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Base level changes, river avulsions and Holocene human settlement dynamics in the Caspian Sea area (middle Kura valley, South Caucasus)

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ABSTRACT

Geomorphological, geochronological and geoarchaeological analysis focusing on six tributaries of the Kura River provide valuable data concerning sedimentation rhythmicity and Holocene human settlement distribution at a regional scale. Seven new radiocarbon dates from the upstream part of these hydro-systems complemented the existing radiocarbon dataset ($n = 32$) obtained downstream. These data seem to indicate that upstream hydrosystems also reacted to marine regressions by powerful riverbed incisions and to transgression phases by thick valley infillings from at least as early as the Upper Pleistocene. The retroactive morphogenic effects were also perceived in intra-mountainous areas far from the Caspian shoreline. The land use patterns of the Caucasian societies dwelling in the valley of the Kura hydrosystem were affected by temporary river avulsions resulting in silty fans over the high terraces during the Neolithic–Chalcolithic periods. These river avulsions seem to be governed by local climate and base level changes linked to fluctuations of the Caspian Sea level over time. This is spatially and diachronically evidenced in settlement distribution, with almost exclusive localization on perched silty fans and river runoff from the key period of Neolithic development in the region. These new data must be considered in future geoarchaeological analyses concerning the Caspian Sea Basin and will contribute to the enhancement of the relative Caspian Sea level curve for the past 40 ka.

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1. Introduction

Flooding rhythmicity is primarily driven by climate oscillations and has been a major parameter in the evolution of hydrosystems and riverine human occupations for millennia. Recurring frequencies of Lesser Caucasus flooding were subject to abrupt changes over time, but these have not yet been well defined. This is due to the lack of geomorphological studies over the past decades and to the relative complexity of the parameters involved. Hydro-system modifications are closely linked to the main regional characteristics of the basin throughout time. Given these characteristics, the global basis level to which the river is attached greatly influences its longitudinal profile geometry. The variability of this level also determines the morphosedimentary organization of the alluvial terraces and probably influences human occupations in many ways where the latter record high frequency changes.

The Kura River (Caucasus) and its tributaries are closely connected to the Caspian Sea Basin. Thus, the process of sedimentary deposits and the morphology of these rivers were potentially deeply influenced by base level variations of marine origin. Throughout the Quaternary, the Caspian Sea level underwent several changes. Numerous studies relating to this question reconstruct sea level oscillations, and include sea level variation curves (Kroonenberg et al., 1997; Mamedov, 1997; Rychagov, 1997; Mikhailov et al., 2003; Hoogendoorn et al., 2005; Tudryk et al., 2013; Leroy et al., 2013a, 2013b, 2013c, 2014; Naderi Beni et al., 2013a, 2013b; Ollivier et al., 2015). About six main regression/transgression periods since 30 ka are generally recognized. The largest sea level fluctuation of +50 m/−92 m asl is attested during the Khvalynian/Mangyshlak episodes (17–11 ka BP), the highest levels being recorded between 16.6 and 14.6 ka BP when the Caspian Sea overflowed into the Black Sea through the “Manych–Kerch spillway” (Badertscher et al., 2011), or between 16.7 and 13.6 ka cal. BP, as shown by a compilation of the radiocarbon dates from the Khvalynian deposits (Dolukhanov et al., 2010 after; Svitoch, 1991;; Rychagov, 1997; and Leonov et al., 2002). High frequency sea-level changes have also been recorded

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over a short time scale (10–100 years) in delta sediments of the Volga and Kura Rivers, spit–lagoon complex or coastal cores and have been clearly described (Kroonenberg et al., 1997; Mikhailov et al., 2003; Leroy et al., 2013a, 2013c, 2014; Naderi Beni et al., 2013a, 2013b; Hoogendoorn et al., 2005). We recently reconstructed and highlighted the inland retroactive impact of the relative Caspian Sea level variations on landscape changes and alluvial terrace organization in the middle Kura Valley over the past 30 ka (Ollivier et al., 2015). Six phases of valley floor aggradation and seven phases of fluvial incision are recorded. The frequency, the speed and the magnitude of these changes significantly influenced the extent and intensification of flooding, as well as the physiography of the riparian contexts of the Kura River and its tributaries (leading to enhanced rates of vertical accretion during transgressions and channel incision during relative falls in sea level, Wright and Marriott, 1993), which are attractive environments for human occupations. Due to the complexity of fluvial systems, simple base-level controlled models do not necessarily apply to most hydrosystems where complex responses (Schumm, 1993) and climatic factors are likely to create highly variable morphosedimentary organizations. The climate plays an important role, providing hydrological flow, increasing or decreasing the efficiency of erosion processes and sediment transfers in the hydrosystems. Palaeoflood records also show that magnitudes and recurring flood frequencies are highly sensitive to climate changes (Blum and Törnqvist, 2000). In our case, the overall physiography of the Lesser Caucasus and the Kura River Valley allows us to consider a dual control of the landscape changes influenced by direct climate variations and retroactive relative Caspian Sea level changes. We propose here a local analysis of areas modified by avulsion and base level induced landscape changes in the Lesser Caucasus and the Kura River Valley. We also observe important environmental changes in the fluvial systems that have directly impacted Holocene societies in the valley. The spatial distribution of the Neolithic to Bronze Age settlements in the middle valley of the Kura demonstrates complex environmental changes and their long-term impact (over several millennia) on human societies. In this context, the aims of this article are 1) to refine the Neolithic to Bronze Age settlement distribution pattern in the middle Kura Valley, integrating climate changes and the Caspian Sea inland impact history; 2) to emphasize the integration of data from the distal tributaries of the main connected rivers, which has never been used before in the definition and chronology of changes in the Late Quaternary relative level of the Caspian Sea.

2. Regional setting

2.1. Broad geological setting

The Caucasus is located between Europe and Central Eurasia and between the Black and the Caspian Seas (Fig. 1). Two separate mountain ranges can be distinguished; the Greater Caucasus in the north and the Lesser Caucasus in the south. Thus, this area lying between the marine climate to the west, influenced by the Atlantic Ocean circulation, and the now well established continental climate to the east, is of major interest for understanding the evolution of the Eurasian palaeoclimatic system. This active volcanic and tectonic region resulting from the collision of the Eurasian and Arabian tectonic plates since the Neogene (Mitchell and Westaway, 1999) formed ca. 28.49–23.8 million years ago. During the Quaternary, this area was uplifted and experienced extensional tectonic movements and intensive volcanic activities. In more detail for our area of study (Fig. 2), the Lesser Caucasus corresponds to a collision front with Paleocene to Middle Eocene series deformed in a fold and thrust belt structural setting. The Kura Basin, where most of the Quaternary sections were studied, corresponds to a foreland basin in front of the

Greater Caucasus mountain belt with thick Miocene formations deformed by recent tectonics related to its uplift (Sosson et al., 2010).

2.2. Kura Basin

The Kura River rises in Turkey near Lake Kartsakhi at approximately 2740 m above sea level (Fig. 1). It then flows into a large valley between the Great and Lesser Caucasus across Georgia and Azerbaijan. It joins with the Arax in Azerbaijan and opens into the Caspian Sea at −26.5 m below sea-level. With a total length of 1515 km from the source to the estuarine zone, the watershed is 198,300 km². The Kura ranks among the largest rivers flowing into the Caspian Sea (Rustanov, 1967), with a current average flow of 443 m³/s (max. 2250 m³/s, min. 206 m³/s). The watershed of our study area is mainly represented by the Lesser Caucasus which dominates the Middle Kura Valley from an altitude of ~2000–3000 m. The lithology of the different upstream basins is composed of volcanic, intrusive and metamorphic rocks, mostly from the Paleogene, Neogene and Quaternary periods. Outcrops of Jurassic and Cretaceous limestone are also significant in the foothills. The large Kura-Arax confluence is linked with Miocene and Pliocene rocks as well as Quaternary alluvial fans and terrace formations. The Kura River and its tributaries follow an area of uplifted relief with areas of subsidence parts where the river flows closer to the Caspian Sea. The uplift rate is around 0 to 4–6 mm per year in the upstream part of the basin with 0–2 mm/year values in the middle section (Mosar et al., 2010). On the proximal Lesser Caucasus piedmont, the uplift process is greater with rates around 4–6 mm/year. Downstream, the uplift values are negative with subsidence rates of around −4 mm/year (Mosar et al., 2010) in the estuarine area.

2.3. Hydrographic units studied

The torrential units studied concern the Kura Basin. This hydrosystem is rich in Holocene archaeological sites and is directly connected to the Caspian Sea and its level changes since at least the Upper Pleistocene (Fig. 3). The Agstafa, Hasensu, Tovuz, Arenji, Zeyem and Shamkir River hydrologic systems present much the same basin morphometric characteristics. Their watershed areas are around 2400 to 2650 km², their length between 133 and 120 km and their mean discharge varies between 0.91 m³/s (Tovuz çayı) and 13.6 m³/s (Agstafa çayı). 45% of their annual water supply comes from groundwater, 35% from snowmelt, and 20% from atmospheric precipitation. The present day Kura Basin physiography, with an average declivity of 0.17% from the Georgian border to the Caspian shore, offers a large and relatively flat valley where relative Caspian Sea level variations can be expressed on a wide spatial scale (Fig. 3). The Tovuz region, located in the upstream part of this geomorphological environment, is subject to significant tectonic activity with an average uplift of 4–6 mm/year (Mosar et al., 2010). This geodynamic could contribute to the amplification of the signatures of sea level changes in morphosedimentary terraces.

2.4. Caspian Sea

The Caspian Sea is a vast endorheic system with a surface of 371,000 km² and a volume of 78,200 km³. It is bounded by Russia, Azerbaijan, Iran, Turkmenistan, and Kazakhstan. It is divided into three sections (the northern, middle, and southern Caspian) according to their particular morphometric components and hydrological regimes (Birkett, 1995; Arpe and Leroy, 2007). From north to south its maximum depths increase from 5 to 788 and 1025 m (Shiklomanov et al., 1995). Like the Black Sea, the Caspian Sea is a remnant of the ancient Paratethys and became landlocked about 5.5 million years ago due to tectonic uplift and a fall in sea level.



Fig. 1. Location map including the hydrological basin of the Kura River (after UNEP/DEWA/GRID-Europe, 2007; modified).

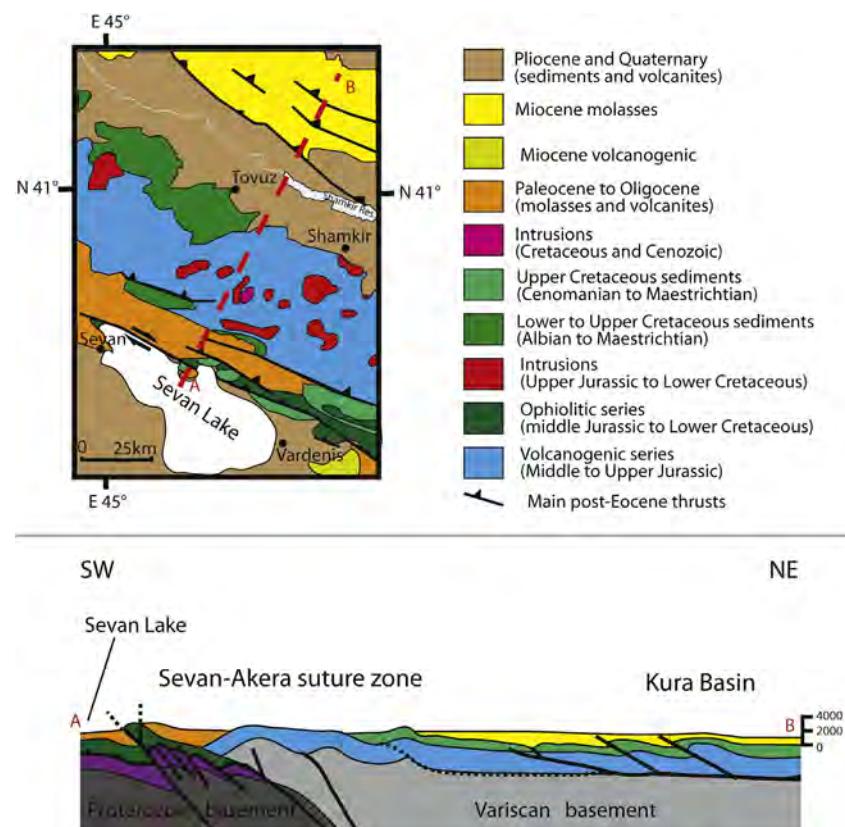


Fig. 2. Geological map and profile of the Lesser Caucasus in the studied area (adapted from Sosson et al., 2010).

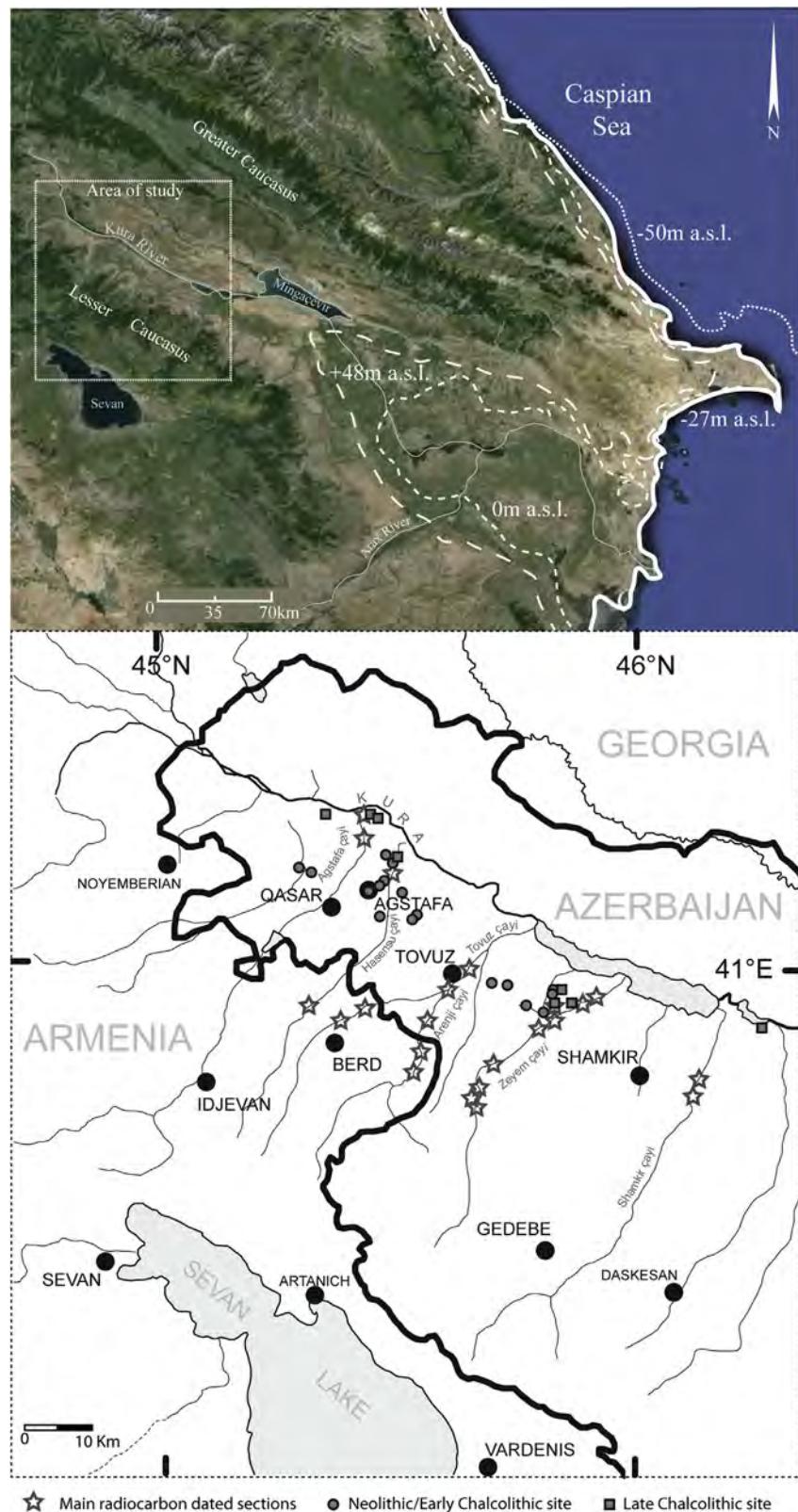


Fig. 3. Past Caspian Sea shorelines (adapted from Kislov et al., 2014) and map of the Kura river with detail of the studied Kura tributaries (Shamkir, Zeyem, Tovuz, Arenji, Hasensu and Agstafa Rivers). The location of the radiocarbon dated sections and archaeological sites are reported.

Nowadays, the Caspian Sea level depends on the flow of its eastern European tributaries and its Caucasian and Iranian rivers (Vali-Khodjeini, 1991). It could also be influenced both by northern European and western Himalayan climates (Leroy, 2010). Modern human

activities also play an important role. More generally, during the course of the Quaternary period, the palaeohydrology and water budget of the Caspian Sea are both influenced by climate changes and tectonic activity. In the Upper Pleistocene, significant fluvioglacial

discharge from the Tian Shan and Ural mountains and possibly from Siberia during the last deglaciation (Grosswald, 1980, 1993) supplied the Caspian Sea through the Aral Lake. During the Holocene, it was directly filled in by the Amu Darya River or was connected to the Aral Lake through the Uzboi channel or Sarykamish Lake at 3500–1,600 yr BP (Létoile, 1992, 2000, Boomer et al., 2000, 2009, Leroy et al., 2007, 2013a,b,c). Tectonic activity in controlling the Amu Darya course also played an important role at this time. But for the last major highstands, which occurred at around 2600 BP and during the Little Ice Age, some of the results point to a coincidence with global cooling events associated with minima in solar activity, influencing millennial precipitation changes in the Volga drainage basin (Kroonenberg et al., 2007; Naderi Beni et al., 2013a).

2.5. Archaeology

The distinctive geographical situation of the Southern Caucasus as both a barrier and a land bridge exposed the region to countless influences from the north and south, from Mesopotamian civilizations as well as Eurasian steppe populations. There is no doubt that the Southern Caucasus harboured a number of prehistoric cultures throughout the millennia. A few sites like Chokh in mountainous Daghestan (summary in Lyonnet, 2007) or Kmlo 2 in Armenia (Arimura et al., 2012) have been discovered, but have not yet revealed local developments towards plant and animal domestication at the beginning of the Holocene. However, discoveries of Halaf sherds in Araxes Valley and the close similarities in the material culture of the Leilatepe/Boyuk Kesik sites with that of Northern Mesopotamia during the first half of the 4th mill. BCE (Lyonnet, 2007) suggested that the Fertile Crescent and Northern Mesopotamia played a major triggering role in cultural development. Substantial research and excavations by Caucasian and Russian archaeologists in the 1960–1980s provided startling evidence for the existence of a number of original prehistoric cultures over the millennia. These different groups include the so-called Somu-Sulaveri (Chataigner, 1995; Lyonnet and Gulyev, 2010), Kültepe and Alikemek (Mahmudov and Narimanov, 1972), Sioni and Tsopi and Leilatepe (synthesis in Lyonnet, 2007) cultures, and a material culture comparable to that of the Kura-Araxes groups reported at a large number of newly discovered sites. This attractive region was occupied by communities who took up farming and herding towards the end of the 7th mill. BCE at the latest (Lyonnet, 2007). Subsequent to this first period of settlement, during the 6th mill. BCE, several transformations affected both settlement patterns and lifestyles. For unknown reasons, archaeological sites dated to the 5th and 4th mill. BCE are barely visible in the archaeological record. At the beginning of the 4th mill. BCE, new types of monuments, such as visible burial mounds or Kurgans, appear. Some of the burials contain metal weapons and symbolic leadership objects with exotic items (Lyonnet et al., 2008) which circulate in more extensive areas from the end of the 5th mill. BCE onwards. Given these archaeological assessments, current research programs (LIA, ANR-CNRS) focus on understanding how some of the great transformations visible in the settlement history of southern Caucasus took place – Neolithization, the development of short term settlements from the 5th mill. BCE onwards and the advent of ostentatious burial sites in the 4th mill. BCE – as well as the role of environmental factors in these developments. This latter aspect concerns the geomorphological research in this work.

3. Material and methods

3.1. Geomorphology

Geomorphological field surveys focused on the progressive upstream to downstream reading of the Kura tributaries,

measuring terrace heights and the alluvial fan surface thickness recording fluvial levels. Once the morphosedimentary and sedimentary sequentiality was recorded and the relative chronology established, samples for radiocarbon dating were taken from stratigraphic sequence ruptures and at the base and the top of the infilling in order to obtain an event chronology (Ollivier, 2009). Pleistocene to historical period formations were analyzed. The pattern of environmental changes proposed is compared to the isotopic data from GRIP (Andersen et al., 2006) and Sofular Cave (Fleitmann et al., 2009) to obtain a representative analysis based on two step climatic records (Ollivier et al., 2015). The paleo-shoreline localizations over time are based on the interpolation of radiochronological data and topographic altimetry of the Azerbaijan territory (Shuttle Radar Topography Mission of the NASA, Farr et al., 2007) and on recent work by Kislov et al. (2014).

3.2. Archaeological data

The archaeological data, and notably the map in Fig. 3, are from the fieldwork and excavations conducted over the past few years as part of the French-German ANR research program on Ancient Kura (Lyonnet et al., 2012), the French Ministry for Foreign Affairs missions and from the database of the Caucasia GIS and Navigasig developed by the CNRS and the BRGM (Copyright BRGM 2001–2009, Courcier, 2010). Around 60 sites were visited, including visible mounds and surface scatters of sherds. These data are used without deterministic preconception to place the geomorphic changes in the context of the development of prehistoric societies.

3.3. Radiocarbon dating

A total of 32 radiocarbon measurements had previously been performed (Ollivier et al., 2015) on charcoal and organic matter (Table 1) to construct the pattern of landscape evolution in relation to the impact of the Caspian Sea level changes. We have now added five new radiocarbon dates from the very upstream part of the Hasensu, Tovuz and Arenji rivers located in Armenia (Table 1), and two others from the Tovuz-Arenji River and Zeyem River (perched archaeological site) from the downstream part in Azerbaijan. Due to the rapid accumulation of organic matter in the terraces, pedogenesis is greatly reduced and organic matter is buried rapidly and homogeneously without a significant turnover effect. Thus, the isotopic signal might be only slightly altered and the measured ^{14}C activity may reflect that of the vegetation or the humus (Hatté et al., 2001a, 2001b; Lang et al., 2003). All samples were prepared following a standard procedure (Délibrias, 1985) at the LSCE Laboratory (Gif/Yvette). Charcoal samples were treated following the ABA (Acid: Base: Acid) method. Sediments were then sieved using meshes finer than 250 μm to remove possible roots. The fine fraction was decarbonated with HCl 0.6 N (Gauthier and Hatté, 2008), rinsed, dried at 50 °C, and homogenized. The samples were then combusted at 900 °C in an evacuated quartz tube with copper oxide and silver foil. Radiocarbon activity was measured using AMS facilities of LMC14 (ARTEMIS) at Saclay. Conventional ^{14}C ages are expressed in years before present (BP), with 1 σ error. Ages were calibrated using OxCal v4.2.3 Bronk Ramsey and Lee (2013): r5 IntCal13 atmospheric curve (Reimer et al., 2013). Calibrated dates are given with a level of confidence of 95.4% (2 sigma range). The $\delta^{13}\text{C}$ values used for conventional age calculation are obtained from accelerator measurement and include carbon isotope fractionation due to graphitization and ion beams during measurements. They have no palaeoenvironmental significance.

Table 1
Material dated and conventional radiocarbon ages of sample collected on the Kura tributary terraces. Median and interval of Calibrated dates are given at level of confidence 95.4%. $\delta^{13}\text{C}$ is measured by AMS and is not representative of the carbon isotopic composition of the sample.

N° Gif-	Reference	Site	Altitude (m)	Material	Latitude N	Longitude E	$\delta^{13}\text{C}$	Conventional age	Median date	Date cal BP (2 σ)
ScaA 27934/Gif-12726	KUR 10/01	Zeyem	355	Charcoal	40°55'633	45°50'622	-24.3	140 ± 30	142	-3 - 281
ScaA 34053/Gif-13037	ARM 11/05	Upstream Arenji	700	Charcoal	40°49'263	45°53'361	-34.5 ± 30	393	393	313 - 484
ScaA 26244/Gif-12729	KUR 10/06	Zeyem	289	Charcoal	40°56'554	45°52'889	-30.5	1650 ± 30	1551	1418 - 1687
ScaA 337087/Gif-13058	KUR 13/05	Zeyem	497	Charcoal	40°52'246	45°45'772	-26.3	1745 ± 30	1668	1566 - 1718
ScaA 34053/Gif-13035	ARM 11/03	Upstream Arenji	607	Charcoal	40°52'268	45°33'597	-29.2	1775 ± 30	1696	1610 - 1745
ScaA 34051/Gif-13033	ARM 11/01	Upstream Tovuz	742	SOM	40°55'017	45°26'491	-24.7	3185 ± 30	3409	3360 - 3458
KUR 10/07bis	KUR 10/07	Zeyem	319	SOM	40°56'175	45°53'542	-20.4	3365 ± 30	3608	3486 - 3691
ScaA 21715/Gif-12542	KUR 11/23	Tovuz	457	SOM	40°57'337	45°36'142	-30.3	3420 ± 30	3670	3580 - 3821
ScaA 20996/Gif-12503	KUR 10/07	Zeyem	319	SOM	40°56'175	45°53'542	-24.0	4290 ± 30	4853	4826 - 4959
ScaA 21712/Gif-12539	KUR 11/16	Zeyem	340	Charcoal	40°56'052	45°50'354	-24.6	4495 ± 35	5166	4983 - 5301
ScaA 21716/Gif-12543	KUR 10/09	Zeyem	369	SOM	40°55'309	45°50'147	-22.9	4560 ± 30	5171	5054 - 5436
ScaA 21719/Gif-12546	KUR 10/08	Zeyem	368	SOM	40°55'291	45°50'035	-24.0	9810 ± 35	11225	11188 - 11259
ScaA 20998/Gif-12505	KUR 10/05	Zeyem	305	SOM	40°56'028	45°52'784	-24.3	11610 ± 35	13440	13316 - 13610
ScaA 20997/Gif-12504	KUR 11/02	Zeyem	349	SOM	40°57'776	45°51'054	-18.2	11220 ± 60	14276	14276 - 15208
ScaA 34056/Gif-13038	ARM 11/06	Upstream Arenji	721	SOM	40°56'309	45°21'390	-28.9	12260 ± 50	14130	13915 - 14552
ScaA 21100/Gif-12507	KUR 11/11	Zeyem	561	SOM	40°51'581	45°43'780	-27.7	12670 ± 50	15008	14598 - 15543
ScaA 20994/Gif-12501	KUR 10/04	Zeyem	305	SOM	40°56'028	45°52'784	-22.3	13820 ± 40	16912	16754 - 17087
ScaA 21741/Gif-12498	KUR 10/03	Zeyem	305	SOM	40°56'028	45°52'784	-22.2	18020 ± 50	21471	21240 - 21737
ScaA 20992/Gif-12499	KUR 10/02	Zeyem	305	SOM	40°56'028	45°52'784	-24.3	22690 ± 80	27390	26886 - 27895
ScaA 34052/Gif-13034	ARM 11/02	Upstream Tovuz	830	SOM	40°54'676	45°24'842	-22.2	28010 ± 320	32234	31471 - 35081

SOM: Sediment organic matter

4. Results

4.1. Geomorphological organization of the terraces of the Kura tributaries

Nine new cross sections were studied along three tributaries of the Kura River. Five sequences of the Tovuz, Hasensu and Arenji Rivers are presented in Fig. 4. A composite cross section is reported in Fig. 5 and compared to the most representative section of the downstream part of the Zeyem River (Ollivier et al., 2015). This summary helps to correlate the various terrace levels to earlier work carried out downstream in the Shamkir, Zeyem, Tovuz, Arenji, Hasensu and Agstafa Rivers (Ollivier et al., 2015). The current upstream sedimentary sequences were chronologically framed by five radiocarbon dates. These two complementary studies (Ollivier et al., 2015 and this article) provide a total of eight combined cross sections, 24 sequences and 39 radiocarbon dates for this area. To be concise, we decided to only show previous dating from the downstream Zeyem River and additional new data from the upstream sections of the Kura tributaries studied (Table 1).

Five terrace levels of varying thickness are observed in the upstream part of the torrential units (Fig. 5). The Pleistocene-Late Glacial sedimentary formations (T1), dated to $28,010 \pm 320$ BP and $12,260 \pm 50$ BP (32,234 cal. BP and 14,130 cal. BP) reach a thickness of more than 20 m. The facies of this complex are dominated by well differentiated units of pebbles, silts and sands. The Holocene terraces, dated to 3185 ± 30 BP (T2/T3, 3409 cal. BP), 1775 ± 30 BP (T4, 1696 cal. BP) and 345 ± 30 BP (T5, 393 cal. BP), generally contain more pebbles. These latter deposits are well expressed in the thalwegs where they reach a thickness of 8 to 4 m.

4.2. Landscape changes retroactively driven by climate and Caspian Sea relative level changes

The upstream-downstream correlation in terrace organization, facies, geometry and chronology between the different Kura tributaries allows reconstruction of a detailed landscape evolution pattern. Six phases of valley floor aggradation (27,000–13,000; 11,000–3200; 2900–2100; 1600–1000; 400–150 cal. BP) and seven phases of fluvial incision (>37,000; 37,000–27,000; 13,000–11,000; 3200–2900; 2100–1600; 1000–400; 150–0 cal. BP) are recorded in the downstream sedimentary formations (Fig. 6 and Ollivier et al., 2015).

The new data from the upstream valley in Armenia (Fig. 6) show that the infilling or incision oscillations follow the previous downstream results (Ollivier et al., 2015). The highest amplitudes were recorded during the Pleistocene-Late Glacial transition and the lowest during the Holocene (20–23 m to 2 m thickness). The T1 to T5 upstream chronology and thicknesses are similar all along the hydrologic section to the confluence with the Kura River.

The upstream data also confirm the morphogenic changes determined in our previous work (Ollivier et al., 2015), suggesting that the global (Andersen et al., 2006) or regional (Fleitmann et al., 2009) climate was of secondary importance in terrace organization compared to the major role played by the Caspian Sea level variations. The poor correlation with the global or regional climatic record (Fig. 6) must be linked to the many climate variables that influence the Caspian Sea level (precipitation over Eastern Europe and Russia, melting of western Himalayan glaciers during the Holocene and boreal ice cap melting during glacial and deglaciation periods; Mauri et al., 2014; Scherler et al., 2010; Svendsen et al., 2004).

The T1 high terrace formations begin to settle during the Upper Pleistocene at $28,010 \pm 320$ BP (32,234 cal. BP, Figs. 4–6 and

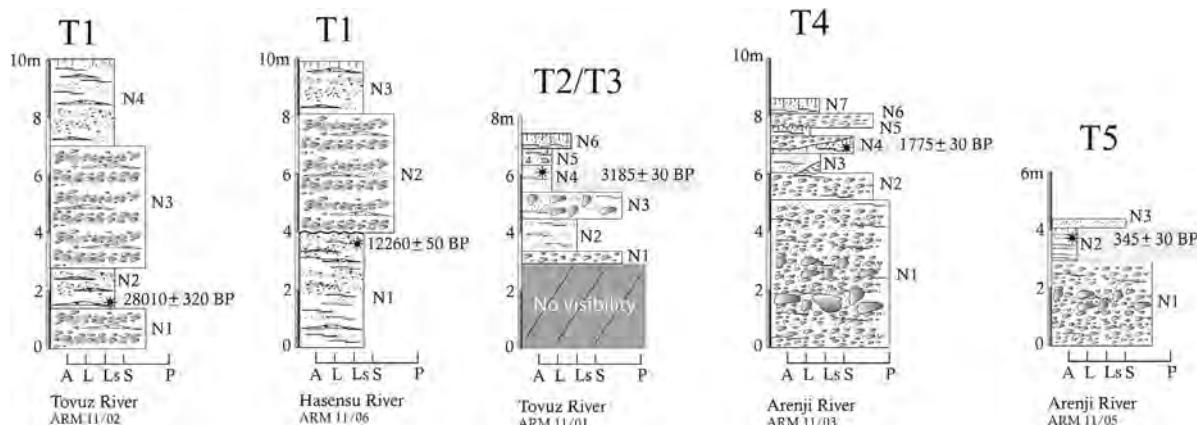


Fig. 4. Tovuz, Arenji and Hasensu Rivers very upstream cross sections with radiocarbon ages and sedimentary components (facies: A: argillaceous; L: silty; Ls: silty–sandy; S: sandy; P: pebbly).

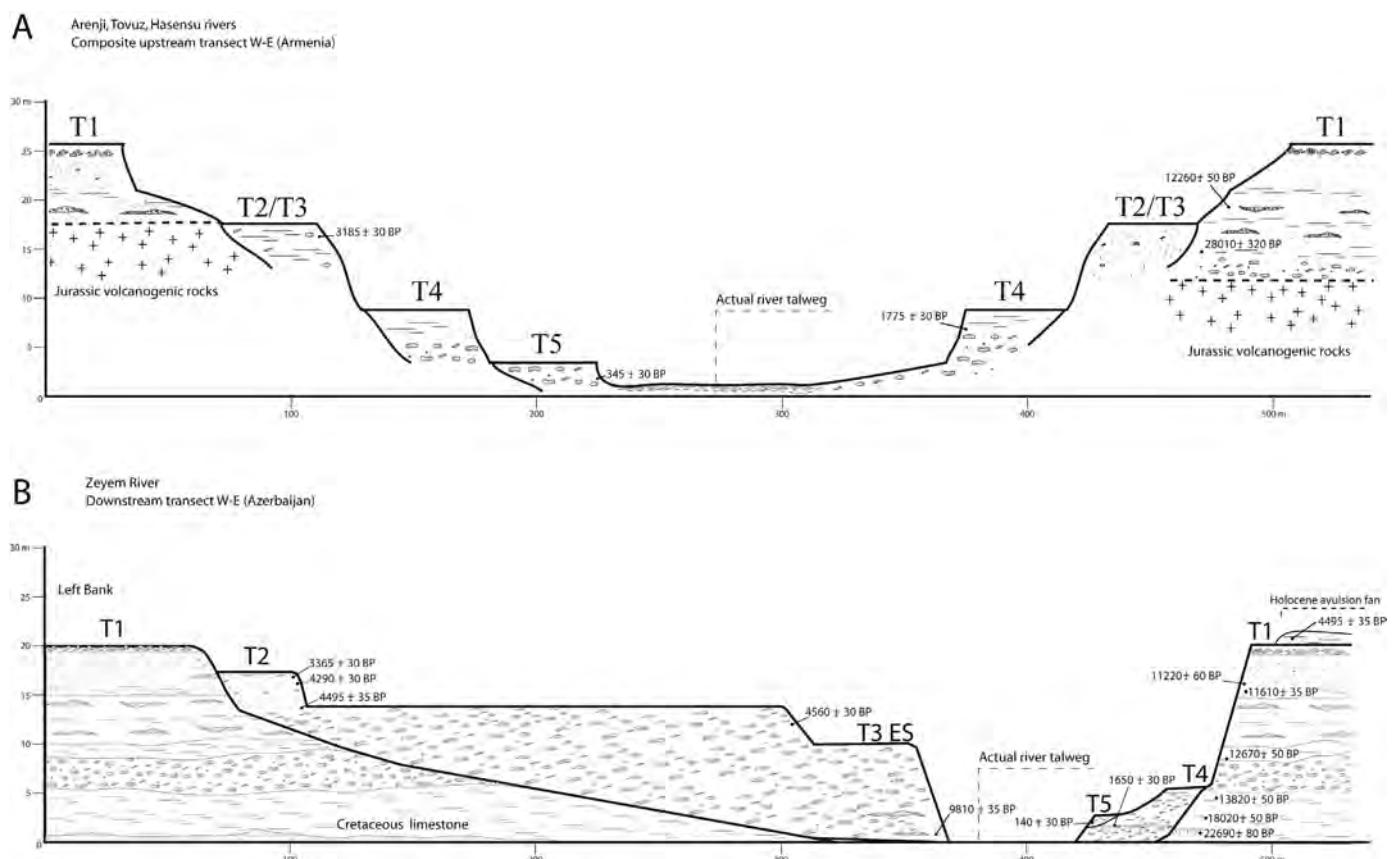


Fig. 5. A: Upstream Arenji, Tovuz and Hasensu Rivers composite stream transect with ^{14}C dating. B: Downstream Zeyem River reference stream transect with ^{14}C dating (from Ollivier et al., 2015).

Table 1), a period recording one of the major Caspian Sea transgressions (The Late Khvalynian). This result, compared with the dating of the top of the T0 terrace at 36,664 cal. BP downstream (Ollivier et al., 2015), indicates an Enotaevkian regression recorded around 35,000 cal. BP in the alluvial infilling and supports the evidenced incision between the T0 and T1 terraces (Figs. 4–6). Upstream valley floor aggradation continues at least until 12,260 ± 50 BP (14,130 cal. BP) during the Late glacial period in the frame of the Late Khvalynian transgression. The downstream data show a major regressive incision starting at the transition with the

Late glacial and the beginning of the Holocene, between 11,610 ± 35 BP (13,443 cal. BP) and 9810 ± 35 BP (11,224 cal. BP). This event is correlated to the Mangyshlak marine regression context and is also recorded by the upstream terrace morphology. This morphogenetic trend is followed by a period of sedimentation (T3/T2) which continues until 3185 ± 30 BP (3409 cal. BP, Figs. 4–6 and Table 1) and which could be triggered by the high levels during the first part of the Holocene, as suggested by dinocysts in the Caspian Sea (Leroy et al., 2007, 2013a, 2013c, 2014). As observed in the downstream part of the Kura tributaries, two deposit phases

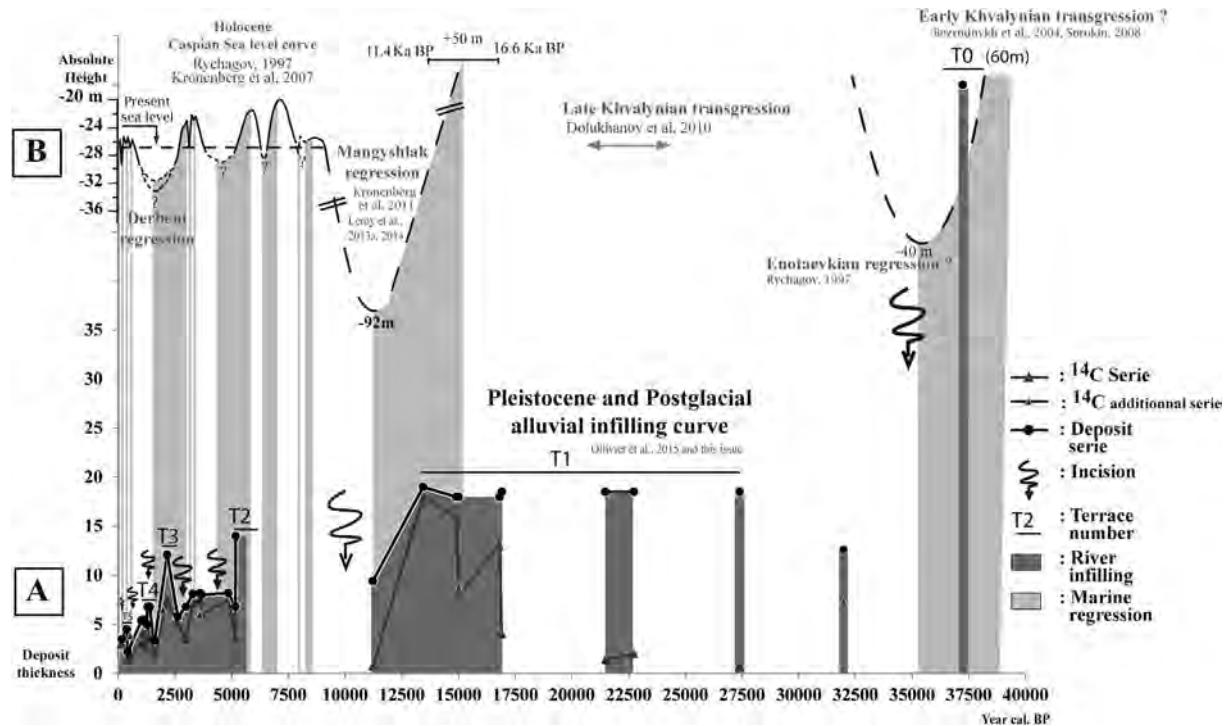


Fig. 6. Variations versus time of: A) ^{14}C dated deposit thickness and terrace organization in the Middle Kura valley with synthesis of Ollivier et al., 2015 data and new upstream tributaries data; B) Holocene Caspian Sea level with new estimation for Lateglacial and Upper Pleistocene periods based on former studies (Rychagov, 1997; Bezrodnykh et al., 2004; Kroonenberg et al., 2007, 2011; Sorokin, 2008; Dolukhanov et al., 2010; Leroy et al., 2013a, 2014; Ollivier et al., 2015) and this work.

between 1775 ± 30 BP (1696 cal. BP) and 345 ± 30 BP (393 cal. BP) occurred (T4 and T5 terraces, Figs. 4–6 and Table 1). These deposit dynamics were separated by a medium amplitude incision estimated downstream between $1,120 \pm 30$ BP– 360 ± 30 BP (1020–414 cal. BP). The ultimate cutting phase started after 140 ± 30 BP (142 cal. BP) and seems to continue today (Ollivier and Fontugne, 2012; Ollivier et al., 2015). Considering these data, it seems that the upstream to downstream Holocene riverbed position illustrates the retroactive geomorphic responses to the base level changes induced by the Caspian Sea fluctuations.

Despite good general correlations, the records are not strictly in phase as the Kura hydrosystem presents a systematic lag compared to Caspian Sea level variations (Fig. 6), due to the inertial time required by the hydrosystem to react to base level changes (Ollivier et al., 2015). The rate of variation depends on the shoreline location (Kislov et al., 2014 and Fig. 3) over time (induced by the importance of sea level oscillations) and the system damping defined by the thickness of the infilling. This retroaction delay is reproduced in comparable rates and correlated to the main high amplitude long-term sea level movement. The estimated response lag ranges between 1000 years for the Khvalynian-Mangyshlak to the middle Holocene period and 400 and 100 years for the second part of the Holocene and LIA, respectively (Ollivier et al., 2015). The almost identical recurrence of this time lag all along the curve supports our results.

4.3. Archaeological settlement distribution

This work concerns the relationship between humans and the environment, and also focuses on the spatial distribution of archaeological sites during the Holocene. In this studied area, the major Neolithic to Bronze Age settlements (notably: Goy-Tepe, Mentesh Tepe and Soyuq Bulaq) are primarily located in the higher Kura and tributaries terrace level. In most cases the T1 terrace level,

attributed to the Upper Pleistocene and Late Glacial periods, shows a specific area with a longitudinal transition of the outcrop facies. The sedimentary formations in the upstream part are composed of silty deposits whereas downstream, in the direction of the Kura, they are mostly made up of pebbles and sands. The Neolithic, Chalcolithic and Bronze Age occupations are mainly located in this silty deposit area. The stratigraphy of the right bank Kura tributaries clearly shows a correlation between erosion contact and silty and pebbly deposits. The observed morphosedimentary organization is related to upstream flooding causing temporary avulsions from the Neolithic to the Bronze Age periods. Generally, this process corresponds to the diversion of the river flow from its established course and is usually intended for major discharge diversions that result in new channels. In our case, it illustrates short term flow switching/conversion resulting in torrential silty fans upstream over the upper terraces. It is in these levels that the Holocene archaeological sites are located. This is particularly visible in the sedimentary formations of the Zeyem (Fig. 7 and Fig. 8), Hasensu, Tovuz and Arenji (Fig. 9) Rivers. In the Zeyem River, a radiocarbon date at 4495 ± 35 BP (5166 cal. BP) in the silty levels fitted into the top part of the T1 sequence dated to $11,220 \pm 60$ BP (14,899 cal. BP). This date is close to the Neolithic to Bronze Age archaeological site of Mentesh tepe (Lyonnet et al., 2012) and confirms the chronology of the event (Fig. 8 and Table 1). The same observation can be made with the date of 3420 ± 30 BP (3670 cal. BP) for another silty fan over the upper terrace (T1) of the Arenji-Tovuz River surrounded by Neolithic to Bronze Age archaeological sites (Fig. 9 and Table 1). In Fig. 10, we show the mapping of the Neolithic-Chalcolithic settlement distribution over the silty fans produced by temporary avulsions of the different studied Kura tributaries. These sites were discovered during several archaeological field prospections (Lyonnet, 2007; Lyonnet et al., 2012). Some, including Mentesh Tepe and Goy-Tepe, are currently excavated as part of an international research program (Lyonnet and Guliyev, 2010; Lyonnet et al.,

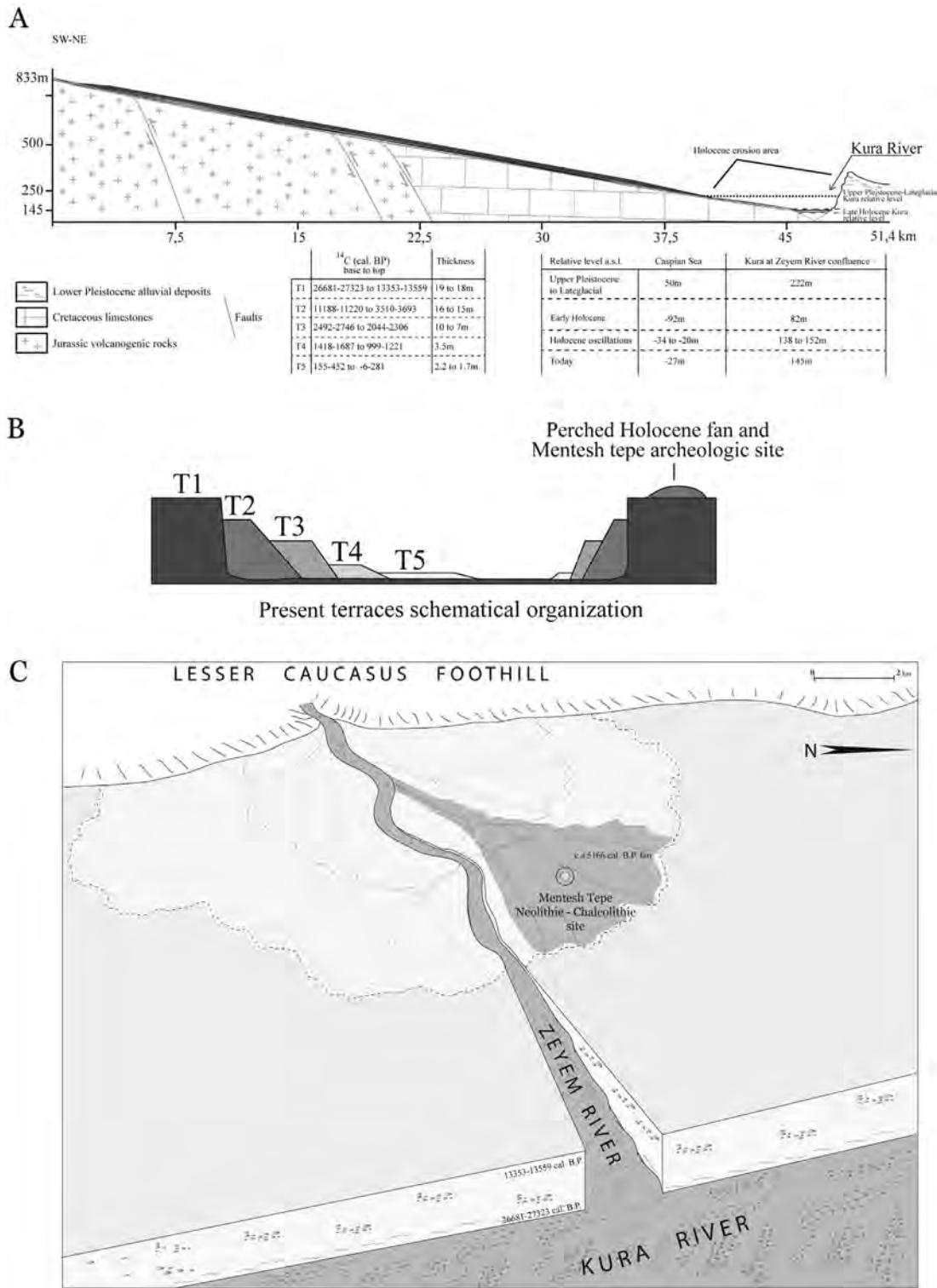


Fig. 7. Reference pattern of morphosedimentary and settlement distribution (Zeyem River and Mentesh tepe Neolithic site). A: Longitudinal organization of the upstream-downstream sedimentary units from the Zeyem River to the Kura River connected to the Caspian Sea (from Ollivier et al., 2015); B: Global terraces organization in the Middle Kura Valley (from Ollivier et al., 2015); C: Position of Mentesh tepe site over avulsion generating silty-fan.

2012). Out of the 24 sites reported on the map (Fig. 10), only six are located outside the area of the Holocene silty fans. This underlines a strong correlation between the location of the Neolithic and Chalcolithic settlements and the development of silty fans by upstream flooding producing avulsions.

5. Discussion

The definition of the long term geomorphic adjustments, the settlement distribution pattern, and their chronology fixed by ^{14}C dating provide several findings:



Fig. 8. Overview of the geomorphological and chronological organization of the alluvial terraces in the Zeyem River hydrosystem reference site (A) with focus on the avulsion silty fan (B, C and D) related to Mentesh tepe archaeological site.

- Compared to the high frequency and amplitude of sea level oscillations (multi-millennial-scale fluctuations of ± 150 m and decadal-scale variations of up to 2 m with estimates based on geological, historical and measured data, as well as model studies), the regional uplift rate of around 6–8 mm/y (Mosar

et al., 2010) implies that tectonic impact must be minimized in relation to the marine signal for the end of the Upper Pleistocene to the postglacial timescale.

- Some of the wider silty fan developments at the end of the T1 aggradation (since ca. 14,900 cal. BP in the Zeyem River)

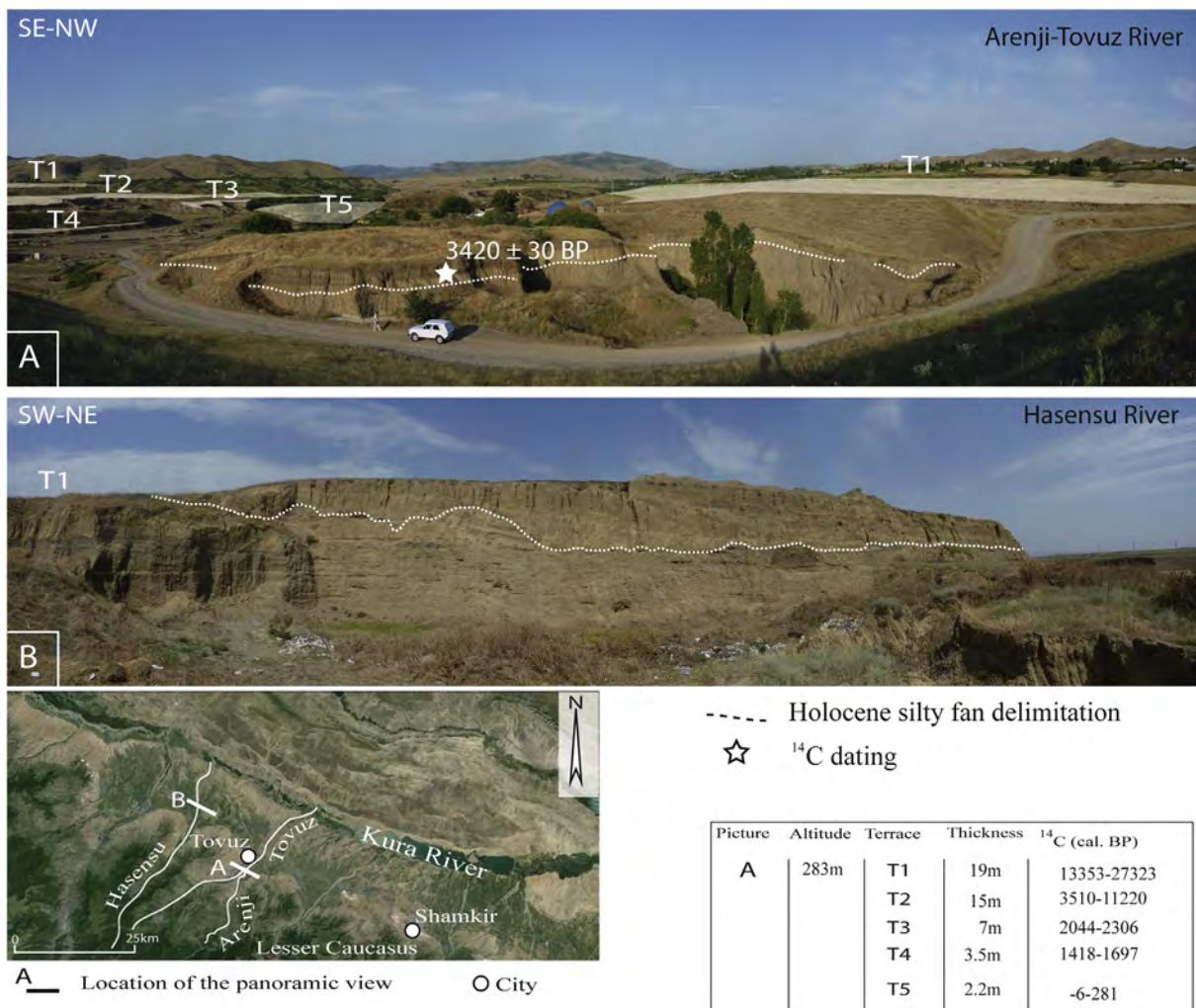


Fig. 9. Arenji, Tovuz and Hasensu avulsion silty fans with their location. Terraces and fan radiocarbon age and organization are reported.

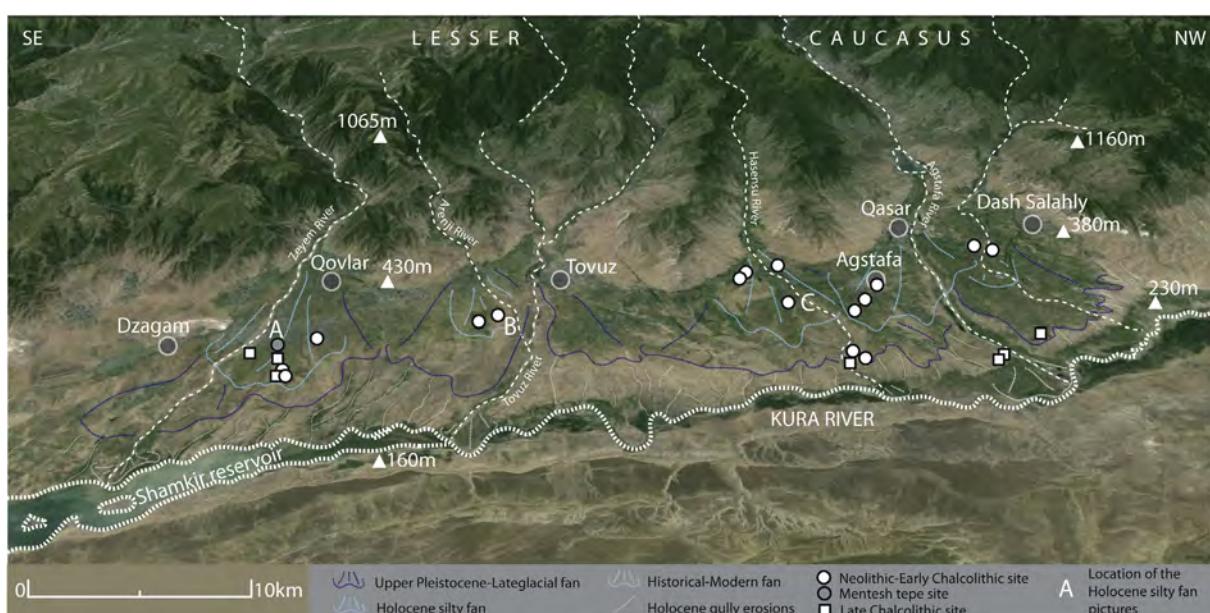


Fig. 10. General mapping of the avulsion silty fans in connection with the settlement distribution (Neolithic and Chalcolithic sites) in the Middle Kura Valley. The location of the Fig. 8 and Fig. 9 fans is reported.

occurred during the Late Glacial period, which is known to be regionally dry and relatively cold with an arid and steppe environment (Wright et al., 2003; Messager et al., 2013; Leroy et al., 2013a). The deposition of the Holocene silty fan over the T1 high fan-terraces occurred at least between ca. 5160 cal. BP and 3670 cal. BP (median ages). The dates from the Mentesh Tepe Neolithic occupation site, which seems to be well developed at ca. 7600–7500 cal. BP on the Late Glacial T1/silty fan deposits and linked with slight river runoff activity in its vicinity, can be used to define the increase in the Holocene river avulsion mode. This morphogenic trend followed more humid climatic phases recorded around 9500–9000 cal. BP (Ollivier et al., 2011, 2012) and 8200–7500 cal. BP (summary in Joannin et al., 2014). Regionally, the Holocene climate underwent drier phases at c.a. 6400 cal. BP, 5300–4900 cal. BP, 3000 cal. BP, (Joannin et al., 2014). According to the geomorphological evidence and radiocarbon dating, two generations of avulsion fans were deposited during the same dry climatic phases. Dryer conditions do not involve powerful, and most of all, continuous flow supplying avulsions and/or channel migrations without base level changes. Low base levels help the longitudinal transit compensate for the weak liquid/solid flow ratio controlling the downstream sedimentary transfer during drier phases. A rapid sea level rise favours high avulsion frequency and multiple channel networks (which can be observed on the present day T1 surface morphology), whereas lower avulsion frequency and fewer channels accompany stable sea level (Törnqvist, 1993, 1994; Aslan and Blum, 1999; Stouthamer and Berendsen, 2007). The Late Glacial gradual avulsion occurs during the high sea level record linked to the Late Khvalynian transgression expressed ca. 13,600–16,600 cal. BP in this area (Ollivier et al., 2015). The deposition of the Holocene silty fan over the T1 high fan-terraces developed during the ca. 7500 cal. BP,

5600 cal. BP and 3700 cal. BP Caspian Sea high relative level phases.

The antagonistic climatic-hydrologic (liquid/solid flow, dryer/wetter climate) and geomorphic (sedimentary transit and erosion) evidence vs. the correlations between high sea-level and avulsion support a base level controlled development (frequency, duration) of the silty fans in the Middle Kura Valley. In some cases, a more humid climate could have strengthened some early Holocene silty flows (around 9500–9000 cal. BP or 8200–7500 cal. BP) but their deposition over the high T1 terraces must be related to a rising base level modifying the longitudinal river profiles.

- Around 3000 cal. BP, a major riverbed linear incision occurs and leads gradually to the end of the avulsion process. The upper terrace levels (T1, T2 and T3) are totally disconnected from the upstream flooding and gradual avulsions after 1668 cal. BP, as shown today by the perched archaeological site and palaeomeander of the Zeyem River in the area of Mentesh Tepe (Fig. 11 and Table 1). This also happened during the 3000 cal. BP and 2200–1500 cal. BP dry phases recorded at Ispani II (Connor and Kvavadze, 2008), Mirabad (Stevens et al., 2006) and other lakes or fens (e.g. Van, Zeribar, Paravani, Zarishat, Turner et al., 2008; Messager et al., 2013; Joannin et al., 2014). Linear incisions are commonly linked to the rise of the hydric balance sheet and/or the vegetation cover. On the other hand, the drier climate accompanying the beginning of deforestation at a regional scale during this period (Messager et al., 2013; Joannin et al., 2014) should be associated with a sedimentary infilling trend. In contrast, the beginning of a sea level fall (around 3000 cal. BP, Fig. 6), followed by the Derbent lowstand period (Kroonenberg et al., 2007, 2008; Richards et al., 2014), and the 'Medieval Warm Period' (with development of pine forest cover,

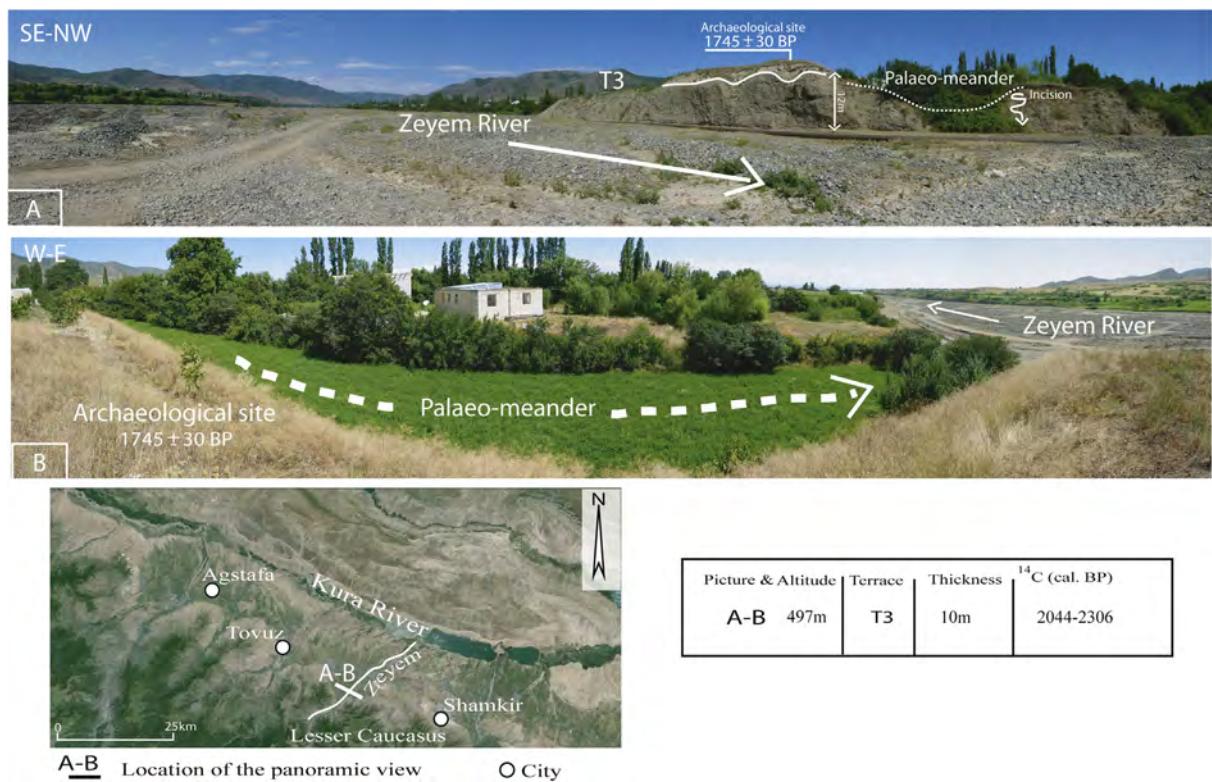


Fig. 11. Illustration of the post-2000 cal. BP incision/regression with archaeological site and paleo-meander present position in the Zeyem River close to Mentesh tepe site.

Joannin et al., 2014) is compatible with the incision disconnecting the high terraces from floods and avulsions after 1668 cal. BP (Fig. 11). More generally, the importance of linear thalweg sedimentary drainage at various timescales should be related to climatic but also to the geomorphic response of base level changes.

- The Kura terrace organization (Fig. 12) is also correlated to the morphosedimentary evolution of the tributaries. The Kura River corresponds here to the proximal base level connected to the Caspian Sea, frequently closer (50 km) or farther (700 km) from the shore during the highest and lowest levels (Fig. 3). Following the principle of nonlinearity of the fluvial response (Schumm, 1977) at a millennial scale, if the Kura River and its tributaries were exposed to similar climatic conditions, their evolution should have been different in the distinct areas. The surprising homogeneity of the geomorphic response in the six Kura tributaries studied indicates more a base level induced control of the infilling and incision phases in this area.
 - The Neolithic-Chalcolithic settlement distribution pattern seems to follow the landscape changes linked to climate and

base level variations. Field prospecting has shown that most of the Neolithic settlements are located in the silty alluvial plain and not in the neighbouring mountainous area. This is probably linked to water supply requirements and agricultural development availability.

- An overview of the different Neolithic-Chalcolithic occupations in the Caucasus area underlines this close link with the riparian environment. Given the torrential hydrological regime of the Holocene Caucasian rivers, settlements were frequently located on the distal banks of tributaries and not on the main flow (the Kura or Arax for example) in order to be protected from the major one-hundred-year flooding. Water accessibility seemed to be orientated towards streams and sites were positioned some hundred meters away (Aknashen in Armenia, Aruchlo in Georgia, [Badalyan et al., 2010](#), [Hansen et al., 2006](#)), or on small terraces dominating the main flows (Kamil tepe in Azerbaijan, [Helwing et al., 2012](#), Aratashen in Armenia, [Badalyan et al., 2007](#)), or over avulsion fans (Mentesh tepe, Goy tepe or Quanly Toyre tepe in Azerbaijan, [Lyonnet et al., 2012](#), [Lyonnet and Guliyev, 2010](#)). In Mentesh tepe, these avulsion dynamics

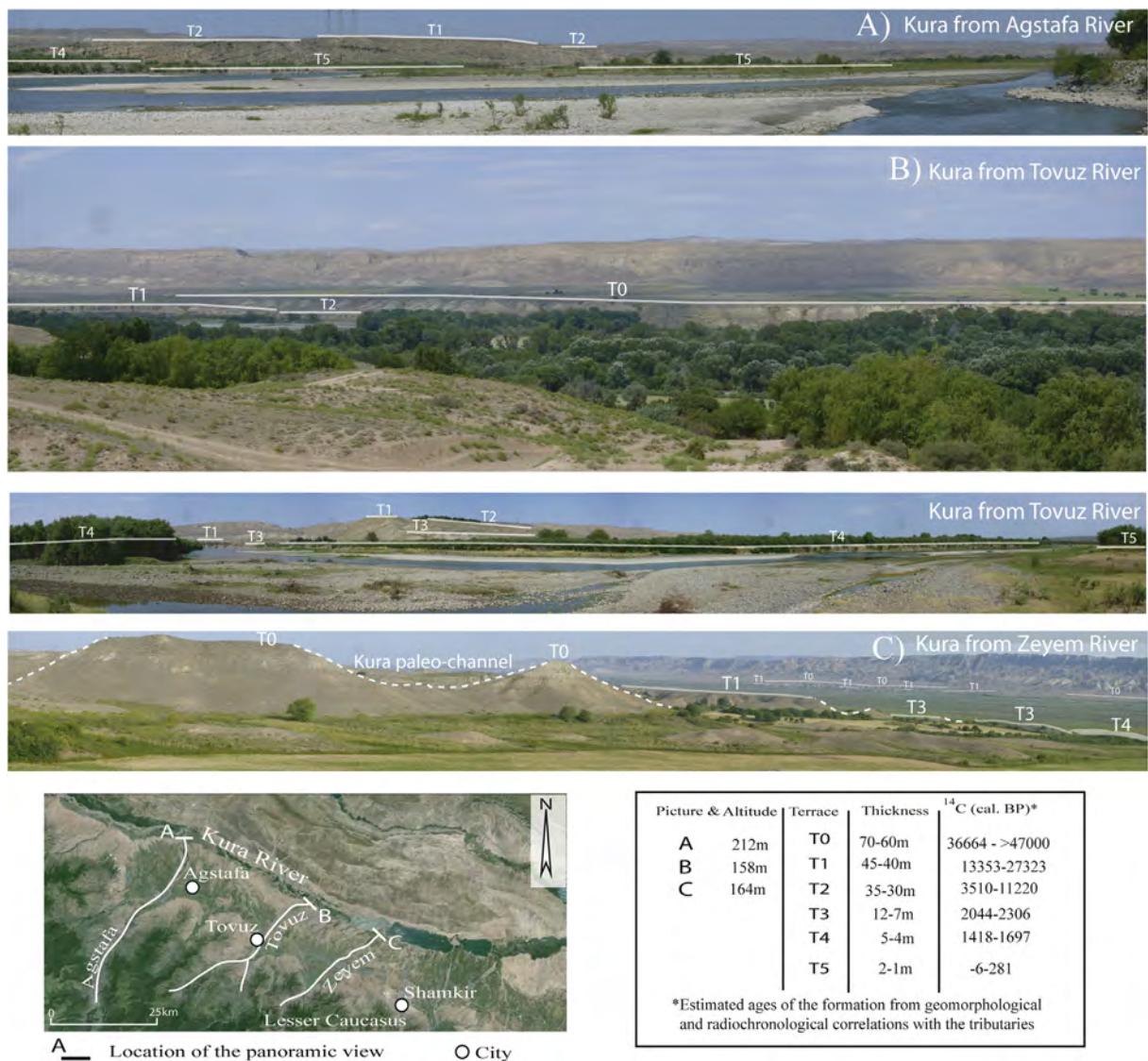


Fig. 12. Kura River terraces organization. Estimated ages of the formations are from geomorphological and radiochronological correlations with the tributaries after the work of Ollivier et al., 2015. Location of the different views is given.

over the highest terraces provided light soils conducive to agriculture and the development of a humid zone with thalwegs with more or less concentrated runoff, contributing to a relatively effective *in situ* water supply. The geological setting also plays an important role in water availability in the vicinity of the settlements. Lithology and faults control the proximity of aquifers and spring re-emergence. The high frequency and importance of the base level changes can be considered as one of the main hydrosystem morphogenetical adjustment variables over time (Newson, 2002).

- Subsequently to the Bronze Age, thalwegs were significantly deeper due to the Caspian Sea low stand. The termination of the settlements may have been due to their position c.a. 30 m above the riverbeds as a result of these new environmental conditions, which provided unattractive drier and perched landscapes. Today, the main parts of the higher terraces are still relatively arid areas, colonized by a steppe cover of Artemisia. The landscape morphosedimentary expression and the sedimentological feature of the Quaternary formations outside the silty avulsion area, dominated by sands and quasi open-work pebble deposits, maintain water infiltration which is observable at the sole infilling by seeping and spring re-emergence. Modern villages and cultures are located on the silty deposits generally occupied during the Neolithic. Obviously, agricultural activities require the same approach to past morphogenetic evolution. Water for irrigation is artificially diverted to the high dry steppe terrace areas. During the Mid-Holocene, irrigation was "natural" (marine transgression and high torrential levels) and active through the avulsion floods.
- The mud brick architecture (and the utilization of mud mortar as well) of the Neolithic-Chalcolithic occupations provides another source of open discussion. Settlement distribution seems to follow the presence of silty-muddy material exclusively concentrated here on avulsion fans. Different studies show that raw materials for mud brick preparation are mostly acquired from local soil exposures around settlements (Canaan, 1932–33.; Dalman, 1928–42; McIntosh, 1974). However, the origin and requirements of this raw material are difficult to appreciate as they may involve cultural or technological, rather than environmental parameters.

6. Conclusions

Marine sea level rise can be very fast on a global scale (Melt Water Pulse-1A, Deschamps et al., 2012). In the case of the Caspian Sea, the closed basin characteristics make them even more rapid and reactive to environmental variability. Based on this, the hydrosystem and human occupations of the Caspian Basin were even more sensitive to regional base level changes. Alluvial valleys provide the link between processes that control sediment flux to the continental margin and processes that control dispersal into the basin. The volume of sediment transported to the margin reflects hinterland drainage areas and large-scale relief (Blum, 2003). The valley incision probably characterizes the lowest of low stands (Posamentier, 2001). Pleistocene and Late Glacial regressive or transgressive variations are of great amplitude (+/-150 m) and are likely to have significantly affected the fluvial morphology and the morphogenetic dynamics of the Kura and its tributaries. The relative changes in the Caspian Sea Holocene curve do not exceed an altitude of -21 m/-19 m during the transgressive phases (Naderi Beni et al., 2013a), i.e., about 6 m higher than the current level. However, the modest Holocene variations, of around 6 m, also seem significant enough to provoke the crossing of a geomorphic threshold (Schumm, 1977; Yang and Song, 1979) for the Middle Kura Valley

hydrosystems. This positive feedback of the Kura tributaries to the Caspian movements is expressed through valley infillings during the high stand by the multiplicity of sediment inputs available from upstream. The regressive incisions during low stands back up far away to the inland and spread to the mountains torrential units. Favourable climatic conditions are necessary to promote each type of development of morphogenetic trends. Given the important slopes encountered, the foothill hydrosystems can be considered as sensitive units reacting strongly to medium/high amplitude but also to the long-term relative level changes of the Caspian Sea (Leroy et al., 2014). This is well illustrated by the synchronicity between upstream and downstream hydrological units with the connected Kura River system. The regional geomorphologic configuration, with thick Late Quaternary formations with a soft and responsive substratum to incision processes and significant sedimentary stock supplying the valley infilling phases, also affected the geomorphic response to base level changes and in turn optimum settlement location. The avulsion development forming silty fan areas during the high sea levels shows the rejuvenation of perched floodplains leading to new attractive lands for Neolithic and Chalcolithic populations. Settlement abandonment after the Bronze Age period when base levels were low, linear thalweg incision and the interruption of the avulsion process, underline the close relationship between some societies and the evolution of the fluvial context. Such landscape dynamics provided a changing ecological setting for human activity, resulting in societal adaptation to environmental variables. The present study suggests that the motivation for floodplain settlement during the Neolithic and the Bronze Age may have been the exploitation of flat foothill landscapes with riverine and riparian resources. This would explain the extensive settlement system along the right bank of the middle Kura Valley and the perched tributaries Holocene fan. These various resources are essential in the relatively dry Neolithic climatic context, but are however surprisingly exposed to the variability of the Caspian Sea level, generating significant changes in regional landscapes and some long term vulnerability of the selected modes of human occupation. Ongoing work in upstream Georgia, Armenia and south-western Azerbaijan will certainly provide more evidence showing original diachronic geomorphic influences on the Lesser Caucasus societies and the need to integrate this approach in future geoarchaeological analyses.

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