



Natural and anthropogenic influences on depositional architecture of the Ural Delta, Kazakhstan, northern Caspian Sea, during the past 70 years



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ABSTRACT

This paper focuses on the Ural Delta in the northern zone of the Caspian Sea, an area with particular characteristics, where intense influence from anthropogenic and natural factors exists, which acts on the fragile delta system. We built a database to integrate the data from the published sources, bathymetric survey, and recent images in the geographical information system (GIS) environment. The results were linked to the Caspian Sea level (CSL) curve, which had many variations, changing the Ural Delta system's dynamics and in its architecture. In addition, the anthropogenic changes contribute to shaping the actual Ural Delta architecture. Through the link between the results and CSL, we reconstructed an evolution model for the Ural Delta system for the last century and identified three different architectures for the Ural Delta, determined by the energy that acted on the system in the last century and by the anthropogenic changes. This work identifies six different delta phases, which are shaped by CSL changes during the last 70 years and by anthropogenic changes. The delta phases recognized are: i) a Lobate Delta phase, shaped during high CSL before 1935; ii) Natural Elongate Delta 1935–1950 formed during rapid CSL fall; iii) Anthropogenic Elongate Delta 1950–1966, formed during rapid CSL fall and after the Ural-Caspian Sea canal construction, which modified the sedimentary deposition on the delta; iv) Anthropogenic Elongate Delta 1966–1982 shaped during low CSL phase; v) Anthropogenic Elongate Delta 1982–1996 formed during a rapid CSL rise phase; and vi) Anthropogenic Elongate Delta 1996–2009 shaped during high CSL that represent the last phase and actual Ural Delta architecture.

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1. Introduction

The direct and indirect influences from environmental and anthropogenic factors on the coastal system, including deltaic and estuarine systems, produce changes in their morphology, and these

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changes are elements to be considered in the studies concerning recent coastal system evolution (Martin et al., 1987; Stanley and Warne, 1994; Stanley, 2001; Frihy et al., 2003; Banna and Frihy, 2009; Simeoni and Corbau, 2009; Anthony et al., 2014; Anthony, 2015; Kakroodi et al., 2015; Wang et al., 2015; Schlacher et al., 2016). In many cases, changes in the architecture of the coastal systems may be caused by the actions to mitigate the coastal system problems such as the measures to contain the coastal erosion process or coastal flooding phenomena. Others actions economically exploit the coastal systems, such as harbor construction, coastal urbanization, and excavation of navigation channels (Yi et al., 2003; Zhen et al., 2006; Werner and McNamara, 2007;

Monge-Ganuzas et al., 2013; Jin et al., 2015; Aouiche et al., 2016; Mateus et al., 2016; Scarelli et al., 2016). These actions increase the pressure on the system and may influence the system dynamics and consequently the system evolution (Barnard and Davis, 1999; Dallas and Barnard, 2011; Di Stefano et al., 2013; Acciarri et al., 2016; Maanen et al., 2016; Wei et al., 2016).

This is the situation of most deltaic systems worldwide, which were economically exploited from centuries ago to the present, as their innumerable resources have been widely modified, affecting their morphology and dynamics (Turner and Boyer, 1997; Lotze et al., 2006; UNEP, 2006; Syvitski and Saito, 2007; Elliff and Kikuchi, 2015; Genua-Olmedo et al., 2016). Moreover, the deltaic systems are complex, which are very susceptible to changes. Small and rapid changes can cause larger changes that may permanently modify the entire behavior of the deltaic system or may require many years to re-establish the same conditions as before the changes (Short, 1999). These changes are a fundamental key in their morphological evolution (Anthony, 2015). Moreover, these changes may affect sediment transport and their distribution in the adjacent waters, which may directly affect human activities and local ecosystem in the deltaic zones (Dong et al., 2011; Wang et al., 2014, 2015; Zeng et al., 2015).

To understand the effects and magnitude of the changes on coastal morphology and deltaic system architecture, it is essential to consider the natural factors that act on the system under study, considering the relative sea level (RSL) changes, sedimentary dynamics, energies that act on the system, and features that characterize the system (Simeoni and Corbau, 2009). The sedimentary transport in deltaic systems, combined with the energies that act on the system, are the primary factors to control the system equilibrium and determine the architecture of the deltaic system (Wright and Coleman, 1973; Wright, 1985; Bever et al., 2009). The equilibrium between the sediment supply and the energy of the river, waves, or tide determines the architecture of the deltaic system (Galloway, 1975), where the nomenclature of the system morphology, shaped due to this equilibrium, is well defined and validated by the scientific community (Correggiari et al., 2005). This definition is fundamental to characterizing deltaic systems because it defines the main energy acting on the system, giving fundamental information to build the deltaic system evolution (Wright and Coleman, 1972, 1973; Coleman and Wright, 1975; Wright, 1985; Syvitski and Saito, 2007; Simeoni and Corbau, 2009).

The Ural Delta zone (Caspian Sea, Kazakhstan) is a typical deltaic system in which all characteristics mentioned above are present. With a rich biodiversity and habitat diversity, as a particular ecosystem with global importance (Aubrey, 1994; GEF-UNDP, 2007), it is also under intense anthropogenic pressure and is exposed to Caspian Sea level (CSL) variations. This makes it a natural laboratory for the study of the anthropogenic effects and the CSL influence above the deltaic system dynamic and how these changes are reflected in the delta architecture, allowing this concept to be applied in other deltaic systems. In addition, the studies about Ural Delta evolution will integrate and increase the knowledge about the delta systems, and allowing the comparison with other rivers delta in CS. Being complementary with studies about Volga Delta (Kroonenberg et al., 1997; Overeem et al., 2003; Richards et al., 2014), Terek Delta (Bolikhovskaya et al., 2016), Sefidrud Delta (Haghani et al., 2016; Ignatov et al., 1993; Kazanci and Gulbabazadeh, 2013), Kura Delta (Hoogendoorn et al., 2005), Emba Delta (Richards et al., 2017), may help to build a general framework about CS coastal and marine environment behavior during CSL changes. Because of this, the work proposes characterizing the morphology and building the evolution model based on the last 70 years for the Ural Delta. The main aim of this study is to research the deltaic morphology changes due to variation of

sedimentary transport and fluvial dynamics, presuming that the deltaic system under study is influenced by fluvial and waves energy, anthropogenic factors and by CSL variation.

2. Study area

The Ural Delta is located in the northern part of the Caspian Sea (Fig. 1) in the area called the Caspian Depression, a continental depression below average sea level (Caspian Datum: 28 m below the Baltic Datum as a regional reference) (AGIP-KCO, 2006; GEBCO, 2010; Kouraev et al., 2010). The Caspian Sea is an endorheic basin, isolated by tectonic activity during the Late Miocene (Messinian), and is the largest closed water body on earth (Kroonenberg et al., 2000; Arpe and Leroy, 2007). It is subdivided into three parts based on its bathymetry, the northern, middle, and southern Caspian Sea, where the north part is characterized by shallow waters at a few meters in depth with an extremely low onshore and offshore gradient (~5 cm/km) as the continuation of the North Caspian Plain (Kroonenberg et al., 1997, 2000). The tide regime in the northern part of the Caspian Sea is microtidal with a non-significant astronomical tide component (less than 1 m) (Overeem et al., 2003; Sharifi et al., 2013; Medvedev et al., 2016) but short-term variations (measurable in hours) due to the storm surge events, which are frequent in the zone and may change the CSL by a meter in 48 h (Islamailova, 2004).

The CSL is characterized by rapid changes over time. As an endorheic basin, CSL is controlled by the components of the water budget: evaporation, precipitation, and river runoff (Kaplin and Selivanov, 1995). Moreover, the Volga River is the biggest water budget contributor with 80% of the Caspian Sea inflow (Arpe and Leroy, 2007; Kroonenberg et al., 2007), the Kura River at southern Caspian Sea is the second contributing with 6% (Zonn et al., 2010), while the Ural River, whose drain basin is about 230,000 km², and is 2,530 km length, is the third biggest, supplying 5% of the inflow, and the flow is almost completely fed by glaciers melting (CEP, 1998; Dumont, 1998), discharging approximately 9.7 km³/yr (Demin, 2007). The seasonal changes due to evaporation and fluvial discharge usually increase CSL during the summer season and decrease it during the winter (AGIP-KCO, 2006).

According to Kroonenberg et al. (1997, 2000, 2007), Richards et al. (2014) and Kakroodi et al. (2015), during the Quaternary, five orders of magnitude of variation were identified in the sea-level cycles of the CSL. Due the runoff from melt-waters after the Last Glacial Maximum, CSL was +50 m during the early Khvalynian highstand period (late Pleistocene), and during Mangyshlak period (early Holocene) CSL was −113 m. In the last century, oscillations of several meters in CSL (Fig. 2) were detected. However, not many studies about these oscillations in CSL have been conducted, and the works done concerning CSL present different theories (Kroonenberg et al., 2007), linking the oscillations with chaotic behavior (Naidenov and Kozhevnikova, 1994) as well as geochemical (Clauer et al., 2000) and tectonic causes (Lilienberg, 1994). However, according to the main works, CSL is influenced by the river inflow, mainly supplied from the Volga River, and these fluctuations during the last century are linked with changes due to climatic anomalies, such as the North Atlantic Oscillation (NOA) or El Niño Southern Oscillation, which affect the Volga River Basin, reflecting on CSL, shown in Fig. 2 (Kaplin and Selivanov, 1995; Kroonenberg et al., 1997; Kislov and Surkova, 1998; Arpe et al., 2000; Kroonenberg et al., 2000; Kosarev, 2005; Arpe and Leroy, 2007; Kroonenberg et al., 2007; Richards et al., 2014; Kakroodi et al., 2015).

The last significant oscillations, which are linked with the Volga River inflow and climatic anomalies (NOA, ENSO), were recorded in 1977 when the water level in the Caspian Sea increased. The CSL

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