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Late Cenozoic regional uplift and localised crustal deformation within the northern Arabian Platform in southeast Turkey: Investigation of the Euphrates terrace staircase using multidisciplinary techniques

Tuncer Demir [a], Ali Seyrek [b], Rob Westaway [c,d,*], Hervé Guillou [e], Stéphane Scaillet [e], Ant Beck [f], David R. Bridgland [g]

[a] Department of Geography, Harran University, 63300 Şanlıurfa, Turkey
[b] Department of Soil Science, Harran University, 63300 Şanlıurfa, Turkey
[c] Faculty of Mathematics, Computing and Technology, The Open University, Abbots Hill, Gateshead NE8 3DF, UK
[d] Newcastle Institute for Research on Sustainability, Devonshire Building, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
[e] Laboratoire des Sciences du Climat et de l'Environnement, Domaine du CNRS, Bâtiment 12, Avenue de la Terrasse, 91198 Gif-sur-Yvette, France
[f] School of Computing, Leeds University, Leeds LS2 9JT, UK
[g] Department of Geography, Durham University, South Road, Durham DH1 3LE, UK

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ABSTRACT

We present the results of detailed field investigations of the fluvial succession exposed along the Euphrates valley adjoining the Atatürk Dam in the northern part of the Arabian Platform within SE Turkey. This work, which has used Differential GPS surveying to obtain accurate heights of deposits and Shuttle Radar Topographic Mission imagery for location purposes, has included documentation of many fresh sections exposed by quarrying. The work has been supplemented by unspiked K–Ar dating of late Middle Miocene to Late Miocene basalt flows, which are widespread in the region, providing a chronology for the early stages of development of this river system following regional emergence above sea-level in the early Middle Miocene. For example, beside the Atatürk Dam Lake at Siverek İskelesi, basalt dated to 10.24 ± 0.22 Ma ($\pm 2\sigma$) caps a polymict Euphrates gravel some 80 m above the modern river; this is the oldest Euphrates terrace currently recognised. However, amounts and rates of fluvial incision are shown to vary across the northern Arabian Platform in a complex manner, due to the interaction between regional uplift and localised vertical crustal motions caused by slip on active reverse faults beneath anticlines. The study reach downstream of the Atatürk Dam includes the footwall of one such fault, beneath the Bozova Anticline; we estimate that the resulting rate of localised subsidence, superimposed onto the regional uplift that has also been occurring, has been ~0.01 mm a^{-1} during the present phase of crustal deformation, which began at ~3.7–3.6 Ma, but was higher, maybe ~0.03 mm a^{-1}, during the previous phase, which began at ~6 Ma, when the pattern of plate motions in the surrounding region was different. A large palaeo-lake centred north of the present study region around the city of Adıyaman is inferred to have existed during this ~6 Ma to ~3.7–3.6 Ma phase of plate motion, apparently because the relatively rapid localised hanging-wall uplift on the northern flank of the Bozova Anticline 'dammed' the Euphrates valley near the site of the modern Atatürk Dam. The uppermost part of a thick fluvial aggradation west of the Euphrates near Karababa Bridge, inferred to date from around the Mid Pliocene, reaches ~100 m above the modern river and, after correction for an estimated ~30 m of localised subsidence and by ~50 m for subsequent downstream lengthening of the Euphrates channel, indicates ~180 m of subsequent regional uplift. The Euphrates then incised to within ~20 m of its present level by the mid Early Pleistocene, then a switch to regional subsidence accompanied the deposition of a second thick fluvial aggradation, the top of which is ~70 m above the modern river. Subsequent renewed regional uplift, following the Mid-Pleistocene Revolution, has resulted in the development of a succession of fluvial terraces, typically inset into these older aggradations, which are correlated with the cold stages of Milankovitch climate cycles. The early part of the Euphrates chronology, constrained mainly by the disposition of basalt flows, indicates ~800 m of regional uplift since the early Middle Miocene, of which an estimated ~330 m is masked by the subsequent downstream lengthening of the river. Components of localised uplift and subsidence, caused by slip on reverse faults beneath anticlines, are superimposed onto this regional pattern, the hanging-wall

* Corresponding author.
E-mail address: r.w.c.westaway@open.ac.uk (R. Westaway).

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uplift being much larger (in one case, roughly five times larger) than the footwall subsidence. Our results provide, for the first time, detailed documentation of the complex development of the Euphrates valley in SE Turkey during the Late Cenozoic, due to the interaction between regional uplift and localised crustal deformation. This work also demonstrates the benefits of applying multidisciplinary techniques to investigate an important, but hitherto poorly documented, river system.

1. Introduction

Analysis of long-timescale fluvial sequences provides important evidence for Late Cenozoic landscape evolution (e.g. Bridgland and Westaway, 2008a,b). The northern Arabian Platform (SE Turkey and NE Syria; Fig. 1) is a significant repository for information of this type, derived from the terrace sequences of the rivers Euphrates and Tigris (e.g. Bridgland et al., 2007; Demir et al., 2007a,b, 2008; Westaway et al., 2009). This crustal province adjoins the southern margin of the eastern Anatolian Plateau across the suture of the former Southern Neotethys ocean (Fig. 1), which closed here during the Eocene as a result of northward subduction (e.g. Aktaş and Robertson, 1984; Allen and Armstrong, 2008). Both the Euphrates and its principal tributary in this region, the Göksu, flow from eastern Anatolia through the Neotethys suture zone and into the Arabian Platform (Fig. 2). Clasts of lithologies not found in situ locally, such as ophiolitic rocks from the suture zone and granite, schist and quartzite from eastern Anatolia, allow recognition of the ancestral

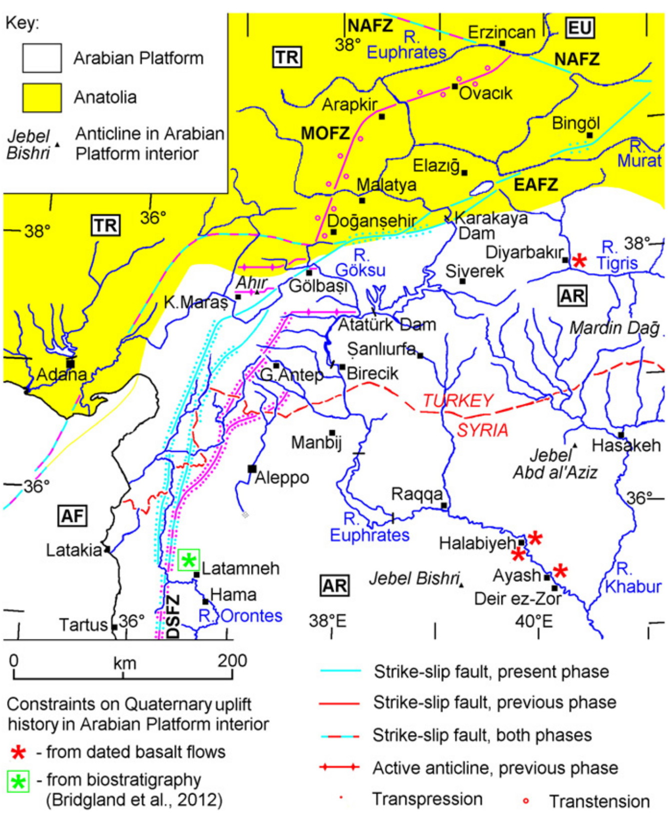

Fig. 1. Map of northern Arabia and central-southern and southeastern Anatolia showing the location of the study region in relation to the rivers Tigris and Euphrates, the active strike-slip faults bounding the Arabian (AR), African (AF), Turkish (TR), and Eurasian (EU) plates, and the locations of the principal faults that are thought to have been active during the preceding phase of crustal deformation, prior to ~3.6 Ma. DSFZ, EAFZ, MOFZ and NAFZ denote the Dead Sea Fault Zone (left-lateral), East Anatolian Fault Zone (left-lateral), Malatya–Ovacık Fault Zone (left-lateral) and North Anatolian Fault Zone (right-lateral), respectively. G.Antep and K.Maraş denote Gaziantep and Kahramanmaraş. Modified after Figure 1 of Westaway et al. (2008), simplified from Westaway (2004), which lists original sources of information.

Euphrates deposits within the Arabian Platform, facilitating reconstruction of the palaeo-drainage and landscape evolution.

The modern pattern of plate motions in the region, including the East Anatolian Fault Zone (EAFZ), the boundary between the Turkish and Arabian plates (Fig. 2), developed in the Mid Pliocene, circa 3.6 or 3.7 Ma (e.g. Westaway et al., 2006a, 2008; Seyrek et al., 2007). This was preceded by an earlier phase of plate motion, starting in the latest Miocene (~6.0 Ma; Westaway, 2011), when the regional kinematics were different; unlike at present, there was no continuous interconnected fault zone, analogous to the modern EAFZ, crossing the Neotethys suture (Fig. 2), the relative plate motions at this time were instead accommodated in the vicinity of the plate boundary zone (thought to have been in the Gaziantep–Pazarcık area, in the western part of Fig. 2) by localised folding (Westaway et al., 2008). Beforehand, during much of the Mid Cenozoic (?Late Eocene to Late Miocene), the northward motion of the Arabian Platform relative to Eurasia was accommodated by widespread distributed crustal shortening in both Arabia and Anatolia. Some of the anticlines that were active at this time are illustrated schematically in Fig. 2; the folding of the sediments thus indicated overlies shortening of the basement by slip on blind reverse faults.

In addition to these major plate-bounding faults, Şaroğlu et al. (1992) recognised two active faults south and east of the EAFZ in the region of Fig. 2. These are the Bozova and Tut faults, which are subparallel to and/or adjoin the Bozova and Kozdağ anticlines. Güllü et al. (2008) have estimated, from the lengths of the faults, the maximum magnitude of earthquakes that can occur as 6.2 on the Tut Fault and 6.5 on the Bozova Fault. The largest earthquake in this region in recent decades, with magnitude 6.0, was on 5 May 1986 (e.g. Dziewonski et al., 1987). It had a reported epicentre ~12 km ESE of Gölbaşı; this and its focal mechanism (Dziewonski et al., 1987) are suggestive of a combination of left-lateral and reverse slip on the Tut Fault or the reverse fault beneath the Kozdağ Anticline (Fig. 2). However, studies of historical seismicity (e.g. Ergin et al., 1967; Sbeinati et al., 2005) have recognised a larger event in November 1114, of magnitude ~7, which has been tentatively associated with the Bozova Fault. Nonetheless, the slip rates on the Bozova and Tut faults are too low to be resolved geodetically (e.g. Reilinger et al., 2006) and too little information exists from the instrumental or historical seismicity. However, in NE Syria, Abou Romieh et al. (2009) have documented active faulting affecting Euphrates terraces. Given that the Bozova Fault crosses the Euphrates valley within the present study region (Fig. 2), one objective of this research is to examine the fluvial terrace record for evidence of analogous localised deformation along this fault.

Although other factors (e.g. regional climate) also contribute, it is now evident that the preservation of the fluvial record in this region is largely due to unique conditions; regression of the coastline has resulted in fluvial incision that causes significant underestimation of the uplift that has occurred (e.g. Demir et al., 2008; Westaway et al., 2009). As a result, the local relief is much less than had no coastal regression occurred, so slope processes have been less effective at reworking fluvial sediment. Until the early Middle Miocene, the region that now comprises the northern Arabian Platform uplands formed the Tethyan seaway, linking the Mediterranean Sea to the west to the Indian Ocean to the east. Across much of the northern Arabian Platform, the transition from a marine depocentre to a subaerial