Chapter 4
Changes of the Aral Sea Level

Sergey Krivinogov

Abstract This chapter reviews the available data on the Aral Sea level changes and presents the current thinking on the sea's recessions and transgressions prior to its modern desiccation. The geomorphologic, sedimentologic, paleoenvironmental, archaeologic and historiographic evidence is reconsidered and combined on the basis of calibrated ^{14}C ages. The geomorphologic data appear contradictory and require re-examination. Lithology and paleoenvironmental proxies of the sediment cores provide much consolidated information, as they record lake level changes in sediment constitution by deep and shallow water facies and layers of gypsum and mirabilite, which are of special importance for determination of low levels. High levels are recorded in several on-shore outcrops. The new archaeological data from the now dry bottom of the Aral Sea and its surrounding zone in combination with the historiographic records provide a robust model for level changes during the last two millennia. Discovery of tree stumps in different parts of the bottom indicate low stands of the lake as well. During the last two millennia, there were two deep natural regressions of ca. 2.1–1.3 and 1.1–0.3 ka (1,000 years) BP (Before Present) followed by the modern anthropogenic one. The lake level dropped to ca. 29 m asl. Their separating transgressions were up to 52–54 m asl. The middle to early Holocene record of level changes is probably incomplete. Currently the middle Holocene regressions are documented for the periods of ca. 5.5–6.3, 4.5–5.0 and 3.3–4.3 ka BP. The early Holocene history of the Aral shows a long period of a shallow lake.

Keywords Lithology • Stratigraphy • Paleogeography • Archaeology • Historiography • Aral Sea • Lake level changes • Transgressions • Regressions

S. Krivinogov (✉)
Institute of Geology and Mineralogy, Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russia
e-mail: s_krivonogov@mail.ru

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4.1 Introduction

The idea that the Aral Sea is a notably changeable body of water became clear after the pioneering study by Berg (1908) and later developed by Soviet geologists (e.g., Veinbergs and Stelle 1980; Kes 1983; Shnitnikov 1983; Rubanov et al. 1987). Knowledge of those days was summarized in several reviews (Sevastyanov et al. 1991; Aladin and Plotnikov 1995; Tarasov et al. 1996; Letolle and Mainguet 1997; Boomer et al. 2000). Drops and rises of the Aral level have been considered geomorphologically, sedimentologically, paleontologically, archaeologically and historiographically. In general, the following important theses arose from the initial studies: (1) the Aral Sea is very young and its age is approximately 10–12 ka; (2), the typical mollusk *Cerastoderma* spp. (former *Cardium edule* L.) penetrated into the Aral Sea from the Caspian Sea at ca. 5 ka BP (BP = before present), (3) The highest level of the Aral was in the middle Holocene, and its deepest regression was ca. 1.6 ka BP.

New data obtained by international teams[1] in the first decade of the twenty-first century (e.g., Nourgaliev et al. 2003; Boroffka et al. 2006; Oberhansli et al. 2007; Reinhardt et al. 2008; Boomer et al. 2009; Krivonogov et al. 2010a, b) considerably improved this common knowledge; however a synthesis of the older and newer data has not been done yet. This chapter provides a critical review of the knowledge, adds a portion of the newest data and gives an integrated interpretation of the Aral Sea level changes. All sites discussed in the chapter are shown in Fig. 4.1.

4.2 Terraces

Geomorphologically, changes of the Aral Sea levels are recorded in eight erosional and accumulative terraces and shore bars ranging from 72 to 31 m asl (above sea level) (Fig. 4.2a). However, this scheme is "idealized" and does not reflect a variety of views, especially on the high lake levels, i.e., above 53 m asl, which is a conventional stable level for the middle of the twentieth century.[2]

Berg (1908) found only one 4 m high terrace contoured at 54 m asl, which is commonly recognizing as the "new Aral" terrace. Yanshin (1953) additionally recorded terraces at 60, 62, 64 and 72 m asl, and attributed them to one recent transgression. Neotectonic movements explained the difference in their heights.

[1] Projects: EU INTAS-Aral Sea (2002–2005) and USA-Russia CRDF-RFBR (2008–2010).

[2] Researchers used different altitudinal estimates of the Aral Sea level. The conventional levels were 50.75 m in 1903 (Berg 1908), 52 m in 1911–1931 (Berg 1932) and 53 m in 1960 (official nautical maps). These differences include sizeable corrections by topographic leveling and perennial fluctuations of the lake. The amplitude of mean annual levels was 78 cm for the period of 1911–1931 and 3.09 m for the period of 1874–1931 (Berg 1932). Therefore, both heights and altitudes of terraces provided by individual authors may vary considerably.

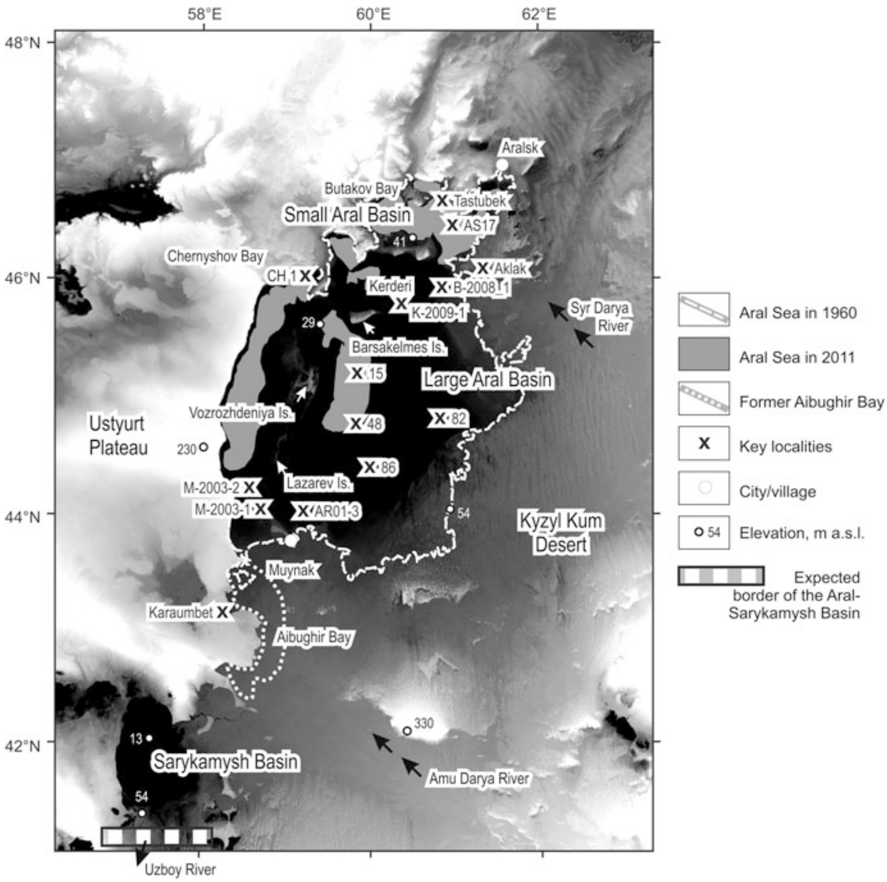


Fig. 4.1 Location map and the SRTM Digital Elevation Model topography of the Aral Sea region

Lymarev (as summarized in Lymarev (1967)) found four terraces from 1 to 10 m above the Aral level, i.e., up to 63 m asl. Epifanov (1961) described two lower and three higher terraces. The lower ones are "late Aral" and "ancient Aral" at ca. (approximately) 54 and 56 m asl, respectively. The higher terraces are 8–10, 12–17 and 22–27 m high, i.e., 61–63, 65–70 and 72–77 m asl (Fig. 4.2b). Locations of the higher terraces are additionally listed in Kiryukhin et al. (1966). According to Gorodetskaya (1978), all the described terraces form hypsometric levels traceable over the whole Aral-Sarykamysh region and representing different stages of the basin evolution. For instance, the hypsometric level above 80–85 m asl represents the late Pliocene lacustrine stage.

Occurrences of the Aral at the highest levels of 58–70 m suggest a topographic border between the Aral and Caspian Seas, which does not exist in modern relief (Fig. 4.1). Khondkarian (1977) and Fedorov (1980) hypothesized such a border. In contrast, Veinbergs (1986) did not find any lake terraces higher than "ancient Aral",

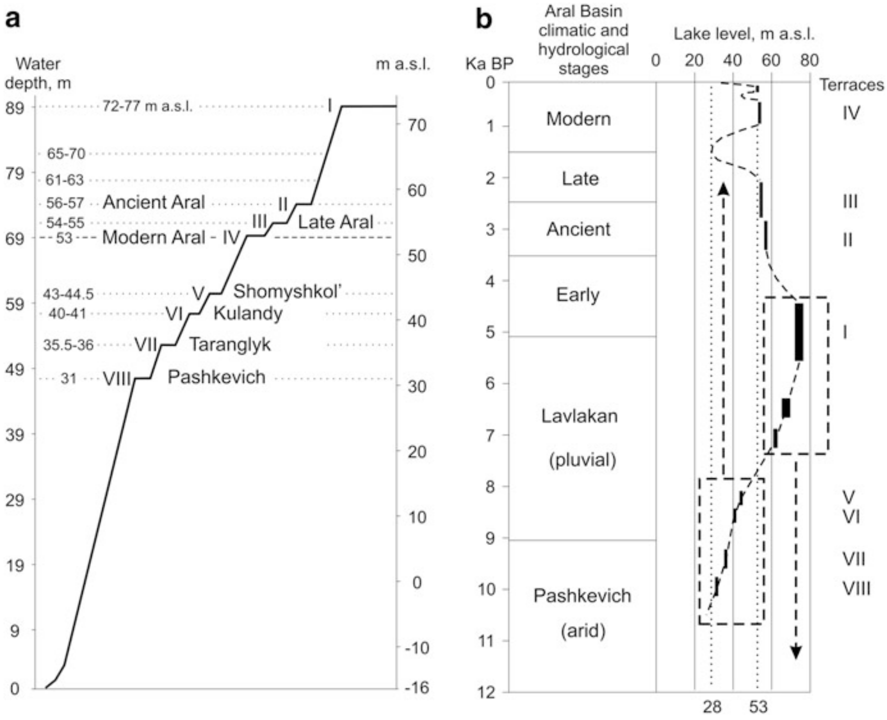


Fig. 4.2 A summary of the common knowledge about the Aral Sea level changes. Modified from Boomer et al. (2000). (**a**) Lake terraces. (**b**) Timing of the events recorded in the terraces. Dashed frames indicate groups of events, whose ages look to be incorrectly defined as discussed in Sect. 4.2. *Arrows* show their probable shifts in age (older and younger)

56–57 m asl, along the northeastern, northern, eastern and southern shores. He suspected that high terraces described by the above-cited authors in fact are surfaces of denudation of Paleogene and Neogene rocks surrounding Lake Aral. The ideas of Veinbergs found support from recent detailed field surveys as well as tachymetric and DGPS-derived altitude measurements in several sites of the northern and southwestern shores of the lake (Reinhardt et al. 2008).

A crucial argument for the high lake terraces is the presence of shells of the Aral Sea mollusks *Cerastoderma* and *Dreissena*, in their sediments or on their surfaces (e.g., Epifanov 1961; Kirukhin et al. 1966). However, some authors raised doubts about such findings on the surface and attributed them to wind transport (e.g., Yanshin 1953; Veinbergs 1986).

The relation of the high terraces to the coastal processes of the Aral Sea is questionable based on their ages. Commonly, the 72 m terrace is dated to the middle Holocene and correlated to the Lavlakan pluvial epoch, which approximately matches the Atlantic climatic phase (Boomer et al. 2000). Alternatively, terraces higher than 56 m asl may be older than the Holocene and have no relation to the Aral. Thus, Pshenin et al. (1984) described an outcrop of a 15–17 m, 68–70 m asl, terrace of the north-western coast, which contains alien pebbles transported from the Mugodzhar Hills situated northward of the Aral Sea. As the basal clays beneath have a radiocarbon age of 24,820 ± 820 (IGAN-372), the authors concluded that powerful water-flows from the West Siberian proglacial lake in the late Pleistocene time formed this terrace.

Archaeological data restrict the age of the "ancient Aral" terrace, at 56–57 m asl, to a Neolithic date of around 5 ka BP, which made it possible to place the older 72 m terrace within the Holocene (Boomer et al. 2000). However, Boroffka et al. (2005a, b, 2006) clearly showed wide distribution of Paleolithic sites, 50–35 ka BP, at 60–70 m, and these areas have never been inundated by the Aral since then (Reinhardt et al. 2008).

Lower "late Aral" and "ancient Aral" terraces (Fig. 4.2) were much less disputed until Reinhardt et al. (2008) asserted that there are no lake terraces above 54–55 m asl, which matches the idea of Berg (1908). Radiocarbon dating of the terraces contradicts their conventional order: 745 ± 80 and 730 ± 80 BP for the "ancient Aral" and 2,860 ± 80, 1,320 ± 120[3] BP for the "late Aral" terraces (Veinbergs 1986). Therefore, the problem of Aral terraces remains unresolved and expert reanalysis of their locations addressed earlier by Yanshin, Epifanov, Kiryukhin, Veinbergs and other scientists is needed.

Shore bars situated on the former bottom of the Aral Sea below 53 m asl indicate lower levels of 35.5–36, 40–41 and 43–44.5 m asl (Veinbergs et al. 1972). The 31 m "Paskevich" level actually was not found in bottom relief, but was suggested from the altitudes of highly mineralized layers in bottom sediments (Veinbergs and Stelle 1980). These authors hypothetically dated the Paskevich basin as late Pleistocene – early Holocene and considered formation of all these shore bars during one phase of lake transgression. This point of view is reflected in the reviews (Fig. 4.2); however, its correctness is questionable. Why are such old landforms well preserved and were not covered by a thick layer of sediments? Just a casual visual examination of satellite images of the modern dry bottom of the Aral shows many shore bars, which reflect the gradual retreat of the lake in modern times. Therefore, any recent transgression or regression could leave the pattern of shore bars described by Veinbergs and others.

4.3 Sediments

4.3.1 Sediment Cores

Dozens of short, up to 1 m, and more than 100 longer, up to 4.5 m, cores of bottom sediments have been obtained over the Aral Sea over the period from

[3] Veinbergs (1986) refers this date to M.E. Gorodetskaya; however, Gorodetskaya (1978) published only the date of 920 ± 120 obtained in VSEGEI from shell material. Veinbergs believed the date was probably younger than the real age of the terrace.

the 1940s into the 1990s. The cores were studied lithologically and geochemically (Brodskaya 1952; Khrustalev et al. 1977; Rubanov et al. 1987; Zhamoida et al. 1997), paleontologically for pollen and spores (Maev et al. 1983) and for diatoms (Zhakovschikova 1981; Aleshinskaya 1991) and isotopically (Nikolaev 1987, 1991; Nikolaev et al. 1989). In general, the sediments consist of the following parts (bottom to top): (i) brown clays of non-lacustrine origin, a substratum; (ii) light gray coarsely laminated clays, silts and sands with gypsum, which reflect conditions of changeable small lakes and salt-marshes; and (iii) greenish-gray clays and silts and gray sands of the Aral Sea (Nikolaev 1991). The last part is rich with marine fauna, whose most characteristic components are shells of the mollusk *Cerastoderma* spp. The lake sediments and paleontological data reflect several changes of the lake from deep-water (clayey silts) to shallow-water (sands with shells). Other evidence of a shallow lake are layers of salts (calcite, gypsum and mirabilite) and peat.

Variations in the sedimentation during lake level fluctuations are well illustrated by lithological studies of the surficial layer. Mapping by Brodskaya (1952) and Zhamoida et al. (1997) show changes in facial structures, which reflects the modern recession of the lake. In the sediment sequences, sulphate and carbonate deposits in the central part of the Aral Sea mainly define low water level events, as does gypsum or mirabilite near the borders (Le Callonnec et al. 2005).

The sediments were dated by the radiocarbon method (Kuptsov et al. 1982; Maev et al. 1983; Kuptsov 1985; Parunin et al. 1985; Maev and Karpychev 1999). However, a major part of about 70 dates (summarized in Krivonogov et al. 2010b) obtained from bulk sediment samples of organics and carbonates are stratigraphically inconsistent. They were found unsuitable for sediment correlation (Rubanov et al. 1987; Ferronskii et al. 2003) and only a few of them originated from plant remains and mollusk shells were used (Table 4.1, sites A and B; Fig. 4.3). Finally, only two well-dated sediment cores no. 15 and 86 from the Large Aral Basin (Fig. 4.1) were comprehensively studied and used for paleolimnological and paleoclimatic reconstructions (Maev et al. 1983; Sevastyanov et al. 1991; Maev and Karpychev 1999; Ferronskii et al. 2003). However, their correlation in Sevastyanov et al. (1991) and Tarasov et al. (1996) was done before obtaining the core no. 86 ^{14}C dataset (Maev and Karpychev 1999). Figure 4.4 corrects for this problem.

The sediment structure in both cores suggests variable lake conditions from deep to shallow. The age vs. depth plots of the cores show two major stages of sedimentation: faster in the upper part and slower beneath (Fig. 4.3). The linear approximation of probable ages shown in the figure is too simple and does not reflect the complicated facial structure of the sediments. The sedimentation rate may vary from one to another layer, and hidden breaks could occur. However, the model presented gives us a chance to correlate layers and to date important lake level changes. Fortunately, exact littoral and beach facies provide good material for dating, which makes it possible to correlate the lake recessionary events. It is worth noting that the shallow lake facies in the cores from distant sites may be diachronous.

Table 4.1 Radiocarbon dates from Aral Sea sediments

Depth, m	^{14}C age, BP	Lab code	Material	$\delta^{13}C$, ‰	Calibrated age, BP[a]
A. Core 15 (Maev et al. 1983)					
1.0–1.03	1590 ± 140	MGU-778	Mollusk shells		1550 ± 280
1.2–1.28	3610 ± 140	MGU-742	Mollusk shells		3930 ± 365
1.48–1.55	4850 ± 90	MGU-741	Mollusk shells		5600 ± 155
1.56–1.64	4960 ± 100	MGU-740	Mollusk shells		5750 ± 170
B. Core 86, reference dates only (Maev and Karpychev 1999)					
1.25–1.3	1510 ± 150	IVP-285	Plant remains		1430 ± 310
2.05–2.21	3450 ± 80	IVP-273	Plant remains		3750 ± 175
2.6–2.87	4810 ± 180	IVP-260	Mollusk shells		5480 ± 445
310–324	5610 ± 220	IVP-268	Mollusk shells		6410 ± 495[b]
310–324	5750 ± 250	IVP-297	Plant organics		6630 ± 535[b]
342–345	6090 ± 150	IVP-258	Mollusk shells		6970 ± 345
C. Core Ar-8 (Nourgaliev et al. 2003)[c]					
0.45			Algal TOC[d]		450 ± 100
1.0			Algal TOC		480 ± 120
3.85			Algal TOC		660 ± 65
4.5			Algal TOC		1100 ± 125
5.55			Algal TOC		1500 ± 125
5.95			Algal TOC		1470 ± 110
D. Core Ar-9 (Nourgaliev et al. 2003)[c]					
4.95			Algal TOC		1150 ± 135
5.9			Algal TOC		1310 ± 90
E. Cores CH 1 and 2 (Austin et al. 2007; Sorrel et al. 2006, 2007)					
0.55	110	POZ-4753	Algal TOC		Modern
1.24	4320 ± 80	POZ-4750	Algal TOC		Rejected
4.65	820 ± 30	POZ-13511	TOC		730 ± 50
5.93	1650 ± 30	POZ-4756	Algal TOC		Rejected
6.04	1230 ± 30	POZ-4758	Algal TOC		1130 ± 60
6.17	1660 ± 30	POZ-4759	Algal TOC		Rejected
6.34	1160 ± 110	POZ-12279	Algal TOC		1100 ± 195
6.93 (7.2)[e]	1400 ± 30	POZ-4762	Algal TOC		1300 ± 35
7.63	1600 ± 40	POZ-4764	Algal TOC		Rejected
7.73 (7.88)[e]	1480 ± 30	POZ-9662	Mollusk shells		1360 ± 50
8.28 (8.6)[e]	1520 ± 25	POZ-4760	Algal TOC		1380 ± 40
F. Core C2/2004 (Píšková et al. 2009)					
0.075	Modern	POZ-	Mollusk shells		
1.12–1.15	775 ± 30	POZ-	Mollusk shells		700 ± 30
1.25–1.26	915 ± 30	POZ-	Mollusk shells		840 ± 80
2.04	1400 ± 30	POZ-	Algal filaments		1320 ± 35
2.07–2.08	1415 ± 30	POZ-	Mollusk shells		1330 ± 40
2.54–2.56	3080 ± 70	POZ-	Mollusk shells		Rejected

(continued)

Table 4.1 (continued)

Depth, m	^{14}C age, BP	Lab code	Material	$\delta^{13}C$, ‰	Calibrated age, BP[a]
2.9–2.98	1820 ± 40	POZ-	Algal filaments		1780 ± 85
3.16–3.18	4875 ± 35	POZ-	Mollusk shells		5620 ± 40
G. Core M-2003-1 (Krivonogov et al. 2010a, b)					
2.6–2.7	1010 ± 30	AA-59339	Shell of *Dreissena*	+1.0	940 ± 40
3.1–3.2	1490 ± 30	AA-59340	Shell of *Cerastoderma*	+1.1	1360 ± 55
4.0–4.1	1330 ± 40	AA-61833	Shell of *Cerastoderma*	+1.1	1240 ± 65
4.2–4.3	1580 ± 40	AA-61834	Shell of *Cerastoderma*	+0.9	1470 ± 85
4.3–4.4	1680 ± 40	AA-61835	Shell of *Cerastoderma*	+0.2	1610 ± 95
6.2–6.3	4790 ± 40	AA-59342	Shell of *Cerastoderma*	−0.9	5530 ± 70
6.9–7.0	4840 ± 40	AA-59343	Shell of *Cerastoderma*	+0.3	5560 ± 90
8.0–8.1	5390 ± 40	AA-59344	Shell of *Cerastoderma*	+0.6	6230 ± 55
H. Core M-2003-2 (Krivonogov et al. 2010a, b)					
2.8–2.92	1190 ± 60	AA-83691	Shells of ostracods and gastropods	+0.9	1090 ± 110
7.2–7.52	6690 ± 80	AA-83690	Shells of ostracods	−2.7	7550 ± 115
16.6–16.72	8740 ± 95	AA-83689	Shells of ostracods	−3.3	Rejected
18.8–18.92	8550 ± 95	AA-83688	Shells of ostracods and gastropods	−3.2	Rejected
I. Core B-2008-1 (Krivonogov et al. 2010a, b)					
0.25–0.27	390 ± 35	AA-83393	Shell of *Cerastoderma*	+2.7	470 ± 45
0.31–0.32	1160 ± 35	AA-83394	Shells of *Caspiohydrobia*	+1.0	1110 ± 65
0.69	4240 ± 45	AA-83396	Shell of *Cerastoderma*	+1.5	4750 ± 125
1.0–1.1	4230 ± 35	AA-83397	Shells of *Cerastoderma*	+1.5	4780 ± 85
1.18	4200 ± 40	AA-83398	Shells of *Cerastoderma*	+0.5	4690 ± 75
5.6–5.7	8030 ± 130	AA-86200	Terrestrial plant remains	−25.4	8930 ± 355
5.7–5.8	9590 ± 120	AA-86199	Terrestrial plant remains	−25.8	10930 ± 285
6.34	19,900 ± 140	AA-83399	Shell of a gastropod	−1.6	23,800 ± 435
J. Core K-2009-1 (Krivonogov et al. 2013)					
0.78	510 ± 45	AA-90634	Plant remains	−27.6	530 ± 35
1.34	410 ± 45	AA-90635	Plant remains (root?)	−25.6	480 ± 50
1.79	310 ± 40	AA90636	Plant remains	−24.6	390 ± 90
1.89	4150 ± 35	AA90637	Shells of *Caspiohydrobia*	2.9	4700 ± 130
2.0	4230 ± 55	AA90638	Shell of *Cerastoderma* (in sity)	0.9	4720 ± 150
2.2	340 ± 40	AA90639	Plant remains (root?)	−26.0	400 ± 90
2.8	360 ± 40	AA90640	Plant remains	−25.1	410 ± 95
7.5	9200 ± 50	AA90641	Shells of *Caspiohydrobia*	2.6	10370 ± 125
K. Aklak (Krivonogov et al. 2010a, b)					
2.5	1,510 ± 35	AA-83390	Shell of *Cerastoderma*	+1.1	1,370 ± 55
2[f]	160 ± 35	AA-83391	Pieces of wood/grass	−20.2	140 ± 140
3[f]	165 ± 35	AA-83391	Grass stem	−27.2	140 ± 140

(continued)

Table 4.1 (continued)

Depth, m	^{14}C age, BP	Lab code	Material	$\delta^{13}C$, ‰	Calibrated age, BP[a]
L. Karaumbet (Reinhardt et al. 2008; Krivonogov et al. 2010a, b)					
0.45–0.5	300 ± 30	POZ	Shells of *Cerastoderma*	c	400 ± 60
2.0–2.1	1810 ± 30	POZ	Shells of *Cerastoderma*	c	1760 ± 70
2.1	1720 ± 30	AA-59338	Shells of *Cerastoderma*	−0.3	1630 ± 75

[a]Intcal09 (Reimer et al. 2009)
[b]Paired dates indicating negligible age difference between mollusk shells and plant organics
[c]From Fig. 1 in Nourgaliev et al. (2003)
[d]*TOC* total organic carbon
[e]Different depth specified by Sorrel et al. (2006, 2007) and by Austin et al. (2007) for the same samples
[f]The sample was collected in the floodplain sediments about 1 km downstream on the Syr Darya River from the Ak-Lak outcrop

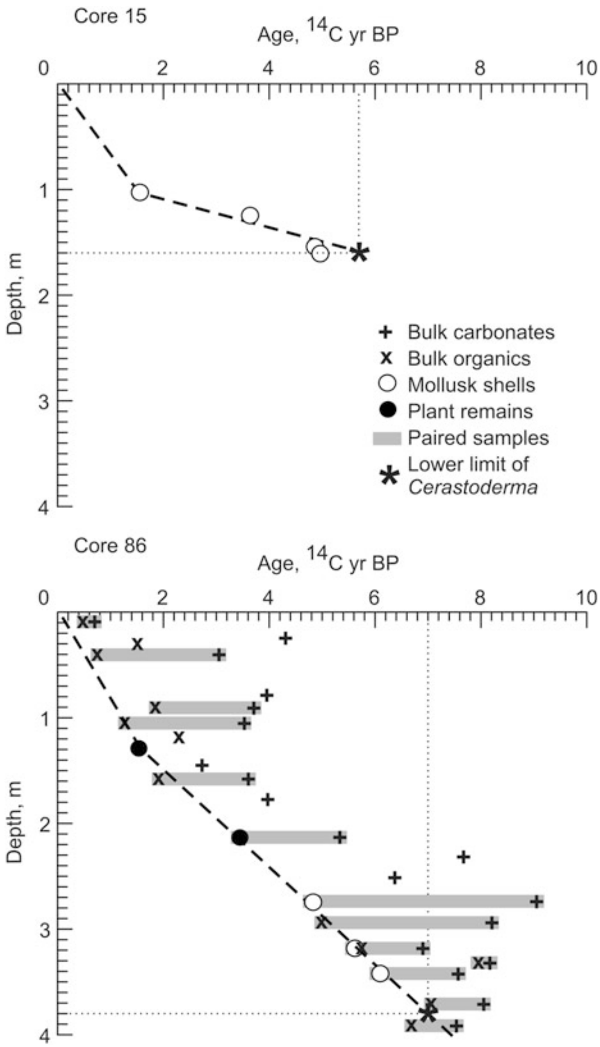
Three layers of shallow water sediments occur in the upper parts of both cores (Fig. 4.4). Their radiocarbon and tentatively interpolated ages show synchronism of low lake levels, which took place at ca. 1.5–1.4, 0.8–0.65 and 0.3–0.2 ka cal. (cal. = calibrated) BP (Table 4.2). In these intervals, the lake level fell to 26–27 m asl. Core 86 has one more distinct layer of beach sediments dated at ca. 7.0–6.6 ka cal. BP, which however is absent in core 15.

Le Callonnec et al. (2005) investigated a 4.4 m long core 48 obtained by Rubanov et al. (1987) in the central part of the Aral Sea at a water depth of 25 m, i.e., ca. 26–27 m asl (Fig. 4.1). The low water levels are represented in the core by five calcium carbonate-rich layers at 51–55, 110–115, 128–130, 150–155 and 210–215 cm, one gypsum-rich layer at 300–310 cm and by the basal sand. Careful geochemical study allowed Le Callonnec et al. (2005) to attribute fluctuations of the lake level to changes in river inflow; however, their timing of events is based on the tentative correlation of core 48 with cores 15 and 86, which is not well founded because core 48 has neither radiocarbon dates nor prominently correlative strata.

Krivonogov et al. (2010a, b) investigated three new cores: M-2003-1, M-2003-2 (Muynak) and B-2008-1 (Barsakelmes) obtained at the heights of 50, 36 and 39 m asl, respectively (Fig. 4.1). Two boreholes, M-2003-2 and B-2008-1, penetrated through the whole lake sediments and entered into the substrate of brown colored dense clays of non-lacustrine origin.[4]

[4] Core M-2003-1 was obtained with a help of a Forestry Suppliers Inc. regular auger. Only the lower, non-contaminated, part of every portion of sediments was collected. Upper 7 m of the core B-2008-1 were obtained with the help of a Livingston-type piston corer, which provides undisturbed sediment columns. Lower part of the core B-2008-1 and the whole core M-2003-2 were obtained with the help of a checking sampler, which is a pipe with a vertical slit. Due to this, the lowermost lots of the cores were contaminated by younger materials during the hoisting of the downhole instrument. This was recently verified by the ^{14}C dating and the previously published stratigraphic columns of the cores B-2008-1 and M-2003-2 (Krivonogov et al. 2010a; Guskov et al. 2011) are corrected (Krivonogov et al. 2010b and this chapter).

Fig. 4.3 Age-to-depth plots for the sediments of cores 15 and 86 (Modified from Maev and Karpychev 1999; Ferronskii et al. 2003)



The lake sediments show alternation of deep and shallow water facies (Fig. 4.5) similar to those in cores 15, 48 and 86. Correlation of the sediments is accurately done by the use of radiocarbon dates, which mostly belong to the shallow water sandy facies enriched by mollusk and ostracod shells (Table 4.1, sites G-I).

The oldest date of 19,900 ± 140 ^{14}C BP (23,800 ± 435 cal. BP) was obtained from a large, 3 cm long, thin-wall Lymnaeidae-type gastropod, which was unluckily broken by the cutter during the core splitting procedure. The shell is from the topmost part of the substratum clays and its age is the likely age minima of the pre-Aral Sea environment. The oldest age of the Aral sediments is 9,590 ± 120 ^{14}C BP (10,930 ± 285 cal. BP). Recessions of the Aral occurred at ca. 11–8, 7.5, 6.3–5.5,

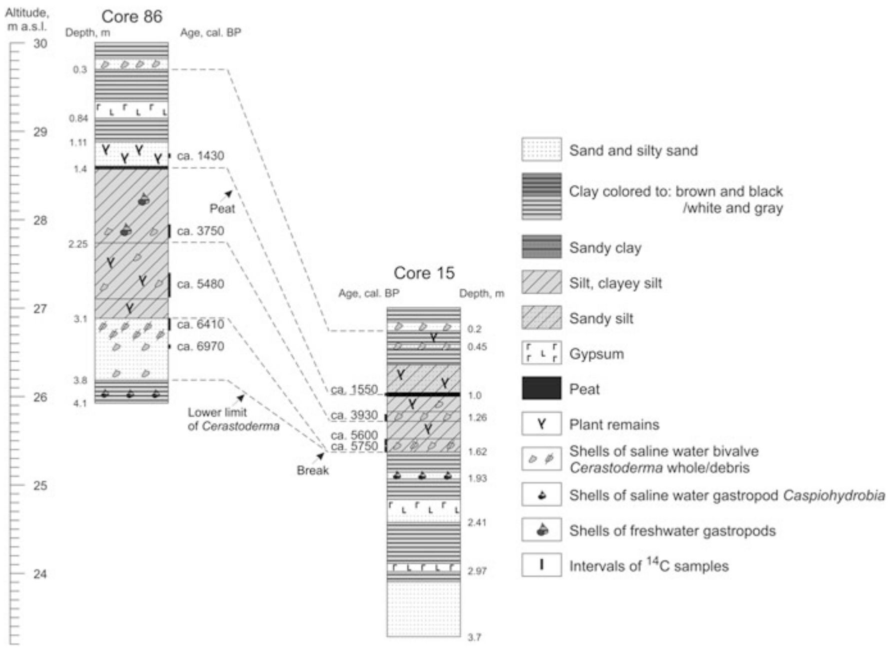


Fig. 4.4 Stratigraphy of cores 15 and 86 and their correlation to the calibrated ^{14}C ages (Based on a summary of the data from Maev et al. 1983; Sevastyanov et al. 1991; Tarasov et al. 1996; Maev and Karpychev 1999 and Ferronskii et al. 2003)

Table 4.2 Age of sediment layers in cores 15 and 86 representing low lake levels

Core 15				Core 86			
Depth, m	Age, ka cal. BP	Sediments	Lake level, m asl	Depth, m	Sediments	Age, ka cal. BP	Lake level, m asl
0.16–0.21	0.2–0.3[a]	Sand with shells	~27	0.17–0.3	Sand with shells	0.2–0.3[a]	~30
0.43–0.45	0.65–0.7[a]	Sand with shells	~27	0.66–0.84	Gypsum	0.7–0.8[a]	~29.5
0.98–1.0	1.5[b]	Peat	26	1.39–1.41	Peat	1.4[b]	~ 28.5
				3.1–3.77	Beach sands with shells	6.6-7.0	26

[a]Interpolated
[b]Based on ^{14}C date

4.8, 1.6–1.3 and 0.5 ka cal. BP. The oldest date of *Cerastoderma* shell is 5,390 ± 40 ^{14}C BP (6,230 ± 55 cal. BP).

Boomer et al. (2009) briefly reported one more newly obtained core AR01-3 drilled in the southern part of the Large Aral at ca. 38.5 m asl (Table 4.1). A *Cerastoderma* shell taken at a depth of 54–60 cm returned a ^{14}C age of 4,420 ± 55

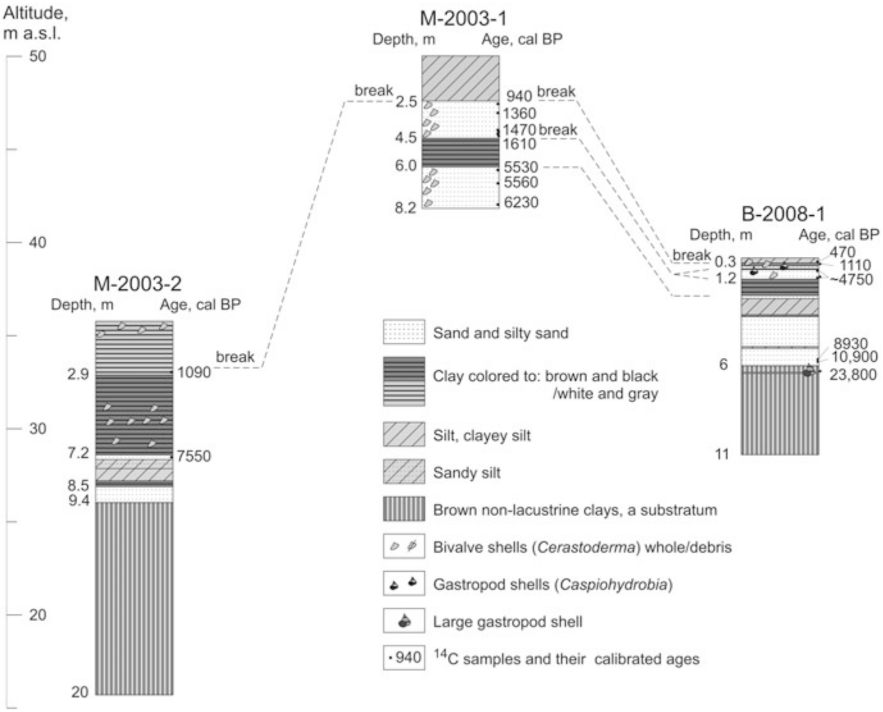


Fig. 4.5 Stratigraphy of cores M-2003-1, M-2003-2 and B- 2008–1 and their correlation to the calibrated ^{14}C ages (A summary of the data from Krivonogov et al. 2010a, b)

BP, which suggests very slow sedimentation. The authors suggest this date to be reworked, while core B-2008-1 taken at about the same height in the northern part of the Large Aral has similar age marks (Krivonogov et al. 2010a, b, Table 4.1, site I), and therefore may represent the same event of the lake level change.

Sediments of the Small Aral Basin were characterized by two ca. 1.5 m long cores that showed alternation of dark gray mineral and black organic rich clays (Boomer et al. 2003). Only one ^{14}C date of 380 ± 40 (0.3–0.5 ka cal. BP) was obtained in the organic rich layer of the core AS17, ca. 27 m asl, (4.1) from the *Phragmites* stem at the sediment depth of 125–130 cm. The date indicates a high sedimentation rate and three organic rich layers with remnants of the near-shore reed (*Phragmites*) indicate several lowerings of the Small Aral in the latest stages of its development.

Sediments of the deep-water northwestern part of the Large Aral were cored to a depth of 1.5–11 m in the Chernyshov Bay; a total of 28 cores were obtained (Figs. 4.1 and 4.6a; Nourgaliev et al. 2003; Sorrel et al. 2006, 2007; Austin et al. 2007; Píšková et al. 2009). The sediments are coarsely laminated and consist of considerable biogenic mud and terrigenous clays and silts (Fig. 4.6b). Alternation of biogenic and terrigenous layers may reflect environmental variations.

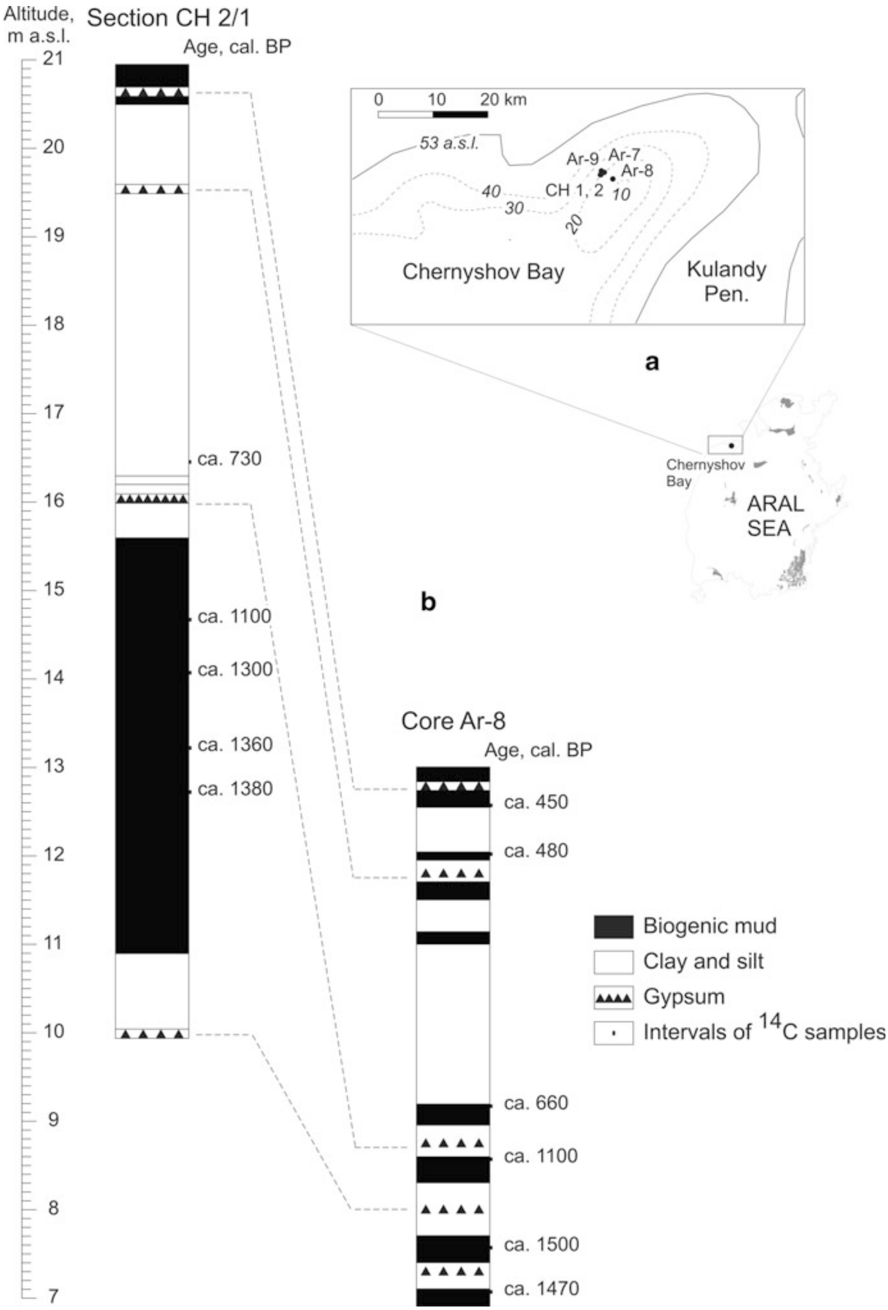


Fig. 4.6 (**a**) A detailed map showing the position of the cores obtained in the Chernyshov Bay. (**b**) Stratigraphy of cores CH-2/1 and Ar-8 and their correlation to the calibrated ^{14}C ages (Based on a summary of the data from Nourgaliev et al. 2003; Sorrel et al. 2006, 2007; Austin et al. 2007; Oberhansli et al. 2007)

However, their sequences in the reference cores CH 1, 2 and Ar-8 drilled at different water depth, 21 and 13 m asl, respectively, are ill matched. Gypsum-rich layers are more reliably correlative as a precipitation of gypsum marks progressive salinization of the lake (Sorrel et al. 2006; Oberhansli et al. 2007).

Radiocarbon dating of biogenic mud layers showed a very young age for the sediments of the Chernyshov Bay (Table 4.1, sites C–E) and their very fast accumulation at an average rate of 4–6 mm per year. The organics of the mud is mostly filamentous green algae *Vaucheria* sp. (Sorrel et al. 2006) and, therefore, the dates look reliable; however, several dates were rejected because of probable contamination by older carbon (Austin et al. 2007). Fast accumulation of the biogenic mud may be attributed to the intensive growth of the algae. Nevertheless, the intervals of clay and silt accumulation in core Ar-8 show an even higher, up to 15 mm per year, sedimentation rate. Thus, fast sedimentation is a specific feature of the northwestern deep part of the Aral Sea.

The correlative gypsum-rich layers indicate increased salinization and, therefore, declines of the lake levels at ca. 1, 4, 0.8, 0.5 ka cal. BP and also recently.

4.3.2 Outcrops

The structure of a limited number of outcrops highlights a problem of determining high stands of the Aral. Sediments of the 60–65 m asl Tastubek Peninsula of the northern shore of the Aral were investigated in a gully situated southward of Tastubek Village (4.1; Reinhardt et al. 2008). A 3.5 m high section consists of sandy, silty and clayey sediments of continental origin including paleosoils and wind erosion horizons. No evidence of a lacustrine layer was found. Probable age of the sediments has an upper limit of ca. 30 ka BP according to the mesolithic artifacts found in the nearest vicinities (Boroffka et al. 2005a). This suggests that the Aral Sea did not rise to a high level during the formation of the sediments and afterward.

A high stand of the lake at 52 m asl is recorded in the Aklak outcrop situated on the left bank of the Aklak reservoir recently constructed on the Syr Darya River near its mouth (Fig. 4.1). The outcrop shows very shallow water littoral sand facies of Aral sediments covered by the deltaic series of the Syr Darya (Fig. 4.7a). The lake sediments contain an abundance of shells *Cerastoderma* and *Dreissena*, having a ^{14}C date of 1510 ± 35 BP (Table 4.1, site K), which suggests a transgression at ca. 1.4 ka cal. BP. The deltaic sediments showed very recent ages of 140 ± 140 cal. BP, which suggests an interruption in the sediment record of the modern Syr Darya mouth (Krivonogov et al. 2010a, b).

Evidence of two high levels of the Aral is recorded in the Karaumbet outcrop, which is situated about 70 km southward from the middle twentieth century southern bank of the Aral Sea (Fig. 4.1). The Karaumbet Basin (39 m asl), is a sinking tectonic structure along the eastern scarp of the Ust-Urt Plateau separated

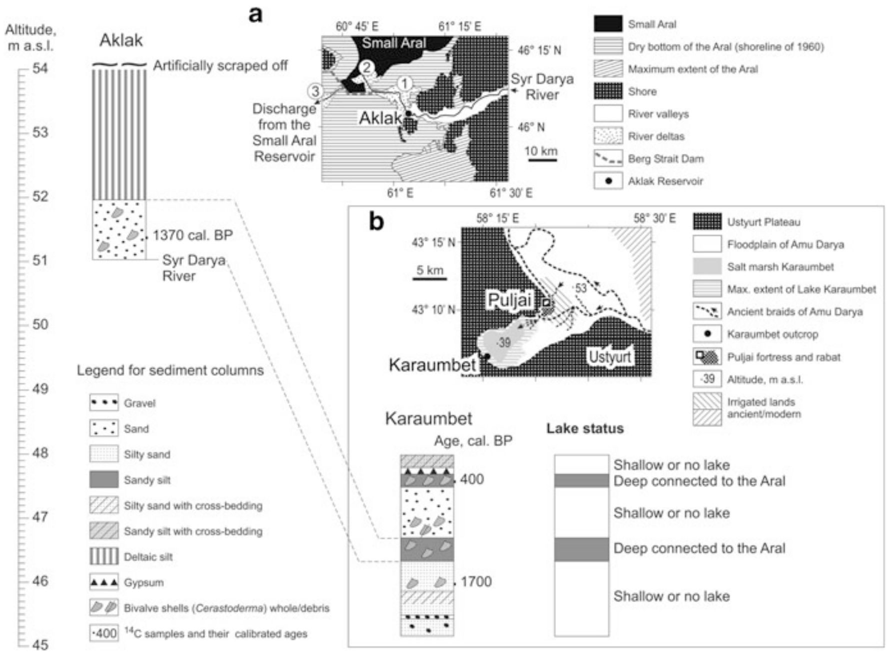


Fig. 4.7 High stands of the Aral recorded in the outcrops of Aklak (**a**) and Karaumbet (**b**) (Modified from Krivonogov et al. 2010a, b; Reinhardt et al. 2008)

from the Aral Basin during its low stands. In the periods of high stands, the Karaumbet connected with the Aral via the shallow Aibughir Bay.

The outcrop is a wall of a 2 m deep gully cut by surface water in the sloped bottom of the Karaumbet Basin at ca. 45 m asl. The sediments consist mostly of sub-aerial fluvial and aeolian series, whereas the lacustrine facies are subordinate (Fig. 4.7b). The typical Aral Sea shells *Cerastoderma* and *Dreissena* are in-situ in the lake sediments and apparently reworked in the non-lacustrine ones. The outcrop shows two layers of sandy silt lake sediments with shells, which represent the highest stands of the Aral (Reinhardt et al. 2008). The dates (Table 4.1, site L) allow us to correlate the older layer with the Aklak event, i.e., ca. 1.4 ka cal. BP, and date the younger layer ca. 0.4 ka cal. BP.

4.4 Paleoenvironmental Proxies

A variety of records obtained from the Aral Sea sediments give us information about climate and lake level changes. In this section we discuss only those records, which are related to lake levels. They characterize two environmental settings: the

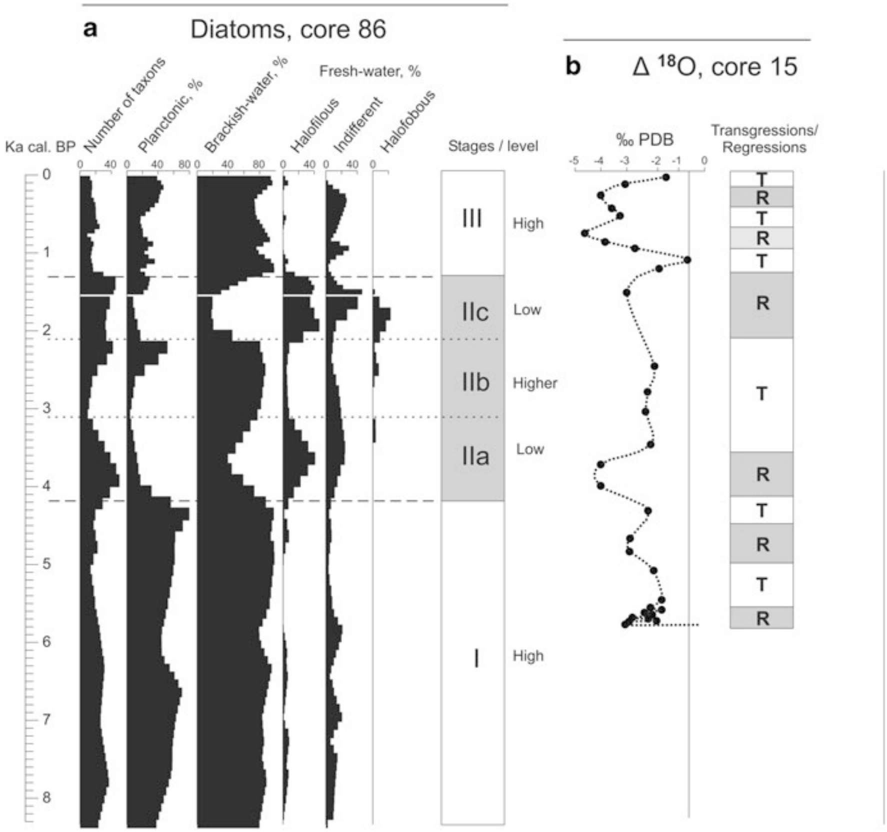


Fig. 4.8 Paleoenvironmental proxies indicating Aral Sea level changes. (**a**) Diatom data from core 86 (Aleshinskaya 1991). (**b**) ^{18}O data from core 15 (Nikolaev 1991)

rather shallow central part of the basin, cores 15 and 86, and the deep-water Chernyshov Bay, cores CH 1and 2 and C2/2004 (Fig. 4.1).

Diatom data from core 86 show three stages of the lake development (Aleshinskaya 1991, Fig. 4.8a) with prominent boundaries at a depth of 225 and 111 cm (Fig. 4.4). Stages I and III represent brackish and saline-water basins, which were typical to the recent Aral of nineteenth to twentieth centuries. Stage II represents desalinization of the basin, which is indicated by the dominance of fresh-water diatoms at ca. 4.2–1.3 ka cal. BP (Fig. 4.8a). Aleshinskaya (1991) explained this phenomenon by the decrease of the lake level and progradation of the Amu Darya Delta. The diatom data match the sedimentological evidence of shallow-water and deltaic conditions in the central part of the Aral Sea (Rubanov et al. 1987). In detail, Stage II includes two peaks of the fresh-water diatoms, which may represent deep regressions of the Aral at ca. 4.2–3.2 and 2.1–1.3 ka cal. BP.

Oxygen isotopes were investigated in several cores in the central part of the basin (Nikolaev 1987, 1991; Nikolaev et al. 1989). The geochronologically referenced record was obtained from core 15 (Fig. 4.8b). Its interpretation is based on the suggestion that increases of ^{18}O in the bottom sediment carbonates reflect regressions (Nikolaev et al. 1989), which therefore occurred at ca. 5.8–5.5, 5.0–4.5, 4.1–3.5, 2.1–1.3, 0.9–0.7 and 0.2–0.4 ka cal. BP.

Cores CH 1 and 2 from the Chernyshov Bay provided data on the level changes in the part of the Aral, which was not dried out during the last 1.5–2 ka. The dinoflagellate cyst and chlorococcalean algae records suggest low level and saline basins at ca. 2.1–1.6, 1.1–0.7, 0.6–0.3 and 0.05–0 ka cal. BP (Sorrel et al. 2006). Additionally, the authors concluded that a very high lake level occurred at ca. 0.7–0.6 ka cal. BP. This explains abundant reworked dinocysts, which could be re-deposited from the shore sediments of Paleogene and Neogene age by wave erosion.

Diatom-inferred salinity indicates low levels at ca. 1.6, 0.8–0.7 and 0.2–0 ka cal. BP (Austin et al. 2007) and increases in salinity coincide with the peaks of total organic carbon. The authors constrained the record by ca. 1.6 ka because of an abrupt transition in the diatom flora and magnetic susceptibility (Sorrel et al. 2006), which suggest a hiatus within the material at a depth of 10.3 m.

Píšková et al. (2009) published the diatom data of a C2/2004 core retrieved by D. Nourgaliev (Nourgaliev et al. 2007) in the Chernyshov Bay at a distance of 25 km SE from the core CH 1, 2 locality at a water depth of ~3 m (ca. 27 m asl.).[5] Changes of the diatom assemblages showed low lake level stages at ca. 2.0–1.75, 1.1–1.0, 0.6–0.55 and 0.1–0 ka cal. BP and high level stages at ca. 1.5–1.1, 0.8–0.65 and 0.4–0.1 ka cal. BP.

The ostracod data from the Small Aral sediments suggest a considerably decreased lake level at ca. 0.5–0.3 ka cal. BP (Boomer et al. 2003, 2009). The level was estimated to have fallen as low as 27–29 m asl., which is the first paleontologic evidence of the Middle Age catastrophic regression.

In addition, Filippov and Riedel (2009) analyzed the ecology of mollusk fauna and stable isotope compositions in mollusk shells in ten short half-meter cores obtained by Zhamoida et al. (1997) in the eastern part of the Aral. Sediment age is controlled by two ^{14}C dates: fruits of water plant *Ruppia* sp. found in core 82 (altitude 33 m asl.) at a depth of 34 and 35 cm gave ages of 690 $\pm$ 35 (KIA-18247) and 710 $\pm$ 40 (KIA-18248), respectively. Despite lacking age control, which does not allow fixing inconsistencies in sedimentation, the authors suggest considerable variations of the lake level during the last millennium with minimums at ca. 0.85 and 0.5 and maximums at 0.65 and 0.35 ka cal. BP.

Boomer et al. (2009) summarized the recently obtained microfaunal data and proposed a scheme of the Aral Sea level changes during the last ca. 2000 years, which suggests low Aral levels during ca. 2–1.6, 1.1–0.65, 0.5–0.35 and 0.2–0 ka cal. BP.

[5] Unfortunately, the referenced paper (Nourgaliev et al. 2007) has no mention of core C2/2004, thus, its exact location is unknown.

4.5 Tree Stumps

Stumps of the *Saxaul* tree were reported in several places across the bottom of the Aral Sea. Their careful investigation would allow us to estimate limits of the past regressions and their duration (by tree rings). However, few of them were dated and, unfortunately, the investigators did not record coordinates and altitude positions of their findings, which decrease the value of this data. In any case, the territory where the *Saxaul* grew is rather dry and therefore the stumps cannot serve as precise markers of levels.

A stump on the strand of the Lazarev Island (Fig. 4.1) investigated by Maev et al. (1983) has ^{14}C age of 970 ± 140 (MGU-734), i.e., ca. 0.9 ka cal. BP. The position of this finding could not be lower than 47 m asl., which marks the Aral level of that time (Kravtsova 2001). Aladin and Plotnikov (1995) and Boomer et al. (2000) briefly mention a *Saxaul* stump of 287 ± 5 ^{14}C age. According to S. Stine[6] (pers. comm.), there are two ^{14}C dated stumps: one sample from the southern part of Butakov Bay is 280 ± 70 (CAMS-2504), ca. 0.4 ka cal. BP, and another one from the exposed bottom northward of the Barsakelmes Island (Fig. 4.1) is 170 ± 70 (CAMS-2503), ca. 0.3 ka cal. BP. According to N. Aladin (pers. comm.), the last site was a forest of *Saxaul* trees currently represented by hundreds of stumps.

Six poorly preserved stumps representing a small *Saxaul* grove were found in the vicinities of the Kerderi 1 (Fig. 4.1) archaeological site at the altitude of ca. 34 m asl. (Krivonogov et al. 2013). The finding is related to human activity, as the geomorphological survey and excavation of the sampled stump show (see Sect. 4.6). The grove was situated near an artificial pond-like basin. A cultural layer with pieces of bricks and an animal bone was found at a depth of ca. 30 cm. The stumps are 10–25 cm in diameter, and one of them was collected for ^{14}C dating (Fig. 4.9). Its upper part, which stood above ground level, is strongly foliated along tree-rings and contaminated by roots of modern plants; therefore we dated the better preserved lower part of the stump, which returned an age of 470 ± 35 (AA-93688), i.e., 0.5 ka cal. BP.

4.6 Archaeological Data

Sites of ancient cultures are widespread around the Aral, which many geologists and geomorphologists considered as an opportunity to date lake level changes (e.g., Yanshin 1953; Kes 1969, 1983; Rubanov et al. 1987; Sevastyanov et al. 1991). The distribution of the sites of different ages has been summarized in several publications (e.g., Tolstov 1962; Vinogradov 1968; Levina 1998). In respect to

[6] Scott Stine, California State University, received these two samples from Ian Boomer in 1991 and dated them. The samples were collected by Nick Aladin.

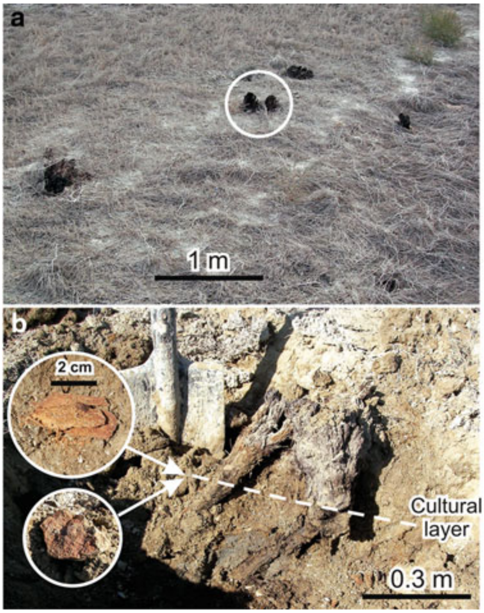


Fig. 4.9 Stumps of the Saxaul trees at the Kerderi-1 locality. (**a**) General view. (**b**) A stump excavated for the ^{14}C dating. The picture shows the position of cultural layer and findings of pieces of a bone and a brick in it (*in circles*) (Photos by S.K. Krivonogov)

the lake levels, Yanshin (1953) and Vinogradov (1981) mentioned the lack of Mesolithic sites around the Aral Sea contrary to the abundance of Neolithic ones, and suggested that this indicated the settling of ancient man closer to the Aral since ca. 10–9 ka BP. This was interpreted as a change from climatically unfavorable conditions of poor water supply to favorable ones, which matches a transition from the Pashkevich low to the Lavlakan high phases of the Aral in terms of the ideas of Veinbergs and Stelle (1980). The Neolithic findings constrain the period of the Lavlakan phase to ca. 9–5 ka BP (Mamedov 1991a).

Nevertheless, the major part of the available archaeological materials characterizes settlement processes away from the Aral shores and mostly represents the development of river deltas, which may reflect variations in climate, river courses and irrigation. Deeper investigation has shown the presence of archaeological sites of different ages, from the Late Paleolithic, ca. 50–30 ka, to modern, near the Aral (Shirinov et al. 2004; Baipakov et al. 2004; Boroffka et al. 2005b), which have never been covered by its water except those situated below 54 m asl. (Boroffka et al. 2005a, 2006). This refutes the concept of a “high”, up to 72–73 m asl, Aral.

A site, which was obviously covered by the Aral Sea is Puljai situated near the eastern edge of the Ustyurt Plateau (Fig. 4.7b). The monument consists of a fortress having a higher position on a cape of the Ustyurt cliff and of a civil settlement (rabat). Rabat occupies a deltaic plain of the Amu Darya at an altitude of ca. 53 m asl. It consists of several manors placed at a distance of 50–90 m along one of the river channels, which flowed into the terminal Karaumbet Lake. Its adobe brick

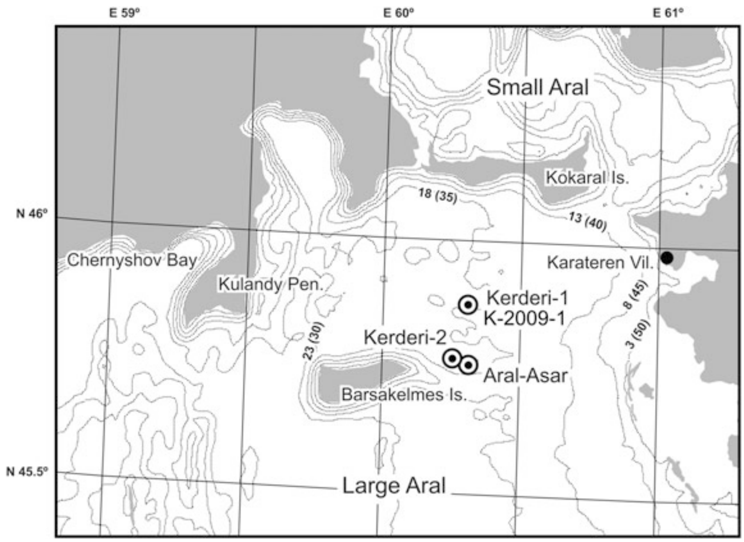


Fig. 4.10 A detailed map showing the positions of the archaeological sites on the dry bottom of the Aral Sea. Topographic situation of ca. 1960. Isobaths are labeled by their depth and altitude asl (*in parentheses*)

buildings now look like clayey mounds because their ruins were flooded by the Aral Sea. That it was flooded is clear from a cover of *Cerastoderma* and *Dreissena* shells, which are abundant on the tops of the ruins. The artifacts date the Rabat to twelfth – end of fourteenth centuries AD, i.e., ca. 800–500 year BP (Shirinov et al. 2004; Boroffka et al. 2005a, b, 2006). Therefore, the transgression occurred later than 500 BP, and it probably was the highest during the last millennium.

The Kerderi monuments situated on the bottom of the Aral Sea to the east-northeast of the Barsakelmes Island are clear evidence of a deep regression (Figs. 4.10, 4.11 and 4.12). They were found by local hunters and excavated by Kazakh archaeologists in the early 2000s (Smagulov 2001, 2002; Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007; Sorokin and Fofonov 2009). The sites include mausoleums Kerderi-1 and Kerderi-2 and the settlement Aral-Asar. The sites occupy areas with altitudes of ca. 34 m asl (Table 4.3), which suggests deep regression similar to the modern one.

Baipakov et al. (2007) suggest a very short period of several decades for the Kerderi – Aral-Asar civilization, which was ended by a sudden rise of the Aral Sea. However, the authors describe a rather developed industrial and agricultural community. The findings from Aral-Asar, which probably appeared as a settlement on the Great Silk Road, indicate extensive livestock and plant agriculture, and trade. The settlement has a necropolis, and its citizens were rich enough to construct two amazing mausoleums ornamented by terracotta, blue-colored

Fig. 4.11 Photographs of the archaeological sites Kerderi-1 (**a**) and Kerderi-2 (**b**). The detailed photo of "b" shows wood excavated by archaeologists from a grave. This wood was used for ^{14}C dating (Photos by S.K. Krivonogov)

ceramics and mosaics, which are architecture and decoration analogues of sacred buildings in Samarkand and other cities of Khorasan, Middle Iran and Azerbaijan (Sorokin and Fofonov 2009). The Kerderi-1 and Kerderi-2 mausoleums were constructed on the weak silty sediments of the Aral Sea, which required reinforced basements. Their basements were made from the Paleogene sandstone slabs, for which the nearest source is the Kok-Aral Peninsula, ca. 50 km northward (Smagulov 2001). Thus, the Middle Age people populating the dried Aral Sea bottom had to have enough time to settle and economically develop the area and also construct various amenities.

Extensive plant agriculture is evidenced by specific large pots used for storage of rice or wheat and millstones, which are abundant in the Aral-Asar settlement, and by paddies and irrigation channels constructed in the vicinities of Aral Asar (Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007) and Kerderi-1 (Krivonogov et al. 2013) (Fig. 4.12). The agriculture implies a sufficient amount of fresh water, which was taken from the Syr Darya (Krivonogov 2009; see Sect. 4.8).

Various authors interpret the archeological age of these sites differently. The Kerdery-1 mausoleum and mosque is dated to the twelveth-fourteenth by Smagulov (2002), to the fourteenth-sixteenth or fourteenth to early fifteenth by Boroffka et al. (2005a, 2006), and to the XIII–XIV centuries AD by Boomer et al.(2009). The Kerdery-2 mausoleum has been assigned an age of late thirteenth to middle fourteenth (Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007) or fourteenth-fifteenth centuries AD (Sorokin and Fofonov 2009). The Aral-Asar settlement is dated by coins as middle fourteenth century AD

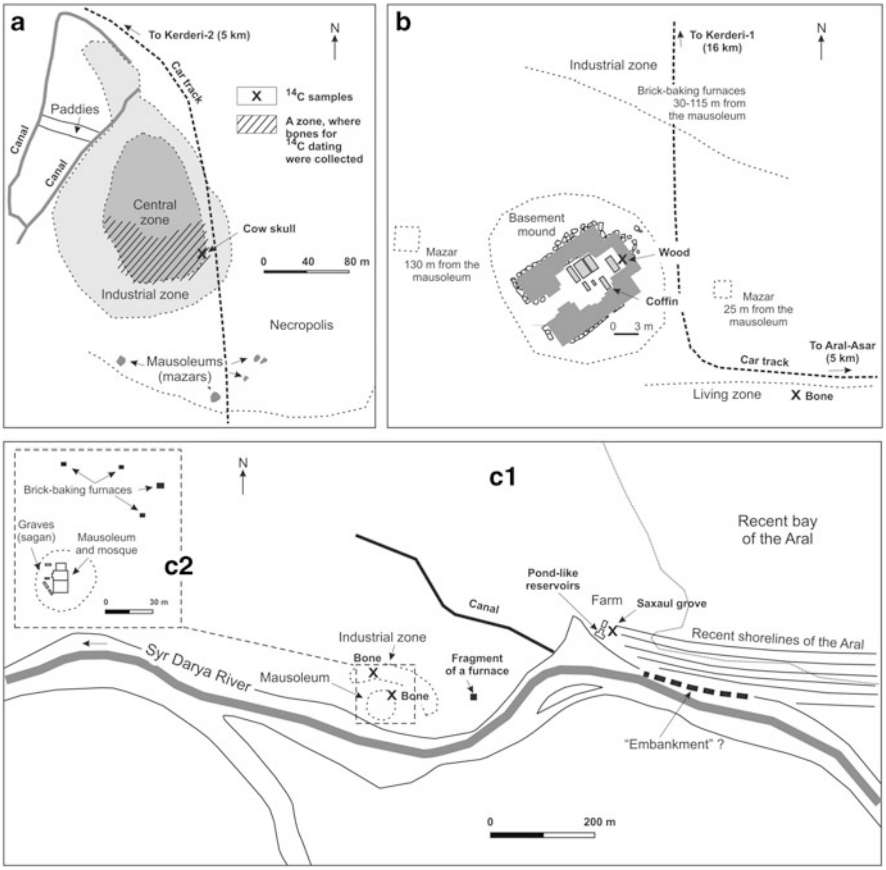


Fig. 4.12 Sketches of the Aral-Asar (**a**), Kerderi-2 (**b**) and Kerderi-1 (*C1* and *C2*) localities (The modified data by Smagulov 2002; Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007; Krivonogov et al. 2013). The drawings show general topography and location of archaeological sites and of ^{14}C dated samples

Table 4.3 Location of the Kerderi monuments

		Altitude, m asl	
Monument	Coordinates, dd	Measured by investigators	From the nautical chart-based DEM
Kerderi-1	N 45.86381 E 60.31314	34[a]	34
Kerderi-2	N 45.72346 E 60.26193	29[b]	33.6
Aral-Asar	N 45.70883 E 60.31687	33[b]	34.8

[a]Boroffka et al. (2005a, b)
[b]Catalogue of Monuments of the Kazakhstan Republic History and Culture (2007)

Table 4.4 Radiocarbon dates from the Kerderi archaeological monuments (Krivonogov et al. 2010b, 2013)

^{14}C age, BP	Lab code	Material	δ^{13}C, ‰	Calibrated age, BP[a]
Kerderi-1				
470 ± 35	AA-93688	Saxaul-tree wood[b]	−23.1	510 ± 35
620 ± 45	AA-93685	Domestic animal bone[c]	−22,1	600 ± 60
640 ± 45	AA-93686	Domestic animal bone[d]	−15.7	610 ± 60
860 ± 35	AA-93687	Shell of *Cerastoderma*[e]	−0.7	750 ± 55
1600 ± 65	SOAN-8176	Cannon-bone of an ancient man[f]		1490 ± 140
Kerderi-2				
580 ± 35	SOAN-8175	Domestic animal bone[g]		590 ± 60
600 ± 65	SOAN-7688	Thin wood stick[h]		600 ± 75
820 ± 55	SOAN-7687	Thick wooden plank[h]		740 ± 65
Aral-Asar				
540 ± 45	SOAN-8174	Caw skull		580 ± 70
630 ± 35	SOAN-8173-1	Domestic animal bone[i]		610 ± 55
910 ± 80	SOAN-7686	Domestic animal bones[j]		820 ± 135
1050 ± 90	SOAN-8173-3	Domestic animal bone[i]		970 ± 205
1750 ± 95	SOAN-8173-2	Domestic animal bone[i]		1690 ± 185

[a]Intcal09
[b]The sample was collected from a stump of the saxaul tree on the farm eastward of the mausoleum
[c]The sample was collected within the industrial zone northward of the mausoleum
[d]The sample was collected in the cultural layer under the saxaul tree on the farm eastward of the mausoleum
[e]The sample was collected from the sediments below the cultural layer in the same excavation as "d"
[f]The sample was collected on the northern slope of the mound of the mausoleum. Probably the bone was washed out from a grave of the sagan surrounding the mausoleum
[g]The sample was collected within the living zone of the mausoleum
[h]The material was collected in the north-eastern part of the mausoleum near a grave, which was robbed before the archaeological excavations in 2055 (Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007)
[i]The samples SOAN-8173-(1, 2 and 3) were selected from a collection of bones used for paleontological identification. The bones were collected in the southern part of the Aral-Asar settlement (Fig. 4.15a). They belong to domestic animals: cow, horse, and sheep/goat (Krivonogov et al. 2010b)
[j]The sample consists of material from several bones

(Catalogue of Monuments of the Kazakhstan Republic History and Culture 2007). All of these datings, constrain the Medieval "Kerderi" regression to ca. 0.8–0.4 ka BP.

The radiocarbon dating of different materials of the sites (Krivonogov et al. 2010b, 2013; Table 4.4, Fig. 4.12) showed two clusters of ages, which suggests two phases of low levels of the Aral at ca. 1.9–1.4 and 1.0–0.5 ka cal. BP with a higher level in between (Fig. 4.13).

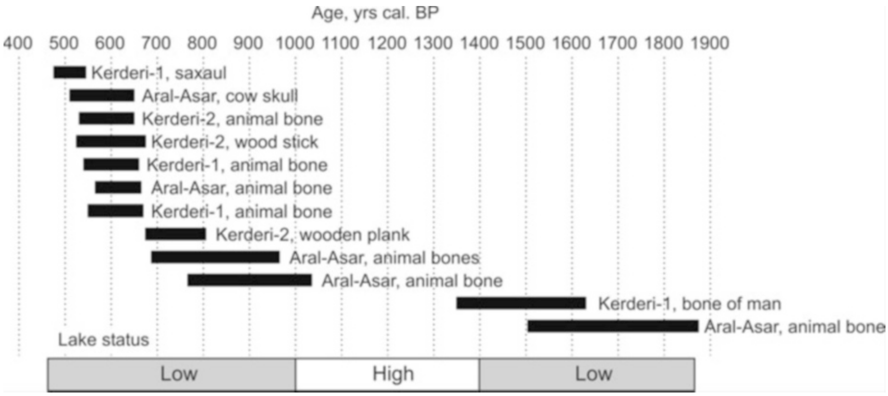


Fig. 4.13 Distribution of the calibrated ages (*black bars*) of the samples dated in the Aral-Asar, Kerderi-1 and Kerderi-2 localities. These data suggest two low level phases of the Aral separated by a high level phase (*lake status bar*)

4.7 Historical Data

The Aral Sea (Kurder, Khoresm or Jend Lake) has been mentioned in geographic treatises, chronicles and other documents since ancient times. Available manuscripts were carefully analyzed by Bartold (1902), whose findings were used by Berg (1908) and by subsequent researchers in their reconstructions of Aral history. However, most of these documents are poor witnesses of Aral Sea changes. More or less reliable information, however, appeared beginning in the middle Ages.

A famous example, often cited in geological literature, is attributed to Genghis Khan whose troops conquered Urgench City, the capital of Northern Khorasan, in 1221 AD. During the campaign, an earthen dam protecting the city from flooding by the Amur Darya River was destroyed and the river turned from flowing to the Aral to the Sarykamysh Basin. Many scientists believe that this event was a major contributor to the Medieval recession of the Aral. However, our dating of the Kerdery sites suggests an earlier onset of the regression at ca. 1 ka cal. BP.

Hafizi-Abru, a chronicler and geographer of the Tamerlane court, wrote in 1417 AD that the Aral Sea "does not exist now" and that the Amu Darya flows to the Caspian Sea (Bartold 1902). Berg (1908, p. 268) considered this evidence of an extremely low Aral as exaggerated and for decades it was dismissed. In light of modern data, the witness of Hafizi-Abru coincides with the main period of the Kerdery sites development.

The subsequent rise of the Aral Sea is evidenced by the Khiva khan Abulgazi, who noted that the Amu Darya turned to the Aral Sea 30 years before his birth, i.e., in about 1573 AD (Bartold 1902). By the end of the sixteenth century, the Aral Sea became fully filled. In "Kniga glagolemaya Bolshoi Chertezh" (Book of the Great

Map, 1627), which was a description to the first map of the "entire Moscow state", the Aral was called "the Blue Sea" with a latitudinal length of 250 versts[7] (Berg 1908). S. Remezov depicted it as a big lake on the maps in 1697 (Berg 1908) and by A. Bekovich-Cherkasskii in 1715 AD (Shafranovskii and Knyazhetskaya 1952).

The actual dimensions of the Aral Sea were geodetically measured by Russian topographers led by Commander A. Butakov in 1848–1849 AD (Butakoff 1853). On the map, its extent looks similar to the size of the sea in the 1960s or even a bit larger, as the map depicts the Aibughir Bay extending about 100 km to the south (4.1).

Berg (1908) summarized the data on the changes of the Aral level since 1790 AD, the record of which was continued later on (e.g., Shermatov et al. 2004). This record shows the level fluctuated within ca. a 3 m range only (see footnote 2 above), which indicates a metastable transgressive state of the lake during the last 190 years.

4.8 Braids of the Syr Darya

The extensive and long (ca. 400 km) Syr Darya Delta possesses several very prominent ancient river courses with well-preserved channels named Karadarya, Inkardarya, Janadarya and Kuvandarya (Fig. 4.14a). They probably functioned in different periods of the Holocene; however, when they were active is not well known (Mamedov 1991b).

Nikolaev (1991) was the first, who found the paleochannels of the Syr Darya on the Aral Sea bottom northward of the Barsakelmes Island and in the middle part of the sea and showed them in a paleogeographic map. The channels were attributed to the 1.6 ka BP drop of the sea (1.5–1.4 ka cal. BP, see Sect. 4.3). Krivonogov (2009) mapped braids with the help of satellite imagery in which the ancient river bed and side channels of the Syr Darya are clearly seen for a distance of more than 100 km (Fig. 4.14a). There are two braids to the north and to the south of the Barsakelmes Island.

The northern braid starts at about 50 km eastward near the village where the present Syr Darya sharply turns to the north. To the west of Oktyabr, the ancient river branches into three channels. The northern channel reaches the Akkol Bay to the south of the village of Karateren and goes further on the Aral's dried bottom for a distance of about 40 km, forming a clearly seen delta. The middle channel reaches the Karashokhat Cape, ending with a little delta, corresponding to the maximum water level of about 53 m asl. The southern channel continues far off to the west; the Kerdery sites are situated along this riverbed.

The delta of the southern channel covers an area of 22 by 22 km to the north of the Barsakelmes Island. The western edge of the delta touches the opposite side of

[7] One verst is approximately 1.6 km.

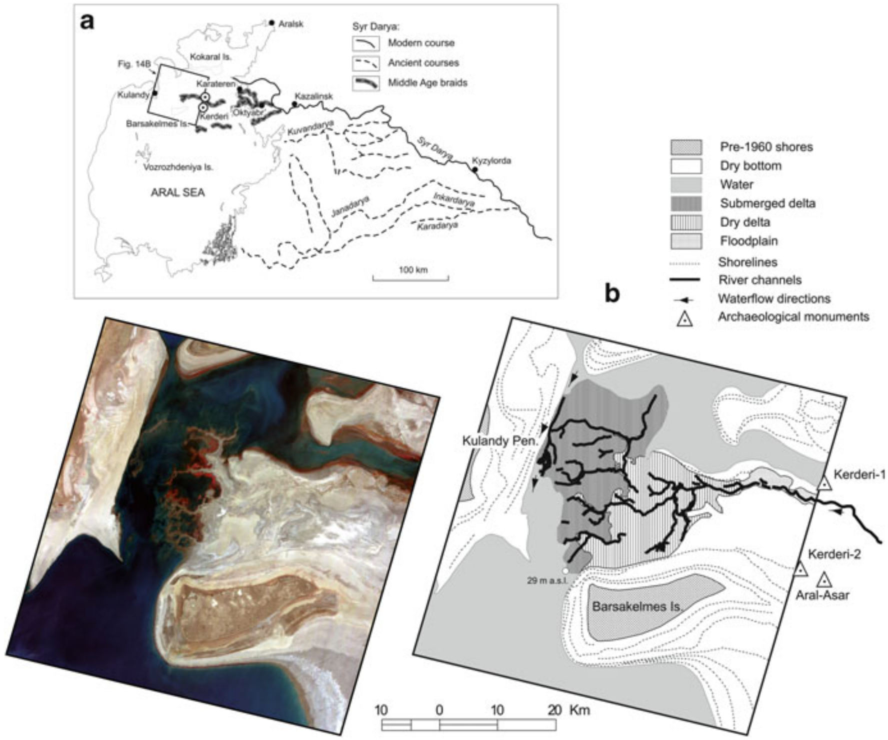


Fig. 4.14 (**a**) The Syr Darya Delta, its main river courses and the Middle Age braids. (**b**) The ASTER satellite image of 2004 (*left panel*) showing a part of the Aral Sea bottom between the Kulandy Peninsula and Barsakelmes Island and its interpretation (*right panel*) showing the medieval delta of the Syr Darya (Krivonogov 2009)

the Aral Sea, namely the Kulandy Peninsula. The edge of the delta has an altitude of about 29 m asl, which marks the medieval drop of the Aral of ca. 0.6 ka cal. BP (Fig. 4.14b).

The delta system of the northern channel is less than those of the southern one, and its surface is complicated with a smaller delta, reflecting a sea transgression. This gives grounds to suggest that the northern channel is younger than the southern one, whereas the middle channel may represent high stands occurring before or after the Kerderi low stand.

Drilling of the riverbeds was performed on a smaller braid of the southern channel near the Kerderi-1 monument, borehole K-2009-1 (Krivonogov et al. 2013; Fig. 4.10). Sandy and silty river sediments were identified at a depth of 0.4–1.8 m in between the lacustrine layers marked by *Cerastoderma*. They are enriched by plant remains (mostly stems and roots of *Phragmites*), which yielded ^{14}C dates of ca. 0.5–0.4 ka cal. BP (Table 4.1, site J). Penetration of roots deeper into the sediments explains dates of ca. 0.4 ka cal. BP at a depth of 2.2 and 2.8 m beneath the lacustrine sediments with *Cerastoderma* dated to ca. 4.7 ka cal. BP. Therefore, the temporal coincidence of the Syr Darya braids and archaeological sites on the bottom of the Aral is obvious.

A similar braid situated to the south of Barsakelmes Island (Fig. 4.14a) has not been dated yet. Good preservation of the channel landforms suggests that it is similar in age to the Kerderi braid. This implies that both braids fed the Aral Sea simultaneously, which provides evidence of quite high-flow of the Syr Darya during the Middle Ages drop of the Aral Sea.

4.9 Level Changes: A Synthesis

Figure 4.15 summarizes all available data about Aral Sea level changes during the Holocene. Gray bars indicate considerable drops of the level, which are confirmed by at least two datasets. The drops of the early, middle and late Holocene are evidenced in different degree and the changes of the last two millennia have the best grounds. Their intervals constrained by different datasets are not identical, which can be explained by incompleteness of the employed sedimentary records, obstacles in radiocarbon dating and its interpretation, and by different responses of certain lake ecosystem components to environmental changes. Therefore, the limits indicated of regressions are not conclusive and are subject to updating in light of new facts.

Thus, during the last two millennia, there were two deep natural regressions of ca. 2.1–1.3 and 1.1–0.3 ka BP followed by the modern anthropogenic one. All three regressions were of similar scale: the level dropped to ca. 29 m asl. Their separating transgressions are well evidenced by the Aklak outcrop inferring the level of ca. 52 m asl, and by the recent (historically documented) high-stand of the Aral at the altitude of ca. 53 m. The highest level of the last transgression could be up to 54 m asl, as the flooded ruins of the Puljai settlement indicate. According to the current data, the regressions look to be longer than the transgressions, but this conclusion requires careful investigation in the future. In any case, it is evident that during the last 2,000 years the Aral Sea experienced several desiccations and the related deaths of its biota, which subsequently naturally recovered.

The middle to early Holocene record of level changes is probably incomplete due to the lack of geological data. Currently the middle Holocene regressions are documented for the periods of ca. 5.5–6.3, 4.5–5.0 and 3.3–4.3 ka BP. The early Holocene history of the Aral is obscure, but the newly obtained data (Fig. 4.15b) confirm a long-lasting period of a shallow lake suggested earlier (Nikolaev 1991).

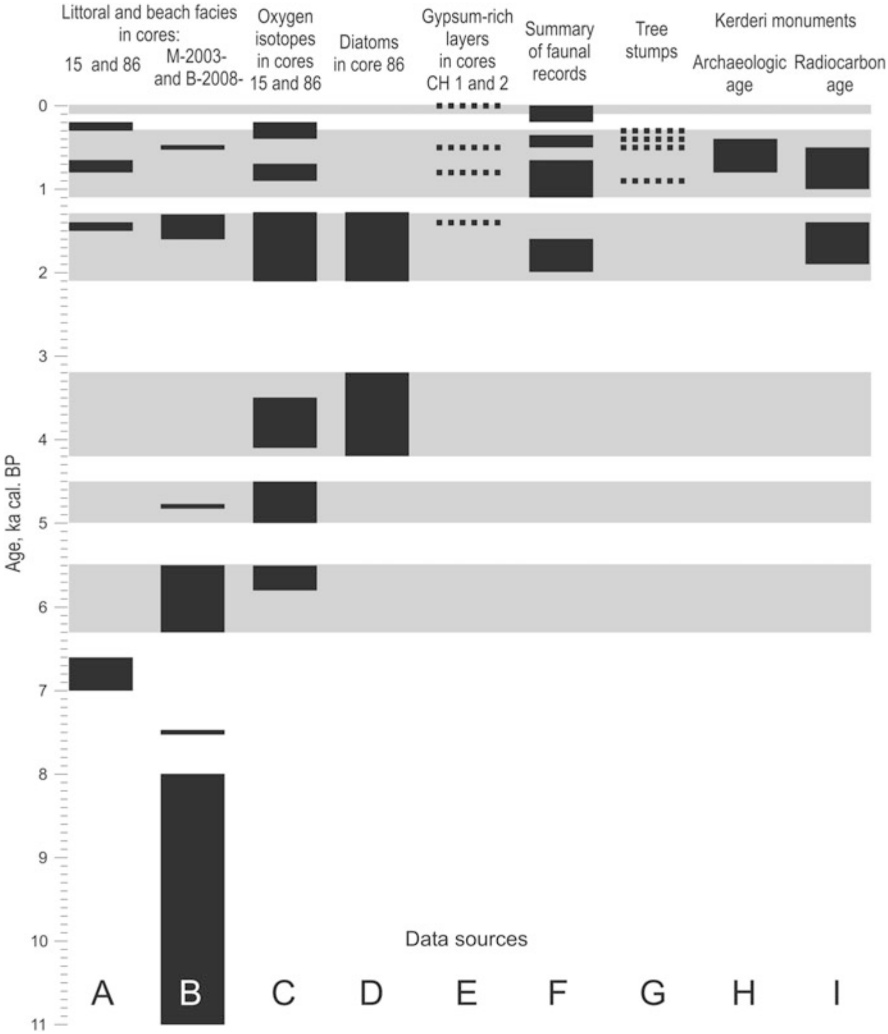


Fig. 4.15 Intervals of low levels of the Aral Sea (*gray bars*) during the Holocene inferred from the available datasets (*black rectangles*). Data sources: *A* – Maev et al. (1983), Sevastyanov et al. (1991), Maev and Karpychev (1999), and Ferronskii et al. (2003). *B* – Krivonogov et al. (2010a, b). *C* – Nikolaev (1991). *D* – Aleshinskaya (1991). *E* – Sorrel et al. (2006, 2007) and Austin et al. 2007. *F* – Boomer et al. (2009). *G* – Maev et al. (1983), Boomer et al. (2000), and Krivonogov et al. (2013). *H* – Smagulov (2002), Boroffka et al. (2005a, 2006), Boomer et al. (2009), Catalogue of Monuments of the Kazakhstan Republic History and Culture (2007), and Sorokin and Fofonov (2009). *I* – Krivonogov et al. (2010b, 2013)

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