2016

Environmental Changes of Orog Nuur (Bayan Khongor Aimag, South Mongolia) Lake Deposits, Paleo-Shorelines and Vegetation History

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Erforsch. biol. Ress. Mongolei (Halle/Saale) 2016 (**13**): 37-57

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M. Walther, V. Enkhjargal, Ts. Gegeensuvd, & E. Odbaatar

Abstract

Using remote sensing data the subrecent shorelines between 1951 and 2014 can be documented. Higher Pleistocene lake levels are identified up to 11 km north of Orog Nuur. It is referred about sediment standards of 4 drilling cores with lake deposits and their paleo-climate implications. Based on the lake deposits one pollen diagram and its interpretation is pointed out.

Keywords: Mongolia, Orog Nuur, Climate Change, Paleo-shore lines, vegetation history, sediment standards

1. Introduction

1.1. Location

Orog Nuur is located north of the Ikh-Bogd mountain range around 750 km southwest of Ulaanbaatar 204 km, southwest of Arweichir and 122 km south of Bayan Khongor and belongs to in the territory of Bogd Som (Bayan Khongor aimag) (fig. 1). The height of the present lake level is 1217 m a.s.l. Geographically the lake belongs together with the Boon Tsagaan Nuur (tributary river: Baidrag Gol), Adagiin Tsagaan Nuur (tributary river: Nariin Gol), Taatsiin Tsagaan Nuur (tributary river: Taats Gol) and Ulaan Nuur (tributary river: Ongi Gol) to the Valley of Gobi Lakes. The characteristic condition of all these lakes is, that the main catchment area is north oriented and include extent parts of the Khangai Mountain range.

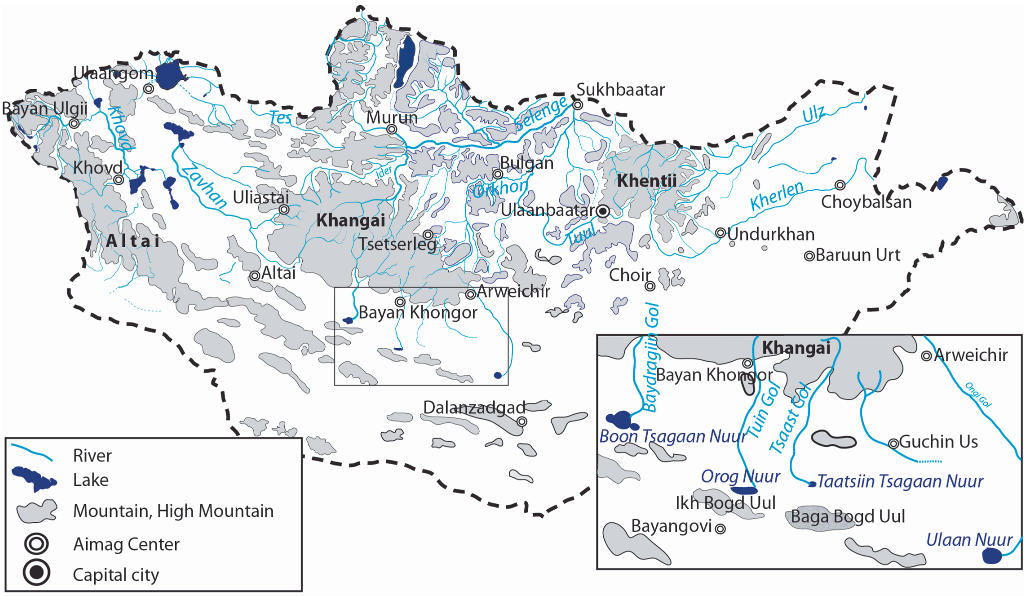


Fig. 1: Location of Orog Nuur.

To the large system of lakes in southern and western Mongolia belong even too the „Basin of Great Lakes“ west of the „Valley of Gobi lakes“ with Uvs Nuur, Khirgas Nuur, Khar Us Nuur, Khar Nuur and Durgon Nuur including the Sharga Depression.

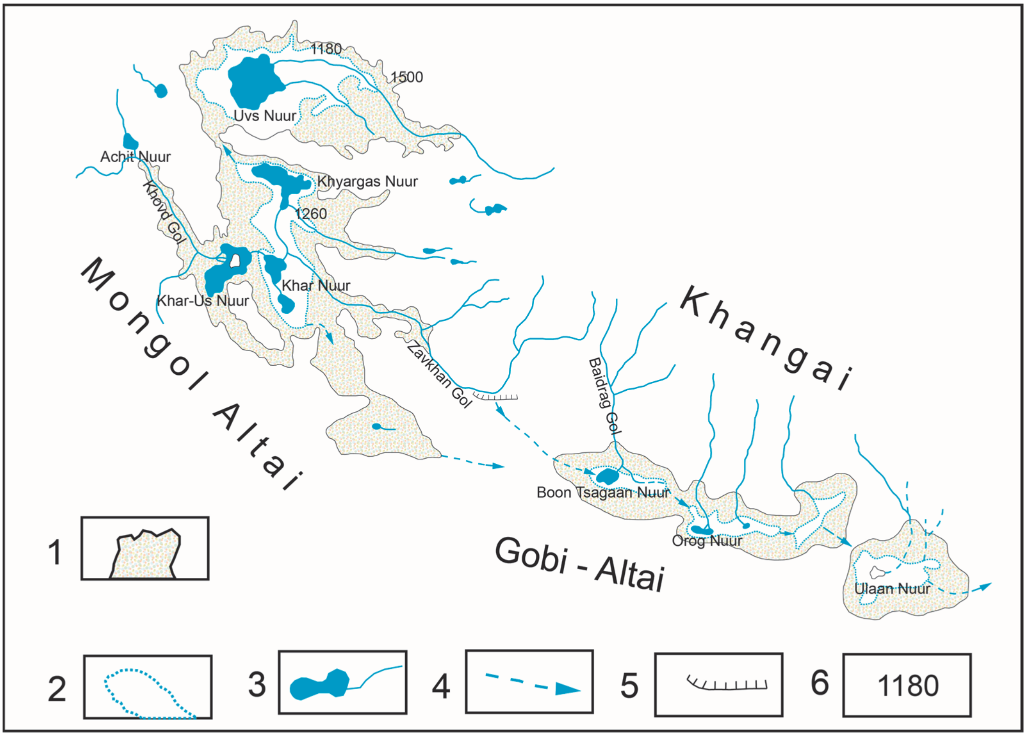


Fig. 2: Distribution of Gobi Lakes (after MURSAEV 1954): Valley of Gobi Lakes and Basin of Great Lakes; 1 = middle-pleistocene lake extension; 2 = young-pleistocene lake extension; 3 = recent lake extension; 4 = Paleo-drainage system and direction; 5 = undercut cliff section.

According to MURSAEV (1975) and TSEGMID (1975) the present-day lakes of Boon Tsagaan Nuur, Adagiin Tsagaan Nuur and Orog Nuur are representing relict lakes of a huge paleo-lake. Paleo-shore lines 19 km north of Boon Tsagaan Nuur and Orog Nuur gives only a rough idea about the former extension of the paleo-lake. THIEL (1958: 406) pointed out paleo-lake levels of heights in 20 – 25 m and 50 – 60 m higher than the present lake levels.

WALTHER (1998) described four different generations of paleo-shore lines with an increasing height above the present-day lake level in the western part of Orog Nuur. Additionally he found paleo-shore lines 11 km north of the lake, 4 km south of Bogd Som with a height of 55 - 60 m above the present-day lake level. These upper levels are dated by LEHMKUHL & LANG (2001).

The pediments described by WALTHER (1998) on the northnortheast bounded slopes of Ikh Bogd can be differentiated into three generations. They are directly combined with the upper foot zone of the mountains and the lowest accumulations are under cut by the lake abrasion in the lake ward located parts of the youngest pediment generation. At some places, the paleo-shore lines are interrupted by erosion and alluvial fan accumulations.

According to the Mongolian Lake Data Base of MOLARE Research Centre (MLDB) recently 1147 lakes are registered with their hydrographical data (www.monnature.org/MOLARE/Different_Topics/Eintrage/2014/4/25_Mongolian_Lake_Data_Base.html). Orog Nuur belongs to the Valley of Gobi Lakes bounded to the Khangai Plateau to the north and the Altai Mountain Range to the south. From the point of the genetic classification Orog Nuur is a tectonic lake bounded to one of the most active earthquake zones in Mongolia, which is west-east oriented parallel to the Ikh Bogd mountain range.

According to the Limnological catalog of Mongolian Lakes (www.oslo.geodata.es/ mongolian_lakes/) Orog Nuur recently belongs to the type 4 („shallow lakes and lagoons both with permeant or temporary waters. Slightly or highly mineralized waters. High water turbidity due to inorganic suspended particles“). The surface of the lake is often changing (121,37 km^2), pH value is 9,4, conductivity of the temporary water is 5.970 S cm^{-1} and the trophic degree is detected as heterotroph (www.oslo.geodata.es/mongolian_lakes/).

1.2. Climate

According to JAMBAAJAMTS (1996), the Orog Nuur lake basin belongs to the desert steppe climate region in the „Valley of Gobi Lakes„ with dry and hot summer. In general, the climate of the lake basin is arid and characterized by extremely continental climate with low and unstable precipitation. Winter is long and cold with mean temperatures below 0°C. Spring is drier and windy and summer is warm or hot. The annual mean temperature is +2°C in the desert-steppe region. An average day temperature in July is 25°C in the southern Gobi. P.K. KOZLOV observed an amplitude in daily temperature near Orog Nuur of 42.4° (-14.2° up to + 28.2°) (MURSAEV 1975). The period when air temperature exceeds +10°C (vegetation period) is 110-130 days in the desert-steppe.

Livestock herders of the Valley of Lakes noticed that once in ten years, a reduction in the Tuin Gol river water discharge reduced the level of Orog Nuur, so that cows and horses could walk on its bottom at the beginning of the 20th century (MURSAEV 1975).

Precipitation reached a minimum during the late 1940s - early 1950s; and a maximum during the late 1960s - early 1970s. By 1990, annual precipitation dropped to a minimum. Subsequently precipitation has gradually increased, apparently to reach a maximum by the late 1990s - early 2000. These climatic oscillations strongly affect vegetation dynamics.

Table 1: Monthly precipitation in desert steppe region (mm) (NATSAGDORJ 2000)

months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	annual
mm	0.7	1.2	1.8	2.9	10.9	11.6	24.9	20.7	9.4	3.3	1.6	0.7	89.7

Table 2: Average annual evapotranspiration (NATSAGDORJ 2000)

region	evapotranspiration
mountains	> 300 mm
mountain valley and forest-steppe	250-300 mm
steppe	150-250 mm
Gobi-desert	150 mm

Table 3: Average annual potential evapotransporation (NATSAGDORJ 2000)

region	evapotranspiration
mountain region	< 700 mm
mountainous and river valley	700-800 mm
forest-steppe and the steppe	800-900 mm
Gobi-desert	> 900 mm

The annual mean precipitation is 50-150 mm in the Gobi-desert. Precipitation varies in both time and space extremely. The mountains have significant effects on the precipitation distribution in Mongolia. More than 400 mm precipitation falls in the Khentii Mountain and 100 mm or less in the Lake basins, the Gobian region of the Altai and the southern Gobi. 85-90 percent of the annual precipitation falls as rain during the summer of which 50-60 % in July and August. The number of rainy days is not only distributed over time, but also over space: 60-70 days in the northern part of the country, but in the Gobi it is 30 days (NATSAGDORJ 2000). Most of the rain falls in a few short periods in heavy rain showers.

Annual evapotranspiration is not high and almost equal to the annual precipitation. Evapotranspiration is 150 mm and less in the Gobi-desert (table 2). The potential evapotranspiration is less than 900 mm in the Gobi-desert (table 3).

During winter (December-March), about 10 mm of snow falls in the desert, and 10-20 mm in the other regions. Accordingly, the number of days with snow cover is 50 and less in the Gobi-desert. The average depth of snow cover is very less: about 5 cm in mountains (the maximum is over 30 cm), 2-5 cm in the steppe (the maximum is 15-20 cm). Winters without snow cover have occurred only in the Gobi region. Orog Nuur is less fed by local precipitation; the lake level is nearly exclusively depending on the precipitation in the catchment area of the Khangai Mountains.

1.3. Vegetation

Regarding the vegetation geographical zonation, Orog Nuur belongs to the desert steppe region of the „Valley of Gobi Lakes“. Related to the salinity of the soil, the region of the valley has poorly developed vegetation. In this region, so far 346 species of 62 families of plants have been recorded (ULZIIKHUTAG 1989). The dominant species of these are *Stipa gobica, Stipa glareosa, Allium polyrrhizum, Cleistogenes soon-gorica, Anabasis brevifolia, Ajania achilleoides, Caragana pygmaea.*

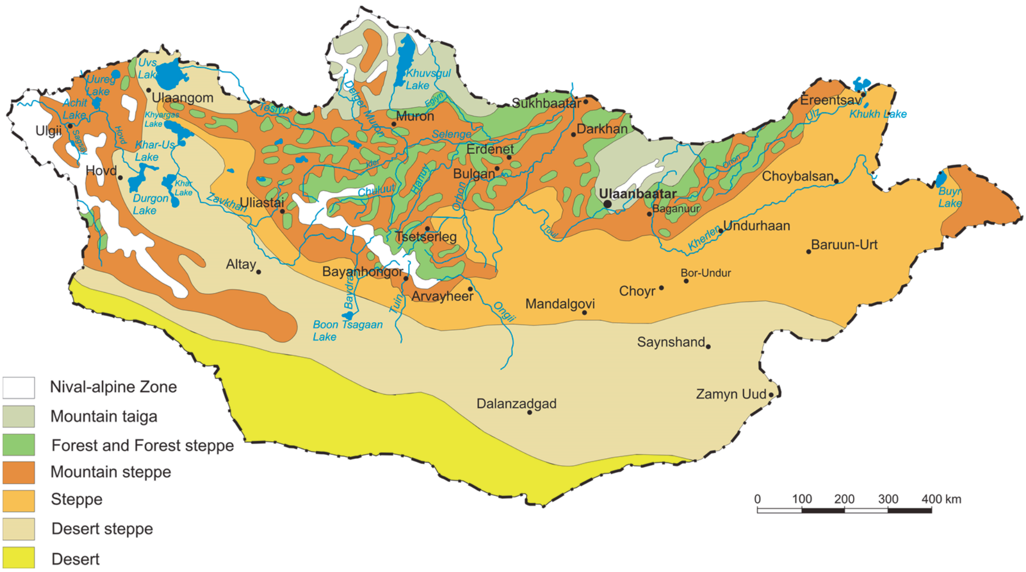


Fig. 3: Vegetation zones of Mongolia (after BARTHEL 1990).

Therefore, some species of hydrophyte plant communities are distributed in this region. In general, the vegetation of the lake basin is sparse and mainly characterized by semi-shrubs and shrubs up to 0.5 m tall and some grasses. Xerophytic and in some places halophytic plant communities of the desert and semi-desert are dominant.

The main species can be indicate by a basic character of the desert steppe region as following: *Polypogon maritimus, Agropyron fragile, Bolboschoenus planiculmis, Iris Bungei, Atraphaxis bracteata, Limonium Semenovii, Chenopodium ficifolium, Suaeda heterophylla, S. Przewalskii, Salsola Ikonnikovii, S. Paulsenii, Halogeton glomeratus, Spergullaria marina, Pugionum dolobratum, Strigosella africana, Goldbachia Ikonnikovii, Tamarix elongata, T.laxa, Potentilla astragalifolia, Thermopsis mongolica, Oxytropis Pavlovii, Linaria hepatica, Artemisia Klementzii, Saussurea ramosa, Jurinea mongolica, Olgaea leucophylla, Taraxacum arneriifolium.*

There have been recorded 54 species of 20 families of plants around Orog Nuur (GANKHUYAG 1995). The main communities are composed by *Glycyrrhiza uralensis, Achnatherum splendens, Leymus secalinus* and *Agropyron cristatum* (GANKHUYAG 1995). On flood plains of desertified steppe, the green sediments in the final succession series are dominated by halophyte and haloxeromorphic species (*Halerpestes salsuginosa, Glaux maritima, Saussurea amara, Plantago salsa, Suaeda corniculata*). Some flood plain areas in the dry steppe zone show an increased content of readily soluble salts (GRUBOV & MIRKIN 1980).

Migratory birds (among them rare species of the Red Book) take the lake for a station. In the western part of the lake, the Altai Osman fish (*Oreoleuciscus potanini)* is observed.

2. Hydrography

2.1. Catchment area

The largest rivers which feed the lakes of the „Valley of Gobi Lakes" are the Ongiin Gol, Tuin Gol, Nariin Gol and Baidrag Gol.

In the northwestern part of the Gobi Region, an extensive hydrographic river net exists, but numerous river beds are only filled with water during periods of heavy rain. All large rivers originate from Khangai Mountains feeding their water southward flow into the interior endoreic Central Asian basin at the foot of the Gobi Altai. The catchment area of Orog Nuur covers ca. 10.500 km^2. Orog Nuur is an endoreic lake type collecting waters of Tuin Gol originated in Khangai Mountains. Additionally there are smaller catchment areas from the Ikh Bogd range. Thus, the lake is fed by precipitation and surface runoff. The total catchment area consist of metamorphic, volcanic and plutonic rocks. Sandstones and carbonatic rocks are not distributed. On the surface of the relief, tertiary and quaternary mantle rocks and sediments of a different genesis are distributed.

2.2. Development of the lake basin and water quality

Regarding the genetic typology of lakes Orog Nuur is a tectonic lake and one of the saline lakes in the Valley of Gobi Lakes. The Color of water is grayish green and the transparency is less than 0.25 m in the western part of lake. In the eastern part the water color is light green and the transparency is between 0.18 - 0.20 m (TSERENSODNOM 1971). Water color can be changed in more light color due to the inflow of Tuin Gol and therefore a surplus of freshwater.

The lake area has reached to 146 km^2, a width to 7.7 km and a perimeter was reached to 75 km because of earthquake in 1957, however the lake area is varying very much due to the inflow of Tuin Gol. In years with less precipitation, it can be dried up (e.g. 1980 s) (TSERENSODNOM 2000). According to available data, Orog Nuur dried up in 1890, 1934-1936, 1952-1953 and 1985-1986. In October 1988 and 1989 GANKHUYAG (1995) measured a water depth of 72 cm. A maximum water depth is 5 m. Since 1991 the water level has risen due to increasing precipitation (GANKHUYAG 1995). In 2002 the water level was 1.5 m at the drilling-/coring sites (fig. 6).

Thermal patterns of salt lakes have been poorly studied in Mongolia thus far. The seasonal thermal pattern is driven by the continental climate. This leads to a rapid and intense warming of lakes in spring and summer, and in winter to an ice cover. Warming begins in March when, after snow has disappeared from lake ice, the temperature of surface water layers begins slowly to rice. After the ice melts in May, the water temperature quickly rises above 4°C, where upon isothermal conditions develop in shallow lakes (EGOROV 1993). Maximum rates of heating take place in July and August, and after August, water temperatures begin to fall. Water temperature of Orog Nuur reaches 15-18°C on the water surface and 11-12°C at the bottom of the lake in May. In July and August, water temperatures can reach up to 25°C on the surface (TSERENSODNOM 2000). In November to April, the lake surface can be covered by ice.

Table 4: Major ionic composition of Orog Nuur water (EGOROV 1993)
[a] A = gl^{-1}; B = equivalent percentage of cations or anions

Value[a]	Salinity (gl^{-1})	Cations			Anions			Source of data
		Na + K	Ca	Mg	Cl	SO_4	HCO_3	
A	50.5	18.0	0.02	0.41	16.9	6.25	8.91	EGOROV (1993)
B		95.5	0.1	4.4	63.3	17.3	19.4	

The lakes of the arid Gobi region are relicts of previously more extensive internally drained water bodies (MURSAEV 1975; DEVYATKIN 1981). These features are the main determinants of the present chemical composition. Thus, the chemical composition of lake water largely reflects the nature of watershed geology. However, the importance of climate is indicated by regional differences in lake composition. In general, there is a gradual increase in salinity and a change in chemical composition from north to south that parallels the increasing aridity along this gradient.

There is also a correlation concerning elevation: decreasing elevation means usually an increase in salinity. High salinity in Gobi region result largely from high evaporation (ca. 1000 mm p.a.) and widely distributed soil salinization (EGOROV 1993).

Water total mineralization of Orog Nuur is registered as a 1.75-5.01 g/l and pH = 9.22 (TSERENSODNOM 2000). The anions such as Cl^-, $SO_4^=$ and HCO_3^- are equally predominant in this lake, while the cations are strongly dominated by Na^+ + K^+ (table 4.). Chemical composition and total mineralization are almost indifferent in the west and east parts of the lake. But in the east part anions HCO_3- and Cl^+, a cation Na^+ have risen and also an ion CO_3- has observed. Horizontal and vertical variations in the salinity of salt lake reflect freshwater inflow and wind-induced mixing (TSEND 1966; TSERENSODNOM 1971).

Concerning seasonal changes salinity decreases in July-August when precipitation is maximal and sometimes also in May when snow melt is large. Salinity increases when water levels are low, as at the end of autumn. Seasonal and long-term salinity fluctuations reflect the continental climate of Mongolia (EGOROV 1993). Since 1850 the climate of central Asia has shown a tendency toward increasing aridity (SHNITNIKOV 1975).

In lakes with a permanent inflow, the general tendency to desiccation may be interspersed with periods, when levels increase and salinity decreases. Such fluctuations are typical for Orog Nuur. One reason of such changes may be increased precipitation in the mountainous regions, followed by increased water-levels in mountain lakes and increased groundwater discharge into the lakes of the Gobi region.

The other factor determining river discharge into lakes of the Gobi region is human use of water, e.g. for irrigation and mining. If deprived of significant inflows, lakes can change from permanent to ephemeral bodies of water. Orog Nuur in the Valley of Gobi Lakes provides an example. In this way, the influence of natural climatic aridity can be reinforced by human use.

3. Geomorphology

Natural habitats and environments of Mongolia are diverse: they include coniferous regions in the north to sandy and stony-desert environments in the south. However, mountains relief covers most of the country.

The first foreign explorers of Mongolia with a modern geo-scientific focus (GRANOE 1910; BERKEY & MORRIS 1927; MURSAEV 1975) reported the earliest observations on the large extension of Pleistocene glaciations in the mountains and high lake-levels in the deserts of Mongolia.

The so-called "Valley of the Gobi Lakes" is a graben zone between the southern slope of the Khangai and Gobi Altai (MURSAEV 1975). The lakes of this area are fed from the Khangai Mountains in the northland the Gobi Altai Mountains in the south. Preliminary descriptions of paleo-lake-levels and terraces of this area of „Valley of the Gobi Lakes" were given by WALTHER & NAUMANN (1997) and WALTHER (1998).

Geomorphological investigations of the „Valley of Gobi Lakes" is conducted by WALTHER (1998) and LEHMKUHL & LANG (2000). The study areas of these investigations are the upper and lower reaches of the Baidragiin and Tuin Gol and lake basins of Boon Tsagaan, Adagiin Tsagaan and Orog Nuur. These investigations focus firstly on different glaciofluvial terraces in the Khangai mountains close to a Pleistocene ice-margin, and secondly on the accumulation pediments and paleo-lake shorelines in the „Valley of Gobi Lakes" between Khangai mountains and Gobi Altai. The chronologies for the sites studied are obtained by luminescence dating of aeolian, colluvial and lacustrine sediments, and allow assessment of the timing of the inferred climatic changes during the Late Quaternary.

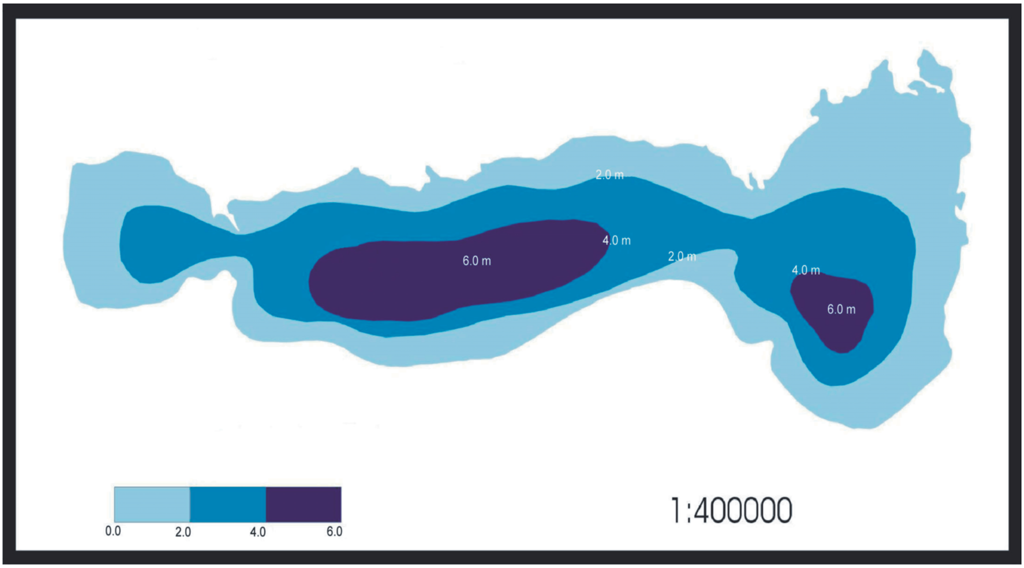


Fig. 4: Bathymetric map of the Orog Nuur recorded on measurements between 1970 and 1988 (after TSERENSODNOM 2000).

3.1 Paleoshorelines

Groups of paleo-shorelines are observed east and west of the lake. At the west side of the lake Walther described the youngest and lowest beach ridge (S1 *sensu*, WALTHER 1998) 3 m above the recent lake level combined with a surf, which is overlain by „Kupsten"-dunes. The next higher beach ridge (S2 *sensu*, WALTHER 1998) is 10 till 12 m above the recent lake level and is impressively located at the west and southwest side of the lake. Less higher than S2 (15 m above the recent lake level) is the beach ridge S3 on the west side of the lake. There is described a 23 m high S4 beach ridge in the direct neighborhood of the present day lake. The paleo-shorelines east and west of Orog Nuur are developed as surface ridges and from point of geomorphology comparable with the valley floor shorelines near Tsagaan Nuur 60 km east of Boon Tsagaan Nuur and Adagiin Tsagaan Nuur west of Orog Nuur.

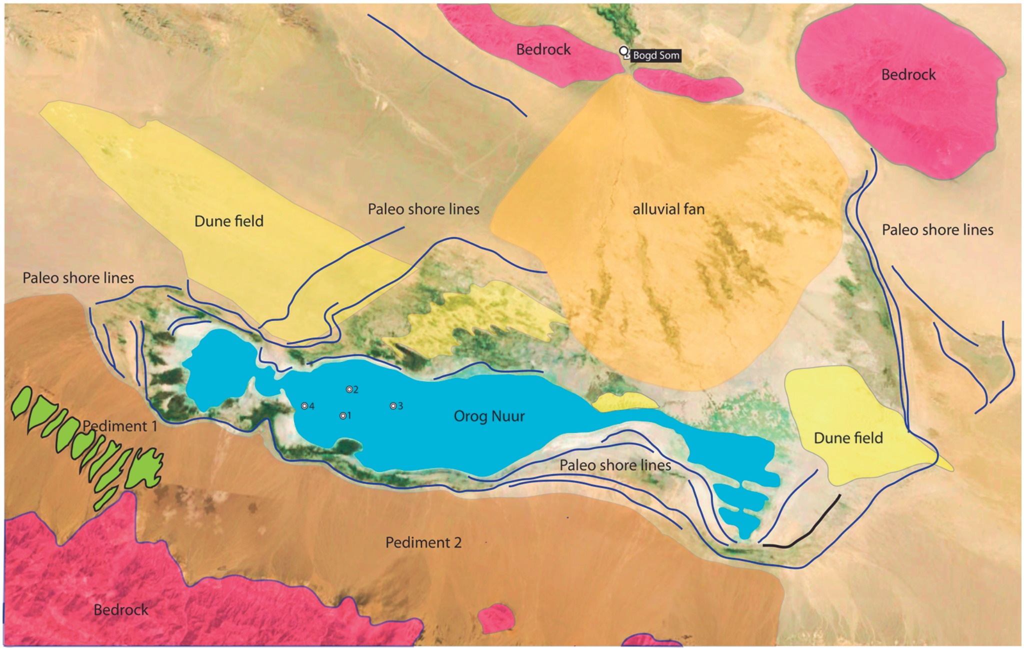


Fig. 5: Localization of the drilling sites and recent geomorphologic units of Orog Nuur based on Landsat TM, 2003.

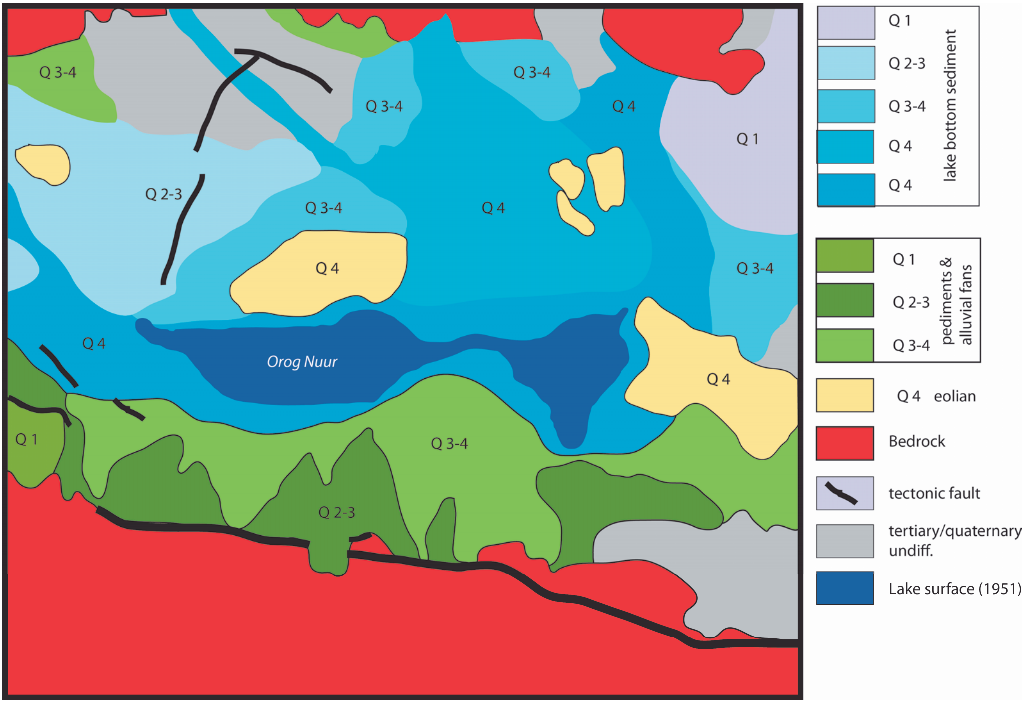


Fig. 6: Geological-geomorphologic map of Orog Nuur (after ZABIOTKIN 1988).

These are relictic beach ridges. KOMATSU et al. (2001) conducted a preliminary study of paleoshorelines features associated with Boon Tsagaan Nuur, Tsagaan Nuur and Orog Nuur using RADARSAT satellite SAR imagery in 2001. Ridges of shorelines are covered with coarse-grained gravel a few centimeters in diameter. Intervening troughs are mantled by fine-grained gravel less than 1 cm in diameter (KOMATSU et al. 2001). It is also possible that higher level shorelines exist on the alluvial fans south of Orog Nuur, but paleo-shorelines are marked in undercutting zones of the pediments and alluvial fans. On the western north side of the lake an old lake bottom covers with more than 10 km length and 1,0-1,5 km width dunes and an aeolian deflation relief. The paleo-shorelines associated with the Tsagaan Nuur and Orog Nuur are complex, large and well established features. This implies that the paleo-lakes were stable for extended periods.

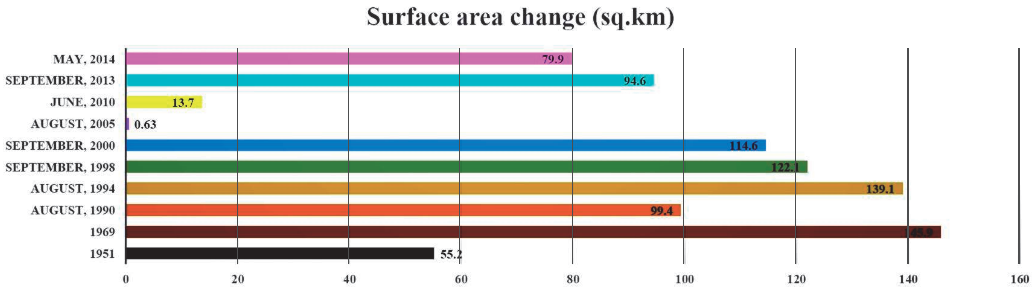


Fig. 7: Lake level development between 1951 and 2014.

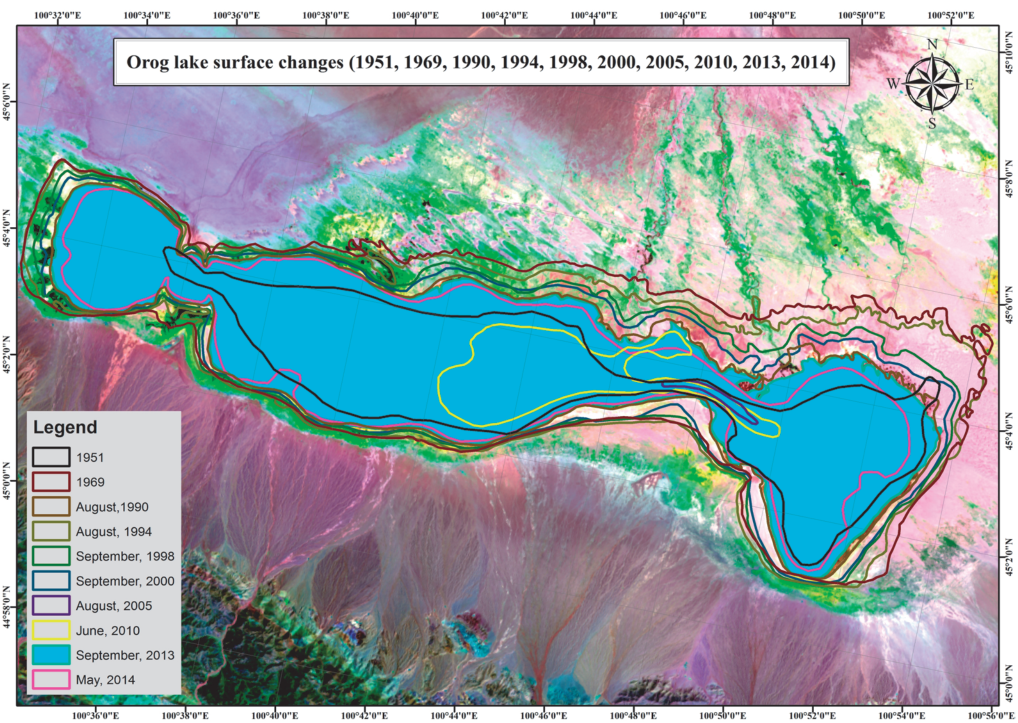


Fig. 8: Map of lake level changes between 1951 and 2014.

The genesis of multiple level beach ridges and wave-cut terraces requires a prolonged history of transgressions and regressions. Depositional features such as spits and deltas are relatively large (like the Tuin Gol delta is a few km long), and this means that the paleo-lakes were „not ephemeral in nature“ (KOMATSU et al. 2001).

Regarding the lake level changes between 1951 and 2014 there had been a nearly desiccation in 2005 (0,63 km^2) and a maximum level in 1969 (145,9 km^2).

3.2 Pediments

Pediments have a concave slope with an angle of 1° to 3°, maximum 5° till 10° with cutting the basic rocks without consideration of their solidity or weakness. Pediments are located in the forelands of high mountain and low mountain regions. Pediments can be formatted under the conditions of combination of running water, influence of vegetation cover, hard rock formations, mountain relief and in certain regions the process of solifluction. The precipitation of such environment is around 100 up to 200 mm/a. Pediments of the Ikh Bogd mountain range are reaching the south side of the lake and at the southern shoreline of the lake, many small fresh water springs gush out of the foot zone of Ikh Bogd.

This is the reason why there is a marshy environment developed on the sub-recent surface. WALTHER (1998) described three different pediment niveaus at the south side of the western bay of Orog Nuur, which are closely combined with alluvial fans.

4. Sedimentology

4.1. Sediment records of the drilling cores

The drilling sites of Orog Nuur are located in the western and the middle part of the lake. Four drilling cores were taken at different depths of Orog Nuur using a USINGER corer with different diameters (80, 55, 30 mm) in vibration drilling method with a drilling platform of 25 m^2.

There are taken four different cores ORO-1, ORO-2, ORO-3, and ORO-4 with a different length (fig. 9 - 12). Sediment samples of all cores are determined as many layers of lake bottom deposits. These layers have been divided into sediment zones, in which the cores are divided. All sediment zones are characterized by their compositions such as carbonate and organic contents and by the colour of sample.

The core ORO-1 is taken from the central part of middle area of the lake at 45°03' 604" N, 100°37'470" E with a total length of 183 cm. This core is included the samples between 200-383 cm from lake bottom deposit. The ORO-1 core is divided into 9 sedimentological zones (Figure 9). Totally this core consists carbonate mud with low or high concentration and organic content. An organic content is not very high (less than 10 %) compared with carbonate. The concentration of carbonate mud is different in each zones along the core.

Description of the different sediment zones of the drilling core ORO-1 (fig. 9):

1. 200-209 cm: This zone contains pelitic carbonate mud and is colored with dark grey (2.5GY 6/1). The zone is characterized by a decrease of organic and carbonate content concerning with rise of water level depended on the humidity of climate condition and low evaporation.
2. 209-223 cm: The zone is colored with dark green (7.5Y 7/2) and defined by carbonate mud. Content of carbonate mud is increased gradually in this zone and it shows that the water level has a decrease related on a warm up and an evaporation rise.
3. 223-228 cm: This zone is dark green (7.5Y 5/2) and characterized by a pelitic carbonate mud with much low content of carbonate. Such low content (less than 10 %) of carbonate mud is influenced by a falling of water level and coolness in this zone.
4. 228-238 cm: Sediment sample in the zone 4 is a light grey (10Y 7/2) mud with the highest concentration (more than 50 %) of carbonate in whole core concerned with less water that is caused of warming and lack of precipitation. An organic content is unchanged. A carbonate content has a sharp increase in this zone.

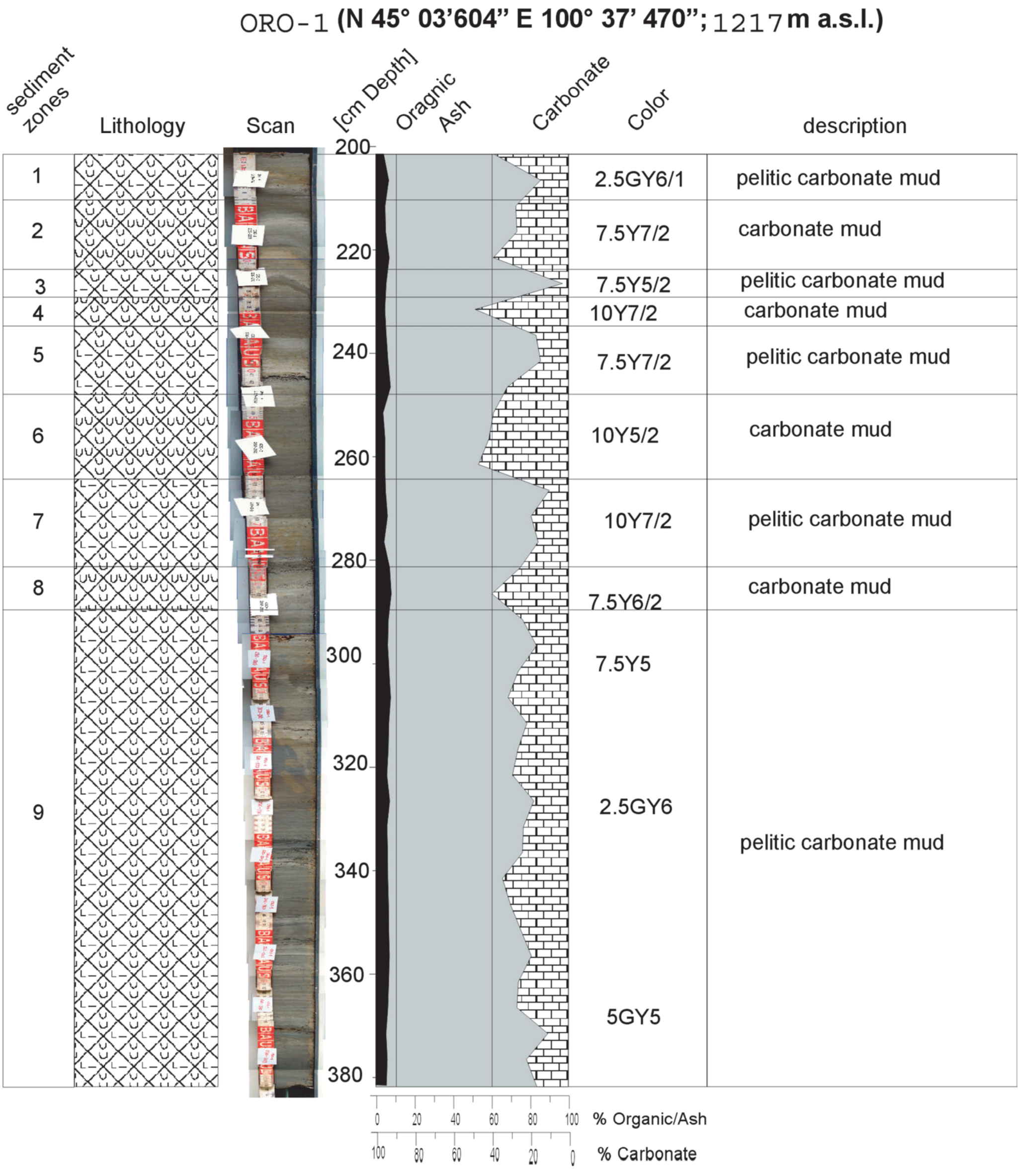


Fig. 9: The sedimentology and scans of the core ORO-1.

5. 238-247 cm: This zone is characterized by a light grey (7.5Y 7/2) pelitic carbonate mud with low concentration. It shows that this period is inlfluenced by cooler climate condition and gradually increase of water level. However, an organic content is increased in this zone because the climate condition influenced not too strong on the vegetation.
6. 247-263 cm: The sample is a carbonate mud with color of dark grey (10Y 5/2) in this zone. The concentration of carbonate is increased up to 50 % and, whereas organic content is stable. An increase of carbonate is depended on the relative warm and subside of water.

7. 63-280 cm: Sediment zone 7 is described by a light grey (10Y 7/2) pelitic carbonate mud what contains rather low concentration of carbonate content. The reason of low concentration is a cool climate condition and an increase of water level. An organic content is not changed almost.
8. 280-289 cm: The sample of this zone is a dark green (7.5Y 6/2) carbonate mud. A carbonate concentration is increasing up to 40% caused of warmer climate condition. As for the organic content, it is not influenced almost.
9. 289-383 cm: This zone is defined by a dark grey (7.5Y 5, 2.5GY 6) and dark green (5GY 5) pelitic carbonate mud with few stripes of sand. The zone is the longest part of the core ORO-1 with length of 94 cm which contains stable content of organic and frequent changes of carbonate content. It shows that the climate was not changing extremely in this period and, the thermal and humidity regime were changed on a small scale.

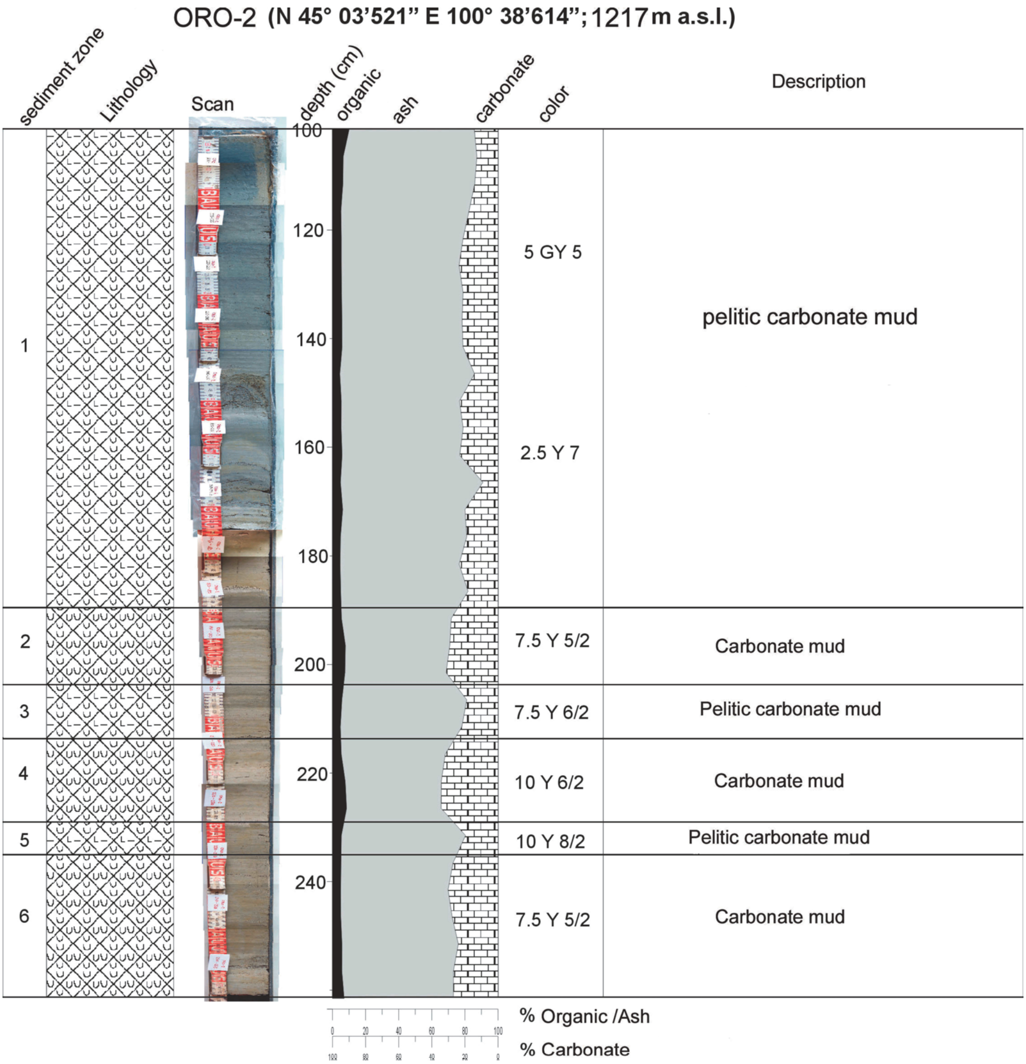


Fig. 10: The sedimentology and scans of the core ORO-2.

The drilling core ORO-2 is taken from the central part of the lake basin at 45°03'521" N, 100°38'614" E with length of 163 cm involved between 100-263 cm (fig. 10). This core contains a pelitic carbonate and carbonates mud with high concentration and, it is divided into 6 sedimentological zones caused of various content of carbonate.

1. 100-190 cm: Sediment sample of it zone is characterized by pelitic carbonate mud as silt and sandy clay with color of olive grey (5GY 5), light olive grey (2.5GY 7) and olive grey (2.5GY 5). The concentration of carbonate is fluctuated gradually between 9 %-24 % during the zone. An organic content is 10 % at 100 cm the top of the core, and whereas, to the down along the zone it fluctuated very less but not higher than 5 %. We assumed that the climate has changed from cool into warm condition with low precipitation in the period of this zone.
2. 190-204 cm: Sediment sample of the zone 2 is a light grey (7.5Y 7/2) carbonate mud with silt clay. The carbonate content is increasing until more than 30 % and organic content is increasing up to 7.7 % too. A growth of carbonate content might be related with the lower water level caused by dry climate condition.
3. 204-214 cm: This zone has silt clay colored by greenish olive (7.5Y 6/2). The carbonate and organic contents have a decrease in this zone.
4. 214-230 cm: Sample is described in this zone by such as silt clay with color of light olive (7.5Y 7/2), greenish olive (7.5Y 6/2); olive grey (10Y 6/2) and light grey (10Y 8/2). The carbonate and organic contents are increased until the highest content of the core ORO-2 (carbonate - 34.3 %, organic - 8.4 %).
5. 230-236 cm: The zone is described by pelitic carbonate sandy mud with color of greenish olive (10Y 8/2). Contents of carbonate and organic are decreased relatively in this zone.
6. 236-263 cm: Sediment sample of this zone is described as a carbonate mud colored of light olive grey (7.5Y 5/2). An organic and carbonate contents are fluctuating gradually in this zone. It might be related with rather small change of the climate.

The drilling core ORO-3 is taken from the east part of the middle area of the lake basin at 45°03'112" N, 100°39'472" E with length of 637 cm (fig. 11). Sediment sample of this core is described by lithological feature and colour, and divided into 20 sediment zones.

1. 0-22 cm: Sediment zone 1 is characterized by a pelitic carbonate mud with color of olive grey (5GY 5/1). Carbonate content is fluctuating between 13-20 % and an organic between 4.7-6.7 % in this zone.
2. 22-59 cm: Sample of this zone is described as a carbonate mud with color of olive grey (2.5GY 5\1). Content of carbonate is increased till 29 %, and although an organic content is changed less between 4.5-5.2 %.
3. 59-73 cm: This sediment zone has been divided into 2 subzones: pelitic carbonate mud and carbonate mud. 1st subzone is coloured with olive grey and the carbonate content is decreasing relatively till 17 % in this zone. As for organic content, this situation is not observed, and it is increased up to 6.8 %. 2nd subzone is described as a carbonate mud. The carbonate and organic contents of this subzone are increased sharply; carbonate - up to 26 %, organic - till 8%.
4. 73-92 cm: Sediment sample is defined by a pelitic carbonate mud with colour of olive grey (10Y 5/2) for this zone. This zone contains the highest content of carbonate and organic of the core ORO-3: carbonate - 39.7 % and organic - 9.2 %.
5. 92-267cm: This zone is the longest one of the core and characterized by a carbonate mud with colors of olive grey (10Y 5/2), light grey and dark olive grey (7.5Y 7/2, 5GY 5/1). Contents of carbonate and organic are changing with a short frequency (carbonate - 16-35 %; organic - 4.3-8.0 %). Totally this zone has more contents than the other zones.
6. 267-291 cm: Sample of this zone is determined by greenish grey (5G 5/1) carbonate mud. Total content of carbonate is decreasing (9-18 %) and an organic content is between 3.7-8.1 %.

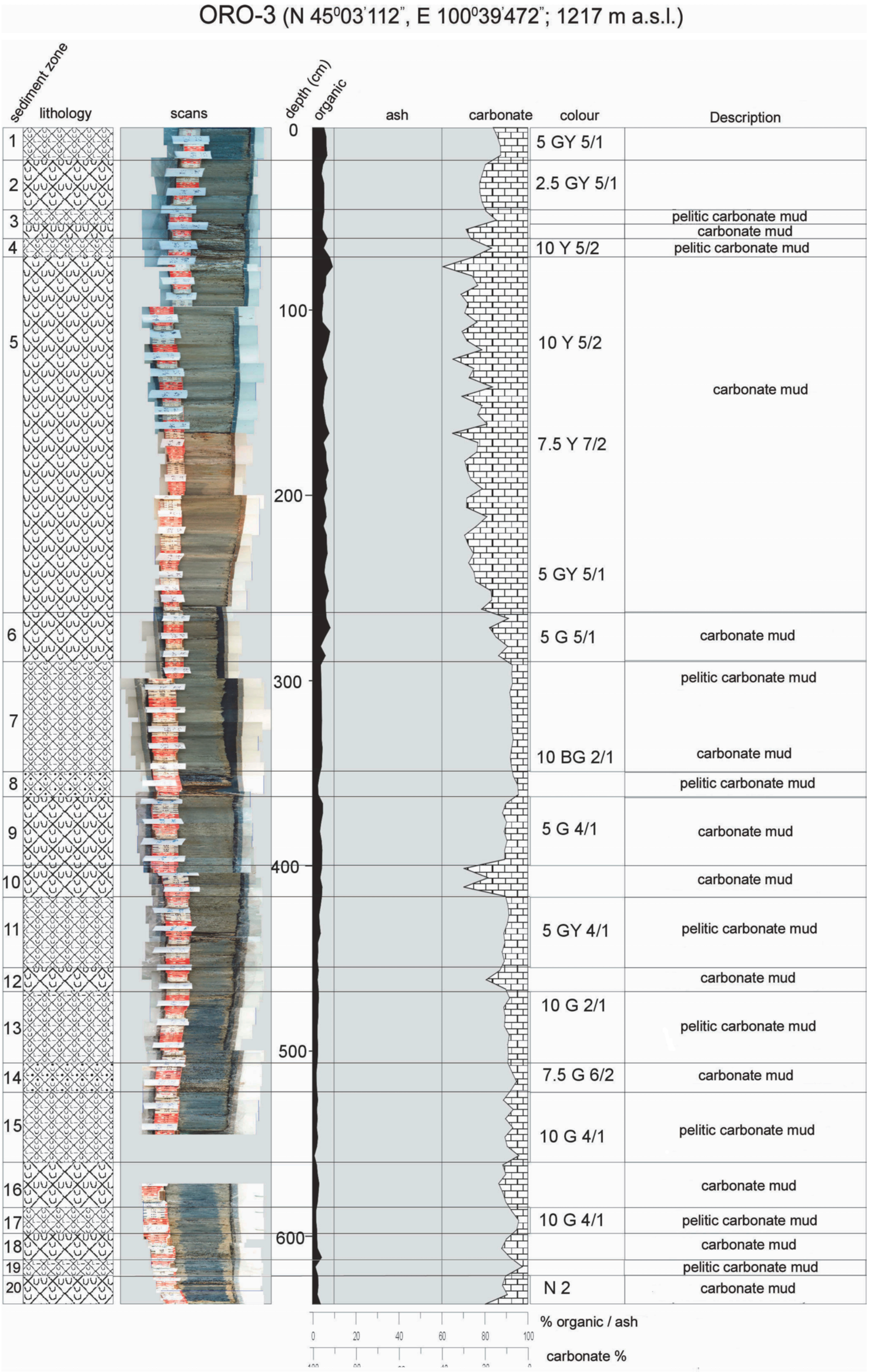


Fig. 11: The sedimentology and scans of the core ORO-3.

7. 291-352 cm: The zone is described by a pelitic carbonate dark-colored (10BG 2/1) mud. A change of contents of carbonate and organic is very less compared with the other zones.
8. 352-365 cm: Sediment zone 8 is characterized by a pelitic carbonate mud with sandy stripes. Color of sample was dark greenish grey (5G 4/1). Content of carbonate has a decrease in this zone till 4.7 % and an organic content is decreasing too till 2.4 %.
9. 365-405 cm: This zone is defined that carbonate mud with color of dark green (5G 4/1). Carbonate content is increasing up to 12% and an organic till 4.7 %.
10. 405-418 cm: Sample of this zone is described by a carbonate mud with color of dark green. Content of carbonate has considerable sharp increase up to 30% in this zone compared with others and, as for organic content, this occurrence was not found. Content of organic is between 3.4 and 4.4 %.
11. 418-450 cm: Sediment sample is determined that pelitic carbonate mud with some sandy stripes. Color of sample is black grey (5GY 4/1). An increase of carbonate content is not observed, in contrast, it is decreasing to 12 %. Content of organic has no extreme change; it is fluctuating between 2.4-3.6 %.
12. 450-469 cm: This sediment zone is characterized by a carbonate mud with colour of dark olive grey (5GY 4/1). Content of carbonate is increasing considerably up to 20 %. As for organic content, such increase is not occurred; it is around 2.5 %.
13. 469-510 cm: Sample of sediment for this zone is defined by pelitic carbonate mud as sandy silt clay colored by greenish black (10G 2/1). Content of carbonate is decreasing till 9.3 % and content of organic is not changed almost.
14. 510-525 cm: Sediment zone 14 is described by grayish olive (7.5G 6/2) carbonate mud with sandy stripe. Carbonate content has an increase till 11.3 %, and an organic content is 2.4 % in this zone.
15. 525-558 cm: This zone is defined by a pelitic carbonate mud with color of dark greenish grey (10G 4/1). There are observed some sandy stripes on the sediment samples. Content of carbonate is changing frequently between 7-10 %. An organic has no higher content than 1.8 %-2.4 %.
16. 558-583 cm: Sample of sediment of this zone is described as carbonate sandy mud. There is observed an increase of carbonate and organic contents in the sediment zone 16. Carbonate content is going up to 12 % and an organic till 3 %.
17. 583-597 cm: Sediment zone 17 has a pelitic carbonate mud with colour of dark greenish grey (10G 4/1). Sandy compounds were observed in the sample of sediment of this zone. Contents of carbonate and organic are decreasing; carbonate - to 4.5 %, organic - to 1.5 %.
18. 597-612 cm: This sediment zone is characterized by carbonate mud as a silt clay colored by black (N 2). Compositions of sample as carbonate and organic are growing in the zone 18. Carbonate content is increasing till 12.4 % and, an organic up to 4.1 %.
19. 612-620 cm: Sample is defined as a pelitic carbonate sandy mud. Content of carbonate in the sediment is decreasing considerably. It is 2.8 % in the zone. As for the content of organic, it is going down too till 1.2 %.
20. 620-637 cm: The last zone of the core is zone 20. This sediment zone is described as a carbonate sandy mud with color of black (N 2). Compound of the sediment as carbonate content is fluctuated between 9.8-19.8 %. An organic content is changing also between 2.1-3.6 %.

Total carbonate content (TCC) and total organic content (TOC) are changing in every sediment zone of the core ORO-3. Furthermore, the color of sample is different in every zone caused by the concentration of carbonate and organic.

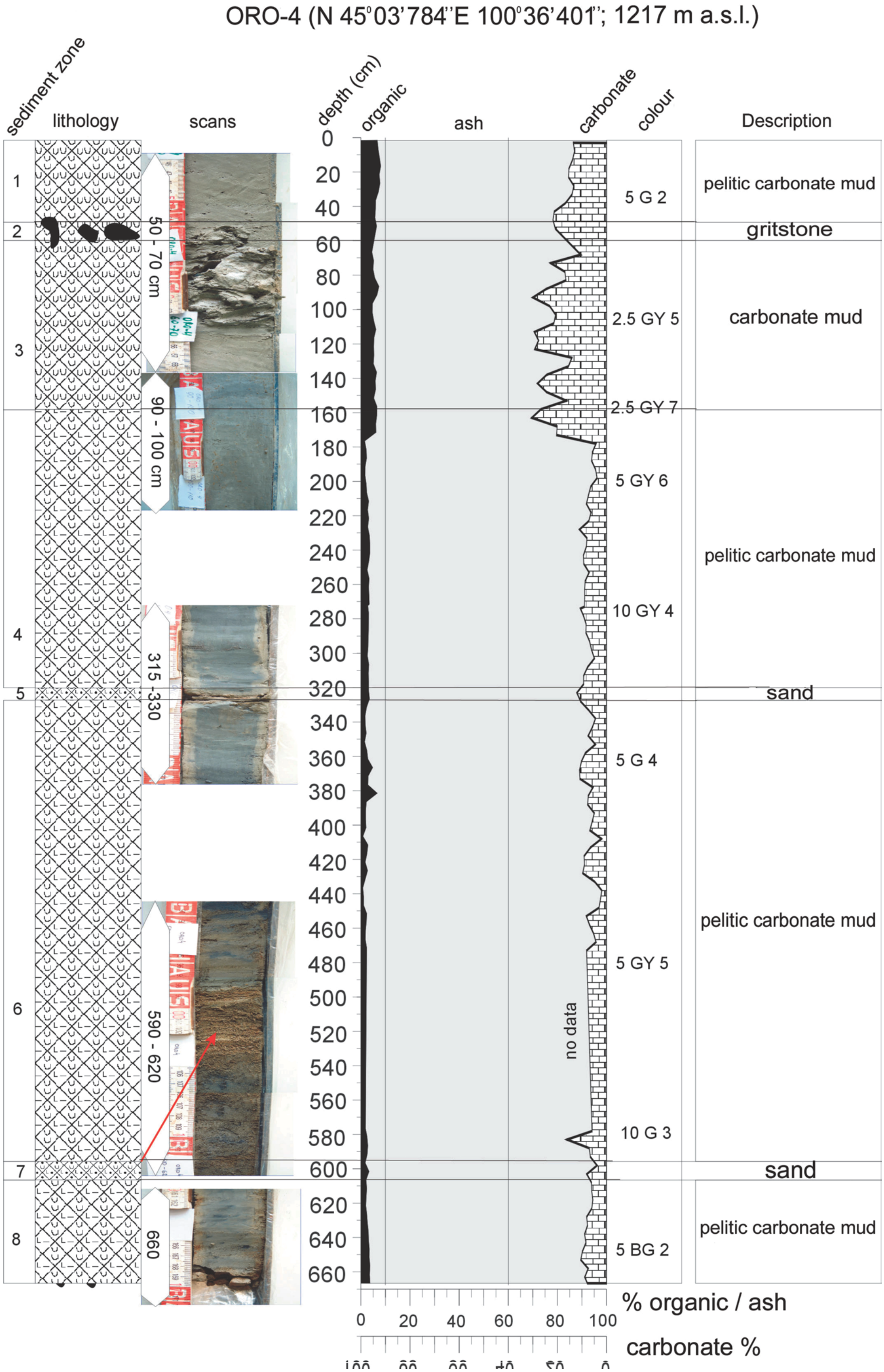


Fig. 12: The sedimentology and scans of the core ORO-4.

The drilling core ORO-4 is taken from the North West part of the middle area of lake basin at 45°03'784" N, 100°36'401" E with length of 670 cm (fig. 12). This core is divided into 8 sediment zones, which are characterized by amount of contents of carbonate and organic.

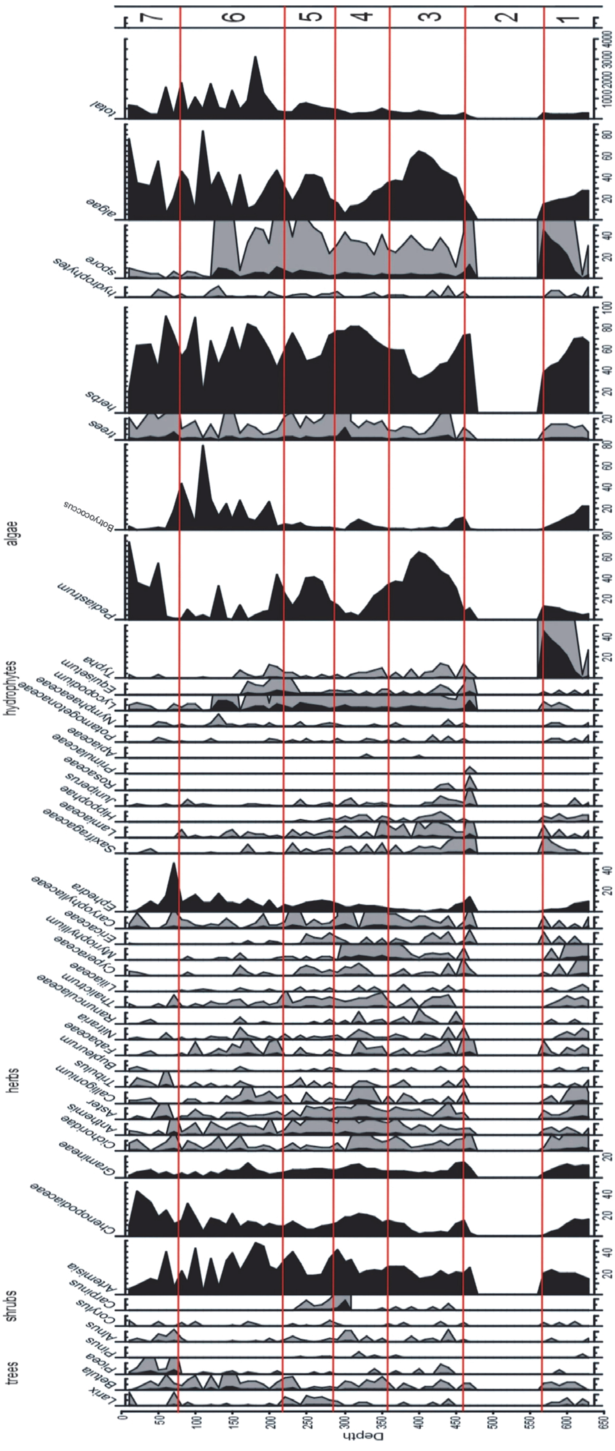
1. 0-53 cm: First zone of the core ORO-4 is described by pelitic carbonate mud. Sample of sediment is determined as a silt clay with color of greenish black (5G2) and clay colored by greenish grey. This zone has carbonate content of 13.4-22.2 % and organic of 5.7-8.1 %. Carbonate content is increasing from top to the down, as for an organic, content is decreasing to the down.
2. 53-65 cm: Sediment sample of it zone is grit stone clay what has no content of carbonate and organic. The sample is not analyzed for loss of ignition (LOI).
3. 65-156 cm: It zone is characterized by carbonate mud as clay colored by light olive grey (2.5GY 7) and silt clay with color of olive grey (2.5GY 5). Total content of carbonate of this zone is the highest in whole core ORO-4. However, carbonate content is fluctuating between 11-30% inside the zone. As for an organic content, that occurrence is occurred too. Content of organic is the highest, and it is varied from 4.4 % to 6.6 %.
4. 156-317 cm: This zone is longer than others and so, it has many layers which are characterized by different following types of sediment: silt clay with colors of light olive grey (2.5GY 7), olive grey (2.5GY 5) and dark blue grey (10BG 3), sandy silt clay colored by olive grey (5GY 6) and blue black (5BG 2), greenish grey (10GY 5) clay and greenish grey (7.5GY 5) medium clay. Totally it zone is described by pelitic carbonate mud.
5. 317-320 cm: Sediment sample of this zone is determined as sand mud.
6. 320-595 cm: It zone is the longest one of the drilling core ORO-4 with pelitic carbonate mud. Sample has had many layers such as sand, fine sand with color of dark olive grey (5GY 4), clay with colors of dark greenish grey (5G 4), olive grey (5GY 5) and dark greenish grey (10G 3), sand clay colored by dark bluish grey (5BG 3), silt clay with colors of olive grey (5GY 6) and bluish black (10BG 1.7), fine sand clay layer colored by dark greenish grey (5G 3) and dark bluish grey (5B 4, 5BG 3). Sediment sample of in between 480-560 cm is lost and so there is no data.
7. 595-607 cm: Sample of sediment of it zone is characterized by sand mud.
8. 607-670 cm: It zone has pelitic carbonate mud with layers of silt clay colored by bluish black (5BG 1.7, 5BG 2) and dark bluish grey (5BG 4); sand and clay with color of grayish olive (7.5Y 6/2).

5. Vegetation development

5.1. Pollen records of the core ORO-3

Sediment cores with diameter of 5 cm were analyzed for palynological investigation. Chemical preparation including an acetolysis was done in the Laboratory of MOLARE Research Centre. 34 pollen and spore types have been determined from the lake bottom deposits of Orog Nuur. A calculation percentage of pollen content is based on the sum of groups including trees, shrubs, herbs/grasses and hydrophytes, but excluding spores. Pollen types are determined with 40x and 100x magnifications of microscope and documented with pictures (fig. 14). Pollen diagram (fig. 13) was designed with the software „TILIA“.

According to pollen analysis, the dominant types are *Larix, Betula* and *Picea* type as trees, *Artemisia*, Chenopodiaceae and Gramineae as herbs. Occurrence of types is not constant in the different depths of the core. Total content of arboreal types such as *Larix, Betula* and *Picea* is less than 10 % in the entire core. *Betula* occurred at the depth of 80 and 190 cm and *Larix* is recorded with values of about 10% at the depth between 100 and 60 cm also between 20 and 10 cm. *Picea* is less than 5 % in between 85 and 10 cm of the core. Shrubs like *Alnus* and *Corylus* have a very poor content at the depth between 110 and 100 cm and 75 - 65 cm too.



The abundant types of NAP are *Artemisia* and Chenopodiaceae, subdominant types are Gramineae and *Ephedra*. Generally, *Artemisia* is decreased from bottom to top of the core. It shows the vegetation cover was influenced by human impact from older to younger time of the profile. However, this decrease does not exist in entire core. It is a description of that the climate condition was changing by short-term events. Highest percentages of *Artemisia* are located in between 210 and 140 cm as 20-50 %, but this content changed sharply at the depth of 130, 110, 90 and 70 cm into 2-10 % and at the depth of 120, 100, 80 and 60 cm it is increased again up to 30-40 %.

Chenopodiaceae are described by 10-40 % in the entire core, although had a negative correlation with *Artemisia* type. The content of Chenopodiaceae is increased from the bottom to the top. We assume that it is an expression of drier conditions from older to younger time. Chenopodiaceae is typical vegetation for a desert and dry steppe. The highest percentage of type is 40 % in between 50 and 10 cm. At 210 to 50 cm Chenopodiaceae is increased gradually, but at 110 cm it is decreased considerably till 5 %.

Gramineae are distributed by 5-10 % in the entire core; however, there is observed a change at the depth between 130 and 50 cm.

This change occurred in the same time with *Artemisia* and Chenopodiaceae. That correlation of *Artemisia*, Chenopodiaceae and Gramineae may express the temperature change related with humidity. *Ephedra* type is less than 20 %, but it reached its highest content at the depth of 70 cm to 50 %.

Fig. 13: Pollen profile of lake bottom deposits of the Orog Nuur; drilling core ORO-3; det.: GEGEENSUVD.

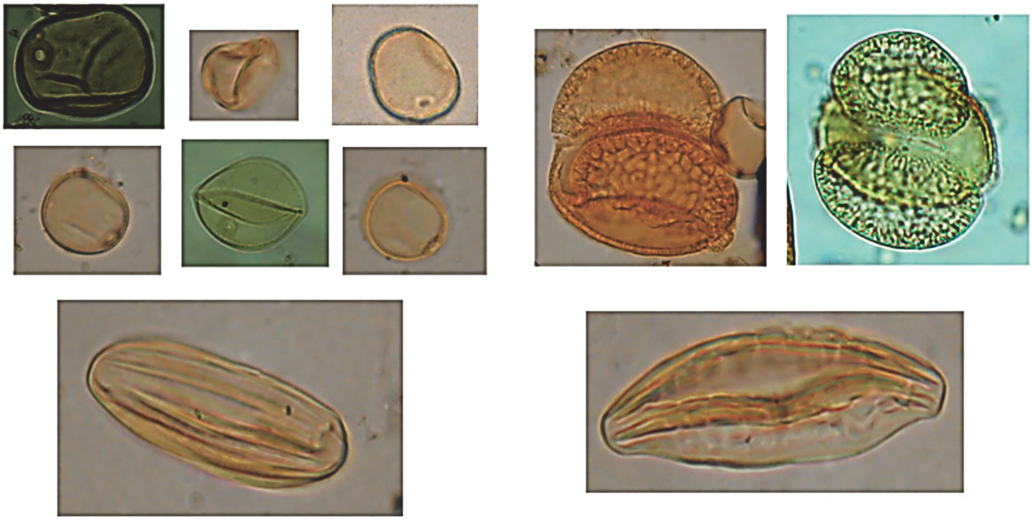


Fig. 14: Pictures of some pollen types: above left - Gramineae, above right - *Pinus*, below - *Ephedra fragilis* and *distachya* types.

Two types of algae such as *Pediastrum* and *Botryococcus* were determined from the Orog Nuur deposit core. *Pediastrum* spores are occurred with values of 45 % at the depth of 210 cm, 30 % at 130 cm, 55 % at 50 cm and 80 % at 10 cm depth. *Botryococcus* occurred with 30 % at the depth of 200 cm, 80 % at 110 cm and with 45 % at 80 cm depth. It is decreasing up to the top.

Hydrophytes like *Myriophyllum, Nymphea* and *Potamogeto*n occurred with very low content in the sample.

5.2. Vegetation history

Steppes of Mongolia are dry and characterized by not only grass dominance, but also a broad distribution of pea shrubs (*Caragana microphylla, C. stenophylla, C. pygmaea*) and sagebrushes (*Artemisia* spp.). These southern dry steppes change into desertified steppes further south where tall sod feather grass is replaced by short feather grass (*Stipa gobica, S. klementzii*). Thus to the south the desertified steppes are replaced by semi-deserts which are called desert steppes (LAVRENKO 1978, YUNATOV 1950, 1974), and then by desert grassy meadows (RACHKOVSKAYA 1983, 1993). Recently the desert steppe vegetation dominates in the surroundings of Orog Nuur. During the field work at the lake a species of tree *Betula microphylla* was observed in the Ikh Bogd Mountain. The habitat of this tree is actually in the Ikh Bogd Mountain range at 2000 m a.s.l.; that means, it could be transported by wind from there to the lake. The condition for growth of trees does not existing nowadays in the surrounding of the lake. However, *Larix* and *Picea* are recorded in the sample of Orog Nuur. Pollen of trees could have been transported by runoff water from the origin area of Tuin Gol in Khangai Mountain when the area had cooler and wetter climate conditions.

According to record of *Artemisia*, Chenopodiaceae and Gramineae types, the Orog Nuur surrounding areas were steppe, and/or desert steppe regions when dry and warm climate conditions dominated. This is confirmed also by *Nitraria* and *Ephedra* types, which are typical and endemic plants for desert steppe. AP pollen content shows that the basin of Orog Nuur and Tuin Gol was characterized by humid and cooler than in present time in the headwater regions. *Nitraria* grows recently in the catchments areas.

Pediastrum and *Botryococcus* algae are indicators of resurgence of water level of Orog Nuur. Thus, the complete investigation of algae is requested for the lake.

6. Results

The oldest evidences for higher lake levels are assumed by MURSAEV (1954) and highlight a huge area of the Valley of Gobi Lakes as a connected lake area in times of Middle Pleistocene. During Young Pleistocene MURSAEV (1975) marked a smaller area of reduced lake levels, however in the Orog Nuur basin the shore line reached nearly Bogd Som north of the recent lake. TSEGMID (1975), THIEL (1958) and WALTHER (1998) confirmed these highest young Pleistocene lake levels and LEHMKUHL & LANG (2001) reported about OSL-dating, which supported the age of Young Pleistocene. North of the lake, there are Pleistocene lake bottom sediments and eolian deposits and south of the lake pediments are distributed as shown in the map of ZABOTKIN (1988). By glacier melting at the end of the Pleistocene and Early Holocene the Orog Nuur level rise and reach during middle Holocene times levels of up to 25 m above the maximum stage of 1969.

The drilling cores show pelitic muds with a higher carbonate content in the upper part. Due to the relative high content of carbonate in the upper part of mud deposits, it must be assumed that there was an intensive biological activity with shallow water conditions in the lake. According to the pollen profile from lake bottom deposit of Orog Nuur, the surrounding climate condition is very often changeable. Pollen investigation shows humid and cool weather (pollen of coniferous trees - transported from humid and cool condition) in the watershed area. In respect to the pollen diagram, pollen of some plants typical for dry conditions increase up to the top of the profile. We may assume that the environment of Orog Nuur is getting drier over the time. Changing algae presence and maxima of pelitic carbonate mud is corresponding, so that at the site ORO-3 a lake had been existed during Holocene times. Algae content shows that the water level was changing evenly.

The historical lake level changes can be documented between 1951 and 2014 with maps, aerial photos and satellite imagery. The analyses of the these sources show that there can be very short term oscillations of the lake due to shallow water conditions and that wet periods of several years in Khangai Mountains are directly linked with the lake levels. Between 2000 and 2005, the whole water surface nearly disappeared completely and only in the eastern part, a small relict of the lake was still existing.

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