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.

Keywords: River terraces; Uplift; Climatic forcing; Crustal type; Euphrates; Orontes

Highlights

Climatic fluctuation has forced river-terrace formation in the Mediterranean region

Climatic forcing has been over-printed onto the effects of background regional uplift

Differing patterns of fluvial-archive preservation reflect distinct uplift histories

Disparate uplift histories correlate with crustal type and mobility of lower crust

The effects of Quaternary tectonic activity are seen in the deformation of terraces

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; 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 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, (2) stacked sequences in subsiding areas, in which accumulation of sediment is a significant positive-feedback driver of the subsidence, (3) sequences in ultra-stable cratonic regions (coincident with Archaean crustal provinces), which (as noted above) show evidence for neither uplift nor subsidence, but instead for the lateral accretion of sediments of different ages (Westaway et al., 2003; Bridgland and Westaway, 2014), and (4) records intermediate between patterns 1 and 3, showing alternations of uplift and subsidence, as seen in areas with thin mobile crustal layers, often of Proterozoic age (Westaway, 2012; Bridgland and Westaway, 2014; Westaway and Bridgland, 2014; see above). The preservation patterns within archive type 1 are divisible into systems that have formed terraces in approximate synchrony with glacial–interglacial climatic fluctuation, those that have formed terraces less often than that and those (rare) systems in which terrace formation has occurred more frequently than once per glacial–interglacial cycle (Bridgland and Westaway, 2008a).

At no great distance from the NE Mediterranean is an area that has yielded a wealth of fluvial archive data, highly influential in the recognition of the above patterns: the northern Black Sea region. This area is dominated by three important southward-draining rivers: in a west–east direction, the Dniester, Dnieper and Don (Fig. 3). The records from these rivers were synthesized by Matoshko et al. (2004) and further reviewed by Bridgland and Westaway (2008a, 2014), with detail of the prevailing crustal properties and their relation to the fluvial archives was further discussed by Westaway and Bridgland (2014). All three rivers have excellent fluvial archives, benefitting from research over very many years and well constrained by biostratigraphy, loess–soils overburden sequences and geochronology (Matoshko et al., 2004). Despite their relative proximity to each other (Fig. 3A), particularly in terms of global regions and climatic zonation, the sedimentary sequences of these three rivers have markedly contrasting geometries, an observation that can be matched closely with the crustal province in which their valleys are developed. Thus the Dniester, the furthest west, and flowing over through the SW part of the Dniester–Bug crustal domain (Fig. 3A), has formed a conventional terrace staircase in a valley that has been incised into Miocene basin-fill deposits, 'basin inversion' (the start of incision) having occurred at around the beginning of the Pliocene. As Fig. 3B shows, several broad Pliocene terrace formations are preserved, as well as three classified as Lower Pleistocene, after which the river increased the steepness of its incision into the basin fill at around the Mid-Pleistocene Revolution (MPR), when the change to 100 ka interglacial–glacial climatic cycles took place

(Mudelsee et al., 1997; McCymont et al., 2008). Subsequent to this change in the pattern of climatic change, the Dniester has formed a lower staircase of terraces at approximately one per 100 kyr cycle. The overall incision pattern recorded by the Dniester is thus regarded as a response to uplift, which showed comparable changes in reaction to enhanced surface processes resulting from the climatic cooling in the late Pliocene and then again with the onset of the longer climatic cycles, with greater severity of glacials,at the MPR (Westaway, 2002a, b).

The River Dnieper, in contrast to the Dniester, flows on the cratonic crust of the Ukrainian Shield (Fig. 3A). Its sedimentary archives date back to the Miocene but show no evidence of consistent uplift since that time, there having been no progressive incision by the river. Instead the deposits occur laterally distributed over a wide area within a range of a few tens of metres above or below the modern Dnieper (Fig, 3C). This, then, provides an excellent example of the cratonic pattern of fluvial archive preservation noted above. Finally the Don, which flows over the Early Proterozoic crust of the Voronezh Shield or the Lipetsk–Losev crustal domain (Fig. 3A), has an archive of Late Cenozoic sediments that differs yet again in its preservation pattern, with evidence that the valley has experienced periods of uplift interspersed with subsidence. Thus uplift is indicated by the oldest suite of (partly buried) Don terraces, formed during the late Miocene–Pliocene (Fig. 3D). In the Early Pleistocene there were alternating shorter periods of uplift and subsidence, culminating in the aggradation of a continuous sequence representing much of the Middle Pleistocene, following which, from MIS 8 onwards, there has been further uplift and terrace formation (Fig. 3D). This, then, is an example of preservation pattern 4 (see above).

Figs 1–3 hereabouts

1.2 Consideration of other potential mechanisms for terrace generation

The role of sea-level fluctuation as a driver for terrace formation, via its causal linkage with base-level change, has also been promoted by many workers (cf. Törnqvist and Blum, 1998; Tucker and Whipple, 2002), irrespective of crustal movements. In the Mediterranean region (albeit on the Atlantic seaboard) a convincing case has been made for glacial–interglacial eustatic change as a mechanism for terrace generation in Portugal (Martins et al., 2010; Viveen et al., 2013), where the continental shelf is narrow and sea-level change might be expected to exert a significant influence in lower fluvial reaches onshore. This mechanism has also been envisaged as a key driver for aggradation in the Tiber system, Italy (Karner and Marra, 1998), although this latter study did not consider the alternative possibility of a climatic driver. Such base-level forcing is generally envisaged to lead to progressive vertical incision by rivers from their downstream end, by the mechanism of knick-point recession (Whipple and Tucker, 1999, 2002; Roberts and White 2010; cf. Bridgland and Westaway, 2012); for a full review of this approach, and an attempt to reconcile it with evidence from river terrace sequences, see Demoulin et al., this issue).

In the warm-temperate Mediterranean climatic zone there has also been debate about whether Quaternary cycles of varying temperature (glacials–interglacials) have been important drivers of fluvial activity, as is supposed in NW Europe (e.g., Antoine et al., 2000; Bridgland, 2000), or whether humidity cycles (pluvials–interpluvials) have been more important. Humidity fluctuations have been invoked as an important influence on rivers in the eastern Mediterranean, where they might be linked to the fluctuating strength of the Indian Ocean monsoon (e.g., Rossignol-Strick, 1985; Kroon et al., 1998), although much of the evidence is from recent timescales. Conversely Macklin et al. (2002) have compiled evidence from the last two climate cycles and found that temperature is likely to be the most important driver, as it is further north in Europe.

Working in the Gediz River system in western Turkey, which has abundant fluvial archives but has been disrupted by Late Cenozoic – Quaternary volcanism, Veldkamp et al. (2015) found evidence to support climatic forcing of river terrace formation in the Early Pleistocene. This evidence took the form of a sequence of rubified palaeosols and laminated calcretes formed at the top of fluvial (Gediz) sediments and within colluvial overburden. From micro-morphological and stable-isotope analysis they concluded that rubified soils had formed in a warm, moist and forested environment, whereas the calcretes recorded cooler and drier periods with an open (non-wooded) landscape. They inferred that the colluvial sediments represented colder periods of landscape instability, during which fluvial incision might have occurred, thus suggesting down-cutting at cooling transitions in this system. From the Ar–Ar age of a capping lava (~1.3 Ma) they suggested a tentative correlation between the formation of the various Gediz terraces and major climatic transitions during the late Early Pleistocene.

The present paper will review evidence from work carried out by the authors in Syrian and southern Turkish river systems that has a bearing of these various debates and further suggests a strong linkage between patterns of fluvial archive preservation and crustal type. The text will be organized according to crustal provinces.

2. Fluvial records from the northern Arabian platform

The crust of the northern Arabian Platform is of Late Proterozoic age, having consolidated during the latest Precambrian 'Pan-African' orogeny. However, it shares a characteristic with older Proterozoic crust elsewhere, in that it consists of a thick basal mafic layer overlain by a relatively thin layer of mobile felsic lower crust (cf. Demir et al., 2007a). Representing a separate tectonic plate, it is bounded to the west by the Dead Sea Fault Zone (DSFZ), which separates it from the African Plate, and to the north by the East Anatolian Fault Zone, which marks its separation from the Turkish Plate (Fig. 2). The northern Arabian Platform is drained southwards to the Persian Gulf by the twin rivers of Mesopotamia, the Tigris (Dicli) and Euphrates (Firat), while its western fringe is drained northwards by the Orontes, which follows the DSFZ for much of its course (Fig. 2).

2.1. The River Euphrates in Turkey and Syria

The fluvial record of the Euphrates has been studied by the authors in both Turkey and Syria (Demir et al., 2007a, b, 2008, 2012; Abou Romieh et al., 2009); comparison can also be made with the sequence (downstream) in Iraq, based on studies there by Tyràček (1987). This system will be considered first, as it has a more central location within the Arabian Platform. In Syria geochronological constraint on the ages of Euphrates deposits has been provided by Ar–Ar dating of basalt lavas that cap terrace gravels between Raqqa and Deir ez-Zor (Demir et al., 2007b; Fig. 4). These basalts date from 2.717 ± 0.02, 2.116 ± 0.039 and

0.402 ± 0.011 Ma and seal gravels ~65, ~45 and ~8–9 m above the modern river, respectively. Previous work by Besançon and Geyer (2003) showed that the Pleistocene sequence of the Euphrates occupies a deep infilled palaeochannel incised well below the level of the modern valley (Fig. 4). The new basalt dates allowed key stages in the formation of this valley to be calibrated, leading to a revised interpretation (Demir et al., 2007b; Bridgland and Westaway, 2014) envisaging a greater age for much of the sequence.

Fig. 4 hereabouts.

The new interpretation recognizes relative landscape stability in the Syrian reach of the Euphrates prior to ~3 Ma, followed by a phase of fluvial incision, then further relative stability before renewed incision, starting at ~2 Ma, which saw the river cut the deep palaeovalley ~30 m below its present level (Fig. 4). A 40–45 m thickness of gravel accumulated, culminating at the level of terrace QfII (using the Besançon and Geyer (2003) scheme), ~23 m above modern river level, after which renewed incision began. This 'inversion' is dated by basalt ages in combination with uplift modelling (cf. Demir et al., 2007a) to around the start of the Middle Pleistocene. It may thus mark the response of the Euphrates system to the effects on fluvial processes of the MPR, and in particular the greater intensity of glacial episodes it brought about, previously suggested as a cause of increased incision in the Dniester (see above).

Further upstream, at Birecik, southern Turkey, the same palaeovalley has been recognized, but it is disposed significantly higher within the landscape (Fig. 5), its base ~5 m above modern floodplain level (Demir et al., 2008). Its fill, the Bilgin Gravel, reaches 56 m above the modern river and has a series of terraces cut into it, presumed to date from MIS 22–12, although this is largely by analogy with the dated sequence in Syria, as there is no available geochronology from the Turkish reach of the Euphrates. This correlation is, however, supported by the occurrence of comparable Acheulian artefacts in the fill sequences of both reaches (Demir et al., 2007a, 2008). Thus the same Early–Middle Pleistocene inversion is evident north of the Syrian–Turkey border, although there has been greater uplift there in the Middle–Late Pleistocene, raising the infilled palaeovalley significantly higher in the landscape and consistent with the general southward tilt of the northern Arabian platform observed previously (Arger et al., 2000).

Fig. 5 hereabouts

In the Birecik reach an older palaeovalley-fill has been recorded, between ~100 and ~140 m above the river. This comprises the İt Dağı and Hancağız gravels, the former attributed to the Euphrates on the basis of its polymict (Anatolian) clast composition and the latter a local limestone fan deposit (Demir et al., 2008; Fig. 5). These are thought, from their disposition within the landscape (both in relation to younger Euphrates deposits and by analogy with dated deposits in the Syrian reach of the Euphrates and in the Tigris in Turkey), to date from the Early–Mid Pliocene. Studies of the Euphrates sequence ~100 km further upstream, where the river is accessible from the Şanlıurfa to Adiyaman road at Karababa bridge, have revealed the same thick sedimentary sequences attributed to prolonged aggradation phases during the Early–Mid Pliocene and during the Early Pleistocene, although the preservation and thickness of these deposits is strongly influenced by active folding thereabouts (Demir et al., 2012). These are the Işık and Kavşut gravels, respectively. The former is associated with Pliocene coastal regression, which led to the mouth of the Euphrates migrating many hundreds of kilometres south-eastward (from north-central Syria probably as far as central Iraq), and concomitant aggradation, even though the landscape in this part of Turkey was uplifting. The Kavşut gravel is attributed to regional subsidence during the Early Pleistocene (cf. Demir et al., 2012). Once again the correlation of the thick Lower Pleistocene Kavşut Gravel at Karababa with the Bilgin Gravel at Birecik and with the equivalent palaeovalley-fill deposits in the Syrian reach of the Euphrates is supported by the recovery of Lower Palaeolithic artefacts from the first-mentioned deposits in gravel quarries in the vicinity of Karababa bridge. Note that the above interpretation includes consideration of changes in the length of the system (i.e. downstream distance to the sea, or base level), rather than an uncritical formula that simply translates elevation to age, in relation to uplift.

The suggested ages of the terraces in the Turkish and Syrian reaches of the Euphrates are largely based on uplift modelling, using the technique of Westaway (2002b, 2007), with important calibration from the basalt dates in Syria (see above). Like many rivers globally, the Euphrates, in its Syrian reach, would appear to have generated terraces during only the most extreme climatic cycles, broadly equivalent to the 'supercycles' of Kukla (2005): MIS 22, 16, 12, 6, 2 (Fig. 4). A comparable sequence can be seen in Kukla's (1975, 1977) central European record from the River Svratka, Czech Republic. The reversals in the direction of vertical crustal movement evident from the Euphrates archive are comparable with those observed in the record of the Don (compare Figs 4 and 5 with Fig. 3D). Both rivers are flowing over crust with a restricted thickness of mobile layer; in the Arabian platform this has been caused by mafic underplating during the aforementioned Pan-African Orogeny.

2.2. The River Tigris in southern Turkey

The Tigris sequence has been studied in the area around and downstream of Diyarbakır (Bridgland et al., 2007b; Westaway et al, 2009c), near the northern margin of the Arabian Platform. The dating of the terrace sequence in this upper part of the Tigris has been facilitated by the interbedding of fluvial deposits with basaltic lava periodically erupted from the large Karacadağ shield volcano centred ~50 km SW of Diyarbakır. At least nine Tigris terraces have been identified (Westaway et al, 2009c; Bridgland and Westaway, 2014; Fig. 6), the highest, ~200 m above present river level, marking the switch from stacked accumulation of fluvial deposits to valley incision (basin inversion), which occurred between the mid Late Miocene and the Middle Pliocene. Widespread gravel ~60–70 m above the Tigris floodplain crops out on both sides of the valley at Diyarbakır, including beneath the basalt city walls. Dated basalts overlying this terrace have proved to represent multiple flows, implying a span of at least 150 ka during which there was no valley deepening: K–Ar/Ar–Ar dates of 1.22 ± 0.02, 1.19 ± 19 and 1.07 ± 0.03 Ma have been obtained from basalts at this level, with the distinction corroborated by different magnetic polarities in basalts on the two sides of the valley (Westaway et al, 2009c; Bridgland and Westaway, 2014; Fig. 6). It is uncertain whether the river was temporarily ponded by any of these lava flows, since no lacustrine sediments, such as have been recorded in the Gediz, in western Turkey (Maddy et al., 2012b, this issue), have been observed in the Diyarbakır reach of the Tigris.

Fig. 6 hereabouts

Lower terraces record the Middle–Late Pleistocene incision by the Tigris through this basalt, forming the narrow incised valley of the modern river, perhaps responding to an acceleration (or re-commencement) of uplift following the MPR (see above). The dating of these lower terraces is further constrained by a younger dated basalt, erupted at 0.43 ± 0.02 Ma (MIS 12), capping gravel ~21–22 m above the modern river (Westaway et al, 2009c; Bridgland and Westaway, 2014; Fig. 6). The application of numerical modelling as a means of obtaining approximate ages for the terrace gravels, using the dated basalts for calibration, suggests a similar Middle Pleistocene record to that in the Euphrates, with only some glacial–interglacial climate cycles represented by terraces (these being fitted to likely isotope stages based on their relative height within the landscape: Fig. 6). The pattern of the modelled uplift history here is compatible with a thin mobile lower-crustal layer (~5–7 km thick), consistent with the known presence of the aforementioned thick layer of mafic underplating at the base of the crust beneath the Arabian Platform (Westaway, 2012; Westaway and Bridgland, 2014). In contrast with the Euphrates, and indeed with the Don (see above), the history of vertical crustal movement indicated by the Tigris sequence (Fig. 6) would appear to be a fluctuation between uplift and stability, rather than uplift and subsidence, suggesting transitional crustal properties, perhaps. The early Middle Pleistocene rate of incision, and thus of uplift, was relatively high, however: ~0.1 mm a^{-1} (Westaway et al., 2009c), with evident slowing of uplift since ~MIS 12, which is represented by a terrace relatively close to the valley floor, its age fixed from a lava date (Fig. 6).

2.3. The River Orontes in Syria

The Orontes has been studied by the authors from near the Lebanon border in western Syria to the Mediterranean SW of the Turkish city of Antakya (Bridgland et al., 2012). A notable feature of its Quaternary record is that this varies considerably between different crustal blocks, the river flowing through two subsiding pull-apart basins within the DSFZ in which stacked sedimentation has taken place throughout the Quaternary and no terraces occur (Fig. 7). There are also three gorge reaches that lack terraces, despite being located on uplifting crust, resistant rocks in these reaches having prevented the lateral migration required for terrace formation (cf. Bridgland and Westaway, 2008a, 2012; Fig. 7).

Fig. 7 hereabouts:

On the eastern flank of the Upper Orontes, upstream of Homs, is preserved an extensive staircase of calcareously cemented Late Cenozoic terraces (Bridgland et al., 2003, 2012; Fig. 8A). Initial attempts to construct an age model for these terraces used upstream projection from a fossiliferous site in the Middle Orontes, at Latamneh, supposing that site to represent an age close to MIS 12 (based on a mixture of early Middle and late Middle Pleistocene mammalian species (Bridgland et al., 2003). Subsequent re-evaluation of the vertebrate evidence from Latamneh has suggested that it is much older; this, coupled with U-series dating of the Arjun terrace to MIS 6, led Bridgland et al. (2012) to propose the revised age model depicted in Fig. 8A. This allocates a terrace tread to every glacial–interglacial cycle following the MPR. The ages of the oldest terraces can only be approximate, but there is an upper limit provided by the 'bedrock' here, which is lacustrine marl representing a basin filling that culminated in the early Pliocene, with inversion occurring, seemingly, before the beginning of the Pleistocene, perhaps related to the late Pliocene global cooling (see above). The lake had existed since the latest Miocene, when the Homs basalt (Ar–Ar dated ~6–4Ma: Searle et al., 2010; Westaway, 2011) was erupted into it (cf. Bridgland et al., 2012).

Fig. 8 hereabouts:

The Homs Basalt gives rise the first of the three gorge reaches along the course of the Orontes, the Rastan Gorge, separating the Upper from the Middle section of the valley (Fig. 7). In the Middle Orontes there is again a well-developed terrace record, newly discovered to extend up the eastern valley side to ~120 m above the modern river, these higher levels (marked by calcreted gravels comparable with those in the Upper Orontes) perhaps representing the Pliocene (Bridgland et al., 2012). The biostratigraphical marker at Latamneh would now be assigned an age in the region of 1.2–0.9 Ma, largely based on small-mammal faunas, interpreted in comparison with the Israeli sites at Ubeidiya and Gesher Benot Yaaqov, which are regarded as older and younger, repectively, than Latamneh (Bar-Yosef and Belmaker, 2010; Bridgland et al., 2012; cf. von Koenigswald et al., 1992; Mein and Besançon, 1993; Goren-Inbar et al., 2000). An important point of contrast with the Upper Orontes is the considerable thickness of the sediments at Latamneh: ~25 m. Given that this sequence is now attributed to the Lower Pleistocene, and that the lower-level terraces essentially appear to represent 100 kyr cycles within the late Middle and Late Pleistocene (based on the uplift modelling presented by Bridgland et al (2003), which remains valid: Fig. 8B), a comparison can be made with the sequence in the Euphrates, where thick Lower Pleistocene accumulations were inverted and incised following the MPR (Figs 4 and 5). It is possible that early Middle Pleistocene incision levels (terraces) within the vertical range of the Latamneh deposits have yet to be resolved.

Caution should applied when interpreting the evidence from Latamneh, however, since the locality lies within ~5 km of a dip-slip fault at Sheizar, which marks the eastern side of the subsiding Ghab Basin (Fig. 7) and has clearly been highly active throughout the Quaternary: its minimum Late Cenozoic vertical displacement, calculated from the depth of stacked sediments on its downstream side added to the height of the uppermost terrace deposits in the area upstream, is ~300m. A further complexity is that a tooth of the ancestral mammoth *Mammuthus meridionalis* was found at Sharia (Van Liere and Hooijer, 1961), now within the eastern outskirts of Hama, in deposits that fall within the range of altitude (relative to the valley-floor) of the Latamneh deposits. The Sharia fossil would seem to pre-date the Latamneh assemblage, which includes teeth of the more evolved mammoth *Mammuthus trogontherii* (Bridgland et al., 2012), although it could also belong within an Early Pleistocene aggradational sequence.

Thus the Middle Orontes sequence might have much in common with that in the Euphrates, representing another example of the accumulation–inversion sequence that characterizes fluvial archives from the Arabian Platform. It might be significant that in this reach the river wanders eastwards further onto the Arabian plate (and away from the DSFZ) than other parts of its course (Fig. 2), perhaps explaining why a sequence reminiscent of those on the Arabian Platform is found here. No evidence of this type of record is seen in the Upper

Orontes; the uppermost terraces there, attributed to the late Pliocene and Early Pleistocene (Fig. 8A), were determined from conglomerate outcrops separated by exposures of bedrock marl, indicating that discrete terrace treads are represented.

3. Fluvial records from the young, dynamic crust of the Latakia–Osmaniye area

In the area west of the DSFZ, including the coastal part of NW Syria and the Turkish regions of Hatay and the İskenderun Gulf (Fig. 2) the crustal properties reflect the typical geology of the Mediterranean region, resulting from its Cenozoic deformation in response to the subduction of the Tethys Ocean and the convergence of the African and Eurasian plates. (e.g., Aktaş and Robertson, 1984; Allen and Armstrong, 2008; Seyrek et al., 2014). Such crust, seen already in those reaches of the Orontes that flow close to the DSFZ (see above, especially the Upper Orontes), is considerably more dynamic than that of the Arabian Platform.

3.1. The Lower Orontes

Continuing the story of the Orontes, the river traverses the subsiding Ghab Basin and flows through its second gorge reach, the Darkush Gorge, cut through resistant Palaeogene limestone, which has again minimized lateral migration and prevented terrace formation (see above; Fig. 7). North of this gorge it flows into Turkey and into the second subsiding pull-apart basin, the Amik Basin (for recent discussion, see Seyrek et al., 2014), the flat surface of which forms the Antakya (Antioch) Plain (Fig. 7). Between Antakya and the Mediterranean the lowermost Orontes has contrasting terraced and gorge reaches, both indicative of uplift. Indeed, the river here flows through a coastal region, extending from Latakia (Syria) in the south to the Lower River Ceyhan in the north, near Osmaniye, that can be shown to have experienced very rapid late Quaternary uplift (Bridgland et al., 2012; Bridgland and Westaway, 2014). The Lower Orontes terraces, mapped in some detail by Erol (1963), were shown by Bridgland et al. (2012) to be formed by gravels containing mostly crystalline rocks from the Hatay ophiolite and the Precambrian–Palaeozoic succession exposed in the Amanos Mountains, to the NE. The even spacing of the five documented terraces (the lowest is too low to be shown in Fig. 7) is suggestive of regular formation in synchrony with 100 kyr climatic cycles, leading Bridgland et al. (2012) to suggest correlation with MIS 12, 10, 8, 6 and 2. Calculation of uplift rates on that basis approaches 2 mm a^{-1}, a rate far greater than in the higher parts of the Orontes valley in Syria (see above).

The last of the three Orontes gorges, cut into resistant latest Cretaceous ophiolitic rocks, is entrenched by 400 m (Fig. 7). It ends abruptly at an escarpment that is thought to coincide with an active dip-slip fault (Tolun and Erentöz, 1962; Erol, 1963; Boulton and Whittaker, 2009; Bridgland and Westaway, 2014). Erol (1963) also documented marine terraces bordering the Mediterranean coastline and provided tentative ages for these that were used by Seyrek et al. (2008) to infer a rapid uplift rate of ~0.1–0.2 mm a^{-1} during the latest Middle Pleistocene and Late Pleistocene, in reasonable agreement with the estimate from the Lower Orontes terraces (see above).

3.2. The Lower River Ceyhan, in the area of Osmaniye, southern Turkey

If the rapidity of uplift in the Lower Orontes requires estimation and inference, that indicated by the sequence in the River Ceyhan, ~50 km to the north, is well constrained by Quaternary basaltic lava that overlies fluvial levels down to the 4th terrace (of seven), ~90 m above floodplain level, which has an Ar–Ar age of 278 ± 7 ka, placing its eruption within MIS 9 (Seyrek at al., 2008). The three lower terraces, well spaced in terms of relative height, are thus attributable to MIS 8, 6 and 2 (Fig. 9). These data have provided an uplift rate for the late Middle and Late Pleistocene of 0.25–0.4 mm a^{-1}, increasing upstream (based on heights above the valley floor of well-dated terraces), perhaps in association with movement of the active fault that has uplifted the Amanos Mountains in this part of the northern DSFZ (Seyrek at al., 2008). This work has also elucidated the sequence of earlier terraces, partly preserved within an abandoned reach from which the river was probably diverted as a result of the basalt eruption (Fig. 9). Further upstream, the Ceyhan has cut a substantial gorge, up to ~2000 m deep, through the northern Amanos Mountains, the maximum age for the initiation of incision being the start of the fault movement, ~3.7 Ma (Westaway et al., 2006b), implying an average rate of down-cutting of ~0.54 mm a^{-1}, higher than the range calculated from the lower-level river terraces (see above). As Seyrek et al (2014) have established, this gorge reach of the Ceyhan is in the footwall (upthrown side) of an active normal fault, whereas the terraced reach further downstream is in its hanging (downthrown) wall, all of which is entirely consistent with the aforementioned differential uplift rates.

Fig. 9 hereabouts

3.3. The Nahr el Kebir, NW Syria

The third river draining through this zone of rapid-uplift is the Nahr el Kebir, which debouches into the Mediterranean at Latakia, its terraces interwoven with a sequence of upper Middle–Upper Pleistocene raised beaches (Copeland and Hours, 1978; Sanlaville, 1979; Devyatkin et al., 1996; Bridgland et al., 2008; Bridgland and Westaway, 2014). Considerable research has been undertaken on the Kebir terraces, largely because of their association with Palaeolithic artefacts (e.g., Copeland and Hours, 1979; Hours, 1981, 1994; Besançon et al., 1988). In summary of much work in the late 20th Century, Sanlaville (1979) attributed the fluvial terraces of the Kebir to Pleistocene cold stages (glacials) and the coastal marine terraces to interglacials. Recent work by the authors (Bridgland et al., 2008; Fig. 10) has found that the Sanlaville terrace scheme in the Kebir valley requires revision but has upheld their interpretation as cold-stage deposits, which interdigitate, rather than coalesce, with the raised marine terraces (Fig. 9A). The latter can also be confirmed as raised beaches from their bedding characteristics and patchily preserved molluscan fossils (cf. Devyatkin et al., 1996). These observations provide important corroboration of the view, from Macklin et al. (2002) amongst others, that river terrace formation in the Mediterranean region has been driven by cyclic temperature fluctuation rather than humidity cycles, although it is uncertain whether this is via a direct influence on fluvial activity and slope stability, as envisaged for systems in NW Europe (cf. Maddy, 1997; Bridgland 2000), or through the eustatic control of base level, as posited for Portuguese rivers (see above).

Fig. 10 hereabouts

Whereas the Sanlaville (1979) terrace scheme envisaged four terraces diverging downstream, the revised interpretation (depicted in Fig. 10B) shows four broadly parallel terraces, all significantly steeper than the modern floodplain. One of the Sanlaville terraces has been deleted from the scheme, since it can be shown to consist only of erosional remnants of slope deposits (Fig. 10A), but an additional formation has been identified just above the modern floodplain, from exposures in recent quarry workings. Bridgland et al. (2008) suggested that the four recorded terraces were formed in synchrony with the last four 100 kyr (glacial–interglacial) climate cycles, thus representing MIS 10, 8, 6 and 4–2 (the last cycle encompassing MIS 5(d)–1 inclusive). If correct, the ~40 m vertical separation between the terraces would point to an uplift rate of ~0.4 mm a^{-1}, comparable with that deduced for the Ceyhan and the Lower Orontes (see above).

The distinction between cold-climate fluvial terrace deposits and warm-climate (interglacial) raised beaches in the Latakia area provides important evidence that bears upon the long-standing debate over the climatic forcing of river-terrace formation in the Mediterranean region (see below).

4. Discussion

Thanks to the advances in understanding of Quaternary (and latest pre-Quaternary) fluvial records since the foundation of the Fluvial Archives Group (FLAG), interpretation of the sequences described here can be set in a fully international context. Of particular importance in this respect, as noted above, was the compilation of long-timescale fluvial datasets under the auspices of successive International Geoscience (IGCP) projects, IGCP 449 (Global Correlation of Late Cenozoic Fluvial Deposits: Bridgland et al., 2007a) and IGCP 528 (Fluvial sequences as evidence for landscape and climatic evolution in the Late Cenozoic: Westaway et al., 2009b). Synthesis of these data revealed patterns of sediment and aggradational terrace preservation that varied between different crustal provinces, as has been alluded to above, requiring explanation in terms of localized (regional) causal mechanisms against background global (predominantly climatic) forcing factors (cf. Bridgland and Westaway, 2008a, b; 2012, 2014).

4.1 Patterns of fluvial archive preservation represented in the study region

Of the main four preservation patterns established above, those numbered 1, 2 and 4 are represented in the study region, but there are no ultra-stable cratonic archives (pattern No. 3). Pattern 1 (classic terrace staircases) is represented by the Upper Orontes, which has apparently formed approximately one terrace per glacial–interglacial cycle, and by the systems in the rapidly uplifting region in the NE Mediterranean, the Kebir, lowermost Orontes and Ceyhan, although the accelerated uplift has prevented the preservation of extensive staircases here except in the Ceyhan through the Amanos mountains, where basalt flows have armoured the older terraces against erosion (Fig. 8). Stacked sequences (pattern 2) are found in the subsiding pull-apart basins of the Ghab in Syria and the Amik in Turkey, both within the DSFZ and drained by the Orontes (Fig. 7). The preservation patterns of fluvial archives developed in the Arabian Platform would seem to belong to Pattern 4, since they show alternations between incision and aggradation, presumably in response to alternating uplift and subsidence (Figs 4–6; 8B). This is thought to be a consequence of the interaction between isostatic compensation by lower-crustal flow and by mantle processes (Westaway, 2012; Westaway and Bridgland, 2014). To clarify, it can be anticipated that isostatic compensation for surface processes can be generally accommodated in weak layers in the upper Earth (mantle and/or lower crust). As argued previously (Westaway, 2012; Westaway and Bridgland, 2014), it can often be difficult to distinguish between alternative locations for accommodation. Variations between different regions in the timescale of the uplift response to the effects of climatic fluctuation on surface processes points to an important role for the lower crust, since the upper mantle (asthenosphere) has long been considered to have similar properties worldwide (e.g., Peltier, 1982).

4.2 Effects of tectonic activity

As noted already, some authors have advocated tectonic activity as a driver for river terrace formation; in the Mediterranean regions this has been linked to crustal shortening in relation to the nearby convergence of the African and European plates (cf. Mather et al., 1995; Stokes and Mather, 2000, 2003; cf. Cloetingh et al., 2005, 2007). However, the widespread distribution of river terraces as ubiquitous landscape features in areas distant from plate boundaries and of known tectonic stability suggests that this mechanism can be of localized importance at best. In fact there is evidence that proximity to active tectonism has had a disruptive influence on fluvial archives in that it has led to poor preservation of clearly defined, well-separated terrace staircases. Such evidence comes from localities where the effects of Quaternary tectonic activity are overprinted onto records that can be supposed to have formed in response to regional–global drivers such as epeirogenic uplift and climatic change. The reach of the Euphrates through NE Syria provides an example, as determined by examination of the terrace record in that system between the Lake Assad reservoir, upstream of Raqqa, and Deir ez-Zor (Fig. 2). This is the reach in which the ages of the terraces are well constrained by interbedded basaltic lavas, dated using the Ar–Ar technique (Demir et al., 2007b; see above; cf. Fig. 4). Although the terraces in this reach are generally well preserved and, indeed, highly prominent landscape features, over a distance of ~40 km around and downstream of Halabiyeh (Fig. 2), they are very badly disrupted by active faulting (Abou Romieh et al., 2009; Fig. 11). As Fig. 11 shows, this disruption takes the form of short sections of terrace at anomalous heights (lower or higher than expected) and/or strongly tilted. This deformation was attributed by Abou Romieh et al. to Quaternary slip on a series of faults, some of which could be matched with faults identified in an earlier seismic survey by Litak et al. (1997). Overall there are localized zones of maximum uplift followed by minimum uplift in downstream sequence across the area of deformation, which, from structural evidence, is one of primarily right-lateral deformation, with a minor component of shortening (e.g. Litak et al., 1997; Seber et al., 2000). This deformation coincides with the northern end of the Palmyra Fold Belt (Fig. 2). From their field evidence, Abou Romieh et al. (2009) calculated an overall crustal shortening rate for the area between Masrab and the Halabiyeh Plateau ~0.1 mm a^{-1} as well as invoking the existence of a 'Syrian microplate', moving relative to the Arabian Plate to its south-east (Fig. 2). The Palmyra Fold Belt thus accommodates clockwise rotation of the Arabian Plate relative to the Syrian microplate to its north-west. This tectonic zone was previously considered to be inactive (cf. Rukieh et al., 2005) but, from the newly recognized fluvial archive data, can now be recognized as a potential cause of historic earthquakes in the Damascus–Palmyra region as well as a future seismic hazard.

Such vertical disruption occurs when there is a significant dip-slip component to fault movement. In both the Halabiyeh and Damascus areas this is due to components of reverse slip (Abou Romieh et al., 2009, 2012). In other localities discussed, such as the Middle and Lower Orontes (Fig. 7) and the Ceyhan in the Amanos Mountains (Seyrek et al., 2014), rivers have interacted with normal faults. However, in each of these cases fluvial terraces have been identified only on one side of the fault, so their tectonic disruption is less readily apparent; as already noted, some of these localities indeed mark switches from fluvial terrace development in uplifting footwalls to stacked deposition in subsiding hanging-walls (cf. Fig. 7). Nonetheless, in the aforementioned Amanos Mountains reach of the Ceyhan, fluvial terraces are preserved in the hanging-wall, indicating that this locality is uplifting; given the component of upthrow on the fault, the adjacent footwall is evidently uplifting faster, indeed uplifting so fast that no fluvial terraces have been preserved and only a gorge is evident. Conversely, in most other parts of the eastern Mediterranean region the predominant sense of active faulting has been strike-slip, notably in most of Dead Sea Fault Zone, EAFZ and NAFZ (see Fig. 2). There are many localities within these fault zones where rivers have been laterally offset by slip on such faults, the rate of this movement having been quantified from dating of the fluvial deposits or other evidence (e.g., Barka and Kadinsky-Cade, 1988; Westaway, 1994; Demir et al., 2004; Westaway et al., 2006b; Seyrek et al., 2014).

Fig. 11 hereabouts

4.3 Temperature or humidity as the key driver

The debate over whether the formation of river terraces in the Mediterranean region has been driven by glacial–interglacial temperature fluctuation, as seems clearly to be the case in NW Europe, or by fluctuations in humidity (pluvials–interpluvials) was outlined in the introduction. In the eastern Mediterranean, pluvials (periods of enhanced precipitation) can broadly be correlated with sapropels, which are organically enriched sea-floor sediment layers (e.g. Kallel et al., 2000; Casford et al., 2002, 2003). Pluvials and sapropel formation have both been broadly correlated with interglacial/interstadial periods in lower latitude areas (e.g., Deuser et al., 1976; Spaulding, 1991; Kallel et al., 2000), with glacials generally coinciding with drier episodes in the Mediterranean (cf Veldkamp et al., 2015).

One of the case studies reported here, the record from the Nahr el Kebir in NW Syria, has particular bearing on this debate. Notably, the new data from the Kebir confirm the view, previously expressed by Sanlaville (1979), that the river terrace deposits here represent the cold Pleistocene stages, just as with comparable fluvial gravels in NW Europe. Indeed, the interdigitation of cold fluvial and warm marine terraces seen in the lowermost Kebir system is similar to the relationship between comparable deposits on the south coast of England, where raised beaches formed at the northern margin of the English Channel are interwoven with river terraces in various south-coast English rivers (cf. Bridgland et al., 2004). This evidence from the Kebir is of considerable importance for the study area as a whole, given the paucity of fossils in the fluvial deposits generally and the non-occurrence of Quaternary periglaciation in lowland Mediterranean valleys; without the evidence for palaeoclimate from fossils or the direct evidence of intense cold from periglacial structures and the cryogenic disturbance of sediments, there is little that can be brought to bear on this issue from the inland parts of the region.

5. Conclusions

Data on fluvial archives from the NE Mediterranean region reinforce previous ideas that climatic forcing has been influential in river terrace formation and that uplift and/or subsidence has had a significant influence on patterns of fluvial deposition and valley evolution, with crustal type a critical control. Some crustal blocks have been experiencing subsidence throughout the Quaternary, examples being the faulted basins along the Dead Sea Fault Zone drained by the Orontes. Sedimentary isostasy is thought to be an important positive-feedback mechanism that has sustained progressive Quaternary subsidence in these basins. Such subsiding regions represent one of four identified patterns of fluvial archive preservation. Two others are well represented in the study area. First, rivers flowing over dynamic young crust to the west of the Arabian Platform have experienced progressive uplift during the Quaternary and have formed terraces in approximate synchrony with glacial–interglacial climatic fluctuation. This applies to the Upper Orontes south of Homs in Syria and also to the Kebir in Syria and the Ceyhan and Lower Orontes in southern Turkey. However, the last three are in a region where there has been especially rapid late Quaternary uplift, so that their terraces are widely spaced and archives older than Middle Pleistocene have not survived erosion.

On the Arabian Platform the fluvial archives show a pattern implying alternating episodes of uplift and subsidence, as in the Euphrates in all studied reaches in Turkey and Syria and also in the Middle Orontes at Latamneh, or uplift and stability, as in the Tigris at Diyarbakır. Comparable patterns have been observed previously on crust that has mafic underplating at its base, constricting the overlying mobile layer to a few kilometres thickness and, thus limiting inflow of crustal material beneath uplifting areas and lessening the positive-feedback enhancement of uplift in response to erosion. Archives of this type are prevalent in crustal provinces dating from the Early or Middle Proterozoic, but are also known from younger crust with thick mafic underplating, of which the Arabian Platform is an example.

The fourth preservation pattern of fluvial archives, which is not found in the study region, occurs on cratonic crust of Archaean age and is indicative of complete absence of net uplift during the Quaternary. The nearest example to the NE Mediterranean is found in the northern Black Sea region, in the case of the River Dnieper, as described in the introduction and illustrated in Fig. 3C.

In the Latakia area of NW Syria the interrelated preservation patterns of Mediterranean marine terraces (raised beaches) and River Kebir terraces show that the latter formed during Quaternary cold stages, given that they interdigitate with the former, rather than merging with them.

The contrasting fluvial archives described here reveal the important influences of crustal properties and climatic forcing on valley evolution but do not support the view that Quaternary tectonic activity has had a significant impact on the patterns of preservation that have been recorded. Indeed, the uplift and subsidence that has occurred has generally been isostatically driven, albeit sometimes differentially affecting fault-bounded crustal blocks in such a way as to indicate Quaternary fault movement. The effects of Quaternary tectonic activity are considered more likely to have been disruptive of these patterns, however, as in the Euphrates reach that crosses the Palmyra Fold belt, between Raqqa and Deir ez-Zor.

Acknowledgements:
Work in Syria was funded in part by small grants from the British Council for Research in the Levant and through collaboration with the Syrian National Earthquake Center. The illustrations were drawn by Chris Orton of the Cartographic Unit, Department of Geography, Durham University.

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Figure captions:

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

Figure 2 – The study area of southern Turkey and Syria, showing the location of systems described in the text in relation to crustal provinces and tectonic plate boundaries. DSFZ = Dead Sea Fault Zone; EAFZ = East Anatolian Fault Zone

Figure 3 – The Rivers of the northern Black Sea region (modified from Bridgland and Westaway, 2014; after Matoshko et al., 2002, 2004). A – Map, showing locations of transects B–D in relation to the Ukrainian Shield. B – Idealized transverse profile through the Middle–Lower Dniester terrace sediments, which are inset into Miocene fluvial basin-fill deposits; C. Transverse profile across the Middle Dnieper basin,~100 km downstream of Kiev (~240 km long); D. Transverse profile through the deposits of the Upper Don near Voronezh.

Figure 4 – Idealized transverse profile through the Euphrates terrace sequence between Raqqa and Deir ez-Zor, Syria (see Fig. 2). The stratigraphical locations of Ar–Ar dated basalts, critical for the Euphrates age model, are indicated; Euphrates deposits older than the level

of the Halabiyeh upper gravel are omitted. After Bridgland and Westaway (2014); modified from Demir et al. (2007a, b).

Figure 5 – Idealized transverse profile through the Euphrates terraces in the Birecik area, southern Turkey (see Fig. 2). Holocene flood deposits that overlie the terraces assigned to MIS 6 and 2 (cf. Kuzucuoğlu et al., 2004) are omitted. After Bridgland and Westaway (2014); modified from Demir et al. (2008).

Figure 6 – Idealized transverse profile across the River Tigris at Diyarbakır, SE Turkey (see Fig. 2), showing the disposition of terrace gravels and dated basalts. Heights were obtained by Leica dGPS with reference to Shuttle Radar Topographic Mission imagery (see Bridgland et al., 2012; Demir et al., 2012). After Bridgland and Westaway (2014); modified from Westaway et al. (2009c).

Figure 7 – Longitudinal profile of the River Orontes system, showing the distinctly different records in particular crustal zones (see text for explanation). Note the contrast between terraced reaches, gorge reaches and reaches across subsiding fluvio-lacustrine basins. Normal faults at the edges of the subsided basins are only shown where known in detail. Summaries of post-Early Pleistocene uplift histories of the terraced reaches are also shown. Modified from Bridgland et al. (2012).

Figure 8 – Comparison of the Upper and Middle terraced reaches of the River Orontes in Syria (modified from Bridgland et al., 2012). A - Idealized transverse section through the terrace sequence upstream from Homs (see Fig. 2), showing suggested ages and MIS correlations. B - Idealized transverse section through the terrace sequence of the Hama–Latamneh area (see Fig. 2), showing the thick sequence at the latter location. Suggested MIS correlations are shown. Modified from Bridgland et al. (2012), with data from Besançon and Sanlaville (1993) and Dodonov et al. (1993).

Figure 9 – Cross-section across the Ceyhan valley in the proximity of the Aslantaş Dam, near Dűziçi (Turkey), showing the relation of river terrace deposits to dated basalt lava flows. Modified from Bridgland et al. (2012), with extension to show abandoned valley section and associated terraces.

Figure 10 – Fluvial and marine terraces in the lower valley of the River Kebir, near Latakia, Syria. A – Cross section through the Kebir valley ~10 km upstream from Latakia, showing the relative disposition of the river terraces now identified, as well as the slope deposits that give rise to the (now deleted) Berzine (QIII) terrace level (see text). These same slope deposits form considerable overburden, rich in Palaeolithic artefacts, above the Jinnderiyeh terrace (Bridgland et al., 2008). B – NE–SW longitudinal profile of the Kebir terraces. After Bridgland and Westaway(2014); modified from Bridgland et al., 2008). Note the combination of deformed (interglacial) marine terraces and steeply graded colder-climate gravel terraces, which intersect with the much shallower downstream gradient of the modern (Holocene) valley floor. The deformation of the marine terraces reflects increasing uplift rates in an eastward (inland) direction.

Figure 11 – Longitudinal sections showing variations in heights of Euphrates terraces and associated basalts on the right side (a) and left side (b) of the river in the reach between Raqqa and Deir ez-Zor. Note the effects of active faulting, with increasing deformation with age of terrace. Both projections are oriented N35^{o}W–S35^{o}E with distance measured from an origin at UTM co-ordinates DV 65000 70000; the maximum deformation, at ~km 90–100, is ~10 km downstream of Halabiyeh (see Fig. 2). The French Qf (Quaternary fluvial) notation for terraces is retained, with QfI and QfII identified as distinct features. QfIII is complex; its oldest and highest division is given the temporary designation QFIIIz here, shown in purple, whereas below this are several separate fragments shown in green, various disrupted and also variously interbedded with the lava flows identified in this reach (Modified from Abou Romieh et al., 2009).