northwest-Mongolia). Erforsch. biol. Ress. Mongolei (Halle/Saale) 2010 (11).
53. Williams D., Peck J., Karabanov E.B., Prokopenko A.A., Kravchinsky V., King J., Kuzmin MI. 1997. Lake Baikal record of continental climatic response to orbital insolation during the past 5 million years. Science 278:1114-1117. DOI: 10.1126/science.278.5340.1114
54. Wen, R., Xiao, J., Chang, Z., Zhai, D., Xu, Q., Li, Y., Itoh. S. Holocene precipitation and temperature variations in the East Asian monsoonal margin from pollen data from Hulun Lake in northeastern Inner Mongolia, China Boreas,39 (2) (2010), pp. 262-272, DOI: 10.1111/j.1502-3885.2009.00125.x
55. Wei Wang, Yuzhen Ma, Zhaodong Feng, Narantsetseg Ts, Kam-Biu Liu, Xinwei Zhai.2011. A prolonged dry mid-Holocene climate revealed by pollen and diatom records from Lake Ugii Nuur in central Mongolia. Quaternary International. Volume 229, Issues 1–2, January 2011, pp. 74-83. DOI.org/10.1016/j.quaint.2010.06.005
56. Uyangaa, U., Hasebe, N., Davaadorj, D., Igarashi, Y., Hasegawa, H., Baasansüren, G., Katsuta, N., Shuukhaaz, G., Ichinnorov, N and Fukushi.K. 2020. Statistical Approach on Preliminary Geochemical Records from Olgoy Lake, Valley of the Lakes, Mongolia. Transactions, Japanese Geomorphological Union 41-3, pp. 261-275 (2020)
57. Yu, K., Lehmkuhl, F., Diekmann, B., Zeeden, C., Nottebaum, V. and Stauch, G. (2017) Geochemical imprints of coupled paleoenvironmental and provenance change in the lacustrine sequence of Orog Nuur, Gobi Desert of Mongolia: Journal of Paleolimnology 58,pp. 511-532. DOI:10.1007/s10933-017- 0007-7
58. Zhang, C., Zhang, W., Feng, Z., Mischke, S., Gao, X., Gao, D. and Sun, F. (2012) Holocene hydrological and climatic change on the northern Mongolian Plateau based on multi-proxy records from Lake Gun Nuur: Palaeogeography, Palaeoclimatology, Palaeoecology pp. 323-325, 75-86. DOI:10.1016/ j. palaeo.2012.01.032