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River terrace development in the NE Mediterranean region (Syria and Turkey): Patterns in relation to crustal type

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ABSTRACT

It is widely recognized that the optimal development of river terraces globally has been in the temperate latitudes, with NW and Central Europe being areas of particular importance for the preservation of such archives of Quaternary environmental change. There is also a growing consensus that the principal drivers of terrace formation have been climatic fluctuation against a background of progressive (but variable) uplift. Nonetheless river terraces are widely preserved in the Mediterranean region, where they have often been attributed to the effects of neotectonic activity, with a continuing debate about the relative significance of fluctuating temperature (glacials–interglacials) and precipitation (pluvials–interpluvials). Research in Syria and southern–central Turkey (specifically in the valleys of the Tigris and Ceyhan in Turkey, the Kebir in Syria and the *trans*-border rivers Orontes and Euphrates) has underlined the importance of uplift rates in dictating the preservation pattern of fluvial archives and has revealed different patterns that can be related to crustal type. The NE Mediterranean coastal region has experienced unusually rapid uplift in the Late Quaternary. The relation between the Kebir terraces and the staircase of interglacial raised beaches preserved along the Mediterranean coastline of NW Syria reinforces previous conclusions that the emplacement of the fluvial terrace deposits in the Mediterranean has occurred during colder climatic episodes.

1. Introduction

River terraces occur in most parts of the world (Bridgland and Westaway, 2008a, b; 2014) and are common throughout the Mediterranean region (Fig. 1), being found in southern Europe (Harvey and Wells, 1987; Karner and Marra, 1998; Schoorl and Veldkamp, 2003; Stokes and Mather, 2003; Santisteban and Schulte, 2007; Meikle et al., 2010; Candy et al., 2004; Cunha et al., 2005, 2008, 2017; Zagorchev, 2007; Martins et al., 2010; Viveen et al., 2012a, b; 2013), Turkey (Demir et al., 2004; Westaway et al., 2004, 2006a; Maddy et al., 2005, 2007, 2008, 2012a), Syria (Besançon et al., 1978; Besançon and Sanlaville, 1984), Egypt (Said, 1993; Zaki, 2007; Woodward et al., 2015) and Morocco (Aït Hssaine and Bridgland, 2009; Westaway et al., 2009a). It is widely agreed that such terraces have formed in response to latest Cenozoic uplift (Van den Berg, 1994; Maddy, 1997; Antoine et al., 2000; Maddy et al., 2000, 2001; Bridgland, 2000; Van den Berg and van Hoof, 2001; Westaway, 2002a; Starkel, 2003), with an equally prevalent view that the triggering of the different fluvial activity that has led to terrace formation (essentially an alternation of down-cutting and aggradation) has been related to Quaternary climatic fluctuation, typically (but not invariably) at a glacial–interglacial frequency (for recent inter-regional reviews, see Bridgland and Westaway, 2012, 2014). While most workers have envisaged the uplift responsible for the widespread phenomenon of river terraces to be regional, epeirogenic and 'atectonic', rather than caused by plate-tectonic processes or contemporaneous fault movement (cf. Maddy et al., 2000), some have made a case for the involvement of 'active tectonics'; in the Mediterranean region these include Mather et al. (1995) and Stokes and Mather (2000, 2003), in

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Fig. 1. The Mediterranean region, showing the location of fluvial systems with significant Quaternary records. The location of Fig. 2, which depicts the study region in more detail, is indicated.

the fault-bounded basins of southern Spain, and Boulton and Whittaker (2009) in the lowermost Orontes (Asi), Hatay Province, Turkey (see below; Fig. 2). Westaway (2002a), who has strongly advocated regional uplift as a principal control on river terrace formation, has demonstrated that the relative spacing of such terraces can be used as an indication of the strength and rapidity of the uplift. This approach has shown that uplift accelerated markedly, generally from a very low or non-existent rate, in the late Pliocene and again at the start of the Middle Pleistocene (following the Mid Pleistocene Revolution, when the 100 kyrs climatic cycles began), suggesting that the increasing severity of cold (glacial) climate cycles was an important influence, through coupling between climatic variation and Earth surface processes (Westaway, 2002a; Bridgland and Westaway, 2008a, b; 2014; Westaway et al., 2009b).

Westaway (2002a, 2006) has suggested compensation within the mobile lower continental crust as the most likely mechanism for sustaining the observed progressive regional uplift; this is envisaged as a long-term isostatic effect of the redistribution of material by erosion and sedimentation, but, unlike with glacio-isostasy, the effect is generally permanent (cf. Bridgland and Westaway, 2012, 2014). Thus lower crust has been squeezed from areas subsiding under the weight of sediment and has accumulated beneath uplifting areas, maintaining their additional elevation and providing important positive feedback in support of the isostatic effect. This mechanism cannot operate in areas where the lower crust is not mobile, as in Archaean cratons, in which the crust has cooled and solidified throughout its depth. Indeed, the observed absence of terrace sequences in such areas would seem to corroborate the envisaged mechanism, in the absence of any other explanation for such patterns of terrace occurrence (cf., Westaway et al., 2003; Bridgland and Westaway, 2008a, b; 2014; Westaway et al., 2009b). Thus the characteristic river terrace staircases observed in areas such as NW Europe have formed on relatively hot, dynamic Phanerozoic crust. It has also been shown that rivers on crust of an antiquity intermediate between Archaean and Phanerozoic (i.e., Proterozoic), which generally has a limited thickness of mobile lower crust, have produced fluctuating patterns of terrace formation and accumulation, suggesting oscillations between uplift and subsidence (Westaway, 2012; Bridgland and Westaway, 2014; Westaway and Bridgland, 2014).

1.1. *Patterns of fluvial archive preservation*

Four main patterns of sedimentary fluvial archive preservation have been recognized thus far from the various surveys undertaken under the auspices of the Fluvial Archives Group, including successive International Geoscience (IGCP) projects: IGCP 449 (Bridgland et al., 2007a) and IGCP 518 (Westaway et al., 2009b). These preservation types are as follows: (1) typical terrace staircase archives on dynamic (Phanerozoic) crust with a mobile lower layer,