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An integrated assessment of landscape evolution, long-term climate variability, and land use in the Amudarya Prisarykamysh delta

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We jointly examine the natural history and the land-use history of the Prisarykamysh delta over the last 5000 years. The study area is located in the southern part of the Aral Sea Region in Central Asia and can be described as an anthropogenic desert as well as a land reserve for the development of irrigated agriculture in the lower reaches of the Amudarya river. We compiled a series of landscape– archaeological maps for different periods, including the Neolithic, Bronze, and Iron Ages, the Antiquity, the Middle Ages, and the Modern Age. The maps are based on the analysis of remotely sensed data (both satellite and aerial photography) and on the results of fieldwork conducted by the authors. We suggest that there is a correlation between the timing of irrigation cessation and the current state of landscapes (from heavily salinized solonchaks to clayey takyrs to sandy deserts).

Keywords: landscape-archaeological studies; satellite and aerial photography; landscape evolution; integrated assessments

Introduction

The Prisarykamysh delta of the Amudarya river (often referred to as the Prisarykamysh alluvial-deltaic plain) is located in the southern part of the Aral Sea Region in Central Asia (Fig. 1). Politically, it is divided between the Karakalpak and Khorezm regions of Uzbekistan and the Tashauz region of Turkmenia. For the period of survey (1980–1991), the Prisarykamysh delta was a vast, very sparsely populated desert. During the historical time, landscapes and cultures changed in a consistent manner in the study region, driven by (1) processes of aridization, and (2) social and economic processes. During the 5000 years of human presence in the delta, the area experienced alternating periods of prosperity and decline. Landscapes evolved under

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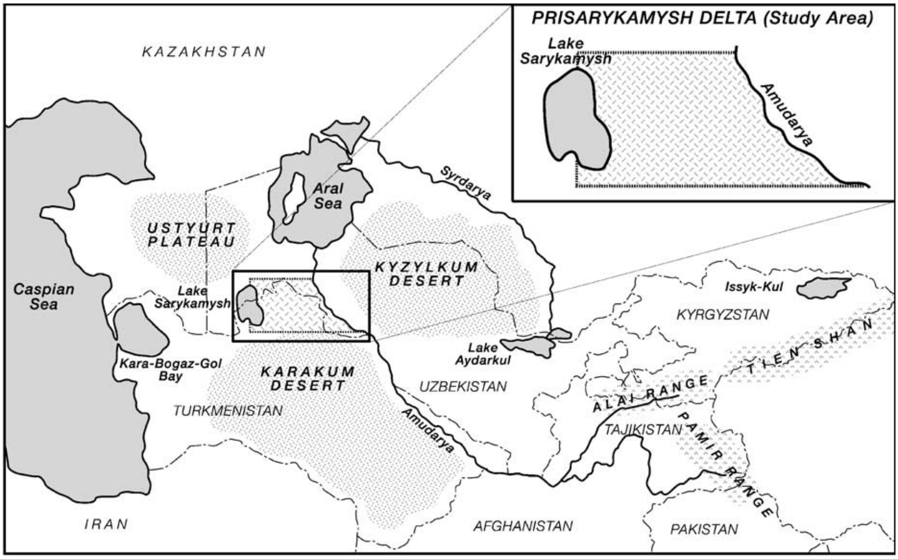

Figure 1. The study region.

considerably changing climatic conditions, fluctuations of water supply in the delta, continuous meandering of deltaic streams, change of natural landscapes from forest and steppe to deserts.

Over the historical time, the entire area of the Prisarykamysh delta has experienced irrigation. Both at present and in the past, irrigated lands, when subject to excessive salinization, were abandoned; they could be classified as solonchak (salt pan) plains. Landscapes of solonchak plains, when abandoned, were exposed to the natural processes of desalinization and takyr formation, and as a result were transformed into takyr plains. Takyr plains in turn, were subject to oversanding (i.e. eolian weathering and redeposition of sandy sediments) and as a result were transformed into landscapes of eolian (sandy) plains. The latter are the most stable landscapes in the region, and are characterized by the highest diversity of plant species (with the exception of irrigated oases). A detailed description of these processes is given in Glushko & Tsvetsinskaya (1995). The demand for rehabilitation of lands of ancient irrigation in order to expand the area under agricultural production is at the root of explaining the importance of studies of the contemporary state and evolution of anthropogenic modifications of landscapes in the study region.

Synthesis of historical–geographic and archaeological data has proven useful for studies of human migrations in the historical past that were associated with deltaic stream migrations and changes in land-use practices under different geomorphological situations (Kes' *et al.*, 1980; Vainberg *et al.*, 1995). We conducted a comprehensive analysis of climate, hydrological, landscape, and archaeological data for the period of human presence in the Prisarykamysh delta, since the 4th millennium BC. We suggest a hypothesis that for a given land parcel in the Prisarykamysh delta, there exists a relationship between the time of irrigation cessation and the current type of dominant landscapes. We put forward a premise on the existence of temporal landscape evolution series in the study area and discuss it by compiling a map of present landscapes and overlaying it with archaeological maps, in particular with maps showing the time of abandonment of irrigated lands because of their excessive salinization.

This paper is based on an earlier publication (in Russian) by Vainberg *et al.* (1998) in the journal 'Russian Archaeology' published by the Russian Academy of Sciences. We have expanded this earlier piece by providing a more detailed study of the natural landscape evolution processes and the current state of ecosystems in the study area. We use many terms common in Russian desert landscape ecology (e.g. solonchaks, takyrs) that may not be familiar to a western reader. A good summary of those terms can be found in Glantz (1999).

In this paper, we first discuss the methodology employed and present results of earlier studies. We then present a brief physiographic description of the study area, followed by a comprehensive analysis of results from our archaeological and landscape studies in the Prisarykamysh delta. In the final sections of the paper we propose, and discuss, the concept of temporal landscape evolution series and summarize the conclusions derived from our research.

Materials and methods

We conducted a comprehensive landscape–archaeological study in the Prisarykamysh delta and mapped the major archaeological sites and contemporary landscapes. Landscape patterns were studied using satellite imagery received from the Russian cartographic satellite 'Kosmos' at the scales of 1:1,000,000 and 1:200,000 with spatial resolutions of 30 and 10 meters, respectively. Landscapes were mapped using photoplans (sets of overlaid images) that cover the entire study area and are made up of satellite images enlarged to the scale of 1:500,000. They present the natural situation for 1983–1985. An example of a satellite image used in this study is given in Fig. 2. Remotely sensed data were processed using the methodology of Glushko (1988, 1991, 1995). In addition, many cartographic materials (Geomorphological Map of the USSR, 1987; Vegetation Map of the USSR, 1990; Soils Map of Turkmenian SSR, 1984) and results of earlier landscape pattern studies (Kes', 1991; Glushko & Tsvetsinskaya, 1995) were used in our research. We also analysed field data collected by the authors during the complex environmental expedition of the Soil Science Department of Moscow State University to the Prisarykamysh delta in 1991.

Evolution of landscapes in the historical past was mainly affected by two groups of factors: natural–climatic and historical–economic. To study the first group of factors, we analysed a large amount of data from existing literature. We examined climatic fluctuations in the study area during the last 5000 years, focusing on research of Klige *et al.* (1996), Vinogradov & Mamedov (1991), Mamedov (1980), and Shnitnikov (1983). We also considered results of Vainberg (1991*a*, *b*), Kes' (1991) and Kes' *et al.* (1980), who analysed the different stages of evolution of the Prisarykamysh delta corresponding in time with the migration of deltaic streams from the south to the north under conditions of periodic flooding and drying of the delta and filling of the Sarykamysh depression with water. Changes in the zonal types of landscapes and their intrazonal variations in the historical past were studied by Vinogradov & Mamedov (1991), Kes' (1991), and Stepanov (1980). Dominant processes of desertification in the region were discussed in Kostyukovsky & Sanin (1991). Effects of irrigation on land degradation in the study area have been examined by O'Hara (1997) and Krutov (1999).

Comprehensive analysis of the second group of factors included an examination of the conditions under which cultures and oases were formed in different historical ages of evolution of the society. We incorporate results of archaeological and hydrographic investigations carried out in the Prisarykamysh delta by members of the Khorezm Expedition of the USSR Academy of Sciences (Lower Reaches, 1960; Andrianov, 1969; Vinogradov *et al.*, 1986; Vainberg, 1991*a*). Special attention is paid to results of

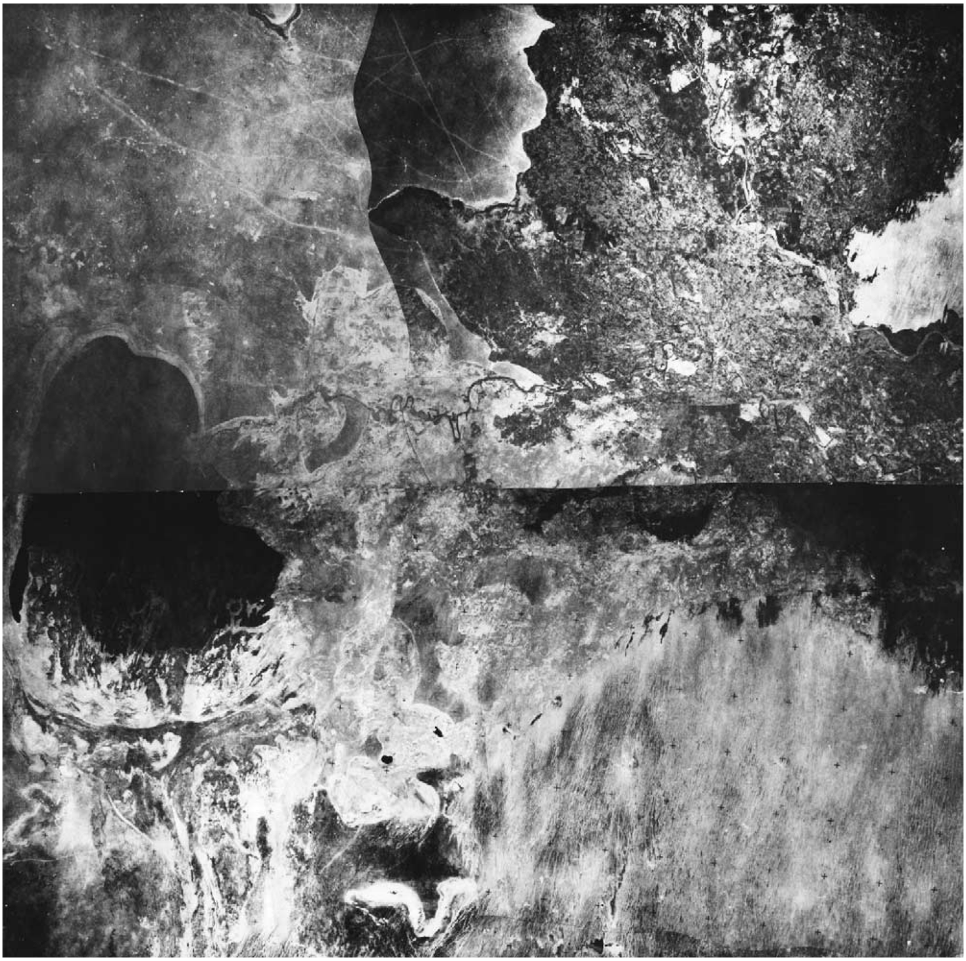

Figure 2. Photoplan of the study region, i.e. set of overlaid satellite images taken from the Russian satellite 'Kosmos'.

long-term research of the division of the Khorezm Expedition headed by B.I. Vainberg, which focused on the interaction between farmers and animal breeders on this territory in the Antiquity, the Middle Ages, and in the 19–20th centuries (Vainberg, 1960; 1989; 1991*a*, *b*). All archaeological studies included extensive analyses of large-scale aerial imagery. Archaeological data were processed in accordance with existing methodology (Vainberg, 1960; Andrianov, 1969, 1991). Regional and local features of the evolution of anthropogenic modifications of desert landscapes under human long-term economic activity were identified through a comprehensive analysis of landscape pattern, condition, and evolution. Essential information was also derived from archaeological studies of sites of different ages.

Brief physiographic description of the study area

The Prisarykamysh alluvial–deltaic plain occupies an extensive southwestern part of the Aral Sea Region in Central Asia. Its formation dates back to the late Quaternary and Contemporary periods. The surface of this extensive and rather monotonous alluvial plain is tilted towards the west, from the absolute level of 80–100 m near the Amudarya down to 50 m near the Sarykamysh. The area is made of an alluvial layer of sand and clay, whose thickness varies as it is underlain by an uneven, strongly eroded layer of bedrock. The monotonous landscape is interrupted by flat table rocks of bedrock material, 20–60 m high.

The ancient deltaic plain is cut from the east to the west and northwest by many dry riverbeds of the ancient Amudarya (the Dar'yalyk, the Daudan or the Mangyrdarya, the Tonidarya and others), which vary in shape and size and can be clearly identified on remotely sensed images. In their lower reaches, the riverbeds divide into many branches forming deltas, some of which reach the Sarykamysh and end at various levels of its eastern slope. Others disappear in the outer parts of the plain. The entire surface of the delta is cut by ancient irrigation canals, with sand bars on both sides. The large number of irrigation canals (which were used by farmers and animal breeders) suggests intensive agricultural development of the region in the past.

The well-defined present boundary of the Prisarykamysh alluvial–deltaic plain is easily traced on remotely sensed imagery. It is defined in the south by the sediments of an old branch of the Amudarya, the Daudan, which meanders around the northern edge of the Zaunguz Karakum desert. The northern boundary of the Zaunguz Karakum desert is very winding. This is a result of the action of the branches of the Amudarya, which have for a long time not only eroded this elevated Pliocene plain, but also cut into its northern outposts, disintegrating considerable portions of parent material and causing tablerock formation. On remotely sensed photographs, the deltaic sediments have patchy patterns—a combination of light clay sediments and darker sandy sediments. A distinct pattern is also created by the meandering Daudan river. On both sides of its riverbed, a darker strip follows the riverbed configuration. Its homogeneous pattern (darker than the riverbed) is due to sandy sediments which formed as a result of the blowing out of the riverbed alluvium.

The eastern boundary of the Prisarykamysh alluvial–deltaic plain is defined by the current delta of the Amudarya river. The look-alike riverbeds of the left-hand tributaries of the Amudarya river are easily traceable on remotely sensed images due to the darker homogeneous grey tone of eolian sands that form dunes along both sides of the riverbeds. The northern boundary of the plain is defined by the cliffs (referred to as 'chinks') of the Ustyurt plateau. Because of the very steep slopes and the exposure of the parent rock material to the surface, the chinks have a distinct very light color and winding pattern on remotely sensed images. The western boundary of the alluvial–deltaic plain is well defined and corresponds to the edge of the western tablerocks (i.e., the boundary between the Sarykamysh depression and the Ustyurt plateau).

The largest river valley in the Prisarykamysh delta of the Amudarya is the Dar'yalyk. It is formed by a stream which has existed longer than any other in the Prisarykamysh delta. As can be seen on remotely sensed images, the Dar'yalyk has had a number of branches, mainly in its lower reaches, which can be identified by the dry riverbeds. At present, the Dar'yalyk is a well-drained river, and has been so since the drainage of irrigation waters from the Khorezm lowland began. The Dar'yalyk stretches in the northwest direction and reaches the Sarykamysh.

At present, the Prisarykamysh alluvial–deltaic plain is cut by a system of canals and collectors, which dispose water from irrigated fields (Fig. 3). Most collectors were built in place of dried out branches of the Amudarya. Irrigation water from the fields of the Tashauz region of Turkmenia and the Khorezm region of Uzbekistan is being disposed into the Sarykamysh depression. Collectors 'Dar'yalyk' and 'Ozyerny', which direct water into the depression, are constructed in the ancient riverbeds of the Amudarya—the Dar'yalyk and the Daudan. A few dozen kilometers before reaching the lake, the collectors merge; this final stream has a water fall, 3–4 m

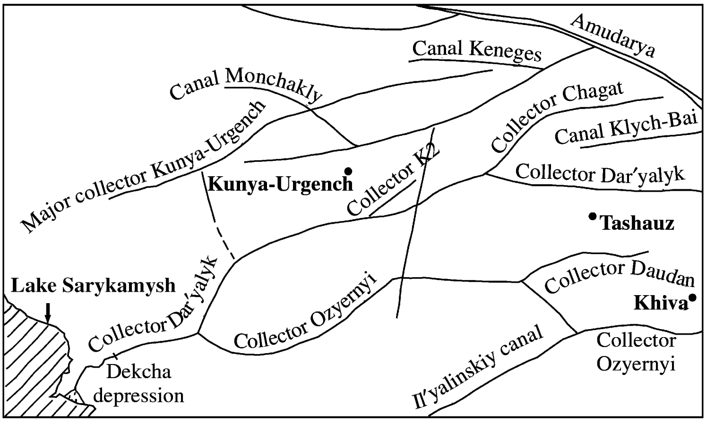

Figure 3. A schematic of irrigation canals in the Prisarykamysh delta. Based on Shaporenko (1987).

high and 150–200 m long, in the Dekcha area. In the southern part of the Prisarykamysh alluvial–deltaic plain, the Il'yalinsky collector was built along the ancient Kangadarya riverbed.

Comprehensive archaeological and landscape studies

We have studied in detail various sources of information pertaining to different scientific disciplines and compiled a summary table of the evolution of landscapes of the Prisarykamysh delta (Table 1). The data show precise correspondence in chronological time between the major stages of evolution of the environment and land-use practices in the study area. The temporal correspondence between the climatic periods, changes in land cover and land-use practices, and stages of the evolution of local culture in the historical past constitutes the grounds for explaining the natural and anthropogenic factors of the evolution of landscapes, also providing the basis for a more objective definition of the major stages of exploitation of the alluvial–deltaic plain. The gradual change from humid to arid climatic conditions since the Neolithic Age through the Antiquity, the Middle Ages, and into the Modern Age predetermined the sequence of changes of phases of economic development for the population of the delta. However, in different historical ages, interaction between the environment and society manifested differently.

The comprehensive analysis of Table 1 enables one to reconstruct the general pattern of the evolution of natural environment and its change by humans over the last 5000 years. In the third millennium BC, during the climatic optimum remaining at the end of the Lyavlyakanskiy pluvial, there existed an abundant water supply into the Prisarykamysh alluvial–deltaic plain. Numerous deltaic lakes were encircled by reeds. Tugai forests composed of broadleaf trees, such as maple and ash (alder and birch were also likely present) grew alongside the streams. Considerable area of lowlands adjacent to the lake Sarykamysh was swamp land. The Sarykamysh and the Assake-Audan depressions remained filled with water, which assured the flow of the Uzboy river into the Caspian Sea (Mamedov, 1980; Glushko, 1990). Such a massive drainage of the Prisarykamysh delta as during the Lyavlyakanskiy pluvial has not occurred since. Under the conditions of abundant water supply into the delta, tribes of hunters and fishermen of the late Neolithic Age settled mainly in the southern peripheral part of the delta, along the Kangadarya and the Uzboy rivers, and along the banks of the

Sarykamysh on the boundary with steppe landscapes that existed in place of the Zaunguz Karakum desert (Kes', 1991). A unique burial ground of Tumek-Kichidjic, which was studied in the 1970s, provides evidence of economic activity of tribes of the Kelteminarskaya culture in the inner space of the delta (Vainberg, 1991*a*; Vinogradov *et al.*, 1986). Presently, landscapes of sandy deserts prevail in the areas of concentration of sites of the late Neolithic Age (Fig. 4).

One of the most pronounced transitions in the evolution of the natural environment and the society occurred at the turn of the third and second millennia BC. The shift from the Lyavlyakanskiy pluvial to the Tubelekskiy arid at that time resulted in the cessation of water supply into the Prisarykamysh delta, a drop in water level of the lake Sarykamysh, and in the drying out of the Uzboi river. People abandoned the delta.

By the second millennium BC, due to sediment accumulation in the Prisarykamysh delta and the resultant slower drainage, the main branch of the Amudarya began to move northward, at first along the Daudan riverbed forming a lake in the Tyunyuklyu depression, and later along the Daryalyk riverbed. In the drying out natural depressions solonchaks were formed. Even though it was predominantly fine dispersed sediments that accumulated in the delta, alluvial sediments containing layers of sand were also present. As the drying occurred, those layers were transformed by eolian processes. As a result, sand bars and barkhans formed after the drying of the branches and deltas.

A minor pluvial period, which began in early first millennium BC, marked a new period of water supply into the Prisarykamysh delta and the lake Sarykamysh, as well as the time of restoration of the forest–shrubland tugai vegetation. Archaeological investigations of recent decades provide undoubted evidence of stable water supply into the Prisarykamysh delta of the Amudarya during the period from the end of the 8th century BC until the 4th–5th centuries AD. At that time, the area of the delta reached 15,000–18,000 km^2, with numerous streams of predominantly latitudinal direction of flow that were bringing water into the Lake Sarykamysh. Continuous runoff into the Uzboi existed since the end of the 5th century BC. The largest archaeological site of this period in the Prisarykamysh delta is the fortress of Kyuzeli-gyr (6th–5th centuries BC), which is related to the beginning of the Khorezm civilization of the Antiquity. When we examined archaeological sites in the study area, we located settlements and irrigation facilities of ancient farmers; numerous sites (burial grounds and settlements) of animal breeders were identified as well. Farmers and animal breeders interacted in the study region primarily through economic cooperation, an important role in this process was played in the Antiquity by the Khorezm state. For example, along the western border of the Khorezm state in the areas traditionally populated by animal breeders, settlements of farmers were found with vast fields, vineyards and wineries, storage facilities for wine, kilns.

Conditions of the functioning ('alive') delta predetermined the features of irrigation facilities of the western part of the Khorezm state (the territory located on the left bank of the Amudarya river, in contrast to the eastern part of Khorezm state located on the right bank of the Amudarya). In the Antiquity, there were only two large canals here. One of them—Kunya Uaz canal—was constructed during the period when Khorezm was a satrapy of the Achaemenid Empire (according to P'yankov [1965], Khorezm becomes a separate satrapy of the Achaemenid Empire in the fourth century BC). The other—Chermen Yab—was constructed in the first centuries AD along a dried out riverbed of the extreme southern branch in the delta (which had dried out by then), lower reaches of which had been heavily exploited by animal breeders since as early as the 7th–6th centuries BC. The Chermen-Yab waters fed the drying streams in the lands of animal breeders in the southwestern part of the study region (Figs. 4 and 5). Agricultural oases along the Chermen Yab canal were rare, limited to the Shakh-Senem oasis, areas to the North and East of the fortress Kyzylcha-kala, and agriculatural oases around fortresses Gyaur-kala1 (Tolstov, 1948) and Gyaur-kala2 (Nerazik, 1976).

The major settlement type in the area was moderate size oases located between two parallel streams. Irrigation canals were built to flow from the northern stream into the southern (with the general direction of flow NE–SW). Examples of such settlements are the moderate size ($\sim 10\,km^2$) oases to the south and north from the Tuzgyr upland in the vicinity of the religious center Kalaly-gyr2 (4th–2nd centuries BC).

It is likely that larger oases of this type existed in the interfluve of the Daudan and the Daryalyk rivers, on the territory heavily exploited in the Middle Ages and in the Modern Age. This assumption is also supported by the topography of the major sites of the Antiquity (settlement of Kandum-kala, fortress in the settlement of Kunya-Urgench, Kaladjik-baba and Kurgan-kala). Such an organization of irrigation prevented excess water from concentrating in the end sections of canals and maintained an ecological balance. A large number of dams, levees and other facilities were found in the Nurumskiy oasis south from the Tuzgyr upland; they were located at a distance from the oasis and supported the above system of water supply for 600 years.

There are a number of characteristic features associated with animal breeding in the functioning delta. Since the 7th century BC, settled animal breeders (pastoralists) lived in the Prisarykamysh delta, with their settlements located along the functioning rivers. An important part of their economy was horse breeding. At the turn of the 4th and 3rd centuries BC, animal breeders of different ethnic origin came to the region; their economic traditions were different (most likely they were sheep breeders). However, under the conditions of a functioning delta they were also unable to migrate for distances in excess of 50 km. In the following centuries, their culture indicates close economic ties with the farmers of the Khorezm state.

Archaeological data enable us to put forward a hypothesis on a certain state policy of the rulers of the Khorezm, who used animal breeders as a strong military contingent and paid for their service with grain, wine, ceramics and other pieces of craft, which were produced in settlements deliberately created for this purpose in the western extremes of the Khorezm in the area traditionally populated by animal breeders.

Horse breeding was a traditional branch of economy in the western Khorezm up to the beginning of the 20th century. Abundant rich forage available in the flooded delta combined with settled and semi-settled animal breeding practices typical for this area, provided the conditions for development of horse breeding with animals kept in stalls and the best breeds being raised. Recently found pieces of fine art of the 4th–2nd centuries BC show that Tekinskie and Iomudskie breeds of horses were already known at that time. This can be the argument in favor of the special role played by the Khorezm oasis in the development of alfalfa seed breeding (data of N.I.Vavilov), which is one of the major fodder crops.

After the 4th–5th centuries AD, the Prisarykamysh delta dried up completely. Settlements were abandoned at that time throughout the study region (e.g. Dev-Kesken in the north, settlements between Tarym-kaya and Tyzgyr uplands, whose irrigation was based on natural stream flow). Presently, lands of ancient irrigation developed in the Antiquity are predominantly oversanded takyrs. The next time when the Prisarykamysh delta was put under exploitation was much later, in the 9th–10th centuries and onwards. Since the 9th century AD, the aridity of climate began to decrease, water flow in the Daudan and the Daryalyk rivers resumed, providing water for irrigation and stimulating concentration of settled farmers along the banks of these rivers (Fig. 6).

A new minor pluvial period started in the 13th century. Several archaeological finds in the Prisarykamysh delta indicate that flooding of the delta and spreading of the forest and shrubland vegetation on alluvial–deltaic plains started even earlier (Vainberg, 1989, 1991*a*, *b*). Steppe landscapes were common over most of the Central Asian plains. An earlier accepted assumption that the destruction of irrigation systems of the Khorezm by the mongols in the early 13th century was the only reason why part of the Amudarya waters started to flow through the Daryalyk river into the

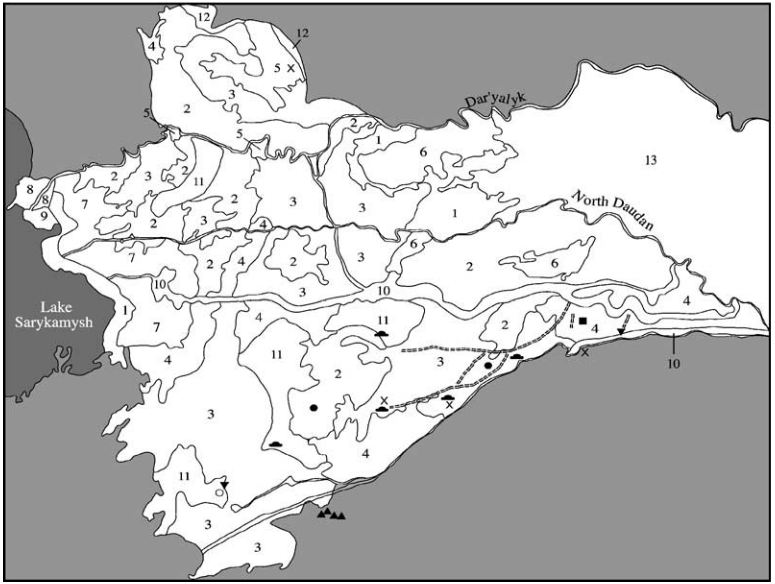

Figure 4. Landscape–archaeological map of the Prisarykamysh delta for the Neolithic Age, Late Bronze Age (8th century BC), and Early Iron Age (7th–5th centuries BC).

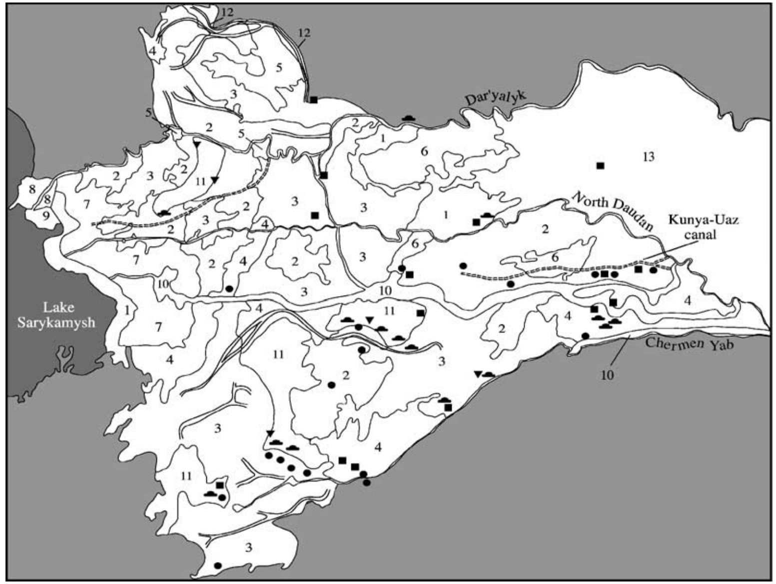

Figure 5. Landscape–archaeological map of the Prisarykamysh delta for the Antiquity (4th century BC—5th century AD). Note that Il'yalinskiy collector has been built in place of the Chermen-Yab canal.

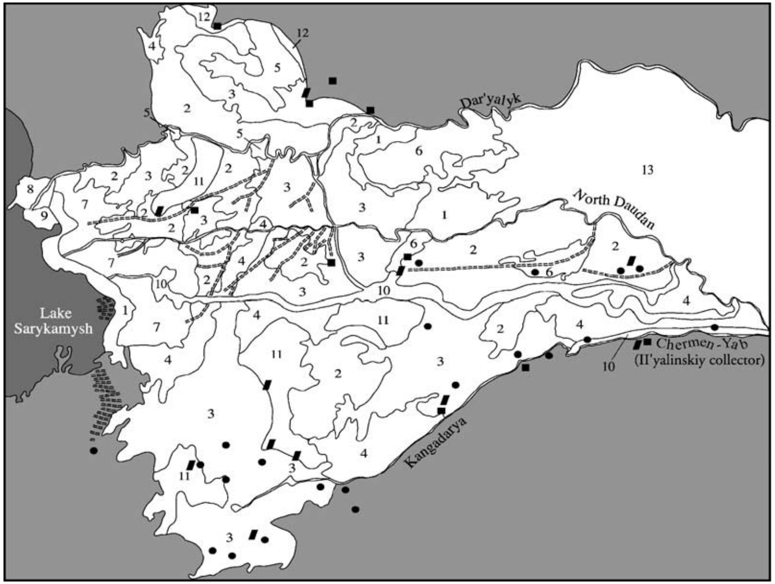

Figure 6. Landscape–archaeological map of the Prisarykamysh delta for the Middle Ages (10th–16th centuries AD).

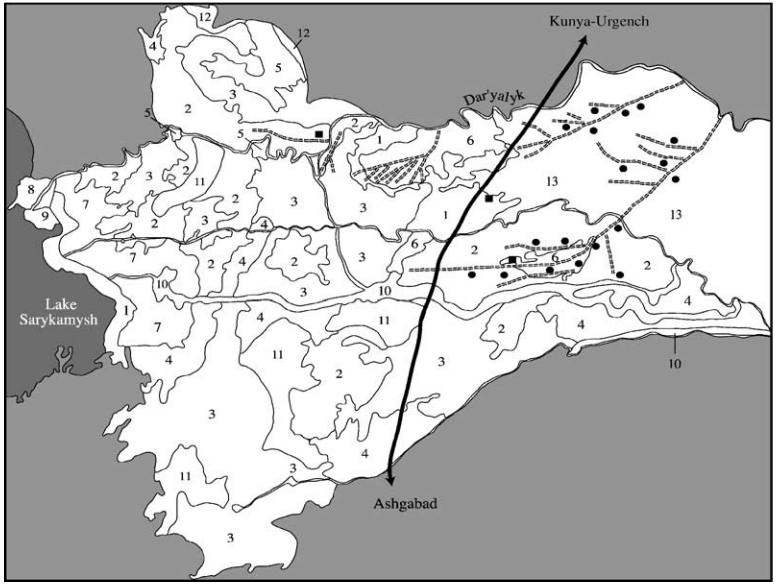

Figure 7. Landscape–archaeological map of the Prisarykamysh delta for the Modern Age (19th–20th centuries AD).

Figures 4–7: Legend for landscape-archaeological maps of the Prisarykamysh delta.
LANDSCAPES:

1. Flat alluvial–deltaic plains with halophyte vegetation (*Salicornia Herbacea*, *Salsola Lanata*, *Salsola Paulsenii*) on solonchak soils;
2. Flat and gently rolling plains with halophyte–shrubland vegetation (*Haloxylon Aphyllum*, *Salsola Orientalis*, *Salsola Lanata*, *Salsola Paulsenii*) on solonchak and takyrlike heavily salinized soils with patches of takyrs, unstabilized sands, and underlying bedrock;
3. Flat and gently rolling plains with halophyte–shrubland vegetation (*Haloxylon Persicum*, *Salsola Orientalis*, *Salsola Lanata*, *Salsola Paulsenii*) on takyrlike soils;

Sarykamysh, and later for a short period of time into the Uzboi, now cannot be justified in light of the new discoveries. A moderate-size farmstead of the Middle Ages discovered in the Pishkekuinskaya depression in the vicinity of Baimurad-kala with well-preserved archaeological finds of the 13th century already depended on a stream, which carried outflow water from the full lake Sarykamysh (through the Kangadarya delta). By the end of the century, and no later than in the early 14th century, the farmstead was already flooded as a consequence of a sharp increase in the level of the lake (Vainberg, 1989, 1991*a*). After the mongol invasion, the southern part of the Prisarykamysh delta, which after territorial division became part of the state of Timur, experienced desolation. Dams and dikes were destroyed by the troops of Timur (end of the 14th century). As a result of the destruction of many irrigation facilities, the southern branches of the Amudarya naturally flowed westward, into the Sarykamysh. Both the Sarykamysh and the Assake-Audan depressions were filled with water at that time. The northern part of the delta, adjacent to the city of Urgench (presently Kunya-Urgench), in the 13th–14th centuries after a short period of decline became

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Landscape caption for figures 4–7—*continued.*

4. Hillock–eolian plains with ephemeral–shrubland vegetation (*Haloxylon Persicum*, *Anabasis Salsa*, *Artemisia Terrae-Albae*) on oversanded takyrlike soils;
5. Hillock–eolian plains with ephemeral–shrubland vegetation (*Haloxylon Persicum*, *Ammodendron Argenteum*, *Halochemum Strobilaceum*) on desert sandy soils;
6. Leveled, gently sloping, and flat plains under agricultural crops on takyrlike cultivated salinized soils;
7. Flat plains with karst depressions, with halophyte–shrubland vegetation (*Artemisia Terrae-Albae*, *Salicornia Herbacea*, *Salsola Lanata*, *Salsola Paulsenii*) on gray-brown salinized soils;
8. Modern delta of the Daryalyk with reeds on wetland solonchaks;
9. Ancient delta of the Daryalyk with halophyte vegetation on solonchak soils;
10. Ancient levees with psammophyte and halophyte vegetation (*Haloxylon Persicum*, *Salsola Lanata*) on desert sandy soils with patches of solonchaks;
11. Table rocks with ephemeral–shrubland vegetation (*Haloxylon Ammodendron*, *Artemisia Terrae-Albae*) on gray-brown soils;
12. Bottom slopes of table rocks with halophyte–shrubland vegetation (*Haloxylon Aphyllum*, *Salsola Lanata*, *Salsola Paulsenii*) on gray-brown salinized soils with patches of solonchaks and on shallow rocky soils;
13. Modern delta of the Amudarya with leveled, gently sloping, and flat plains with oases on irrigated and fallow alluvial–grassland highly salinized soils, with patches of solonchaks. This unit also includes leveled, gently sloping, and flat plains with woodland–shrubland vegetation (tugai forests) on alluvial–grassland soils of river-bank levees with localized patches of solonchaks.

ARCHAEOLOGICAL SITES:

(▲) sites of the Neolithic Age (4th-3rd millennia BC); (✕) solitary finds of the Neolithic Age (4th-3rd millennia BC); (○) finds of the Late Bronze Age (8th century BC); (●) settlements and single farms; (■) fortresses and cities; (▼) fortified settlements in elevated areas; (⏶) burial grounds of various types; (▰) burial grounds of the Middle Ages (10th-16th centuries AD); (⚌) canals; (⚌) major ancient riverbeds; (▬) paved road.

very prosperous. The Golden Horde state promoted crafts and trade in the Khorezm in many ways. Many agricultural oases were located on the territory adjacent to the Daryalyk and the North Daudan rivers (Fig. 6).

It is unlikely that in the late 14th–15th centuries, the general pattern of water supply into the delta changed. No later than in the early 14th century, the level of the lake Sarykamysh reached +50 m mark (same as in the 1st century BC); from this level permanent runoff into the Uzboi river began. No later than at the end of the 14th century, the level of the lake reached its maximum for the Middle Ages, +53 m–+55 m above sea level (Vainberg, 1989, 1991*a*). The medieval chronicles testify that in 1448, during a march of khan Sheibani to the Daryalyk delta, one of his people reported on the existence in that area of a large lake, Kara-Tengiz (Tolstov *et al.*, 1954). Later in the 15th century (most likely at the end of the century), the level of the Sarykamysh gradually receded. By the 16th century, water level in the lake dropped dramatically, down to +40 m mark, with the concomitant cessation of the runoff of the Uzboi river and any form of water supply into the southwestern part of the Prisarykamysh delta, which used to receive water from the Sarykamysh through the Kangakalinskaya delta (Vainberg, 1989, 1991*a*). It should be mentioned that runoff into the Sarykamysh at that time existed through both the Daryalyk and the North Daudan rivers. Remains of irrigation systems were found on the eastern, southeastern, and western shores of the Sarykamysh, and along the shores of the lake Karasazakly (Tolstov *et al.*, 1954). These irrigation systems were rather complex, made up of long narrow canals connecting rounded reservoirs. Such an organization allowed for the transport of the Sarykamysh water to higher elevations. We note that in the 14th–15th centuries, groups of turkmen and uzbek settled and semi-settled animal breeders also lived to the east and northeast of the Sarykamysh (e.g. extensive complex of the Middle Ages Kanga4). Presently, oases of the Middle Ages in the Prisarykamysh delta are dominated by takyr plains, except for the shores of the Lake Sarykamysh, where due to the high level of underground water table, solonchak plains dominate (Fig. 6).

In the 19th century, short-term but relatively strong floods of the Amudarya waters through the Laudan stream into the Daryalyk created conditions favorable for farming in the northern and northwestern parts of the Prisarykamysh delta. In accordance with an agreement with the Khiva khans, turkmen tribes farmed these lands. At first, there were mainly fortified settlements of animal breeders with moderate-size fields adjacent to dams; the dams provided a certain level of water in the Daryalyk river enough for irrigation. Later, in the second half of the 19th century, as a result of a tough struggle with the khan power for land and water, turkmen settlements with sophisticated irrigation systems and agricultural oases began to dominate along the banks of the Daryalyk river, in the interfluve of the Daryalyk and the North Daudan rivers, and in the Uaz oasis on the Shamurat canal south from the Daudan river. A good example of such sites is the settlement Mashryk-sengir (‘sengir’ in the local language means fortification, ‘mashryk’ is a tribal division) of the 19th century, on the right, northern, bank of the Daryalyk (Glushko *et al.*, 1995). Lands where irrigation ceased in the Modern Age are presently dominated by heavily salinized takyr plains (Fig. 7).

Since the beginning of the contemporary arid period in the middle of the 19th century, the Prisarykamysh delta has been drying out. Natural periodic runoff of the Daryalyk river was registered only in several wet years (Shnitnikov, 1983). In the beginning of the 20th century, almost all turkmen settlements along the Daryalyk river were abandoned as there was no water available for irrigation. People shifted to nomadic animal breeding practices. Since the 1930s, lands on the right bank of the Daryalyk river have been put under irrigation again; they have been cultivated by collective farms of the Kunya-Urgench region using irrigation canals that withdraw water from the Amudarya river (Vainberg, 1960). Lands that were irrigated at that time but are not used any longer are presently dominated by solonchaks, typical for the eastern part of the delta. They are particularly common in the periphery of modern oases (Fig. 7).

Deltaic streams, which dried up in the 19th century, are presently used as collectors for drainage water disposal from adjacent irrigated fields into previously dry deltaic lakes and the lake Sarykamysh (Sanin *et al.*, 1991). Over the last several decades, the Amudarya river delta has experienced a steady increase in the area of irrigated lands that has also affected the eastern peripheral part of the Prisarykamysh delta. At present, most of the delta to the east from the Tashauz-Ashkhabad highway is used for agricultural production. Drainage water from irrigated oases has been discharged through the Daryalyk and the Daudan rivers into the lake Sarykamysh, and until recently through the Ilyalinsky collector into deltaic lakes. In most recent years, the Ilyalinsky collector has been flooded with fresh water for irrigating new fields. The lake Sarykamysh, which receives drainage waters, has filled up again. Such an anthropogenically induced vast spatial extent of stream flow in the study region in effect mimics the hydrological situation under pluvial climatic periods. Since the 1960s, certain changes in plant cover have been documented along the functioning collectors (e.g. Yarbekir-kala and others) that have occurred in response to increased water availability to plants. Predominant processes on the dry alluvial–deltaic plain are those of postirrigational desertification.

Temporal landscape evolution series

As a result of our comprehensive study, we compiled a series of landscape–archaeological maps for the Prisarykamysh delta (Figs. 4–7). Landscape units shown on the maps (types and subtypes of landscapes) are indicated with numbers, major archaeological sites are shown with symbols. Analysis of the maps indicates a clear correspondence between the location of archaeological sites of different historical ages and that of certain landscapes, which are at different stages of evolution in the process of postirrigational desertification.

The nature of landscape changes on alluvial–deltaic plains in the process of postirrigational desertification has been studied by a number of scientists. Minashina (1978) gave a detailed description of the mechanisms of soil formation and evolution on ancient alluvial–deltaic plains of Central Asia under conditions of natural desertification and on lands of ancient irrigation. On lands abandoned as a result of salinization, the transformation of landscapes from solonchak plains (salt pans) to clayey and later sandy plains occurred over thousands of years. Sandy plains are a final climax stage of landscape evolution, both formation of zonal types of landscapes and their stabilization characterize this stage. The above sequence of land cover changes was identified by Glushko & Maslennikova (1987) in the Lower Mesopotamia. It takes centuries to millennia for such landscape changes to occur, depending upon regional characteristics of landscape pattern of an area and upon its land-use history. In our study area, completion of the entire landscape evolution sequence took 4.5 thousand years (Vainberg *et al.*, 1995; Glushko, 1995).

In the Prisarykamysh delta, lands taken out of production in the 20th century (most recently) because of excessive soil salinization are presently dominated by landscapes of flat alluvial–deltaic plains with halophyte vegetation (*Salicornia Herbacea*, *Salsola Lanata*, *Salsola Paulsenii*) on solonchak soils. Small strips of solonchak plains are scattered over the entire territory of the delta and are mainly concentrated in the periphery of modern oases (Figs. 4–7, contour 1). Solonchak plains are characterized by relatively small areas of manifestation, which most likely is due to the lack of water resources experienced by the study region in the recent past, and is not a consequence of the suggested rapid development of processes of desalinization and takyr formation.

Note that solonchaks are alkaline, highly saline (thus of whitish color) soils found in arid and semi-arid regions. Soluble salt accumulations are typical on the soil surface (white efflorescence) or just beneath the surface. Note also that a detailed description of natural and managed ecosystems of the southern Aral Sea Region, in the English language, can be found in Novikova (1999). Archaeological sites found on solonchak plains are those of the Modern Age (19th century) and the modern period. Typical for this landscape is a large number of irrigation canals, which are characterized by complex dendritic structure. The canals are well preserved and can be clearly identified on aerial photographs.

Over a considerable extent of the Prisarykamysh alluvial–deltaic plain, especially in its western part, landscapes are dominated by flat and gently rolling plains with halophyte–shrubland vegetation (*Haloxylon Aphyllum*, *Salsola Orientalis*, *Salsola Lanata*, *Salsola Paulsenii*) on solonchak and takyrlike heavily salinized soils with patches of takyrs, unstabilized sands, and underlying parent bedrock (Figs. 4–7, contour 2). These landscapes were formed as a result of desalinization of solonchaks and are the ecotone ones. The majority of archaeological sites discovered in the study area are located in these landscapes and are dated to the Modern Age (19th century). The large number of sites of the Modern Age indicates intensive settling of the study area at that time and is also a consequence of the relative newness of these sites (i.e., insufficient time has yet passed for the destruction of these sites). An important indicator for determining the time of settling of a given landscape is the condition of the ancient irrigation systems. Canals abandoned in the Modern Age can be identified on aerial photographs and satellite images with a high degree of certainty. On images of landscapes that were settled in the Modern Age, both major distribution canals and small aryks (irrigation ditches) are easily recognizable. This allows for detailed maps of anthropogenic complexes to be compiled through use of aerial photographs. Irrigation systems of the 19th century were very diverse, ranging from powerful waterlifting dams, headworks with semi-dams and conjunction points, canals with back-up reservoirs to agroirrigational systems of different shapes and sizes. In a number of settlements, major abandoned irrigation canals of the Middle Ages were reconstructed. The majority of irrigation systems of the Modern Age (that are located primarily in solonchak plains and modern oases) are characterized by a complex dendritic shape, which is clearly recognizable on aerial and satellite photographs.

Further development of processes of takyr formation and desalinization resulted in the formation of landscapes of flat and gently rolling plains with halophyte–shrubland vegetation (*Haloxylon Persicum*, *Salsola Orientalis*, *Salsola Lanata*, *Salsola Paulsenii*) on takyrlike soils. These landscapes occupy small areas over the entire territory of the Prisarykamysh delta and are the dominant ones in its central and eastern parts (Figs. 4–7, contour 3). This landscape is extremely monotonous, with vegetation represented mainly by bushes of *Haloxylon Persicum*, which grow at a distance of about 1 m from one another, with ephemeral species and halophytes growing between them. The fractional canopy cover is about 5–10%. The surface of the plain is extremely flat, and is covered with takyr crust. Note that takyrs are clay depressions, shallow and without water flow, found in the deserts of Central Asia. They can periodically get flooded; after the water evaporates, a dried crust with fissures (or cracks) forms on the surface. Takyr soils, typical for the landscapes of takyr plains, are formed over the parent rock material of alluvial sediments. Under the bushes of haloxylon, the soils are buried under a thin (5–10 cm) layer of sand. A profile of the takyr soil, described in the vicinity of Shah-Senem, is described in Fig. 8. The characteristic of this soil is that its upper horizon is represented by the takyr crust (a very dense and porous material of pale pinkish color), and the entire surface is cracked into polygons.

The dominant archaeological sites in the landscapes of takyr plains are of the Early Medieval (pre-Mongolian) and Late Medieval (post-Mongolian) Ages. They are few, however. Medieval sites are characterized by improved irrigation systems, which

0 — 12 cm:	Crust of red-brownish color (on the surface – pale pinkish color), compacted, thickness of 1 mm. Most of the horizon is spongy, with large pores. Sandy loam. Dry. Splits into horizontal particles (layers). Substantial number of live and dead (barely decomposed) roots. The boundary is even. The transition is sharp in terms of color, structure, and density.
12 — 22 cm:	Dry. Pale brownish. Structureless. Very dense. Dusty fine-fraction sandy loam. Rusty red spots along root passages. Large number of small roots. Salts are present as whitish dusting. Boundary is uneven. Transition is gradual.
22 — 33(35) cm:	Dry. Same color as previous horizon. More porous than previous horizon. Compacted, essentially structureless. Dusty fine-fraction sandy loam. Boundary is uneven. Transition is gradual.
33(35) — 110 cm...:	Dry. Homogeneous layer of pale grayish color. Yet more porous than the previous horizon. Dusty fine-fraction sandy loam. Individual roots.

Figure 8. Profile of a takyrlike soil* described in the vicinity of Shakh-Senem**.

*We note here that many takyrlike soils examined in the study region, including soils in the vicinity of Shakh-Senem site, incorporated barried agroirrigational horizons. The depth at which they occurred can be related to historical times at which irrigation took place. **Shakh-Senem site dates back to the Antiquity (4th century B.C. – 5th century A.D.) and was later revived in the Middle Ages (11th – early 13th centuries A.D.).

become of dendritic configuration and are easily identified on aerial and satellite photographs. Land within irrigation systems is used more efficiently than in the previous periods, which is a result of the widespread use of a water-lifting wheel, chigir', unknown in the Antiquity. One of the typical features of the Medieval irrigated lands is the presence of extensive garden-park complexes in the vicinity of ancient cities. In this respect, the garden-park complex near the fortress Shakh-Senem, dated to the 12–13th centuries, is typical. In this complex, the network of irrigation canals forms a clear geometric pattern, divided by perpendicular strips of alleys, and surrounded by a quadrangular fence, with garden pavilions in the corners and in the center. Major canals are clearly distinguishable on aerial photographs by a double dark line (i.e., the shadow from levees on each bank) against a light background of takyrs (Vainberg *et al.*, 1995).

Most takyr-like plains in the Prisarykamysh delta of the Amudarya are subject to deflation, which leads to eolian accumulation and oversanding of takyrs. As a result, rolling hillock–eolian plains with ephemeral–shrubland vegetation (*Haloxylon Persicum*, *Anabasis Salsa*, *Artemisia Terrae-Albae*) on oversanded takyrlike soils are formed (Figs. 4–7, contour 4). These landscapes are quite interesting. Hills of up to 15–20 m high are formed by sand (its thickness increases with height). The relief of the sand hills is complicated by microaccumulations of sand near the stems of haloxylon and other plants. On sand, the species composition is considerably more diverse; there are many ephemeral species, saltworts. The depressions between the hills are relatively flat, and are topped with takyr crust with takyr soils below it. The fractional canopy cover in such depressions is very low (around 5%). Surface cracking into polygons is typical. Similar takyr crusts are likely to be located under the sand hills as well. In the past, they dominated in this area but were buried under the sand as a result of the so-called process of oversanding of takyrs. Most archaeological sites found in these landscapes are dated to the Antiquity (Kangyuiskaya and Kushanskaya cultures). Ancient irrigation canals currently resemble ridges slightly elevated over the surrounding territory, with rounded or flat tops, framed by a broken chain of the remnant bank levees.

Long-term intense development of the processes of deflation and eolian accumulation has led to oversanding of takyrs and later to the formation of hillock–eolian plains with ephemeral–shrubland vegetation (*Haloxylon Persicum*, *Ammodendron Argenteum*, *Halochemum Strobilaceum*) on desert sandy soils. These landscapes are typical mainly for the southwestern, central, and northwestern parts of the Prisarykamysh alluvial–deltaic plain (Figs. 4–7, contour 5). These landscapes are most resilient to human pressure; they are characterized by the highest diversity of plant species and the highest fractional canopy cover in the Prisarykamysh delta (with the exception of modern oases). Archaeological sites found in the landscapes of eolian plains are dated primarily to the Neolithic Age. However, the number of sites is very small; they are located in the sands of the outer portions of the delta and in the proximity of table rocks, in the southwestern part of the Prisarykamysh alluvial–deltaic plain. Up to the 4th century BC, when irrigation was introduced into agricultural production, anthropogenic factor barely affected the landscape evolution.

Lands currently under irrigation with agricultural crops on takyr-like cultivated salinized soils are located on the leveled, gently sloping, and flat plains in the eastern part of the delta, in the proximity of the Daudan and the Daryalyk rivers (Figs. 4–7, contour 6).

The western part of the Prisarykamysh delta of the Amudarya is dominated by unique flat plains with karst depressions, covered with halophyte–shrubland vegetation (*Artemisia Terrae-Albae*, *Salicornia Herbacea*, *Salsola Lanata*, *Salsola Paulsenii*) on gray-brown salinized soils. This region borders the Lake Sarykamysh, which influences the character of soil salinization (Figs. 4–7, contour 7). On the lake shore at a distance of 10–15 m from the water edge, salts appear on the surface. The plant species composition is very poor and consists primarily of saltworts. Another unique feature of this area is the presence of karst depressions, the diameter of which is 1.5–3 m. No settlements were found in these landscapes.

Conclusions

In summary, our research suggests that there exists a relationship between the current state of landscapes and their land-use history, in particular the timing of irrigation cessation. We identified a temporal landscape evolution series for previously irrigated lands. A pattern is suggested, according to which landscapes where irrigation ceased in the Modern Age (19–20th centuries) correspond to the youngest stage in the landscape evolution series, that of the solonchak plains. Landscapes where human economic activity ceased in the Middle Ages (9–15th centuries) have evolved into takyr plains. Areas abandoned in the Antiquity (4th century BC-5th century AD) are currently oversanded takyr-like plains. Results of our comprehensive study of past climates, landscapes, and land-use history can now provide the basis for historical geoecological monitoring of the Prisarykamysh delta with the application of aerial photography and satellite remote sensing.

We note here that our conclusions about the timing of fluctuations in water supply into the Prisarykamysh delta from the Neolithic Age though present are largely qualitative since they are based on such proxy data as results of archaeological site analysis and historical landscape reconstructions. Undoubtedly, when utilizing archaeological data for landscape paleoreconstructions, especially when the number of archaeological sites of a given age is considered in the analysis, one should pay due respect to both the issue of archaeological visibility and the socio-economic conditions under which cultures of the past were formed. Due to the sheer length of time that has passed since the Neolithic Age, one would expect many fewer Neolithic sites to still be preserved compared to the more recent sites. Sites located in certain geographical environments (on top of or near table rocks) have a better chance of having been discovered than sites in other environments (in the moving sands in the southern extremes of the study region). As one moves in time from the Neolithic Age to the present, socio-economic conditions begin to play an ever increasing role in the appearance and disappearance of settlements and irrigational facilities. We tried to account for these societal factors to some degree by bringing in references to historical documents, i.e. local chronicles and travellers accounts. Finally, we note that even though the study area presently is largely uninhabited, certain agricultural and residential development has taken place in recent years, directly affecting several archaeological sites.

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