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Archaeology and Climate: Settlement and lake level changes at the Aral Sea

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ABSTRACT

We present new archaeological and geomorphologic data collected adjacent to the Aral Sea that evidences lake level stands during the late Pleistocene and during the past 5000 years. On the N and S Aral Sea shores archaeological sites representing Palaeolithic through to the Late Middle Ages show various cultural orientations and economies. Changes in settlement activity during the Mid-Holocene are related to several major lake level oscillations. Some of them, especially those which occur at approx. 350-450 cal. yrs BP (Little Ice Age), 700-780 cal. yrs BP, around 1400 cal. yrs BP and 1600-2000 cal. yrs BP, are also documented as lithological changes in sediment cores retrieved from Aral Sea and furthermore observed in shore line shifts. Previously published lake level stands are reconsidered. We show, that a maximum lake level at 72/73 m a.s.l. cannot be corroborated. The highest lake level, which was also reached at the beginning of the 20th century, probably never exceeded 54/55 m a.s.l.. Furthermore, we observed a previously unknown low-level stand at 42/43 m a.s.l., dated to the Bronze Age (ca. 4000 – 3000 yrs BP). The regression during the 1200-1300 cal. yrs A.D.,

formerly underestimated, was lower than the present day lake level, which now is at 30/31 m a.s.l.. The observed environmental changes, except since the 1960s, are most probably driven by climate variability, though human activities (e.g. by irrigation) can amplify the impact.

INTRODUCTION

The Aral Sea region is an excellent location for tracing human reactions to past climate changes. In this climatically sensitive area, alternating between semi-arid and arid conditions, human influence can be traced back to the first millennium B.C. The Aral Sea Basin with extended arid semi-deserts and deserts has potential agricultural plains along the two major inflows (Amu Darya and Syr Darya), which were actively cultivated far back in historical time. Such border regions might record very sensitively both natural environmental and anthropogenic changes. While older lake level oscillations and human reactions have hardly been studied previously, the modern regression, starting 1960, has received much attention since the political opening of the former Soviet Union (e.g. Aral'skij krizis, 1991; Létolle and Mainguet, 1996; Micklin and Williams, 1996). The latter is clearly triggered by man, and its effects on the environment and the life of local populations have become a subject of discussion far beyond the scientific community.

In the frame of the INTAS-Project „CLIMAN“ (Holocene climatic variability and evolution of human settlement in the Aral Sea Basin) (<http://www.CLIMAN.gfz-potsdam.de>) we started an interdisciplinary study, which may help to distinguish between climatic variations and/or anthropogenically controlled environmental changes in the past. In a geomorphologic survey onshore we focus on previous lake level changes, as recorded in shoreline marks during the last 5000 yrs and relate the observations to archaeological findings. Furthermore we report on lake level changes occurring during the last 2000 yrs as inferred from cores retrieved in Chernishov Bay, the NE Large Aral Sea (Figure 1). We discuss displacement of human settlements and try to evaluate human influence on the water balance (e.g. by irrigation) and

compare the observations to the water balance as reconstructed for the last 2000 yrs from the relative Ca abundance, a proxy for the gypsum deposition, from sediment cores.

GEOLOGICAL AND ARCHAEOLOGICAL BACKGROUND

Recent and past climate changes have been studied in sediments since the late 1960s. Rubanov et al. (1987) and Maev and Karpychev (1999) investigated and dated the climatic events from a core retrieved at the centre of the Large Aral Sea. They reported lake-level low stands from approx. 400-600 yrs A.D., 1100-1200 yrs A.D. and 1500-1600 yrs A.D.. Recently, Nurtaev (2004) documents that besides climatically controlled hydrological changes and anthropogenically directed irrigation activities (Andrianov, 1969) also geodynamic displacement can influence the lake water level. He reported that deformation and uplifting rates could reach up to 12 mm/y. According to this author, such vertical displacements could modify the drainage pattern and hence have to be considered when discussing past modifications of river discharge to the endorheic Aral Sea Basin. However, the timing of the geodynamic events is barely known and thus will not be further discussed.

Levina (1998) and Boroffka et al. (2004) recently reviewed the present state of archaeological knowledge around Lake Aral. The authors showed that the documentation of settlement activities is fairly good for the region south of the lake but rather scanty or patchy for the northern shore. Previous archaeological studies, mostly carried out in the 1950s and 1960s when the lake level was fairly high (53 m a.s.l.), were hence limited to arid regions partly far beyond the highest shorelines. During the CLIMAN project expeditions, archaeological sites in areas flooded in the south in 1960 but now fallen dry have been studied for the first time. Along the northern shore of Lake Aral the Palaeolithic period, and Neolithic to Medieval Age material was newly documented in this project, so that now considerable gaps in the settlement history of the area could be reduced.

Previous studies focussed either on geomorphology and geology (Berg, 1908; Rubanov et al., 1987) or on archaeology only (Tolstov, 1962; Levina, 1998). Yet collaboration between the two disciplines occurred in a study of the southern part of the Aral Sea (Tolstov and Kes', 1960; summarized in Sevast'ianov et al., 1991, pp. 215-270). The CLIMAN project addresses lake level changes as recorded in palaeo-shorelines as well as lacustrine and terrestrial sediments, and the reconstruction of climate changes in the Aral Sea Basin during the Late Holocene. Moreover, as reaction to environmental change, the human settlement history is evaluated and the human influence on the water balance is considered (e.g. irrigation).

METHODS

Screening archaeological publications we identified areas for potential of site survey. Based on these areas we investigated the N and S shores of Lake Aral during two expeditions in 2002 and 2003 (Figure 1). During these studies archaeological traces (e.g. artefact scatters indicating settlements, grave mounds, irrigation channels) were positioned by Geographic Positioning System (GPS) data. We recorded concurrently the relationship to ancient or modern shorelines. The identified sites were dated by conventional archaeological methods, and by comparing archaeological assemblages to radiocarbon-dated material from analogous sites. The complete repertoire of archaeological finds (toolkit) was studied to reconstruct the economic basis for each settlement. Moreover, for evaluating the economical situation, we considered the composition of domestic and wild animal remains.

For a better understanding of the lake level history we mapped typical features of fossil shorelines, like littoral terraces, beach ridges, and wave cut escarpments (cliffs), which have formed partly by littoral processes. Local characteristics of the drainage network such as channel alignments to palaeoshoreline features were also considered. All sites and features were positioned by conventional GPS, while the elevation of palaeoshoreline features was determined with differential GPS (DGPS) and tachymetry measurements. All data were

integrated into a Geographic Information System (GIS). Additionally we used Landsat ETM+ satellite images as well as the digital elevation model SRTM for analysing the spatial distribution and vertical position of littoral features at specific locations. Based on the digital elevation model SRTM-3 the vertical position above mean global sea level (a.s.l.) for relevant features was used to reconstruct lake areas for different time windows using a GIS.

The sediment coring site was selected in Chernishov Bay, located at the NW shore of the Aral Sea, a 22 m deep basin, which today is still attached to the Large Aral Sea. With a Usinger piston corer (<http://www.uwitec.at>) we retrieved two sediment cores of 6 to 12 m length. The description of the core lithology is based on smear slide observations (Sorrel, 2006). The relative Ca abundance in sediment cores was measured by scanning at a 1 cm resolution with the XRF Core Scanner (®AVAATECH). The age model for the sediment core is based on AMS ¹⁴C dates on the algae *Vaucheria sp.* and reported as calibrated ages (Nourgaliev et al., 2003; Sorrel et al., in press).

RESULTS

Archaeology:

A total of 219 archaeological sites were geographically positioned in relation to ancient or modern shorelines, most of them newly discovered. In the following we reconstruct a settlement history through the time slices studied which, when available, are compared to lake level stands. Common to most of archaeological findings through time is their similar altitudinal distribution at least along the N shores. The Palaeolithic period (50,000-35,000 yrs BP), represented at three locations, has been identified in the immediate vicinity of Lake Aral for the first time (Boroffka et al., 2004). The toolkit shows large bifacial worked stone tools (Figure 2.1) indicating that hunting of large animals rather than fishing was common. Today these sites lie at the edge of cliffs at an altitude of about 60 m a.s.l.. The preservation of these

sites indicates that they have not been affected at any time, neither by wave action nor have they been covered by aeolian or lacustrine sediments.

After an extended recovery gap, which is not yet well understood, traces of Neolithic (7000-5000 yrs BP) settlements with pottery and silex artefacts belonging to the Kel'teminar culture could be observed both in the N and S. The finds included large numbers of microlithic harpoon insets and small projectile points (Figures 2.2, 2.3), which show that fishing and hunting of small animals and birds were a major part of subsistence strategy. The sites are at similar altitudes as the Palaeolithic remains in the north and along sand dunes extending from Akespe towards the north, probably following an old river course now completely dried up. To the south, the Neolithic sites form a ring around the Khorezm Basin (Figure 1, area 2003/I).

New finds from the northern shores of Lake Aral are of Eneolithic and Early Bronze Age (5000-4000 yrs BP). These show a new spatial orientation in culture and economy to the north. Common large projectile points (Figure 2.4) together with the pottery, demonstrate close analogies to finds from the forest and forest-steppe zones of the Tobol-Ishim-Irtys' river system and the eastern Ural Mountains.

Archaeological materials from the Later Bronze (Figure 2.5) and Iron Ages (Figure 2.6) (4000-2500/2300 yrs BP) were observed along the northern and the southern shores of the Aral Sea. Remains were concentrated in the Khorezm Basin, as well as along the dry beds of the Akcha Darya and the Jana Darya. New finds (Figure 2.9) have been discovered at locations which had been flooded during the 1950s and 1960s but today have fallen dry. They are located at the base of inter-dune depressions and are covered by lacustrine sediments (Figure 1, area 2003/III, northern part). Their distribution follows the old branches of the Akcha Darya and Jana Darya Deltas at an elevation of ca. 42-46 m a.s.l..

For late Classical Antiquity (ca. 1600-1500 yrs BP) a new site, Pulzhaj, was discovered at an elevation of 53 m a.s.l. in the SW, at the foot of the Ust' Jurt Plateau. Several coins were

found, as well as large quantities of high quality ceramics (Figure 2.10), including original imports from China, Iran and Saraj or Sarajchik (capital of the Golden Horde near the mouth of the Wolga River) and are dated to the A.D. 4th – 5th and 13th – early 14th centuries (to be in accordance with what it claimed in the abstract) . The atypical stone foundations of houses, indicating prosperity, are dated to the A.D. 13th – early 14th centuries (to be in accordance with what it claimed in the abstract). A fortified part of the city is located on top of a fossil cliff. Some time after the A.D. early 14th century the lower site was abandoned because of flooding and has been drowned in a newly formed bay of the Aral Sea. The city at the foot of the cliff was subsequently covered by sediments containing a mollusc fauna including *Cerastoderma* sp. and *Dreissena* sp. In an adjacent outcrop, two beds of lacustrine sediments embedded in a series of fluvial/colluvial material could be observed. The upper bed can be connected to the sediments overlying the settlement, while ¹⁴C dating of the lower bed (Aral AS7-9) shows 1717 ± 30 cal yrs BP.

Other new sites from the Middle Ages have been identified both in the north and in the south of the Aral Sea. The sites in the north yielded imitations of Chinese porcellain and high quality glazed pottery, evidencing connections to long distance trade routes known collectively as the northern Silk Route. Further to the south, in the northern part of the Great Aral, a *mazar* (islamic holy grave site) has been identified next to a settlement. Both could be dated to the A.D. 13th – 14th centuries. While the *mazar* lies on an artificial mound and is exposed today at least during the summer season, the adjacent settlement is still mostly submerged (Figure 2.8).

Geomorphology:

Geomorphologic surveys and analyses of satellite images reveal distinct palaeoshorelines, which developed along the various bays and at the base of cliff zones (Figure 3). Tachymetric and DGPS measurements confirm the highest shoreline along the Tastubek Bay (northern

Small Aral Sea) (Figure 3.1A/B) at 53-54 m a.s.l., while the same shoreline along the Chebas and Shevchenko Bays (NE Small Aral Sea) (Figure 3.2A/B) and at Karaumbet (southern Large Aral Sea) is generally 1 m higher, indicating a slightly lower level in the Small Aral Sea. However, they mark the lake extent of the 1960s and previous lake level stands of the first half of the A.D. 20th century as well (Reinhardt and Wünnemann, 2004; Reinhardt, 2005). Above 54 m a.s.l. no shorelines, nor lake sediments or wave-induced abrasion features could be observed, indicating that the Aral Sea earlier probably did not extend beyond this level. Aladin and Plotnikov (1995) and Boomer et al. (2000) reported much higher lake levels during mid-Holocene (ca. 5000 yrs BP) and early sub-Boreal (ca. 3000 yrs BP) time. For example, a cliff section near Tastubek at 65 m a.s.l. shows multiple sequences of colluvial sand and silty-clay of Cenozoic origin, which has been completely redeposited by denudational processes. However, undisturbed artefacts at the top of the section indicate that redeposition took place before 35,000 yrs BP and since then the lake level never reached this altitude and hence deposition of lake sediments did not occur. Comparable conditions have been found at Karaumbet Bay in the southern Aral Sea (Figure 3.3A/B), where the highest littoral facies is preserved at the foot zone of the Miocene cliff (Turk: “*Chink*”) at about 54-55 m a.s.l.. At the N shore the highest palaeoshoreline is likewise located at an elevation of 54-55 m a.s.l..

Sediment cores:

The sediments retrieved consist mostly of dark muds and silty muds with changing organic contents (Figure 4). Based on smear slide observations we can distinguish 4 levels of gypsum-rich mud, forming distinct bright beds (4.95 – 5.05 m and 11.1 – 11.3 m depths) or dark clayey muds with abundant idiomorphic gypsum crystals. At the top of gypsum-enriched beds, a thin layer with authigenic carbonate may be observed. These lithological changes characterised microscopically are corroborated by relative Ca content measured with XRF. As

gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) starts to precipitate when salinity reaches a concentrations beyond a certain level, it becomes a typical indicator for salinisation and we use the element scans of Ca to keep track of its abundance. In the Aral Sea the stage of oversaturation for gypsum was reached in the early 1960s when salinity exceeded 26 - 28 ppt (Bortnik and Chistayeva, 1990). Thus we can use at the limit the relative abundance of this element to estimate beginning changes in the river inflow, which control together with the annual evaporation, the chemical water balance and at a longer time range the lake level of the Aral Sea. In Figure 4 the Ca curve indicates distinct changes through the last approx. 2000 years. High relative Ca contents are taken to indicate rising salinities and thus lowering lake levels. These are observed between 1.30 – 1.50 m, 4.96 – 5.05 m, 7.80 – 8.2 m and below 10.40 m. According to the age model the onset of these events represent approx. 350-450 cal. yrs BP (in the abstract this is 350-450 yr BP), 700-780 cal. yrs BP, around 1400 cal. yrs BP and 1600-2000 cal. yrs BP (Figure 4). Most of these events match with salinity changes reflected by dinoflagellate cyst assemblages (Sorrel et al., in press).

DISCUSSION

According to recent reviews (Aladin and Plotnikov, 1995; Boomer et al., 2000) of the lake level history of the Aral Sea a maximum water level (first described by M.I. Epifanow in 1961) at 72-73 m a.s.l. was dated to the end of the Liavliakan pluvial phase, around 5000 yrs BP (Boomer et al., 2000, p. 1268sq.). Létolle and Mainguet (1996) critically re-examined this level and concluded that these terraces have been subsequently tectonically uplifted by 15-20 m, which would place the highest level after correcting for the later tectonic uplift to 53-58 m a.s.l.. Such a conclusion matches well with the Palaeolithic sites observed at altitudes of 58/59 m a.s.l., which are completely undisturbed. The newly identified Neolithic sites have been observed at 58/59 m a.s.l. in the north and the Bronze Age sites at 46 m a.s.l. in the south. From our observations we conclude that a lake level above 58 m a.s.l. was most probably

never attained during the Holocene and possibly as far back as to the Paleolithic Age. This matches with geomorphologic and satellite observations recognising the highest shoreline at 54-55 m a.s.l., both at the northern and southern shores (Reinhardt and Wünnemann, 2004; Reinhardt, 2005). No traces of flooding or lacustrine sediments were found above this level. Therefore, the maximum lake level, as it is also documented for the mid A.D. 19th century in the map published by Butakoff (1853), probably never exceeded 54/55 m a.s.l.. Given the actual climatic conditions with generally increased global temperatures the present day lake level would most probably be near the highest stand, if human irrigation activities would not be at the excessive stage they are today.

A similar or even more humid climate than today is indicated for the Neolithic (7000 – 5000 yrs BP) by the toolkit including large numbers of harpoons and by the general distribution of the neolithic Kel'teminar culture sites along branches of the Amu Darya “inland delta” (in the Khorezm basin), and around former lakes in the Kyzyl Kum desert (Vinogradov, 1981). In spite of this, no traces of human settlements along the Akcha Darya are yet found from this period. Tolstov (1962) reported that by this time cultural activities were rather oriented to the south and intense settlement occurred along the entire course of the Uzboj, indicating that the Amu Darya River did not uniquely or not at all aliment the Aral Sea. This situation could have resulted in a very low lake water level. Yet there is no geological evidence for such a scenario, as we have no cores of Aral Sea sediments covering this age. However, there is some geomorphologic evidence for this hypothesis. A now dry river course to the south of the Amu Darya River has been observed which possibly drained the Khorezm Lake. This arm of the river, not dated yet, was continuing in direction SW through the Uzboj and on into the Caspian Sea (Tolstov and Kes', 1960, p. 16 sqq. Figure 2; Létolle and Mainguet 1996, p. 91sqq., Figure 2.39; Boomer et al., 2000, Figure 6, 1 – with incorrect dating).

For the Eneolithic and Early Bronze Ages (5000-4000 yrs BP) a pronounced shift of cultural and economic orientation along the northern shore of Lake Aral was observed. The toolkit and the pottery indicate connections to the north and northeast. Judging from the bone assemblages found in the analogous sites, mainly horses were hunted (e.g. Botai in the Ishim region with over 300,000 bones, 99% of horses: Benecke and von den Driesch, 2003), so that a forest-steppe environment characterised this period, i.e. a more humid climate than now, which likewise should result in a high lake level stand.

During the following Bronze and Early Iron Ages, the water level did not exceed 42/43 m a.s.l. (Figure 5.1), though the Akcha Darya and Jana Darya River systems were active and discharged into the Aral Sea. A recently discovered dry lake basin in the SE covers this period. The low-level stand observed between 4000 and 2500 yrs BP has not been described previously, but a high level stand has been proposed instead (Boomer et al., 2000, Figure 6, 2-3).

For Late Antiquity and the Early Middle Ages (mid 1st Millennium A.D.) a regression has been described earlier, when a peat-like layer has been observed in the eastern basin of the Large Aral Sea (Rubanov et al., 1987). It has been dated 1580 ± 140 cal. yrs BP (Sevast'ianov et al., 1991) and might be coeval to the salinity increase recorded in the sediment core between 7.8-8.2 m which starts at 1400 cal yrs BP (Figure 4).

The extensive irrigation systems along the Amu Darya and the Syr Darya (Tolstov, 1962, annexed map), at least partly, date to this period. Reports from Greek sources (Barthold, 1910), although not very accurate by modern standards, indicate that the Amu Darya was flowing to the west, through the Uzboj channel, into the Caspian Sea, so that a regression, possibly intensified by human activities seems evident. For the low level stand dated approx. 600 cal. years A.D., however, no time equivalent archaeological event has been reported yet.

From sediment cores increased salinities are reported for approx. 700 (for consistency with the abstract)-780 yrs BP. Shortly later lake level may still be low, given that Hamdallah Kazwî in 1339 A.D. mentions that the Aral Sea is a salt lake. Shallow basins may have disappeared completely, since the merchant Bedr-ad-dîn al-Khowârizmi does not refer to any lake at all, although he does describe the lower Syr Darya (Barthold, 1910, p. 33sq., p. 39; Létolle and Mainguet, 1996, p. 131sq.). According to ancient documents (Barthold, 1910), the Amu Darya discharged into the Aral Sea until the devastating Mongol invasion in 1221, but only shortly later, irrigation systems and large dams were reconstructed. The onset of a major regression (Figure 2.8), as documented by the gypsum bed from 4.96-5.05 (Figure 4) occurred during the A.D. 13th-14th century. This is not unlikely, since the water level must have been clearly below 31 m a.s.l.. Consequently Kerderi, at an altitude of 32 m a.s.l., became exposed at that time and in November 2002 the lake level has again reached this altitude (Zavialov et al., 2003). This Medieval regression has been described previously though considerably underestimated, when the lake level had been located around 44/45 m a.s.l. (Aladin and Plotnikov, 1995; Boomer et al., 2000).

The following regression, possibly a time equivalent to the Little Ice Age, is clearly documented after 480 ± 120 cal yrs BP in the sediment record (Figure 4). According to Sorrel et al. (in press) climate has changed by this time and as a result meltwater discharge by the main tributaries was reduced. It is only at 1573 according to a report by Khan Abulghazi (1603-1663) (Barthold, 1910), when the Amu Darya changed its course and discharged again into the Aral Sea.

Further support for a second regression during the Little Ice Age comes from drowned Saxaul stands, which had been dated to 287 ± 5 ¹⁴C yrs BP (307 cal. yrs BP) (Boomer et al., 2000, p. 1266). Similar stands (Figures 2.11), yet undated, were also observed near the present shoreline at the southern edge of the western basin (Figure 1, area 2003/IV - at 44° 20' 42" N,

58° 16' 56" E), a region just fallen dry during the last CLIMAN expedition in late summer 2003.

CONCLUSIONS

We show that the Aral Sea region is an excellent area for studying interactions between human activity and water level changes. Close collaboration between geoscientists and historians, as realised in the CLIMAN project, is creative for both disciplines. Most changes in human adaptation strategies, which can be dated by archaeological material, have to be explained to a great part by climate changes.

Several previous conclusions on water level oscillations likewise needed revision. The data from DGPS measurements in the north and geomorphologic profiling from the south of the Aral Sea document the highest shoreline at below 55 m a.s.l.. Thus the transgression at the end of the Liavliakan pluvial period was much overestimated. The low lake water level at 42/43 m a.s.l. (Figure 5.1) dated to the Bronze Age had not been observed previously. The regression of the Middle Ages to less than 31 m a.s.l. (Figure 5.2), was underestimated. But before A.D. 1850 the lake level had reached again about 55 m a.s.l. (Figure 5.3). Until A.D. 1960, the lake level had decreased only slightly (Figure 5.4), and fluctuated around 53 m a.s.l. (Létolle and Mainguet 1996, p. 66). A readjustment of the present low water level is, therefore, basically possible once irrigation activity will be considerably reduced.

However some aspects, like the Uzboj controversy raising the question of when it was active, needs further research. At this stage we cannot exclude that, as mentioned recently by Nurtaev (2004), tectonic activity resulting in differential uplifting might be an important factor at least for such intrinsic deviations of the main river course.

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Figure captions:

Figure 1. Map of the Aral Sea showing the archaeological and geomorphologic study areas and coring sites investigated during the 2 'CLIMAN' expeditions (see text).

Figure 2. Map of the Aral Sea and its major tributaries with locations of selected new archaeological finds: 1 Palaeolithic biface from Tastubek, 2-3 Neolithic insets and projectile points from Akespe, 4 Eneolithic projectile point from Tastubek, 5 Bronze Age pottery from Akespe, 6 Iron Age pottery from Akespe, 7 Iron Age copper cauldron from the Priaral region, 8 Mausoleum at Kerderi (the adjacent settlement is under water in the foreground), 9 Bronze Age pottery from the former lake bed, 10 Medieval pottery from Pulzhaj, 11 Drowned Saxaul stand.

Figure 3. Geomorphological results for selected sites. 1A-3A: Landsat-ETM+ Satellite images. White arrows show location and view of field images 1B-3 B. (1A) Parallel features in the lower left part of the Landsat image represent beach ridges accumulated during the post-1960 regression of the lake. (1B): Plateau scarp south of Tastubek Bay with the 53 m shoreline in the foot section (centre). (2A) Left to right: Post-1960 regressional shorelines below 53 m a.s.l. at Shevchenko Bay. (2B) Example for beach ridges (black arrows) similar to the situation in 2A. (3A) Karaumbet Bay with the highest shoreline represented by a cliff scarp in an elevation of 54 to 55 m a.s.l. (black line). (3B). Scarp of the palaeocliff at the western bay margin. Evidence for former shorelines above 55 m could not be found at any of the shown sites.

Figure 4. Salinity changes and lake water level of the Aral Sea as controlled by river inflow and seasonal evaporation. The water balance is inferred from the relative abundance of the element Ca (counts reflect relative abundance) scanned at 1 cm resolution with an XRF logger in a sediment core retrieved from Chernishov Bay (45° 58.6' N; 59° 14.5' E). Ca mainly traces the abundance of gypsum, which records the onset of salinisation and exceptionally authigenic carbonates (7.75 – 8.05 m depth). Major fluctuations in Ca abundance are assigned to climatically and to some extent anthropogenically driven lake level changes. Important archaeological sites are assigned to specific lake level changes. The age model is based on AMS radiocarbon dates of the algae *Vaucheria sp.* and paleomagnetism (Nourgaliev et al., 2003, Sorrel et al., in press).

Figure 5. Extent of the Aral Sea for different periods: 1 Water level of 42/43 m a.s.l. during the Bronze Age, 2 Water level of 30/31 m a.s.l. during 14th – 15th centuries and again in 2002, 3 Assumed maximum water level of 54 m a.s.l. around 1850, 4 Water level at 53 m a.s.l. before 1960s. Black areas represent shallow water with numerous small islands. Note that images do not show a continuous succession. Databases: 1, 2: GIS-based model according to field results, 3: Digitization based on current satellite images, 4: Digitization S. Krivonogov.