EVALUATION OF THE RATIO OF NATURAL AND ANTHROPOGENIC FORCING IN THE REGRESSION OF THE ARAL SEA DURING THE MEDIEVAL WARM PERIOD

LAB GEOARCHAEO

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MEDIEVAL REGRESSIONS OF THE ARAL SEA

There is large agreement among several authors (Boomer, Boroffka, Sorrel, Gaybullaev, Oberhänsli, etc) about the establishment of very severe regressions of the Aral sea (until below -31 m asl, the level of the Aral in 2004) during the Medieval Warm Period, namely in 1400-1300, 780-750 and 1350-1450 BP, with transgressions of medium entity between those phases. Similar synchronic climatic-environmental fluctuations are documented in the Balkhash, Issykul and Bosten lakes (Endo 2012). (Fig 01)

The causes of such regressions are variously attributed to climatic change toward more arid conditions (Sorrel et alia 2007), or to abrupt events as natural or anthropogenic hazards, mainly earthquakes (in 1208, 1389) or wars (the Mongol invasion of the 1221, the Timur wars between 1372-1388 AD) that disrupted the functioning of dams and irrigation systems at the point of diverting westward the main delta distributary of the Amudarya and activating the Uzboi channel to the Caspian sea. (Fig 02)

In spite of the fact that the main cause of the present regression of the Aral sea is by far the decrease of river inflow due to water withdrawal for irrigation purposes, no author considers the water use of the huge medieval urban and irrigation systems aligned along the Syrdarya and Amudarya courses as a possible factor, together with climate and abrupt events, in influencing the Aral water levels all along medieval times. This is due to three main reasons: underestimation of the size of the urban complexes of West Central Asia and of their potential environmental impact, absence of a data base of the Central Asian urbanization, and absence of geoarchaeological field studies allowing the elaboration of coefficients of paleo water use.

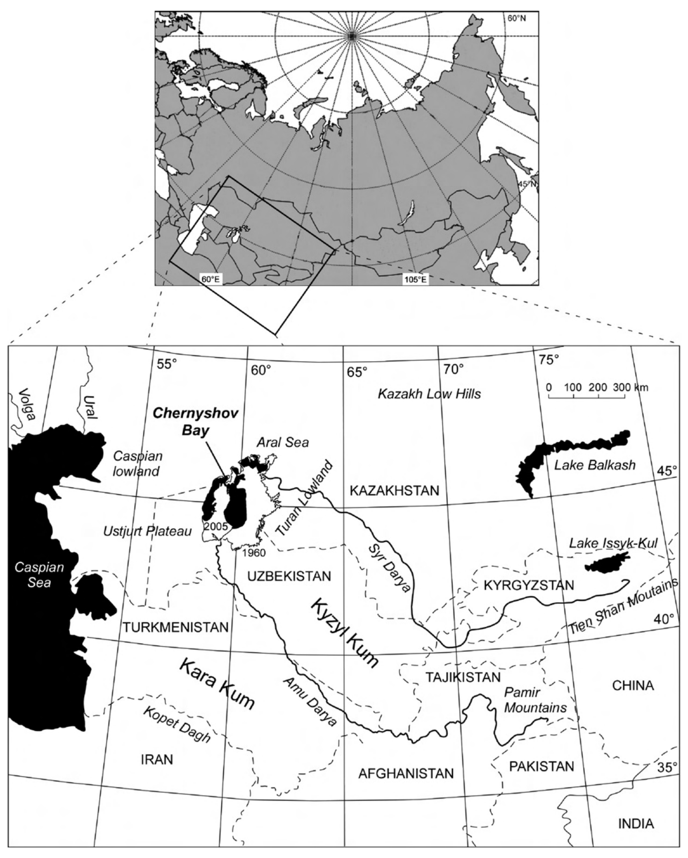

Fig 01: Aral basin. Sorrel 2007

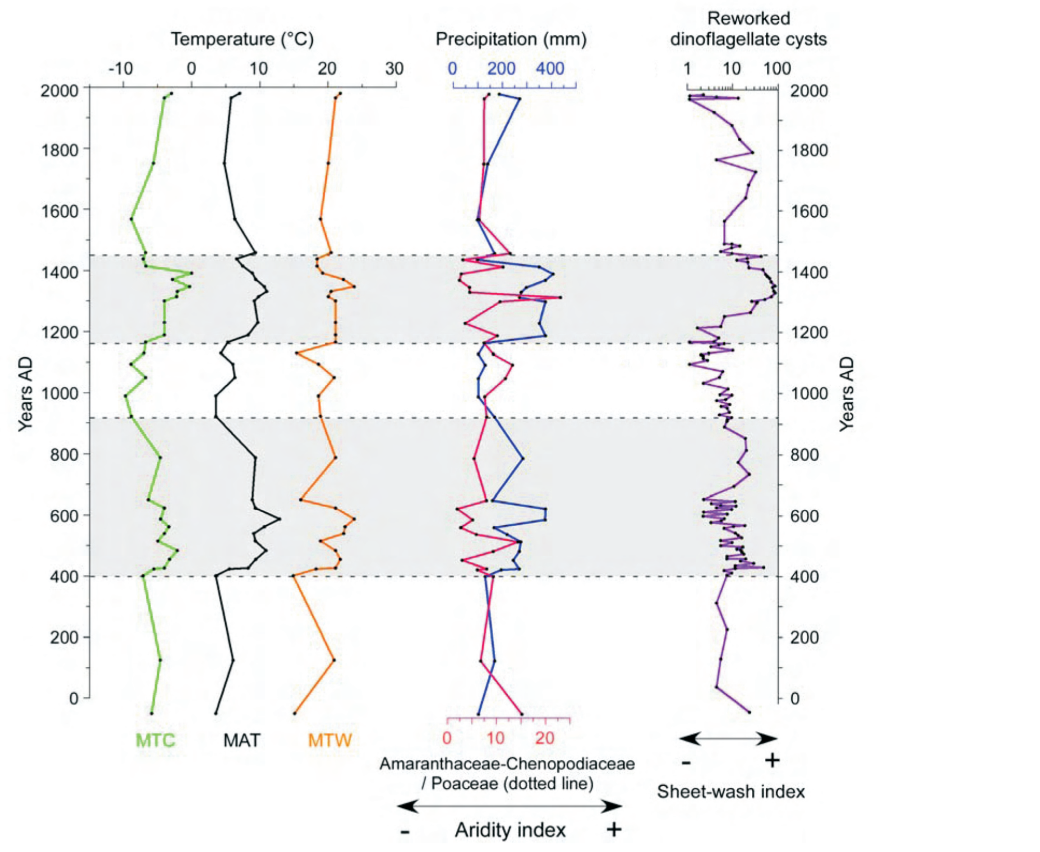

Fig 02: Comparison between reconstructed climate parameters from section of core CH2/1 during the last 2000 years. Sorrel 2007

METHODS OF RESEARCH OF THE MEDIEVAL ANTHROPOGENIC IMPACT ON ARAL WATER LEVELS

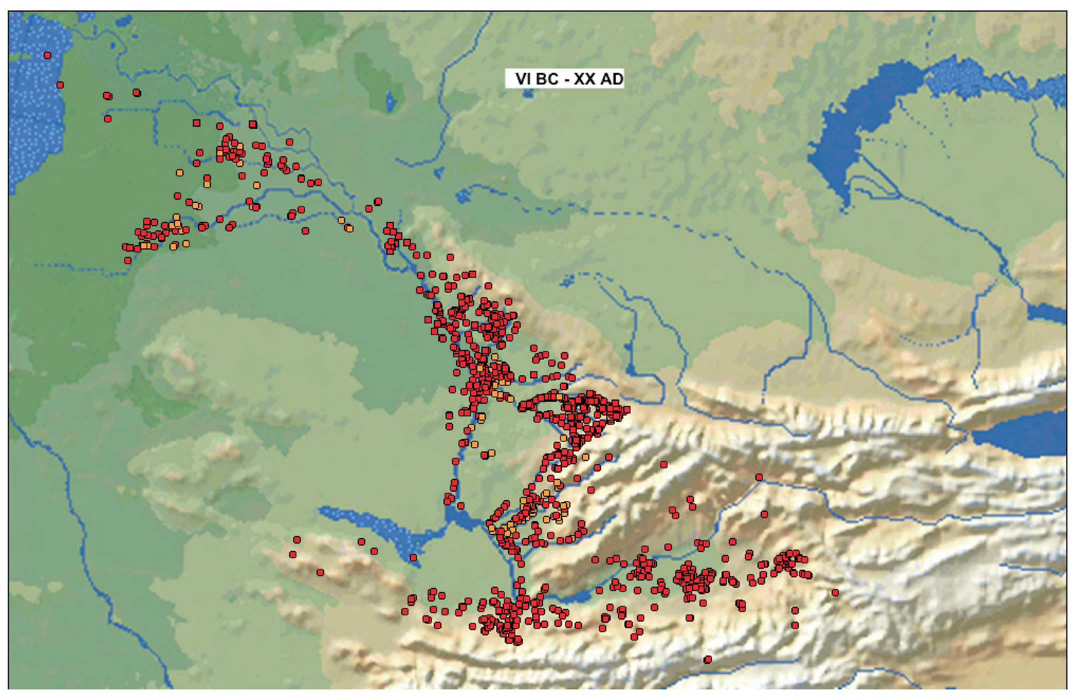

Fig 03: Total urban units along the Syrdarya river from V BC to XIX AD. More than 1050 towns have been documented, covering altogether around 3500 ha. Dots=settlements)

To reconstruct the environmental impact of the urban complexes of West Central Asia, the Laboratory of Geoarchaeology built a data base of all urban monuments recorded in archaeological reports and in the *Svod Pamiadnikov Istorii i kulturi Respubliki Kazakhstan*, and surveyed a large part of the monuments for providing entries of environmental character. (Figs 03, 04)

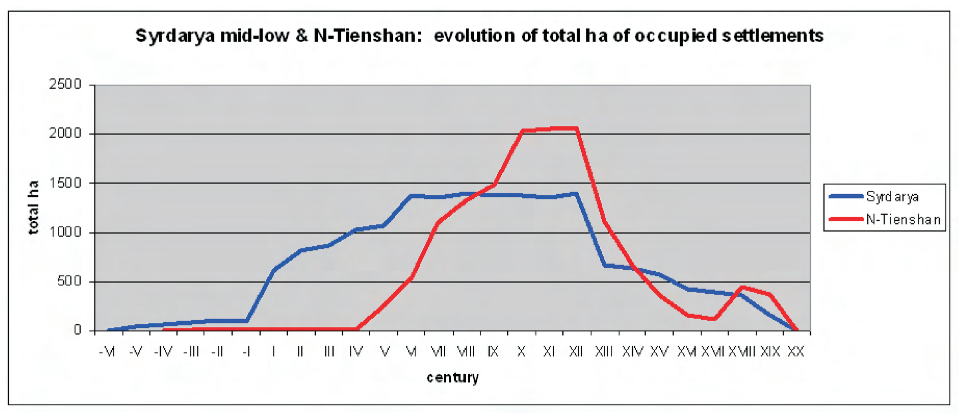

Fig 04: Development of occupied urban area (ha) on the Syrdarya and in N-Tienshan from V BC to XIX AD

In the frame of the project INTAS-2002-2005, the irrigation system of the Otrar oasis (at the Arys-Syrdarya confluence) had been documented, and the X-XII centuries AD schemes in the central part of the oasis became the study object for sorting out coefficients of medieval water use per urban hectare (with 1 urban ha averagely corresponding to 161.63 agricultural irrigated hectares and to a population of 400 persons). (Fig 05)

The irrigation schemes have been simulated into a hydraulic model using the software system HEC-RAS 2009. The use of the CROPWAT software (UN-FAO) provided esteems of water requirements in mm/day under the consideration of crop type, effective rainfall and soil moisture deficit (Clarke et alia 2010).

The coefficients of water use, applied to the entire urban park of the Syrdarya and extrapolated to the one of the Amudarya, provided the average yearly amount of total water withdrawal (in km^3) from the two tributary rivers of the Aral sea during the VI-XII centuries AD.

The esteems are surely under-evaluated, being that small villages have not been considered, several monuments are not been discovered or documented, and the extrapolation to the Amudarya of coefficients of water use based on the Syrdarya oases must be enhanced on the account of the higher urban density, aridity and evaporation rates of the southern regions.

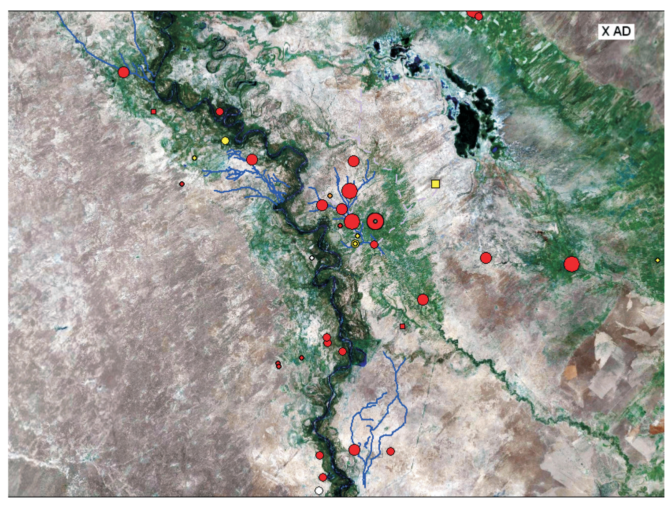

Fig 05: Otrar oasis during the X century AD. Dots=settlements: red=occupied; yellow=newly built; white=just abandoned. Lines=canals; continuous=active; dotted=abandoned

RESEARCH RESULTS

1 - Urbanization and coefficients of water use along the Syrdarya during the VI-XII AD

All together the medieval urban system along the **Syrdarya river** blossoms during the VI-XII AD and its dimension (in total ha) during the period is quite stable (± 3.6%). In the X AD it consists of more than 400 towns covering, together with a 25% of small villages, a **total urban area of 2350 ha**.

In the **X AD** the central part of the Otrar oasis is characterized by a **coefficient of yearly water use of 0.0039 km^3 per urban ha** (or 2.41/10^4 km^3 per irrigated ha) that, when applied to the entire urban system along the Syrdarya, corresponds to a total of **9.20 km^3 of yearly water subtraction**

Under climatic conditions similar to modern (which is a reasonable assumption), the virtual (natural) Syrdarya hydrological regimes would have an average yearly water discharge of 21.4 in upper Fergana valley, of 17.84 km^3 at the end of Fergana (Chardara), and of 13.82 km^3 at the delta (Kazalinsk).

This means that the yearly water withdrawal of 9.20 km^3 of Syrdarya water during the VI-XII AD represents the 51% of the potential yearly stock of the river, leaving just 8.54 km^3 of runoff to the Aral sea.

Being that the modern water withdrawal is of 14.62 km^3, i.e. 81% of the yearly river stock, leaving 3.22 km^3 of runoff to the Aral, the yearly amount of water subtraction from the Syrdarya river during the VI-XII centuries AD represents **the 63% of the modern subtraction**. (Fig 06)

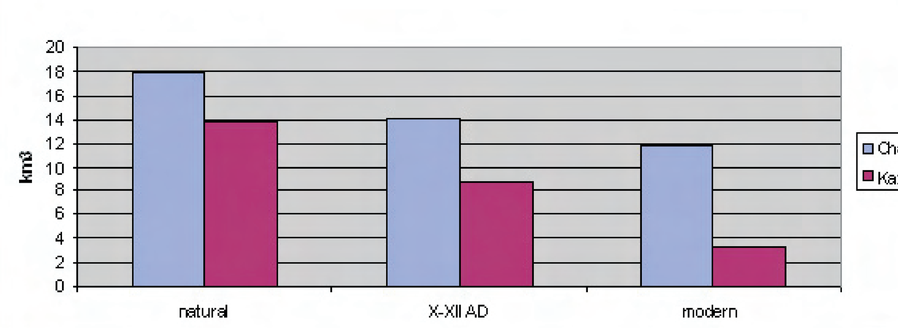

Fig 06: Syrdarya: yearly water stock at Upper Fergana, Chardara (at the start of the Middle Syrdarya) and Kazalinsk (on the Syrdarya delta) under natural and anthropogenic medieval (VI-XII AD) and modern scenarios

2 - Environmental impact of upstream water withdrawal on the Syrdarya delta

The medieval anthropogenic use of Syrdarya waters is not only correlated with the max urbanization of the middle course of the river (VI-XII AD) but also with the progressive total abandonment of the urban structures of the Syrdarya delta (Jety-Asar culture) between the VIII and X centuries AD, as if provoked by upstream withdrawal of water resources. (Figs 07, 08)

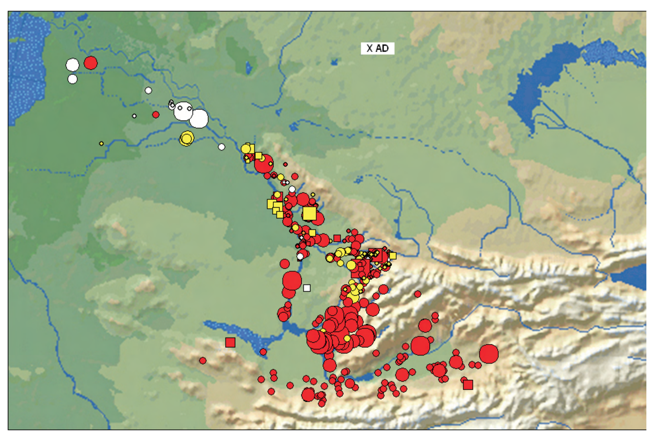

Fig 07: Urbanization along the Middle and Low Syrdarya in the X AD. Dots=settlements: red=occupied; yellow=newly built; white=just abandoned

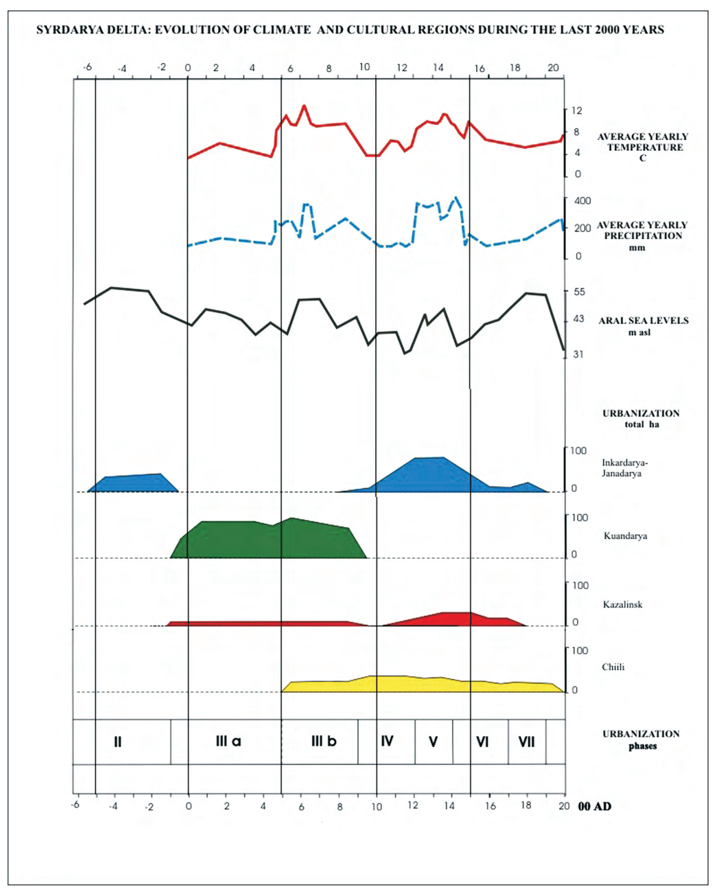

Fig 08: Comparison between climatic and environmental parameters on the Aral sea and urbanization of the Syrdarya delta during last 2500 years

3 - Environmental impact of the Syrdarya and Amudarya urbanization on Aral water levels

Such coefficients of water subtraction (the 51% of the average potential yearly stock), when applied to both the Syrdarya and the Amudarya rivers and assuming the present climatic conditions, would mean a diminution of the total river runoff into the Aral from 47 to 23.5 km3, determining a water balance of the Aral sea similar to the one of 1994, i.e. with water volume of 240 km3, water surface of 28116 km2, and water level at +36.5 m asl.

The consideration of the anthropogenic impact on the Aral sea must constitute the background of paleo-climatic and paleo-environmental reconstructions, in the sense that any anomaly above or below the anthropogenic water level of +36.5 m asl will be respectively attributed to better or worse climatic-environmental conditions than today.

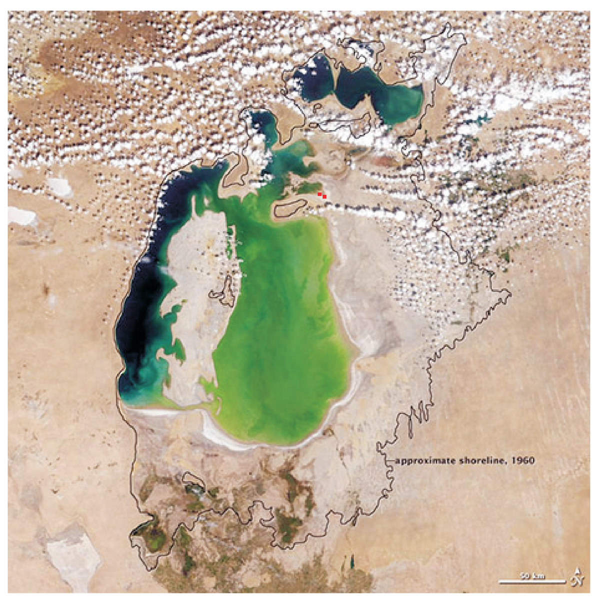

Fig 09: Aral lake in 2002 with water level at +31 m asl. Red dots: Kerderi settlement at +32 m asl on the left, Aral-Asar at +39 m asl on the right, dated to the 1350-1450 AD

The Kerderi mausoleum of the XIII-XIV AD, by being located at 32 m asl, points to a water surface of less than 16500 km^2 (like the Aral in 2002) i.e. to a further decrease of the total river input to less than 14 km^3. This means an additional reduction of the river input by more than 9.5 km^3 that must be totally attributed to **climatic impact** (increased aridity of 1600-1200 and 800-600 BP, Sorrel et alia 2007) and/or to **abrupt events**. (Fig 09)

Abrupt events were most probably related to the very unstable watersheds of the flattest parts of the Aral basin, where geomorphological and/or technogenic factors could easily have induced a series of diversions of delta distributaries: between the XII and the XIV AD, of part of the Amudarya flow into the Sarykamysh lake and the Uzboi channel, as referred in 1665 by Abu al-Ghazi; (Tolstov 2005); and in the XIII-XV AD of the residual flow of the Syrdarya delta into the Janadarya distributary where waters disappeared in sands before reaching the Aral, as referred by the historians Babur and Hafiz-i Abru (Bokoffka 2010).

CONCLUSIONS

In the study of the medieval fluctuations of water levels of the Aral sea, the anthropogenic impact provoked by the agricultural urban complexes of the Syrdarya and Amudarya rivers must be considered as the main forcing factor, as it is today.

More precisely, the Aral regressions of the 1400-1300 and 780-750 BP (of the VIII and XIII AD), when corresponding to water levels at +31 m asl, must be attributed by the 60% to human water withdrawal, and by the 40% to climatic changes.

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