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Geomorphic response and ^{14}C chronology of base-level changes induced by Late Quaternary Caspian Sea mobility (middle Kura Valley, Azerbaijan)

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ABSTRACT

Recent geomorphological studies in Azerbaijan reveal the importance of climato-eustatic influences on landscape changes in the Caspian Sea Basin during the last 40 ka. Radiocarbon-dated fluvial landforms show that the paleohydrosystem of the middle Kura valley and tributaries responded to regressive and transgressive phases of the Caspian Sea. Chrono-sequences and landforms secured by 32 radiocarbon ages show strong correspondence between fluvial sediment accumulation and oscillations of base level in the Caspian Sea.

Six phases of valley floor aggradation (e.g. 27,000–13,000; 11,000–3200; 2900–2100; 1600–1000; 400–150 cal. yr 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. yr BP) are recorded. Morphodynamics of the fluvial landscape show a strong correspondence with fluctuation in sea levels in the Caspian Sea: the major Upper Pleistocene–Late Glacial Khvalynian (c.a. 26,000 to 12,400 cal. yr BP) and various Holocene transgressions as well as the Mangyshlak (c.a. 12,000 cal. yr BP) and Derbent (6th–12th century AD) regressions. These data contribute to refining the Caspian relative sea-level curve for the last 30 ka using the chronology of changes in the aggradation or incision in the connected fluvial system.

1. Introduction

The Caspian Sea has had a long and complex history, and many fluctuations in the sea level over different timescales, ranging from several decades to millions of years. It is a vast closed drainage basin, with a surface of 371,000 km^2 and a volume of 78,200 km^3, bounded by Russia, Azerbaijan, Iran, Turkmenistan and Kazakhstan. The basin 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, the sub-basin depths increase from 5 to 190 and 1024 m (Shiklomanov et al., 1995). Like the Black Sea, the Caspian Sea is a remnant of the ancient Parathethys and became land-locked about 5.5 million years ago due to tectonic uplift and sea-level fall. Previous studies (Rychagov, 1997; Kroonenberg et al., 2007, 2011; Dolukhanov et al., 2010) have focused on the Caspian Sea water budget and the relative importance of climate versus tectonic or human activities in the control of its hydrology. During the last 28,000 years significant fluvioglacial discharge from Tian Shan and the Ural mountains and possibly from Siberia during the last deglaciation (Grosswald, 1980, 1993) through the Aral Lake, supplied the Caspian Sea. During more recent periods, especially during the Holocene, Boomer et al. (2000, 2009) and Létolle (1992, 2000) show that the Caspian Sea was directly fed 10 ka ago by the Amu Darya River or was connected to the Aral Lake through the Uzboi Channel or Sarykamish Lake at 3500 and 1600 cal. yr BP. The Caspian Sea level currently depends on the flow of its eastern European (Volga, Ural, Terek rivers (88%)); Caucasian (Sulak, Samur and Kura rivers (7%)) and Iranian rivers (5%) (Vali-Khodjeini, 1991). Therefore, Caspian Sea levels reflect the cumulative influence of northern European climate through precipitation over Volga basin or ice melting during glacial periods and climate over the western Himalaya. Tectonic activity also has an important role in controlling the course of the Amu Darya (Boomer et al., 2000, 2009; Létolle, 2000).

In spite of the large number of studies concerning Caspian Sea level, no complete and detailed reconstructions are available. Research has focused on sea-level high stands (Mamedov, 1997; Rychagov, 1997), but the dynamics and the amplitude of the oscillations are poorly documented. About six main regression/transgression periods since 30 ka have been identified, with sea-level fluctuations ranging from +50 m/−92 m asl during the Khvalynian/Mangyshlak episodes (11–17 cal. ka BP). The high levels (>25 m asl) were recorded between

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14.6 and 16.6 cal. ka BP, when the Caspian Sea overflowed to the Black Sea through the “Manych–Kerch spillway” (Yanko-Hombach et al., 2007; Badertscher et al., 2011), or between 13.6 and 16.7 cal. ka BP, as given by a compilation of radiocarbon dates of the Khvalynian deposits (Dolukhanov et al., 2010, after Svitoch, 1991; Rychagov, 1997; Leonov et al., 2002). However, high frequency sea-level changes are recorded over a short timescale (10 to 100 yr) in delta sediments of the Volga and Kura rivers. Consequently phases of delta progradation alternating with erosional marine transgressive surfaces rivers have been described for the Kura and Volga rivers (Kroonenberg et al., 1997; Mikhailov et al., 2003; Hoogendoorn et al., 2005). The most recent major highstands occurred around 2600 cal. yr BP and during the Little Ice Age (400–300 cal. yr BP), and suggest a correspondence between global cooling events associated with minima in solar activity, influencing millennial precipitation changes in the Volga drainage basin (Kroonenberg et al., 2007). In recent periods, these rapid changes in the water level have caused substantial socio-economic damage due to their impacts on coastal zones and river mouth processes (Kazancı et al., 2004; Leroy, 2010). Over longer timescales, the role of eustatic variations shows a strong influence on alluvial fan and fluvial development (Klein, 1999, 2001; Robustelli et al., 2005; Labaune et al., 2008). During the Messinian Salinity Crisis (5.96–5.33 Ma) in the Mediterranean Basin and during glacial/interglacial cycles of the Pleistocene, fluctuations of relative sea level and river base levels (Bache et al., 2012) forced significant geomorphological responses, with incision of canyons inland (regressive phases) and aggradation during transgression episodes. The amplitude of Caspian sea-level variations is more comparable to that of the glacial Quaternary marine oscillations than to that of the Messinian (ten times less). Nevertheless, Caspian relative sea-level changes show a higher frequency (Gargani and Rigollet, 2007; Kroonenberg et al., 2011).

Despite numerous studies on sea level in the Caspian basin, little is known of the impact of base-level changes on upstream hydrosystems, particularly river terrace evolution in the upper basins. Some studies underline that changes in the relative sea level induce long-range inland impacts (e.g. 800 km to 150 km) for drainage areas comparable in size to those of the Kura (Schumm, 1993; Blum and Törnqvist, 2000; Heller et al., 2001; Harvey, 2002; Taha, 2007; Ethridge et al., 2009, among others). Here, we present the geomorphology, sedimentology and chronology of the terrace deposits in the middle Kura River valley and its tributaries in northwestern Azerbaijan. Interpretations of formative processes for the sediment landform assemblages allow assessment of the upstream hydrosystems geomorphic response to base-level changes linked to high frequency sea-level fluctuations.

2. Regional setting

The study area (Fig. 1) in northwestern Azerbaijan is a complex region with multiple environments covering mountainous contexts of the Lesser Caucasus to the open landscape of the large Kura–Arax floodplain. Our geomorphological study concerns a main area centered around the Tovuz district and associated archeological excavations (Mentesh tepe, Göy tepe and Soyuq Bulaq) of Neolithic to Chalcolithic and Bronze Age periods (Lyonnet et al., 2012). Five right-bank tributaries of the Kura River have been investigated: the Agstafa, Hasensu, Tovuz/Arenji, Zeyem and Shamkir rivers (çayi). Numerous sections were dated from upstream to downstream of each of these tributaries (Fig. 1). These rivers flow in a transitional area between the piedmont of the Lesser Caucasus and the alluvial plain of the Kura, which is rather embanked in Georgia and widens considerably in Azerbaijan. Due to the distance from the Great Caucasus and to tectonic cliff development, the left bank of the Kura River receives no tributary in the studied region.

The Kura River begins in Turkey near Lake Kartsakhi at approximately 2740 m asl. It then flows into a large valley between the Great and Lesser Caucasus across Georgia and Azerbaijan. It merges with the Arax River in Azerbaijan and opens into the Caspian Sea at a relative altitude of −26.5 m (under present sea level). It has a total length of 1515 km and a watershed of 198,300 km^2. With a current average flow of 443 m^3/s (max 2250 m^3/s, min. 206 m^3/s), the Kura ranks among the largest rivers flowing into the Caspian Sea (Rustanov, 1967).

The watershed of the study area is mainly represented by the Lesser Caucasus which dominates the Middle Kura Valley with an altitude of ca. 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 also make up a significant part of the foothills, as well as the Miocene and Pliocene tectonized rocks and the Quaternary alluvial fans and terrace formations (Fig. 2).

The Kura River and its tributaries dissect an area of uplifted relief with subsidence zones when the river flows closer to the Caspian Sea. The uplift rate (Mosar et al., 2010) is around 0 to 4–6 mm/year in the upstream part of the basin with 0–2 mm/year values in the middle section. Downstream, the Kura basin subsides with rates of around −4 mm/year in the estuarine area (Mosar et al., 2010).

The torrential units studied are part of the Kura hydrosystem. This hydrosystem has been connected directly to the Caspian Sea since at least the Upper Pleistocene. The Agstafa, Hasensu, Tovuz/Arenji, Zeyem and Shamkir hydrologic systems share much the same morphometric basin characteristics. Their watershed areas are around 2400 to 2650 km^2, their length between 133 and 120 km and their mean discharge varies between 0.91 m^3/s (Tovuz çayi) and 13.6 m^3/s (Agstafa çayi). In total, 45% of their annual water supply comes from groundwater, 35% from snowmelt and 20% from rainfall (FAO database, 2008). The present-day Azerbaijan Kura Basin physiography, with an average gradient of 0.17% from the Georgian border to the shore of the Caspian, offers a large and relatively flat valley in which the relative sea-level variations can be expressed on a wide spatial scale (Fig. 3).

3. Material and methods

3.1. Geomorphology

Geomorphological field surveys focused on upstream to downstream progressive reading of the Kura tributaries, measuring the terrace heights and the alluvial fan surface thickness recording fluvial levels.

Synthetic mapping of the geomorphological units of the studied area was also carried out (Fig. 2). On the basis of this first step, a relative chronology was established. Once the morphosedimentary and sedimentary sequential was recorded, the samples for radiocarbon dating were taken in the stratigraphic sequence ruptures, at the base and at the top of the infilling and at different levels of the alluvial terraces, in order to obtain an event chronology (Ollivier, 2009). This systematically integrated methodology is effective for determining the pattern of paleohydrological evolution and the spatial and temporal patterns of variation in sediment supply. Pleistocene to historical period formations were analyzed in order to obtain an overview of the landscape changes and to identify and attempt to quantify the role of external forcing in the morphogenesis. The event chronology used is based on Stage 3 Project (Van Andel, 2002) for the Pleistocene, the INTIMATE group results (Lowe et al., 2008) for the Late Glacial, and Mayewski et al. (2004) for the Holocene. The pattern of environmental changes proposed (sea-level changes and morphogenic trends) is compared to GRIP (Andersen et al., 2006) and Sofular cave (Fleitmann et al., 2009) isotopic data to obtain a representative analysis based on global and local scale climatic records.

3.2. Paleohydrology

The dynamics and variations of the fluvial system are determined using macrofacies sedimentological analysis (adapted from Hjulström,