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Geomorphological analysis of the drainage system on the growing Makran accretionary wedge

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ABSTRACT

The morphology of six adjacent major catchments draining the onshore Makran accretionary wedge in southeast Iran and southwest Pakistan was studied to examine how the channel pattern and the length profiles may reflect the recent and active growth of the wedge. Qualitative field surveys were combined with the quantitative analysis of channel steepness and concavity measured from digital elevation models. These profiles were compared with modelled profiles using a stream power approach assuming homogeneously uplifting, uniform rock substratum. Results show a distinct difference between the studied western and eastern catchments. The three western rivers are in morphological equilibrium; whereas the two eastern rivers exhibit profiles with prominent convexities and knickpoints, thus notably diverging from equilibrium concave-up shapes. All the studied catchments share the same base level, flow on similar lithologies, and developed under uniform climate conditions. Therefore, we interpret the morphometric differences in terms of differential rock uplift rate as a response to local tectonic activity. This interpretation is consistent with both uplift rates of marine terraces along the coast of Makran and the recorded seismicity. The geomorphological analysis presented here extends coastal information to wide inland areas and documents longer term tectonic behaviour than the seismotectonic record. Hence, the steeper surface slope and faster surface uplift rates recorded by the eastern catchments compared to equilibrium of the western catchments are regional, long-term signals relevant for a wide part of the Makran accretionary wedge. We attribute the regional geomorphic difference to Quaternary variations in tectonic regimes that forced differential uplift rates of the wedge surface. We hypothesize that the different tectonic regimes are related to different subduction rates.

1. Introduction

Relief is a result of internal tectonic forces and external surface processes. In the absence of glacial erosion, the fluvial system is the main external factor that dictates the landscape evolution and sculpts the topographic relief of mountain ranges (e.g., Whipple and Tucker, 1999). Many studies have documented the complex relationships between rock uplift and climatically modulated erosion efficiency and discussed the respective influence of these driving factors on channel incision (e.g., Burbank and Anderson, 2001; Kirby et al., 2003; Kirby and Whipple, 2012). Therefore, the river sensitivity to climate and/or tectonic variations makes the quantitative analysis of channel morphology a valued archive of active deformation (e.g., Schumm et al., 2000). Leading models relate channel gradients of tectonically active regions to competition between local rates of bedrock uplift with respect to a far-distant, fixed base level and channel erosion/deposition (Howard, 1994; Howard et al., 1994). Even if the details of the dynamic response of rivers to tectonic forcing remain indeterminate (Whipple and Tucker, 1999), the key role of incised channels and their connection to structures and crustal processes are widely accepted (e.g., Bull, 2009). Quantitative geomorphologic tools are particularly appropriate for regions where deformation rates are low to moderate (e.g., Holbrook and Schumm, 1999; Azor et al., 2002; Ponza et al., 2010). Therefore, we decided to analyse the river system installed on the onshore Makran accretionary wedge to investigate the tectonic and geomorphic history of the wedge.

Relatively weak bedrock (interlayered sandstone, shale, and mudstone), homogeneous climate throughout the area, and nearly no anthropogenic disturbance make Makran an advantageous geological system to extract the tectonic evolution from topographic variations of the wedge. In support for this endeavour, all catchments share the same base level (Oman Sea) and are ice free. Therefore, the fluvial system counts as the main external force responsible for topography relief of the study area. Concentration of cosmogenic ^{10}Be in quartz pebbles from fluvial terraces in the Iranian Makran established a steady incision rate of about 0.3 mm/a over the last 270 ka (Haghipour et al., 2012).

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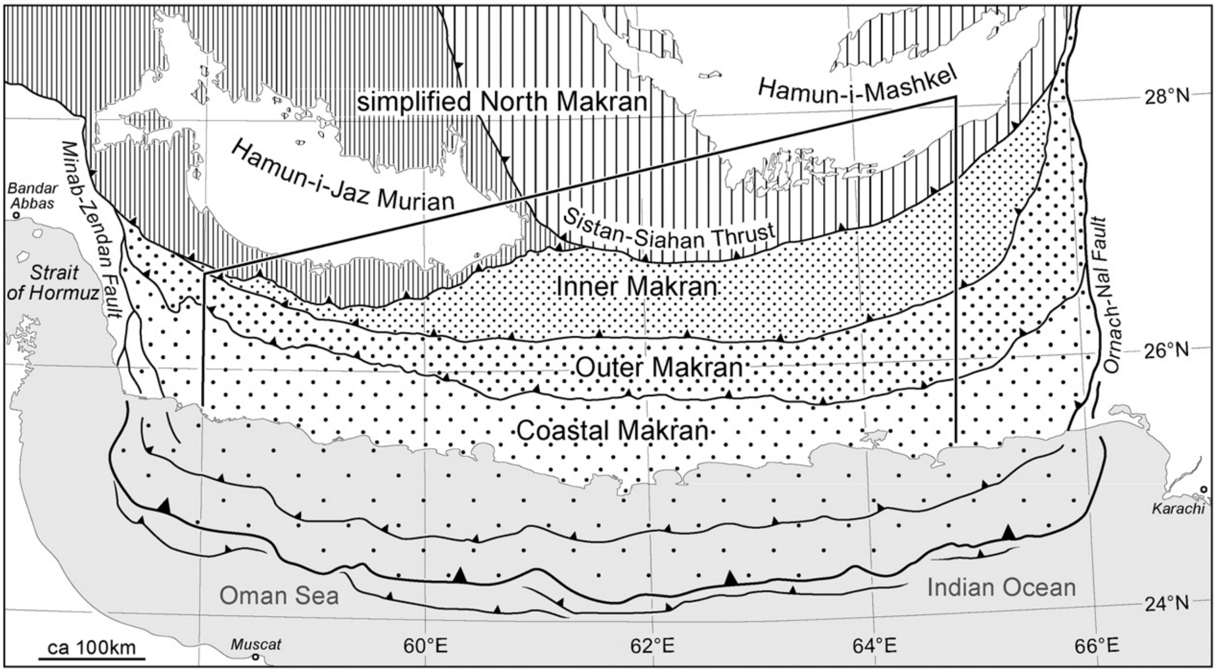

Fig. 1. General setting and simplified structural map of the Makran accretionary wedge. Framed: study area. Offshore structures from Ellouz-Zimmermann et al. (2007), Grando and McClay (2007), and the National Iranian Oil Company, (unpublished).

Such information has importance because, according to the critical taper theory, the slope and the elevation of a wedge surface are integral parts of the structural evolution of the wedge (e.g., Davis et al., 1983; Dahlen, 1990). In this line of thought, we were most interested in knowing whether longitudinal river profiles would document steady-state equilibrium of the wedge surface, on a large scale, or transient states of landscape adjusting changes in tectonic forcing. More precisely, the critical wedge theory predicts that an orogenic wedge will attain a critical surface slope (critical taper) sustained by continued accretion. First, the quantitative description of topographic and longitudinal river profiles, measured from digital elevation models (DEMs), helps to define the spatial distribution of major drainage networks and their controlling factors with reference to erosion and deformation, variations of the base level, and climate changes. The analysis of classical geomorphological indices is extended by comparing measured profiles with modelled profiles using a stream power approach applied to homogeneously uplifting, uniform rock substratum. This calculation helps in characterizing the landscape of the Makran accretionary wedge and in assessing the relative level of tectonic activity. We found noticeable spatial variations over the studied area, revealing an increasingly stronger impact of

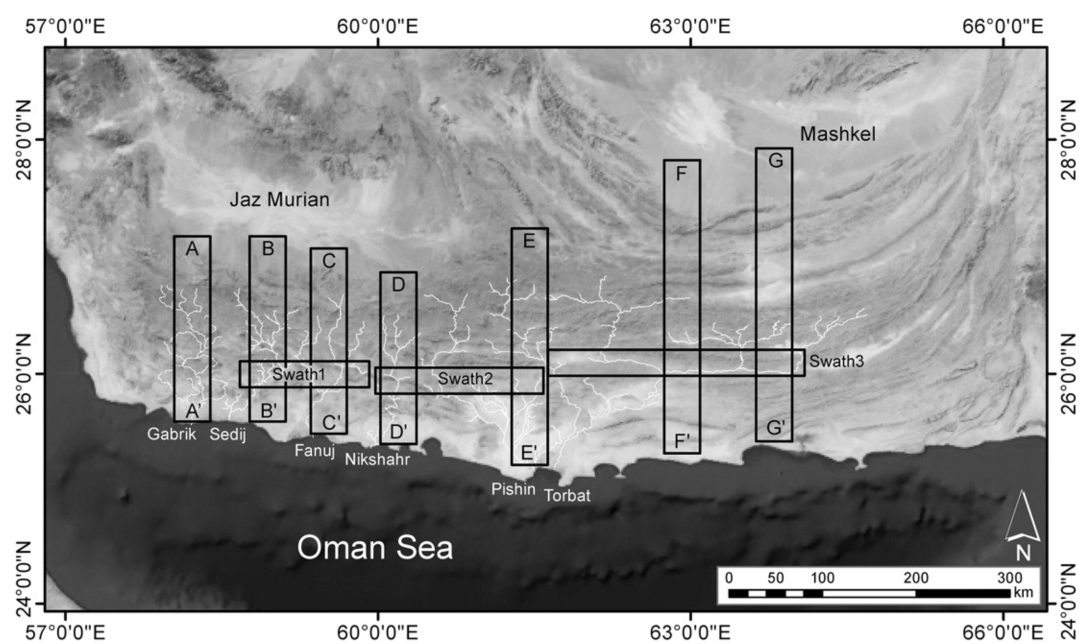

Fig. 2. Studied catchments and rivers (white lines and names) on satellite image of the Makran accretionary wedge. Boxes: swath profiles of Figs. 3 and 4. Google Earth.