Quaternary International 392 (2016) 315–334

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Characteristics of direct human impacts on the rivers Karun and Dez in lowland south-west Iran and their interactions with earth surface movements

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ARTICLE INFO

Article history:
Available online 18 November 2015

Keywords:
Earth surface movement
River channel
Fold
Human impact
Iran

ABSTRACT

Two of the primary external factors influencing the variability of major river systems, over river reach scales, are human activities and tectonics. Based on the rivers Karun and Dez in south-west Iran, this paper presents an analysis of the geomorphological responses of these major rivers to ancient human modifications and tectonics. Direct human modifications can be distinguished by both modern constructions and ancient remnants of former constructions that can leave a subtle legacy in a suite of river characteristics. For example, the ruins of major dams are characterised by a legacy of channel widening to 100's up to c. 1000 m within upstream zones that can stretch to channel distances of many kilometres upstream of former dam sites, whilst the legacy of major, ancient, anthropogenic river channel straightening can also be distinguished by very low channel sinuosities over long lengths of the river course. Tectonic movements in the region are mainly associated with young and emerging folds with NW–SE and N–S trends and with a long structural lineament oriented E–W. These earth surface movements can be shown to interact with both modern and ancient human impacts over similar timescales, with the types of modification and earth surface motion being distinguishable. This paper examines the geomorphological evidence and outlines the processes involved in the evolution of these interactions through time. The analysis shows how interactions between earth surface movements and major dams are slight, especially after ancient dam collapse. By contrast, interactions between earth surface movements and major anthropogenic river channel straightening are shown to be a key factor in the persistence of long, near-straight river courses. Additionally, it is suggested that artificial river development, with very limited river channel lateral migration, may promote incision across an active fold at unusually long distances from the fold "core" and may promote markedly increased sinuosity across a structural lineament.

1. Introduction

Variability of major rivers is an inherent property and applies over a wide range of spatial scales from river reaches to river basins (Leopold and Wolman, 1957; Howard, 1967; Schumm, 1991, 2005). Such variability includes, for example, variations in channel pattern and major avulsions, with these autogenic changes influenced by factors that include topography, river hydrology, and river sedimentology (Lang et al., 2003; Downs and Gregory, 2004). Some variability of major rivers may be driven by allogenic factors that include climate, relative sea-level (or base level) changes, human activities, and tectonics (Jones et al., 1999b; Blum and Törnqvist, 2000; Schumm et al., 2000; Dollar, 2004; Brierley and Fryirs, 2005; Schumm, 2005; Burbank and Anderson, 2012). Of these external factors, human activities and tectonics are especially influential at the river reach scale. Human activities influencing major rivers can be sub-divided into indirect human impacts due to land use changes (such as woodland clearance and

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http://dx.doi.org/10.1016/j.quaint.2015.10.088
1040-6182/

agriculture) and direct human impacts on river channels by river regulation and channel modifications (such as dam construction and channel straightening) (Brookes, 1994; Brierley and Fryirs, 2005; Heyvaert and Baeteman, 2008; Walstra et al., 2010b; Heyvaert et al., 2012). Though there are considerable overlaps, indirect human impacts mainly relate to river catchment and river basin scales, whereas direct human impacts mainly relate to river reach scales.

Earth surface movements by active tectonics can be subdivided into forms of faulting, folding, and tilting (Schumm et al., 2000). Folding has a variety of impacts on river reaches, particularly with major transverse rivers encountering folds. Where rates of fold uplift are less than rates of river aggradation, a transverse river will flow without impedance across the fold, with little or no topographic relief developing (Burbank et al., 1996). Where a fold does develop a surface topographic expression, a river may flow across the fold by developing incising reaches across the fold, and by developing aggrading reaches immediately upstream and downstream of the fold (Holbrook and Schumm, 1999; Douglass and Schmeeckle, 2007). Alternatively, a river may be diverted around the fold by channel migrations and avulsions, or it may be "ponded" in a basin behind the fold, depending on the balance between river aggradation and incision and fold growth (Burbank et al., 1996; Amos and Burbank, 2007; Burbank and Anderson, 2012).

The variety of river response to perturbation can make it difficult to disentangle the influences of direct human impacts from the influences of active folds on major rivers at river reach scales. The aims of this paper are to determine the distinguishing characteristics of direct human impacts on major rivers and to determine the nature of the interactions between earth surface movements and these human impacts. Critically, at locations where direct human modifications to river channels and active folds coincide, there will be interactions between these two external factors, notably if they have significant influences over similar timescales (Schumm, 1991). Such interactions are only very poorly known from previous work; with, for instance, changes to the River Indus in Pakistan from an aggrading, anastomosing river into an incising, meandering river associated with the Jacobabad-Khairpur zone of uplift, being considered to have been enhanced by the Sukkur Barrage which was constructed in 1932 AD (Harbor et al., 1994).

This paper uses a single major river system (the River Karun and its main tributary, the River Dez, in lowland south-west Iran) within a single foreland basin (the Mesopotamian-Persian Gulf Foreland Basin) with similar types and orientations of folds in various stages of development, to delineate and disentangle these complex human–tectonic interactions. The focus is on horizontal spatial scales extending to the reach scale (river channel dimensions to fold dimensions), and temporal scales of mainly decades to millennia (river channel migrations to fold uplift). By having a focus on a single major river at these scales, the various other factors influencing major river responses over similar timescales, such as climate, will be fairly similar over the drainage basin (Potts, 1999; Badripour et al., 2006). As such, the rates of sediment supply from the basin hinterland are likely to be similar at the scale of the river reach (Peng et al., 2010) and relative sea-level changes will be largely controlled, since most of the river reaches are upstream of sea-level influences; that is, upstream of a distance of about 150 km from the shoreline (Shanley and McCabe, 1993) and upstream of the extent of the river backwater length (the distance over which the scoured channel base is at or below sea-level) (Li et al., 2006; Blum et al., 2013). This paper examines a range of reach lengths where human modifications and tectonic folds can be identified and attempts to disentangle their complex histories using the geomorphological evidence available.

2. Study area

The River Karun and River Dez are major rivers in south-west Iran (average water discharges c. 575 $m^3\ s^{-1}$ and 230 $m^3\ s^{-1}$, respectively) which flow from the Zagros orogen in the N and NE across the Upper and Lower Khuzestan Plains into the Mesopotamian-Persian Gulf Foreland Basin to the S and SW (Fig. 1). Their basins extend over a few climate zones with mean annual precipitation decreasing from c. 400 mm–1000 mm in the Central Zagros Zone to less than 200 mm in the Arid Zone of the Lower Khuzestan Plains (Frey and Probst, 1986; Potts, 1999; Badripour et al., 2006; Alijani, 2008; Woodbridge, 2013).

2.1. Tectonics and earth surface movements in south-west Iran

Throughout the Zagros region, the main geological structures are NW–SE trending thrust faults and folds produced by the convergence of the Arabian Plate towards the Eurasian Plate, which is continuing in an approximately N–S direction at rates of c. 16–22 mm yr^{-1} (Sella et al., 2002). Within the Khuzestan Plains and the Zagros region in general, earthquakes have only accounted for a small part (c. 10%–20% at most) of the deformation required by the convergence of the Arabian and Eurasian plates. Most of the earth surface movements (probably c. 95%) on faults and folds are by aseismic folding, faulting, and stable creep (probably due to lubricated décollements on evaporite layers) (Jackson et al., 1995; Masson et al., 2005; Hatzfeld et al., 2010).

Mainly from the Pliocene (c. 5 Ma) onwards, there has been a migration of the deformation away from the orogen towards areas of thinner crust, to produce successions of mainly NW–SE oriented thrust faults and associated detachment folds and fault bend folds (Allen et al., 2004). Typically, these folds are asymmetric anticlines at or near the ground surface, with a more steeply dipping fore-limb to the south-west and a more gently dipping back-limb to the north-east (Blanc et al., 2003). Though there are slight variations between individual folds, river erosion in lowland south-west Iran typically exposes the following fold lithostratigraphy: Quaternary deposits (c. 1 Ma – Present; generally unconsolidated alluvial sands, muds, gravels, and marls) – Middle Pliocene to Pleistocene Bakhtyari Formation (c. 3 Ma – 1 Ma; well-consolidated conglomerates, sandstones, and mudstones) – Middle Miocene to Middle Pliocene Agha Jari Formation (c. 10 Ma – 3 Ma; sandstones, marls, and mudstones) (James and Wynd, 1965; Hamzepour et al., 1999; Abdollahie Fard et al., 2006). The NW–SE oriented folds are generally younger and less developed towards the south-west away from the orogen (Alavi, 1994) and die out in the vicinity of the Zagros Deformation Front (ZDF) (Haynes and McQuillan, 1974; Hatzfeld et al., 2010), a NW–SE oriented line c. 30 km south-west of the demarcation between the Upper and Lower Khuzestan Plains (Figs. 1 and 2).

Within the wedge-top of the foreland basin to the north-east of the ZDF (the Dezful Embayment in lowland SW Iran) there is regional uplift, whereas within the foredeep of the foreland basin to the south-west of the ZDF (the Mesopotamian foredeep in lowland SW Iran) there is regional subsidence (Falcon, 1974; DeCelles and Giles, 1996; Abdollahie Fard et al., 2006). Within the Mesopotamian foredeep there are some mainly N–S oriented folds with very low rates of uplift (Edgell, 1996; Soleimany and Sàbat, 2010; Soleimany et al., 2011).

In addition to these folds, there are a number of structural lineaments in lowland south-west Iran, with a particularly prominent c. 110 km long "concealed fault/deep-seated lineament" oriented E–W at about 31°47′N (Fig. 2; NIOC, 1977).