Complex Analysis of the Development of Lake Balkhash During The Last 2000 Years

Bolat Z. Aubekerov[1)], Saida A. Nigmatova[2)], Renato Sala[1)], Jean-Marc Deom[1)], Kunihiko Endo[3)] and Tsuyoshi Haraguchi[4)]

1) *Department of Geoarchaeology, Kazakh Scientific Research Institute on Problems of the Cultural Heritage of Nomads, Kazakhstan*
2) *Institute of Geological Sciences, Kazakhstan*
3) *Nihon University, Japan*
4) *Osaka City University, Japan*

CONTENTS

The present article reports the preliminary results of laboratory analyses of samples of bottom sediments of Lake Balkhash collected from a 6 m core collected near the Tarasal Peninsula and chronologically attributed to the last 2000 years. The first chapter summarizes the results of coastal surveys and complex laboratory analyses of core samples focusing on lithology, granulometry, soil color, magnetic susceptibility, diatoms and salinity ratios. The second chapter reports in detail the results of palynological analyses with the distinction of eight palynozones. All together, these various proxy data allow the reconstruction of changes in the climate and water level of Lake Balkhash during the last 2000 years.

1. Complex analysis of the evolution of coasts and bottom deposits of the New[1] Lake Balkhash

The solution of the problem of the structure and formation of the coasts and sedimentary layers of Lake Balkhash has a huge value for the understanding of the conditions and history of the formation of the lake itself. This fact lies at the basis of a new wave of scientific studies of the coasts and bottom of Lake Balkhash, which were started in the years 2007 - 2008 by a scientific team putting into cooperation experts of Kazakhstan and Japan.

1.1. Sedimentary structure of coasts and bottom

The study of the geomorphological structure of the coast and bottom of Lake Balkhash was implemented though reading of existing scientific literature, land surveys of the coast (lead by Profs. Endo, Nakayama, and Aubekerov) and through a geophysical survey of the lake bottom (lead by Prof. Haraguchi).

1.1.1. Geomorphological structure of the coasts

The joint Kazakhstan-Japan studies of the structure of the coasts verified the validity of the scientific records concerning macrostructural elements and processes provided by Soviet geologists; and implemented a detailed study of terraces in three coastal sites of Northern Balkhash by analysis of satellite images and a land survey. The preliminary results of the general survey of terraces are included in par. 2.4.2, sub-aerial deposits; the results of the specific analysis of three cases of coasts in Endo et alia 2009.

Referring to Lake Balkhash, M.P. Rusakov (1933) differentiates three types of coasts.

- Low alluvial coast. This covers the entire southern lake depression and also the mouths of some rivers of the northern coast like the Mointy on the west, the Torkau in the center, the Bakanas in the west, and others. These coasts consist of lowlands covered by reeds.
- Coast of cross-sectional type. This prevails on the western coast where the shoreline is generally cut obliquely by rock folds.
- Coast of longitudinal type. This is more characteristic of the northern coast where the shoreline quite often runs parallel to the total extension of the sedimentary thicknesses (peninsulas of Tasaral, Shaukar), or parallel to their border with effusive rocks, or according with the line of dislocation of these parts occurring in dry areas of the coast. By the degree of incised bays, the northern coast stays considerably behind the western.

According to L.S. Berg's definition, the southern Balkhash coast consists of a sandy desert, the western coast a stony desert, and the northern coast a clay desert (Rusakov, 1933). The formation of the southern coast is due to the action of lake regression, the formation of the Ili deltas, and the

[1] for the definition of the Old and New Balkhash, see the article of Aubekerov *et alt*., Prehistorical and Historical Stages of Development of Lake Balkhash in this volume.

formation of the aeolian inter-fluvial relief.

The formation of the western, northwestern and northern coasts is different, and is basically the consequence of lake level changes and of neotectonic movements. Everywhere a major role is also played by wind activity. Changes in the water level of the lake and wave-cutting activity created lagoons that, because of water evaporation, turned first into separate lakes and later into solonchak (saline soils).

- Western Pre-Balkhash, which occupies the coastal territories from the Saryshagan to the Chimpek Gulf, belongs to the northeastern slope of the Chu-Balkhash watershed plateau. Here the plateau consists of a denudated sculptural surface that has been substantially eroded, represented by sharply dismembered low lakeside low-hills with relative altitude anomalies of 20 - 40 m. This part of the coast has an ingressive character with numerous islands. (Fig.1)
- The northwestern parts of the coast tend to rise, causing the formation of flat valley bottoms and superimposed valley terraces. (Fig.2) This part of the coast is complicated by breaks, therefore we can observe here the existence of a steep rocky coast and a rather small number of lagoons. Moreover, in this coastal site a tendency to flexure existed, as reflected by its geomorphological structure, and contributed to the stabilization of the location of the delta of the river Ili.
- An important role has been also played by the formation of water-flow in the valleys of Northern Pre-Balkhash. These valleys determined the intensity of the discharge of fragmentary material and formed the low coast in their delta areas. During the existence of the modern aquatorium of Lake Balkhash, the water flow from the Northern Pre-Balkhash valleys has been congested and its share does not exceed 8 - 10 % of the general inflow to the lake.

Fig.1 The ingressive character of the southwestern Balkhash coast, with numerous islands.

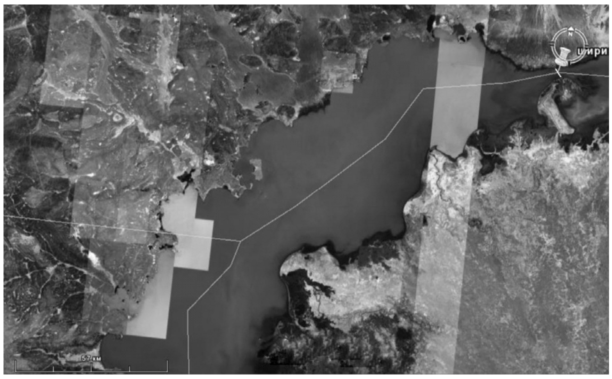

Fig.2 Satellite image of the large valleys of the northwest coast of Lake Balkhash, with flat bottoms and superimposed terraces

1.1.2 Geophysics of the lake bottom

The profiles sorted out by geophysical studies conducted in the eastern part of Lake Balkhash ascertained that the larger eastern part of the lake depression is shallow with a depth rarely exceeding 10 m, and that the thickness of the friable bottom deposits is 0 - 10 m.

Under the bottom deposit, buried valleys with erosive terraces are quite visible “at 325 m, 330 m, and 335 m, being 5 m to 15 m lower than the present level of 340 m above sea level asl” (Endo et alia, 2009). Their presence suggests that at the time of their formation, the lake most probably did not exist and the plains at the north of the Balkhash depression were located at the above altitudes.

In several locations at the bottom of the modern lake the speed of the undercurrent is so high that the contemporary bottom deposit is almost absent and only rough material remains.

1.2. Stratigraphy of bottom deposits

A complex study of the stratigraphy of the bottom deposits was conducted by means of geophysical scanning of the bottom of the lake and analysis of a core drilled near the Tasaral Peninsula (Tarasal core). The core was six meters long, with its bottom preliminarily dated to 2000 BP. Japanese experts led complex analyses of the core: lithological and granulometric structure, magnetic susceptibility (residual magnetization), color and salinity of bottom deposits, diatom species, and absolute dating (AMS-method of radiocarbon dating, ^{210}Pb and ^{137}Cs dating). (Endo *et alia*, 2007, 2009).

Kazakhstan specialists led the drilling tasks and palynological analyses of core samples of which a preliminary report is given below. (Fig.5)

1.2.1. Lithology, granulometry and soil color

The lithologic and granulometric structure of the core is quite homogeneous, consisting of dark and light greenish-grey silty clay and clayish silt.

The sequence of sediment colors shows a yellowish anomaly between the core depths of -3 and -2 m, in correspondence with the IV and III palynozones and the most abrupt transgression of lake water level.

1.2.2. Magnetic susceptibility

Paramagnetic susceptibility is inversely proportional to the value of the absolute temperature. The length of the Tarasal core shows variations between 0.2 and 0.4 Si/g, with minimum peaks at core depths of -5.9, 5.5 and 2.9 m; and maximum peaks at -5, -2.5 and 0 m. The maximum peaks are consistent with the results of palynological analyses and the individuation of transgressive stages of lake water levels; the minimum peaks deserve further investigation.

1.2.3. Palynology

To reconstruct and correlate landscape and climatic changes, percentage variations in groups of grassy plants were examined. It has been established that the content of the spore-pollen spectrum depends on ecological conditions at both the coastal line and in the territory of the catchment basin of the lake, and also on the morphology of the bottom which defines the speed of reaction of the coastal line to increases or decreases of reservoir depth. In conditions of shallow water depth, 3 - 7 m or less, gently sloping costal areas will react to the establishment of an arid phase (i.e., reduction of river inflow and lake water level) by drainage of part of the bottom, expansion of the coastal zone, overgrowth of the coastal zone with aquatic vegetation (canes, reeds, thickets, sedges, etc.), and an increase of pollen of coastal water vegetation in lake bottom deposits. By contrast, the steep banks of western Balkhash will react to a pluvial phase and related increase of water level with a reduction of the shallow coastal zone, a reduction of the water vegetation cover of the coastal zone, and a reduction of coastal pollens in bottom deposits. Referring to the entire lake, a net increase of pollen of various coastal water plants, a relative prevalence of chenopodiaceae over artemisiae, and a constant content and percentage of arborous remains are observed in the palynospectrum related to an arid phase.

In the region where the samples of bottom deposits were collected, modern vegetation is represented by northern and middle desert vegetation consisting of hemipetrophyte complexes, with communities of Artemisia terrae-albae, Salsola arbusculaeformis, Anabasis salsa and Atriplex cana (Fig 3).

Palynological analyses of 106 samples from the 6 m long Tasaral core revealed that the palynospectrum was of rather homogeneous content, reflecting the vegetation typical of northern and central deserts.

A detailed report of the results of the palynological analyses is given in the second half of this article.

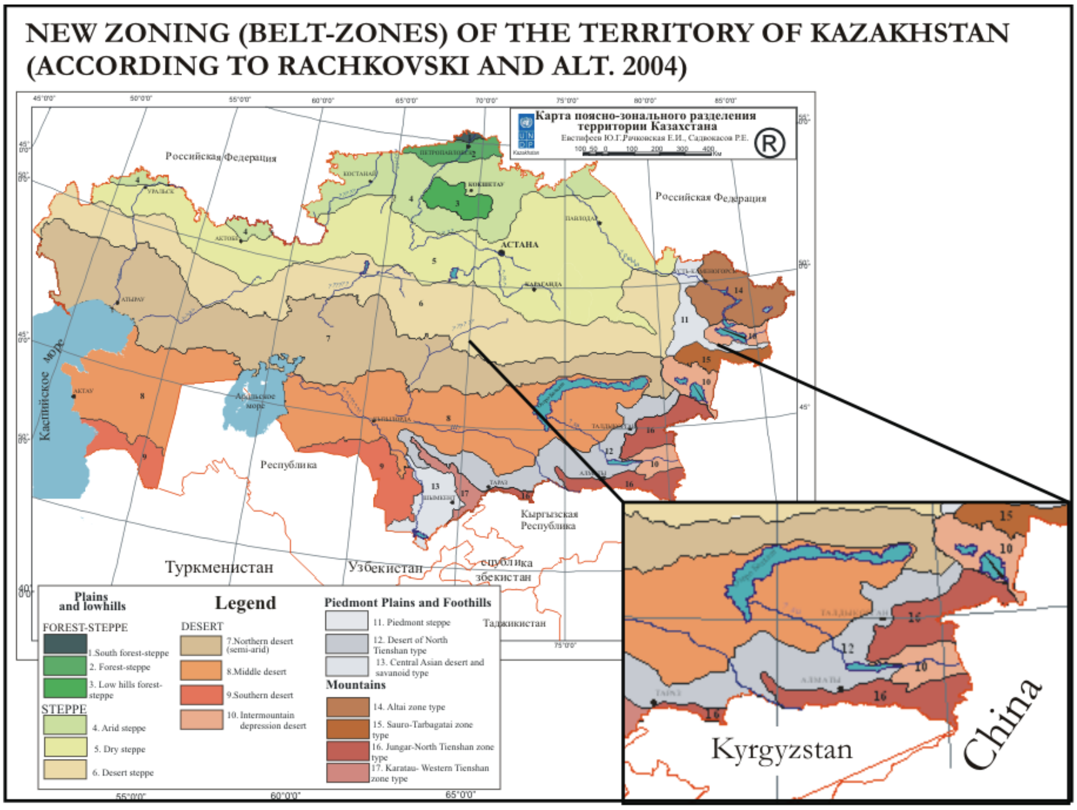

Fig. 3　New zoning (belt-zones) of the territory of Kazakhstan (Rachkovskaya and alia, 2004)

1.2.4. Diatom algae

Diatomaceous algae (Bacillariophyta) living in various ecological conditions are good indicators of the quality of the water (salinity), its depth, and other ecological factors. Their type and number depend on water depth and salinity, and in closed lakes, can be successfully used for the reconstruction of changes of water level.

Japanese experts have analyzed the development during the last 2000 years of percentages of planktonic species, epiphytes, and benthic and brackish diatom species in samples collected from the Tarasal core at an interval of 2.4 cm (Endo *et alia*, 2009). Benthic and brackish species develop with rising levels of salinity, and planktonic species and epiphytes develop in fresh water environments. Preliminary results show (Fig.4):

- significant changes at core depths of -580 and -280 cm, indicating a rapid drop of lake level and increase in salinity. Above these horizons the quantity of fresh-water plankton increases, indicating a rapid increase of lake level and desalinization
- similar changes but of smaller amplitude at core depths of -150 and -500 cm.

Consequently, the analyses of diatom algae reveal to be a good indicator of salinity and therefore of level changes in the Balkhash lake.

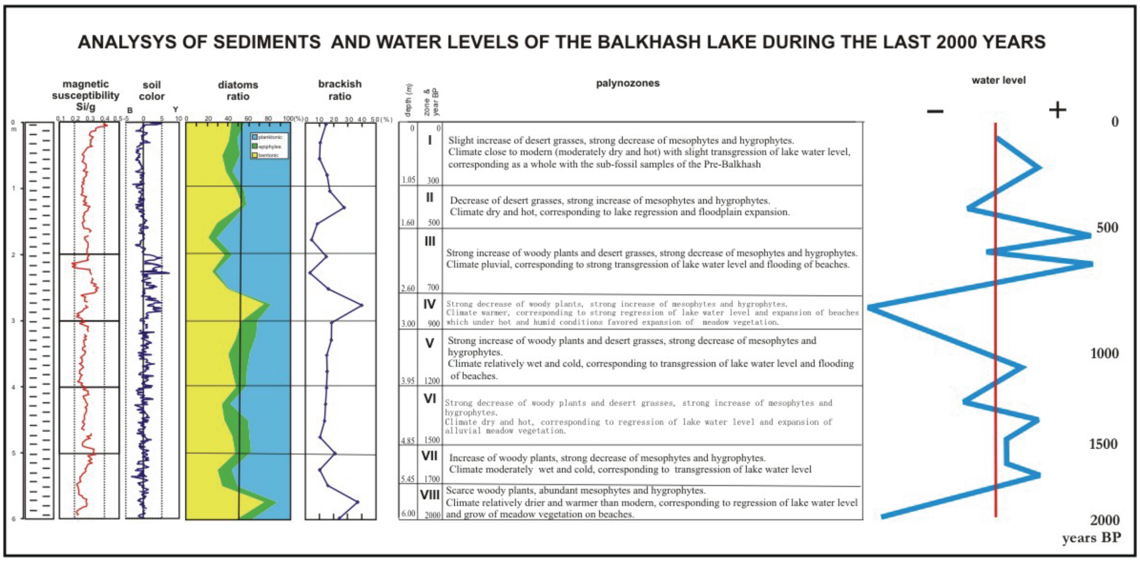

Fig 4 Reconstruction of relative changes of water level of Lake Balkhash during the last 2000 years based on different proxies; from left to right: magnetic susceptibility, soil deposit color (B-blue, Y-yellow), percentages of diatom species (yellow-benthic, green-epiphytes, blue-planktonic), percentage of brackish species, palynozones, and lake water levels.

1.3. Multi-proxy reconstruction of changes of water level of Lake Balkhash during the last 2000 years

A combination of the magnetic susceptibility (residual magnetization), soil deposit color, percentages of diatom species, percentage of brackish species, content of the palynospectrum of coastal epiphytic plants, and absolute dating allows a preliminary reconstruction of the relative fluctuations of the depth of Lake Balkhash during the last 2000 years. (Fig.4)

2. Scientific report on palynological analyses of the Tarasal core

The palynological analysis, based on the study of plant pollens and spores, represents the most important part of the paleogeographical and paleoclimatological reconstruction. It allows not only the establishment of the type of vegetation existing in a given territory at a given period of time and the allocation of minor climatic changes reflected in the redistribution of separate groups of plants, but also the determination of well-marked climatic parameters.

2.1. Contemporary vegetation of the region

The territory under study is located on the borders of the Sahara-Gobi Desert province and in the Irano-Turanian sub-province (Botanical Geography 2003). Here two climatic conditionally sub-zonal types of desert replace each other from north to south: middle ("real") deserts and piedmont deserts (Map of vegetation 1995). They are followed in the south by the Zailiski Mountain sub-province. Lake Balkhash is located in the zone of middle deserts. (Fig.3, Fig.5)

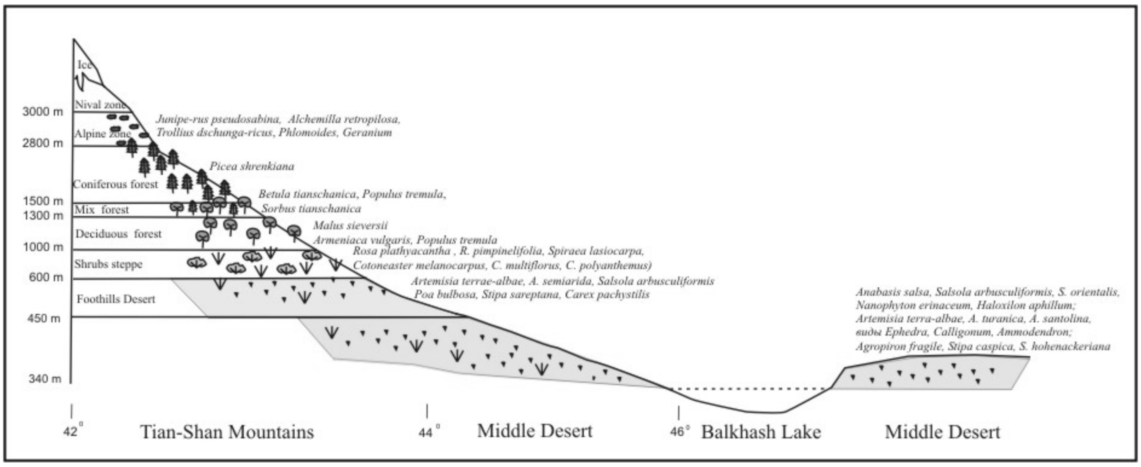

Fig. 5 Distribution of vegetation by vertical zones from middle deserts to Northern Tienshan high mountains

2.1.1. Middle deserts

In middle deserts the general climatic conditions testify to a significant increase of aridization. The soil type of this zone consists of gray-brown frozen desert soil.
Here perennial glasswort (*Salsola*) prevails, up to 62 % of total vegetation. Botanical Geography 2003 quotes the presence of *Anabasis salsa, Salsola, arbusculiformis, Nanophyton erinaceum,* and *Salsola orientalis;* and from pollen analyses, *Artemisia terrae-albae,* and *A. turanica*. Saksaul *(Haloxylon aphyllum, H. persica)* is very widespread on sand, as well as psammophilous shrubs and sub-shrubs *(Calligonum, Ephedra, Ammodendron, Ceratoides papposa, Salsola arbuscula)*, and from pollens, *Artemisia santolina, A. kelleri, A. songarica,* and *A. terrae-albae.* Synusia of graminoids *(Agropyron fragile, Stipa caspia, S. hohenackeriana)* is only found as a community in sands and pits.

2.1.2. Piedmont deserts

Piedmont deserts are located more to the south and embrace all piedmont plains bordering the Northern Tienshan (from East Tienshan to the NE slopes of the Syrdaryan Karatau) and the Jungarian Alatau. Here are characteristic dwarf sub-shrubs and desert shrubs with ephemeroids *(Catobrosella humilis, Poa bulbosa*) varying with elevation, in proximity to mountains, and in steppe-deserts with the addition of cereals *(Stipa sareptana, S. richteriana*) and ephemeroids (*Poa bulbosa, Carex pachystilis* of *Gagea* and *Tulipa* type). Northern Turanian pollens are dominant *(Artemisia terrae-albae, A. semiarida, A. sublessingiana)*, and in the eastern parts, *A. heptapotamica* and black saltwort (*Salsola arbusculiformis*). In piedmont deserts the most active role is played by communities of wheatgrass.

2.1.3. Zailiski mountain sub-province

The Zailiski mountain sub-province embraces the chain of the Zailiski Alatau, located in the central-northern part of the Tienshan range. The vegetation is of Zailiski-Northern Djungarian zone type. (Rachkovskaya *et alia* 2003). The piedmonts consist of feather-grass-wormwood deserts with ephemeroids. In the steppes of the entire low-mountain band (dry and desertic) a significant role is played by ephemeroids. This is particularly true of the steppe zone of the Zailiski Alatau (which is clearly divided into 3 sub-zones): spring ephemeroids play a significant role in the sub-zones of the desertic and dry steppes. In Northern Tienshan scrubs are characteristic of the steppe zone and are represented basically by rosaceae, but other species are also present. The basic dominants are roses *(Rosa plathyacantha, R. pimpinelifolia)*, spiraea (*Spiraea lasiocarpa)* and species of cotoneasters *(Cotoneaster melanocarpus, C. multiflorus, C. polyanthemus)*.

The woody vegetation in Northern Tienshan is mainly distributed on slopes with northern exposure:

- at the bases of the mountains (700 - 900 m asl), various kinds of bushes grow
- at 1000 - 1200 m asl, bushes are replaced by deciduous forest
- at 1300 m asl, the Tienshan fur-tree is added to the deciduous forest. A characteristic feature of this sub-province is the presence of deciduous woods of apple-trees (*Malus sieversii*), apricots (*Armeniaca vulgaris* of Zailisky Alatau), and aspen (*Populus tremula*)
- from 1500 up to 2800 m pure fur-tree forests grow
- above 2800 asl the fur-tree is replaced by prostrate-type juniper.

These changes are reflected in the sub-fossil palynospectrum, which by further interpretation allows precise division and classification of mineral spectra. Our database of surface sub-fossil spectra helped to differentiate several stages of climatic and vegetation changes and to connect them with water levels of Lake Balkhash.

2.2. Methods and materials

For the implementation of the palynological study of the 6 m Tarasal core of the bottom deposits of Lake Balkhash, 112 sediment samples were collected at 5 cm intervals. Pollens and spores were extracted by methods successfully developed and implemented over a long period of time by the palynological group of the Institute of Geology of Almaty. The basic steps for the preparation of sediment samples are as follows:

1. The sediment samples are processed by a 10 % solution of hydrochloric acid (HCl) and subsequently washed (cleaned).
2. The sediments are cooked in a caustic solution (KOH) and subsequently washed.
3. The sediments are processed by a 10 % solution of nitric pyrophosphate, followed by prolonged decantation by distilled water until a transparent water column above the rock is attained.
4. Triple centrifugation of the sediments in heavy liquid is performed for separation of organic and inorganic fractions, and then the last fractions are washed out.
5. The organic deposit cleared by distilled water is collected and processed by iced acetic acid.
6. Acetolysis is performed, followed by a subsequent washing by distilled water.
7. The sample is processed by spirits and silicate oil or glycerin is added.

The calculation of pollens and spores is preceded by not less than 3 rounds of preparation in order to provide samples with a high pollen saturation.

To obtain significant data, sub-fossil samples were also collected and studied along the whole profile of the Pre-Balkhash region, from the Zailiski Alatau to Northern Pre-Balkhash. This made it possible to obtain reliable material concerning the formation of the palynospectrum in this region and to reconstruct the vegetation of different climatic phases of the Holocene.

2.3. Basic results

The study of 112 samples from the bottom deposits of Lake Balkhash individuated 30 species of pollen and spores (Fig.6), the chronological sequence of which was provided by absolute dating based on micro-radiocarbon analyses.

Due to the stability and low reactivity of the middle desert environment surrounding Lake Balkhash, additional samples of palynological sequences must be collected and analyzed from the lake bottom and from the coastal area in order to provide a sound reconstruction of average yearly precipitation and temperature.

The novelty represented by the Balkhash site is the fact that the lake environment supports some hydrophytic and mesophytic plants that are highly reactive not so much to climate but to changes of lake water level. Based on this fact, the palynological studies referenced by this article allowed the reconstruction of water level changes during the last 2000 years (Fig.4).

2.3.1 - Examining the entire content of the spectra, we differentiated pollens and spores. Among pollens we differentiated four kinds related to four zones of origin: woody plants, desert grasses, mesophytic herbs, and hydrophytic herbs. Positive and negative variations of pollen ratio of woody plants and desert grasses are related respectively to wetter or dryer phases. Positive and negative variations of pollen ratios of mesophytic and hydrophytic herbs are related respectively to negative and positive changes of water level of the lake, which respectively expose or flood fertile subaquatic soils. These categories of plants are listed below in order of distance of their habitat from the shore of Lake Balkhash, together with their significance for paleo-environmental and paleoclimatic reconstructions.

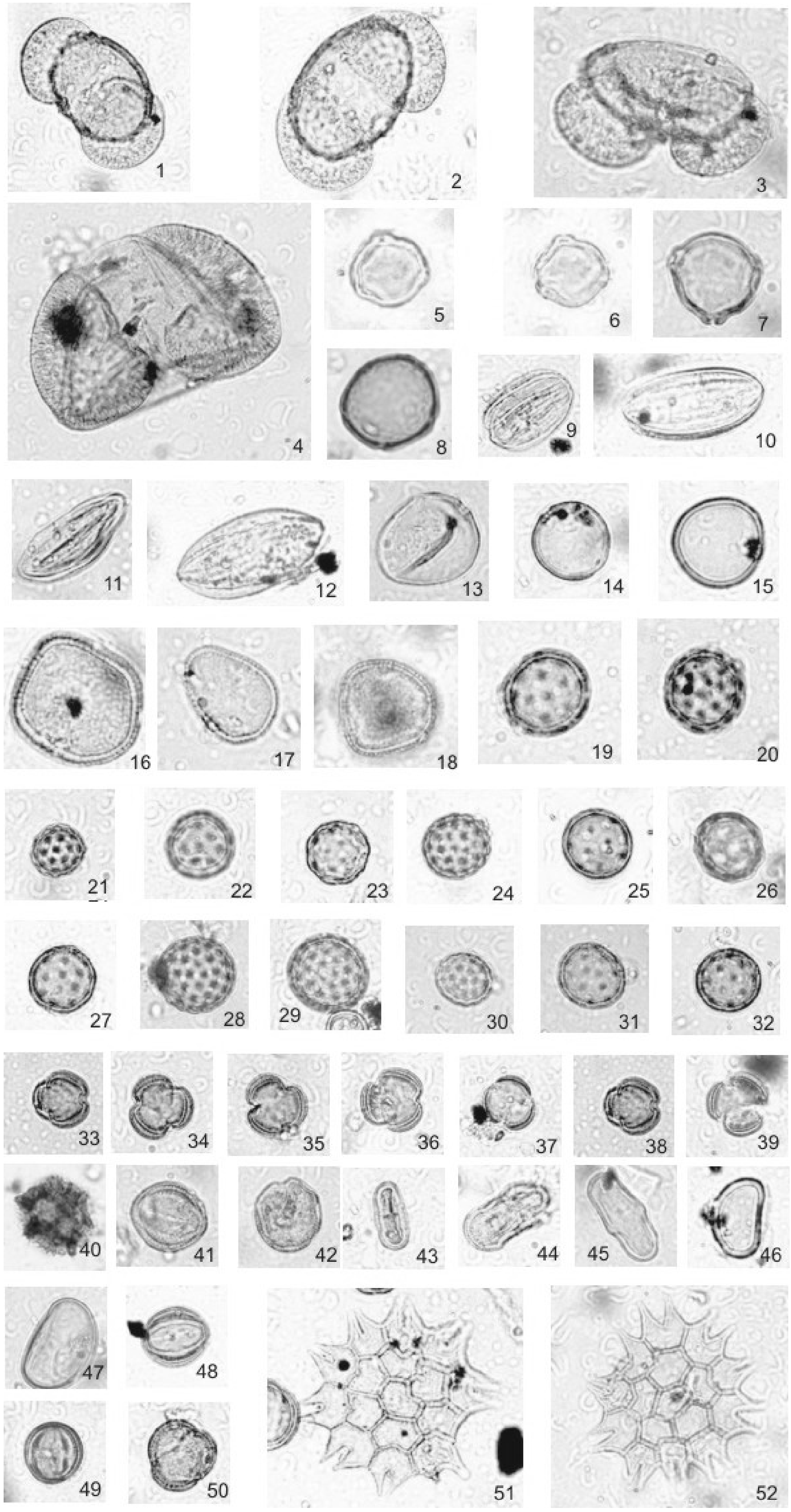

Fig. 6 Photo-table of 20 of the most relevant species and types of pollens and spores from the Late Holocene bottom deposits of Lake Balkhash, ordered as in the palynogram of Fig 7.

1-3 *Pinus sp. (type P. silvestris)*
4 *Picea shrenkiana*
5-7 *Betula sp.*
8 *Ulmus sp;*
9-11 *Ephedra sp.1*
12 *Ephedra sp.2*
13-15 *Poaceae*
16 *Sparganium sp*
17-18 *Typha sp*
19-32 *Chenopodiaceae*
[19-24 *Eurotia type*]
25-26 *Salsola type*
27 *Nanophyton type*
28-29 *Anabasis type*
30 *Atriplex type*
31-32 *Suaeda type]*
33-39 *Artemisia sp.*
40 *Cichoriaceae*
41-42 *Brassicaeae*
43-45 *Apiaceae*
46-50 *Polypodiaceae*
51-52 *alga Pediastrum sp.*

- Woody plants that do not grow in proximity to the lake and could be brought both by wind and river water: pollen of alien species, mainly conifers (*Pinus, Picea*). Also found are pollens of some herbs and shrubs characteristic of distant regions and brought by the Ili river to the southern coast of Lake Balkhash. The number of this class of pollens increases during wet-cold climatic phases and strong winds.
- Desert grasses: pollen of middle desert herbs and shrubs *(Chenopodiaceae, Artemisia)*. Their number increases during wet-cold climatic phases.
- Mesophytic herbs from coastal meadows and riverbeds: Poaceae and various kinds of forbs (*Cychoriaceae, Brassicaceae, Lamiaceae*, etc). Their number increases during dry-hot climatic phases and recession of lake water levels.
- Hygrophytic plants of order *Cyperales* (*Carex)* and *Typhales* (reeds like *Sparganium, Typha)*. Their number increases during dry-hot climatic phases and recession of lake water levels.
- Spores of ferns and algae

2.3.2 - Relative ratio of different species:

- The pollen of herbal plants is 91% of the total, constituting the basis of the palynospectrum.
  - Pollens of salt tolerant desert plants are dominant, with the percentage varying between 73 - 95% among samples: the grass families of Chenopodiaceae (*Atriplex, Salsola, Eurotia, Kochia*, *Anabasis,* etc.) are 35 - 45%, and Asteraceae (*Artemisia terra-albae, A. lessingiana*) is 35 - 42%.
  - An appreciable proportion of 5 - 17% comes from mesophytic plants from coastal meadows: cereals (*Poacea*) 3.5 - 10%, sedges 1 - 8%
  - The 0.5 - 12% proportion of hygrophytic coastal water plants like sedges is also significant, *Carex*, *Sparganium*, and reed-mace (*Typha*).
  - Pollens of various herbs and shrubs (Ephedra) brought by the Ili river to the southern shore of Lake Balkhash lake in proportions not exceeding 3 - 5 % are found in practically all spectra.

- Pollen of arborous plants are scarcer, constituting 7 - 9% of the total number of grain and spore pollens: pine (*Pinus silvestris*) 3.5 - 5%, fur-trees (*Picea sp.*) 2%, birches (*Betula*) 3.5 - 5%, as well as individual cases of willows, alder and linden (*Salix, Alnus, Tilia*). The rather stable and insignificant percentage of arborous pollens points to transport as a formative factor of this part of the palynospectrum.

- Sporous plants are very scarce, represented by individual ferns *(*genus *Polypodium* and *Lycopodium)*. The presence of spores of the seaweed *Pediastrum* was found in all samples.

2.3.3 - A palynogram of the sequence of pollen ratios of the 30 species which have been individuated is shown below.

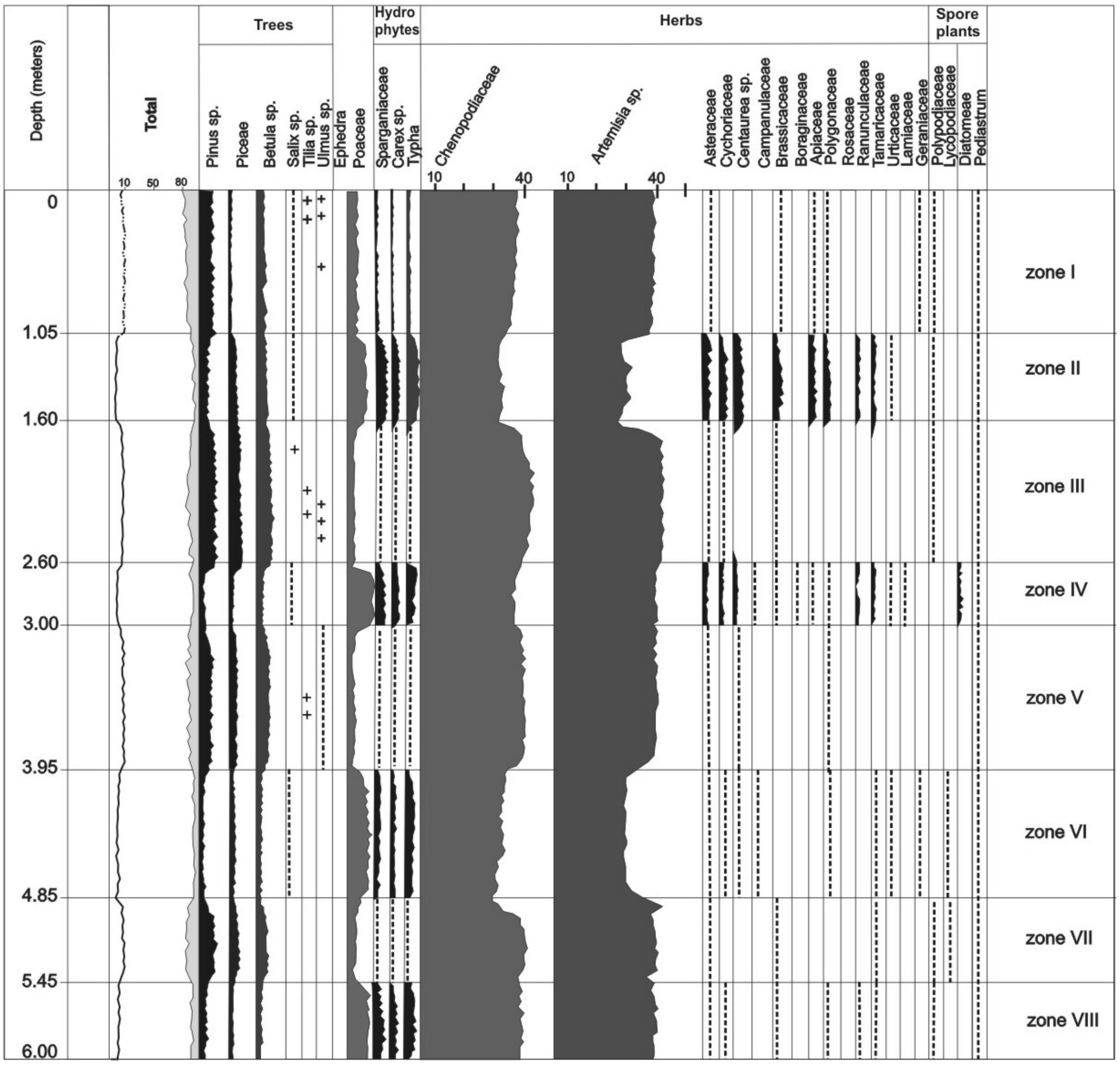

Fig 7 Palynogram of the palynological analysis of the Tarasal core

2.3.4 - Considering the spectra content of different samples of the core, the palynological sequence shows a relatively quiet formation process. We can differentiate, from top to bottom, eight super-posed palyno-zones corresponding to eight climatic stages and lake water level fluctuations.

ZONE *(depth in m)* *&* **STAGE** *(years BP)*	**POLLEN RATIO** **&** ***COMMENTARY***
0 BP **Zone 1** 0 - 1,00	– Woody plants 9% : Pinus silvestris 4.8-5.2%, Piceae individuals, Betula sp. 2-3.2%; – Desert grasses increase* to 75-80%: Artemisia terra-albae & Artemisia lessingiana 38-42%, Chenopodiaceae (Atriplex, Kochia, Salsola, Anabasis and others) 37-38%; – Mesophytes sharp decrease to 3%: Poaceae 2-3%; forbs and others less than 1%; – Hygrophytes sharp decrease to 1.5-2%: Sparganium 1.5-2%, Carex & Typha individuals; – Algae (Pediastrum);

300 BP	*Slight increase of desert grasses, sharp decrease of mesophytes and hygrophytes.* *Climate close to modern climate (moderately dry and hot) with slight transgression of lake water level, corresponding as a whole to the sub-fossil samples of the Pre-Balkhash*
Zone 2 1,05 - 1,60	– Woody plants decrease to 8%: Pinus silvestris 2%; Piceae 2.5%; Betula sp. 3%; – Desert grasses decrease to 68-70%: Artemisia 35-38%, Chenopodiaceae (30-35%); – Mesophytes sharp increase to 12-14%: Poaceae 7 %; forbs and others 5-7% (Cychoriaceae, Brassicaceae, Lamiaceae); – Hygrophytes sharp increase to 8%: Sparganium 2.5-3%, Carex 1,5-3%, Typha 3-5%; – Algae: Pediastrum;
500 BP	*Decrease of desert grasses, sharp increase of mesophytes and hygrophytes.* *Climate dry and hot, corresponding to lake regression and floodplain expansion.*
Zone 3 1,65 - 2,60	– Woody plants sharp increase to 9,5-10 %: Pinus silvestris 4.8-5.5%, Piceae 3%, Betula sp. 3.2-4%; – Desert grasses increase to 90-95%: Chenopodiaceae (Atriplex, Kochia, Salsola, Anabasis and others) 38-45%, Artemisia 38-42%; – Mesophytes sharp decrease to 3.5%: Poaceae 3.5%; forbs and others: individuals; – Hygrophytes sharp decrease to insignificant quantity: Sparganium, Carex & Typha individuals; – Algae: Pediastrum;
700 BP	*Sharp increase of woody plants and desert grasses, sharp decrease of mesophytes and hygrophytes.* *Climate pluvial, corresponding to strong transgression of lake water level and flooding of beaches.*
Zone 4 2,65 - 3,00	– Woody plants sharp decrease to 5%: Pinus silvestris 2%, Piceae 1%, Betula sp. 2%; – Desert grasses 73-80%: Artemisia 38-40 %, Chenopodiaceae 35-40 %; – Mesophytes sharp increase to 13-17%: Poaceae 8-10%; forbs and others 5-7% (Ranunculaceae, Apiaceae, Lamiaceae, Brassicaceae, Polygonaceae); – Hygrophytes sharp increase to 7 %: Sparganium-2.5-3%, Carex 2,5%, Typha 3%; – Algae: Pediastrum; diatomic algae (Bacillariophyta) from families of Coscinodiscaceae, Tabellariaceae, Melosiraceae;
900 BP	*Sharp decrease of woody plants, sharp increase of mesophytes and hygrophytes.* *Climate warmer, corresponding to sharp regression of lake water level and expansion of beaches which under hot and humid conditions favored expansion of meadow vegetation*
Zone 5 3,05 - 3,95	– Woody plants sharp increase to 11-13%: Pinus silvestris 4.8-5.5%, Piceae 3%, Betula sp. 3,2-4,5%; – Desert grasses increase to 78-84%: Chenopodiaceae (Atriplex, Kochia, Salsola, Anabasis and others) 38-42%, Artemisia terra-albae & Artemisia lessingiana 38-42%; – Mesophytes sharp decrease to 3.5%: Poaceae 3.5% (various graminoids individuals); forbs and others less than 1%; – Hygrophytes sharp decrease to 0.5-1.5%: Sparganium & Carex & Typha individuals; – Algae: Pediastrum;
1200 BP	*Sharp increase of woody plants and desert grasses, sharp decrease of mesophytes and hygrophytes.* *Climate relatively wet and cold, corresponding to transgression of lake water level and flood-*

	ing of beaches.
Zone 6 4,00 - 4,85	– Woody plants sharp decrease to 6%: Pinus silvestris 2 %, Piceae 2%, Betula sp. 2%; – Desert grasses decrease to 58-70%: Chenopodiaceae (30-35%), Artemisia (28-35%); – Mesophytes sharp increase to 14%: Poaceae 6%; forbs and others 8% (Cychoriaceae, Brassicae, Lamiaceae); – Hygrophytes sharp increase to 7%: Sparganium 2-2,5%, Carex 1,5-3%, Typha 3%; – Algae: Pediastrum;
1500 BP	*Sharp decrease of woody plants and desert grasses, sharp increase of mesophytes and hygrophytes.* *Climate dry and hot, corresponding to regression of lake water level and expansion of alluvial meadow vegetation.*
Zone 7 4,90 - 5,45 1700 BP	– Woody plants increase to 10-12%: Pinus silvestris 4,5-5,5%, Piceae 3 %, Betula sp. 4 %; – Desert grasses 73-82%: Chenopodiaceae 38-42%, Artemisia 35-40%; – Mesophytes sharp decrease to 4.5% : Poaceae 3,5-4 %; forbs and others: less than 1% – Hygrophytes sharp decrease to 2%: Sparganium & Carex & Typha; – Spores: Polypodiaceae; – Algae: Pediastrum;
	Increase of woody plants, sharp decrease of mesophytes and hygrophytes. *Climate moderately wet and cold, corresponding to transgression of lake water level*
Zone 8 5,50 - 6,05	– Woody plants scarce 7%: Pinus silvestris 2-3.5%, Piceae 2%, Betula sp. 2-2.5%; – Desert grasses average 76-80,5%: Chenopodiaceae 38-40%, Artemisia 38.5- 40.5%; – Mesophytes abundant 15%: Poaceae 8%; forbs and others: 7% (Ranunculaceae, Apiaceae, Lamiaceae, Brassicaceae, Polygonaceae); – Hygrophytes abundant 8,5-12%: Sparganium 2.5-4 %, Carex 2,5-3%, Typha 3,5-5%; – Algae: Pediastrum;
2000 BP	*Scarce woody plants, abundant mesophytes and hygrophytes.* *Climate relatively drier and warmer than modern climate, corresponding to regression of lake water level and growth of meadow vegetation on beaches.*

* The terms “increase” and “decrease” refer to ratio variations of more than ±10%, with differences evaluated in chronological order from bottom to upper zones. The term “sharp” applies to variations ≥50% and always characterizes changes of Poaceae and Hygrophytes pollen ratios.

The highest total ratio is represented by pollens of desert grasses, followed by woody plants, mesophytic plants and hygrophytes.

The highest differential ratios between stages are those of mesophytic plants (always very sharp variations of 2.5 to 3 times) and hygrophytes (sharp variations averaging more than 50%), followed by that of woody plants (10 - 50%) and desert grasses (10 - 20%). The sharpest variations occur in stages 6, 5, 4 and 3.

Variations of ratios of pollens of woody plants and desert grasses (and spores) occur in the same direction; and those of pollens of mesophytes and hygrophytes occur in the opposite direction. The increase of pollen ratios of woody plants and desert grasses is in general correlated with changes to a wetter, cooler climate and transgression of lake water level; their decrease is correlated with changes to a drier and warmer climate and regression of lake water level. The opposite is true of mesophytes and hygrophytes.

The series of data of the palynozones (palynospectrum) bears witness to the establishment, during the late Holocene, of rhythmical climatic fluctuations in eight zones-stages, alternating drier-warmer and wetter-cooler phases and, correspondingly, regression and transgression of lake water level.

These data confirm and enhance the resolution of the previous reconstruction of late Holocene climate implemented within the study of archeological sites of the Southern Pre-Balkhash region (Aubekerov et alia 2003).

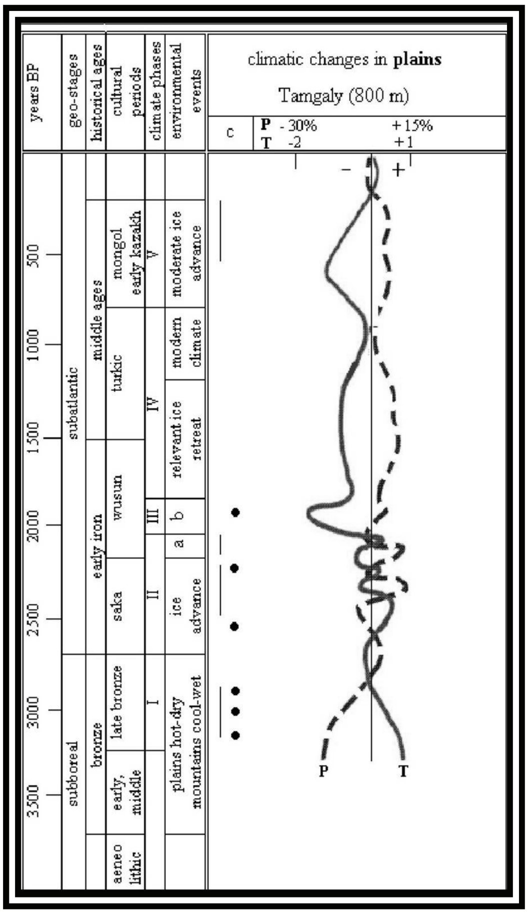

Fig 8 Reconstruction of average fluctuations of temperature and precipitation in the Semirechie plains during the last 3200 yrs (150-yr temporal resolution), based on palynological analyses.

Temperature (T) is shown in solid lines; Precipitation (P) in dashed lines; (a) fires; (b) cryolitic formations; (c) chronological attribution provided by EPR and C^{14} analyses (dots) and archaeological correlation (segments) (Aubekerov, Sala, Nigmatova 2003).

2.3.4 - The bi-millenary variation of water level of Lake Balkhash, which today is at 340 m asl and during the last 2000 years may have varied by ±3 to ±4 m, matches quite well with the average variations of the Aral sea. The sharpest recession of the Balkhash water level happened in zone-stage 4 (900 - 700 years BP) and is well correlated with the building and abandonment of the medieval town of Koktuma (IX - XIII AD), today submerged 3 - 4 m deep in Lake Alakol.

The sharpest regression of water level, which occurred during the XI - XIII centuries AD, is common to both Lake Balkhash and the Aral sea, and in both cases is correlated with natural and anthropogenic factors, i.e., with a dry-hot climatic phase and the highest peak of urbanization and water use in the two basins (Sala 2009). Evidently anthropogenic water use increases during arid phases, and in Medieval times as well as today, acts as positive feedback to the regression naturally induced by the establishment of a dry climatic phase.

Bibliography

Aubekerov B., Sala R., Nigmatova S. (2003) Changes of Atmospheric Circulation, Paleoclimate and Paleogeography in the Tienshan-Balkhash System. In: *PAGES news* vol. 11 n° 2-3. www.lgakz.org

Endo et alia (2007) *Preliminary report on changes of lake level deduced from the Balkhash lake core*. Project Report

Endo K., Komori J., Sohma H., Haraguchi T., Chiba T., Yoshinaga Y., Miyata K., Nakayama Y., Oginj S., Sugai T., Kubota J., Aubekerov B., Sala R., Deom J. M. (2009) *Reconstruction of lake level change and paleoenvironment from Balkhash lake core*. Proceedings of the International Workshop "Reconceptualizing cultural and environmental changes in Central Asia", Kyoto 1-2 February 2009, RIHN

Karta rastitelnosti Kazakstana i Srednie Azii predelakh pustinnoi oblasti, M 1:2500000 (Map of the vegetation of Kazakhstan and Central Asia in desert regions, Scale 1:2500000). Saint-Petersburg 1995

Rachkovskoi E. I., Volkova E. A., Khramtsova V. N. (eds) (2003) *Botanicheskaya geografia Kazakstana i Srednei Azii v predelakh pustinnoi oblasti* (Botanical geography of Kazakhstan and Central Asia in desert regions). Saint-Petersburg, p. 424

Rusakov M. P. (1933) *Geological essay on the Pre-Balkhash and on the lake Balkhash: minerals of the region.* Moscow-Leningrad, Zvetnmetizdat

Sala R (2009) *The Medieval process of urbanization of Northern Tienshan.* Proceedings of the International Workshop "Reconceptualizing cultural and environmental changes in Central Asia", Kyoto 1-2 February 2009, RIHN