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The River Orontes in Syria and Turkey: Downstream variation of fluvial archives in different crustal blocks

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ABSTRACT

The geomorphology and Quaternary history of the River Orontes in western Syria and south-central Turkey have been studied using a combination of methods: field survey, differential GPS, satellite imagery, analysis of sediments to determine provenance, flow direction and fluvial environment, incorporation of evidence from fossils for both palaeoenvironments and biostratigraphy, uranium-series dating of calcrete cement, reconciliation of Palaeolithic archaeological contents, and uplift modelling based on terrace height distribution. The results underline the contrasting nature of different reaches of the Orontes, in part reflecting different crustal blocks, with different histories of landscape evolution. Upstream from Homs the Orontes has a system of calcreted terraces that form a staircase extending to ~200 m above the river. New U-series dating provides an age constraint within the lower part of the sequence that suggests underestimation of terrace ages in previous reviews. This upper valley is separated from another terraced reach, in the Middle Orontes, by a gorge cut through the Late Miocene–Early Pliocene Homs Basalt. The Middle Orontes terraces have long been recognized as a source of mammalian fossils and Palaeolithic artefacts, particularly from Latamneh, near the downstream end of the reach. This terraced section of the valley ends at a fault scarp, marking the edge of the subsiding Ghab Basin (a segment of the Dead Sea Fault Zone), which has been filled to a depth of ~1 km by dominantly lacustrine sediments of Pliocene–Quaternary age. Review of the fauna from Latamneh suggests that its age is 1.2–0.9 Ma, significantly older than previously supposed, and commensurate with less uplift in this reach than both the Upper and Lower Orontes. Two localities near the downstream end of the Ghab have provided molluscan and ostracod assemblages that record somewhat saline environments, perhaps caused by desiccation within the former lacustrine basin, although they include fluvial elements. The Ghab is separated from another subsiding and formerly lacustrine depocentre, the Amik Basin of Hatay Province, Turkey, by a second gorge, implicit of uplift, this time cut through Palaeogene limestone. The NE–SW oriented lowermost reach of the Orontes is again terraced, with a third and most dramatic gorge through the northern edge of the Ziyaret Dağı mountains, which are known to have experienced rapid uplift, probably again enhanced by movement on an active fault. Indeed, a conclusion of the research, in which these various reaches are compared, is that the crust in the Hatay region is significantly more dynamic than that further upstream, where uplift has been less rapid and less continuous.

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1. Introduction

The Orontes ('Asi' in Arabic) is the principal river draining to the Levant coastline of the Mediterranean Sea. From its source in the Bekaa Valley of Lebanon, on the flank of the Lebanon mountain range,

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it flows northwards across western Syria through the cities of Homs and Hama and into Hatay Province, southern Turkey, before turning sharply south-westward to reach the sea ~30 km downstream of Antakya (Fig. 1). In north-west Syria the Orontes forms the axial drainage of the Ghab Basin, a linear valley marking the Dead Sea Fault Zone (DSFZ), the boundary between the African plate (to the west) and the Arabian plate (to the east), along which left-lateral relative plate motion is accommodated (Fig. 1). Upstream of the Ghab Basin, the terrace sequence of the Middle Orontes has been well documented, largely on account of attention from archaeologists interested in its Palaeolithic contents (e.g. Burkhalter, 1933; Modderman, 1964; Clark, 1966a, b, c, 1967, 1968; Van Liere, 1966; Besançon et al., 1978a, b; Besançon and

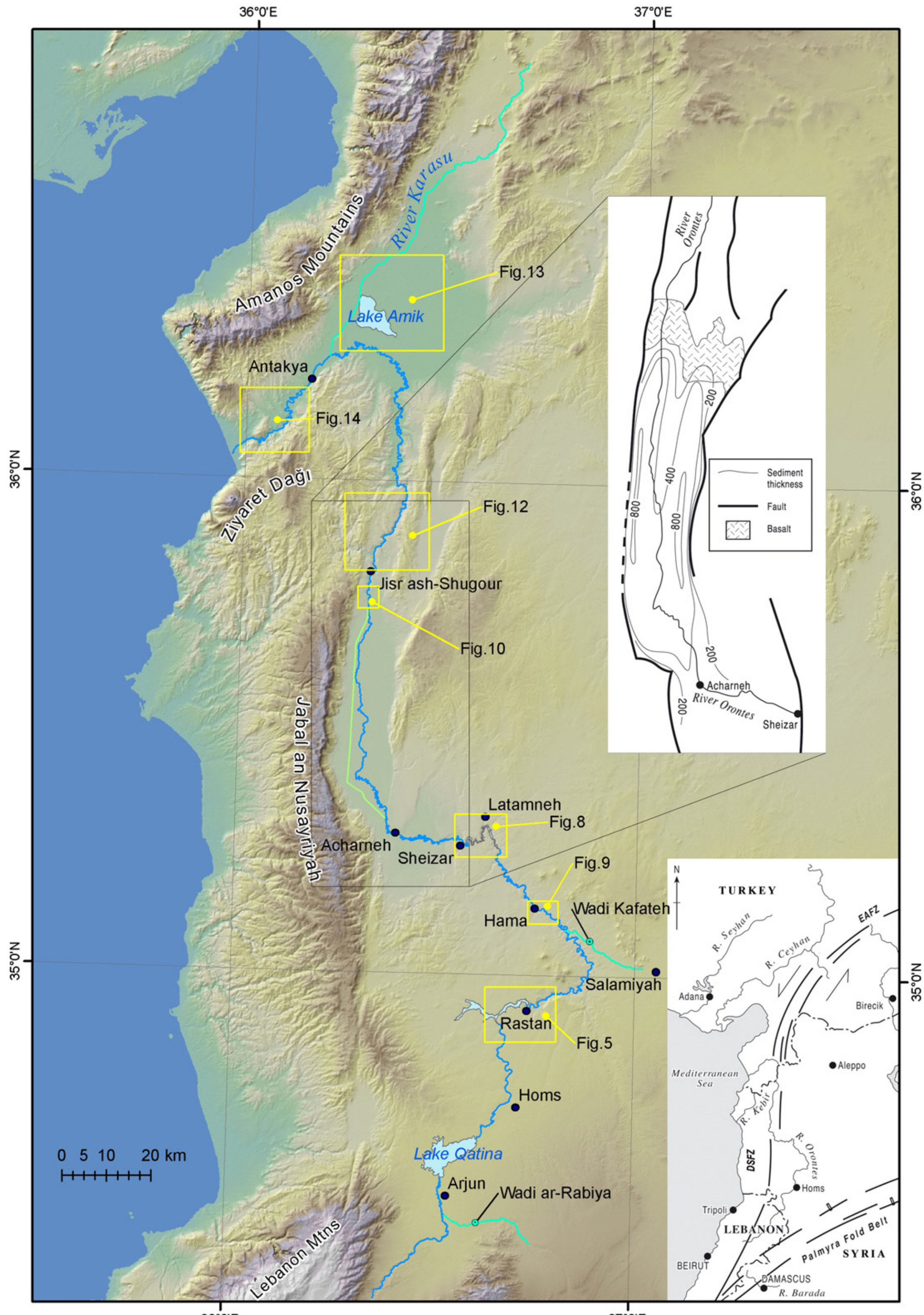


Fig. 1. Course of the Orontes in relation to topography (main image, a DEM derived from SRTM) and structural setting (lower inset). Locations are shown of places described in the paper and of other figures. Abbreviations: DSFZ = Dead Sea Fault Zone; EAFZ = East Anatolian Fault Zone. The upper inset shows the fault control and sediment thickness of the Ghab Basin.

Sanlaville, 1993a; Dodonov et al., 1993; Bartl and al-Maqdissi, 2005). Indeed, the work described here stemmed initially from an archaeological survey of the Homs region (Philip et al., 2005), which included ~700 km^2 of the upper catchment of the Orontes. An extensive sequence of river terraces, previously unrecognized as such, was recorded in the upper Orontes valley as a result of this initiative (Bridgland et al., 2003; Bridgland and Westaway, 2008a). In seeking to obtain a full understanding of the context for this newly discovered long-timescale fluvial record, research on the Orontes was extended downstream and has now been undertaken along the length of the valley between Homs and the Mediterranean, revealing marked contrasts between different reaches. Separating the upper and middle catchments, both of which have terraces, is a gorge, named after the town of Rastan, ~25 km north of Homs. Two further gorges occur: one between the Ghab Basin and the border with Hatay Province and the other downstream of Antakya. Between them is another former lacustrine basin (Fig. 1), occupied until the mid 20th Century by Lake Amik.

This paper relates how multi-disciplinary research has allowed the complex and contrasting records from different reaches of this unusual river course to be reconstructed and reconciled one with another. Methods have included field survey, recording and analyses of fluvial sediments, remote surveying of fluvial landforms (both depositional and erosional) and the use of Geographical Information Systems (GIS) techniques to obtain height data (of considerable value in areas remote from known-height markers such as bench marks). Also valuable has been the study of the fossil and artefact contents of the Orontes deposits, which have provided information on palaeo-environments and possible ages. In addition, the incision recorded by river terraces, which is interpreted as a response to uplift, can be modelled mathematically against time, using computer programs designed for the purpose (Westaway, 2002, 2004a; Westaway et al., 2002). These take account of forcing mechanisms that affect the rate of uplift, which are considered to be driven by climatic fluctuation and linked to surface processes, with the aim of providing an age framework for the interpretation of terrace sequences (Bridgland and Westaway, 2008a, b; Westaway et al., 2009a). This approach has been applied previously to the upper Orontes terrace sequence (Bridgland et al., 2003; Bridgland and Westaway, 2008a; see below).

The aim of the paper is to establish age-related stratigraphical frameworks for those reaches with accessible sedimentary evidence, in the form of river terraces, by pooling the available evidence and applying the most appropriate of the above-mentioned techniques. This will allow correlation and comparison between these reaches and also demonstrate the contrast with reaches in which terraces have not been developed. The importance of these findings is that they can be related to different histories of valley evolution in different reaches, corresponding with separate crustal blocks, for which the causes can be discussed in terms of crustal deformation.

2. Survey methods

Orontes river terraces have been mapped previously between Rastan and the Ghab Basin, based on surveys by geologists and archaeologists in the 1970s and 1980s (Besançon et al., 1978a, b; Besançon and Sanlaville, 1993a; Dodonov et al., 1993). The resultant maps, although detailed, have been found to simplify the complexity of the terrace sequence and to be heavily dependent on geomorphology, with little attention paid to underlying fluvial sediment bodies. Nonetheless, these pre-existing maps represent an excellent resource and, with 'ground-truthing', are superior to anything yet produced in most other reaches, where the more recent surveys conducted by the authors are, by comparison, rudimentary. The only other reach of the Orontes that has hitherto been documented in comparable detail is that between Antakya and the coast, described by Erol (1963). Given the constraints of research visits of limited extent, the recent surveys have relied on a combination of different GIS resources, with field surveys designed to determine the terrace sequence at key points along the course. The locations of these were often determined by accessibility and permissions, although published sources of Palaeolithic and palaeontological evidence were targeted for investigation and re-survey, and searches for new data of these types were undertaken wherever possible.

New and supplementary mapping, including topographic information, has made use of differential global positioning system (dGPS) equipment, specifically Leica System 300, operated in static survey mode, with reference to temporary base stations on high points and to known heights such as bench marks. Optimal results were obtained when the roving station occupied each survey point for at least 100 two-second recording epochs and in cases where such points were not more than 50 km from the base station. Under favourable conditions, however, the technique has been shown to work satisfactorily with the base station and roving stations up to 100 km apart (cf. Demir et al., 2009, 2012-this issue). At certain locations, with limited sky visibility, it was necessary to survey to a point in the open and calculate the distance and height difference, the latter making use of an Abney level. In the earlier surveys, generally those in the Upper Orontes, the dGPS data were processed using Leica SKI v2.3 software. Later survey data have been processed using Leica GeoOffice (version 4.1, 5.0 or 5.1), which incorporates an improved algorithm for eliminating phase ambiguities in its differential GPS solutions (in part because it uses a different approach for treating propagation delays of GPS signals through the ionosphere) and generally provides better data resolution. Where original dGPS raw output had been retained it proved possible to reprocess older data with this improved software but, unfortunately, since the provision of improved software had not been foreseen, much of the Upper Orontes survey output had been retained only in processed form.

GIS resources have included satellite imagery, with emphasis on CORONA high-resolution photographic images from 1960–1972, before the large-scale expansion of agriculture (Galiatsatos et al., 2008), and shuttle radar topographic mission (SRTM) altimetry. Since the 1995 declassification of CORONA (KH-4), it has been thoroughly studied and used in many applications, mostly related to change detection, and photo-interpretation (e.g. Galiatsatos, 2004, 2009; Sohn et al., 2004; Dashora et al., 2007). The archaeological community has shown a keen interest in CORONA, particularly in areas where it is difficult to obtain detailed historical photography, such as the Near East. For the Homs Survey area a digital elevation model (DEM) is now available, obtained from CORONA and ground-truthed by dGPS. The research reported here has also used satellite imagery from the Fragile Crescent Project, a large-scale archaeological investigation of the Middle East (Galiatsatos et al., 2009). In addition to CORONA, the project took advantage of a GAMBIT image that was acquired on 25 April 1966 in the area of Hama. GAMBIT (or KH-7) was, like CORONA, a spy satellite program; it flew 38 missions from July 1963 to June 1967 and was declassified in 2002. It has a spatial resolution of 0.6–1.2 m but, as the relevant documentation remains classified, little is known about the camera system.

Of four versions of SRTM data, Version 1 is the 'raw' data, Version 2, used in the present study, is the result of editing for water bodies and the removal of spikes and wells, whereas Versions 3 and 4 were created and distributed by the CGIAR Consortium for Spatial Information and include improvements in the filling of voids. The SRTM data used (cf. JPL, 1998a, b, 2005) have a resolution of 3 arc seconds of latitude, or roughly 90 m, with a global vertical accuracy of better than 10 m, and horizontal accuracy of ~10 m, depending on the relief of the ground (Rodriguez et al., 2006). However, various applications from Hungary (Kay et al., 2005), Portugal (Gonçalves and Fernandes, 2005) and Turkey (Jacobsen, 2005; Westaway et al., 2006, 2009b; Demir et al., 2012-this issue) have demonstrated a vertical accuracy of better than 5 m in a variety of terrain. Data of this type provide a particularly valuable source of height information for parts of the world where large-scale topographic maps are not readily available; they can be rendered as DEMs in a range of formats using standard GIS techniques. Throughout this study, satellite imagery and imagery generated from SRTM data are displayed using Universal Transverse Mercator (UTM) co-ordinates expressed using the WGS-84 datum; the same co-ordinate system is therefore used for reporting co-ordinates of field sites.

2.1. Supplementary geological techniques

A technique of assistance in terrace surveys is clast-lithological analysis of gravels. This has been particularly valuable for identifying Orontes deposits and distinguishing them from the products of local (tributary) rivers. Clast analysis of cemented gravels, which are common in certain reaches, was, of necessity, conducted in the field. A cardboard sieve plate was used to estimate clast size in order to count only pebbles between the desired sizes of 16 and 32 mm (a recommended standard size range for such analyses: Bridgland, 1986). This works well enough where gravel components, such as the limestones and flints/cherts that characterize the Orontes in Syria (Table 1), are readily distinguished in outcrop, so analyses can be carried out with the aid of a hand lens, a small knife to determine hardness, 10% HCl for confirmation of calcareous lithologies and a suitable pen to mark clasts as they are counted. In reaches where the Orontes gravels were less consolidated it was possible to collect gravel samples and identify loose clasts, although the difficulty and expense of transporting heavy samples meant that analyses were still conducted during fieldwork; with bagged samples this could take place during evenings or even during journeys between locations, optimizing field time for mapping and making records of sections. Downstream of Hama the Orontes gravels become completely dominated by flint (Table 1), there being a rich source of brown flint in the Upper Cretaceous chalk and chalky limestone, through which the river has incised (Clark, 1967), although flint has also been reported in Palaeogene limestones in the region (Ponikarov, 1986). This flint has provided the raw material for the Palaeolithic industries that are well represented in the gravels of this reach, and which first drew the attention of researchers to the Orontes system (e.g., Clark, 1966a, b, 1967; Muhesen, 1985; Copeland and Hours, 1993; Shaw, 2008, in press). The relative monotony of the Middle Orontes gravels, however, means that their analysis is of less value here. Further downstream, in Hatay, the gravels consist largely of crystalline rocks from the local area, including the Hatay ophiolite (latest Cretaceous), supplemented by further travelled material from the Amanos Mountains to the north of Antakya, derived by way of the River Karasu, a right-bank Orontes tributary (Fig. 1; Table 1).

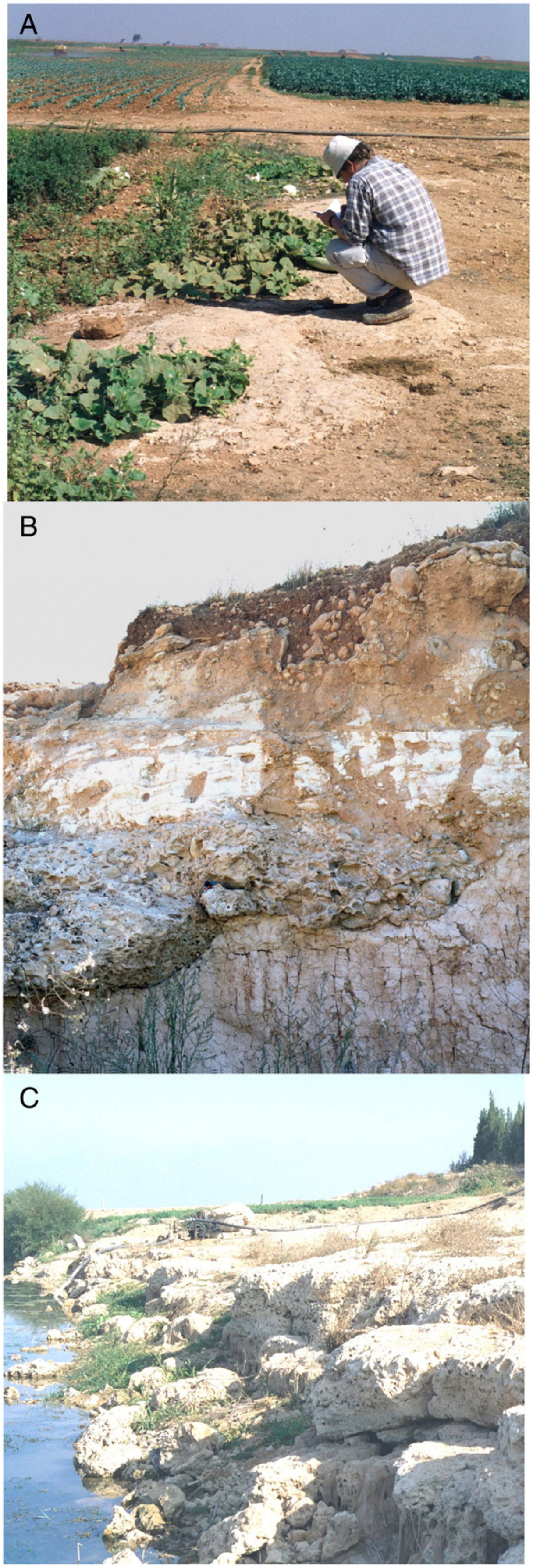
3. Upper Orontes: Lebanon border to the Rastan Gorge

The open, low-relief landscape of the Upper Orontes (Fig. 2A), upstream of the Rastan Gorge, is floored by Neogene lacustrine marl of inferred ‘Pontian’ (latest Miocene) age (Dubertret and Vautrin, 1938). This marl is interbedded with the Late Miocene–Early Pliocene Homs basalt, for which recent re-dating using the Ar–Ar technique indicates an age range of ~6–4 Ma (Searle et al., 2010; Westaway, 2011), superseding earlier whole-rock K–Ar dating that gave generally older (~8–5 Ma) numerical ages (Mouty et al., 1992; Sharkov et al.,

Table 1
Gravel clast lithology counts from deposits attributed to the River Orontes and related systems (in approximate downstream sequence).

Reach	Site	Coordinates	Chert and flint	Limestone	Voids	Quartzite	Basalt	Coarse basaltic	Ophiolite	Others	Total count
Upper Orontes	Al Hauz[a]	BU 73478 28799	53.5	36.0	10.5						275
	Arjun Quarry[b]	BU 74580 25832	33.6	66.4							256
	Al Hussainiyeh	BU 90236 27562	37.9	62.1							253
	Dmaynah[a]	BU 87074 28915	65.9	33.7	0.4						258
	Um al-Sakhr[a]	BU 86728 31399	28.1	56.6	15.2						256
	Tir Mala[a]	BU 90149 53013	60.4	38.5	1.1						273
Wadi ar-Rabiya	Motorway[c]	BU 93392 14769	11.6	85.2						3.2	250
	SE of Al Qusayr[d]	BU 80187 19083	12.9	87.1							255
Middle Orontes	Rastan[e]	BU 93451 66988	40.7	45.8						13.4	253
	Jnan[f]	CU 02201 85047	29.0	71.0							276
	Ain Kassarine[g]	CU 01128 88403	61.5	37.8			0.4			0.4	275
	Latamneh south[h]	BV 83384 09911	27.7	70.8			1.2			0.4	253
	Latamneh Lower[i]	BV 83022 10451	99.2	0.8							251
	Latamneh Upper[j]	BV 83021 10459	99.6			0.4					276
Ghab	Karkour sluice[k]	BV 57282 59073	96.6	3.4							268
Darkush	Gorge[l]	BV 63445 77174	0.7	99.3							149
Amik	Alaattin Köyü[m]	BA 52477 15506	9.8	73.9		0.7	10.1	3.1	0.4	1.8	287
Lower Orontes	Antakya bypass[n]	BA 41382 06943	0.4			1.1	29.8	51.6	14.4	2.9	285
	Şahin Tepesi[o]	BV 38313 99525	1.7	7.0		1.0	42.4	40.4	2.6	5.0	302

[a] Voids probably represent dissolved limestone clasts.
[b] See Fig. 4B.
[c] Others are calcareous sandstone (2.4%) and marl (0.8%).
[d] Chert includes one worked flake.
[e] Gravel also contains boulders of basalt, highly weathered; voids might represent smaller basalt clasts (weathered away) as well as dissolved limestones.
[f] Basalt clasts are conspicuous at larger sizes.
[g] Others = 1 x calcareous sandstone.
[h] Sample was collected from a disused small quarry between Latamneh village and the River Orontes, at a lower level than and ~600 m southeast of the extant Latamneh quarry; the flint includes two worked flakes and four banded cherts of Upper Orontes type; others = 1 weathered bone fragment.
[i] Sample was collected from the lower gravel in the extant' Latamneh quarry; flint includes three worked flakes.
[j] Sample was collected from the upper gravel in the extant Latamneh quarry; flint includes two worked flakes.
[k] Flint includes four cherts of Upper Orontes type.
[l] Undersized sample from valley-floor gravel beneath loam, collected at Hammam ash Sheykh Isa, between Jisr esh-Shugur and Darkush.
[m] Ophiolite includes a single clast of amphibolite; others includes two clasts of weathered schist and a single pottery fragment (?Roman or similar). The schist probably originated in the Amanos Mountains to the north, having been worked into the Amik Basin by the River Karasu. Other constituents of this gravel, such as limestone, quartziite and basalt, may have shared this provenance.
[n] Others are kaolinized crystalline rocks (2.5%) and a single vein quartz (0.4%).
[o] Sample collected from a flat overlooking the left bank of the Orontes apparently from a tributary deposit]; others are weathered crystalline, perhaps related to ophiolite; ophiolites include chert (0.7%), weathered foliated rock (0.7%), schistose with serpentine (1.0%) and olivine-rich ultramafic (0.4%).



1994; Butler and Spencer, 1999). Boreholes east of Homs confirm that marl occurs both above and below the Homs Basalt (Ponikarov et al., 1963a; Fig. 3), suggesting that lacustrine conditions (possibly caused by the damming of proto-Orontes drainage by the earliest basalt eruptions) persisted into the Pliocene. It is also evident, from its interbedding with the marl and from pillow lava formation, seen at a number of localities to the north of Homs, that the Homs Basalt erupted into the 'Pontian' lake.

The Quaternary record of the Upper Orontes received little attention prior to the Homs Survey, although Van Liere (1961) alluded to Neogene–Pleistocene conglomeratic sediments that he attributed to braided fans; these can now be interpreted as (cemented) Quaternary river terrace deposits (Bridgland et al., 2003; Bridgland and Westaway, 2008a; Fig. 2). The eastern valley side of the Orontes in this region slopes gently from >750 m a.s.l. (above sea level) to river level at 480–510 m, over a distance of ~15 km, within which is preserved an extensive sequence of Late Cenozoic terraces (Fig. 4). In the marl areas these are represented by localized but conspicuous chert/flint-rich conglomerates, densely cemented by carbonate, of the type noted by Van Liere (1961); occasionally these record the three-dimensional form of fluvial channels (Fig. 2B), which suggests that they represent 'channel calcretes' (cf. Wright and Tucker, 1991; Nash and Smith, 1998, 2003; McLaren, 2004). The conglomerates are rarely more than ~1 m thick, which has allowed farmers to displace them from field surfaces to boundary lines or informal clearance cairns. In situ conglomerates are seen in occasional quarry sections and road cuttings, or in surface outcrop amongst farmland where they have proved too difficult to remove; they are also seen frequently in the sides or beds of unpaved tracks, such outcrops having been the basis of much of the terrace mapping in the Upper Orontes (Bridgland et al., 2003). In exposure the conglomerates are seen to be interbedded with finer-grained alluvial sediments (Fig. 2B) in sequences showing fluvial bedding structures. The recognition of these conglomerates as Orontes terrace gravels is confirmed by the occurrence of the most extensively preserved conglomerate forming a low-level right-bank terrace (the al-Hauz Terrace), which can be traced for several kilometres beside the river upstream of Lake Qatina (Bridgland et al., 2003; Figs. 1, 2C, 3 and 4). Sections in the cemented Orontes gravels show that their uppermost levels, especially where they are immediately below the land surface, have generally been decalcified, with prominent 'pipe' structures reaching depths of a metre or more (Fig. 2B; online supplement, Fig. A.1.1).

A single example of channel calcrete has been analysed in some detail, in part to determine the potential for dating the calcite cement using the uranium-series method (e.g. Ivanovich et al., 1992; see below). Samples of the cemented channel-fill gravel at Arjun (Fig. 2B) were subjected to petrological and geochemical analyses, which revealed evidence for two phases of calcite cement precipitation. The first, fine grained and brown in colour, was restricted to occasional and sometimes fragmentary pebble coatings, only intermittently present and lacking any preferred orientation. The second, in contrast, was pinkish grey and filled interstices within a clast-supported sandy, silty matrix, thus forming the bulk of the calcrete cement (see online Appendix 2). The fabric of the conglomerates forming the higher (and therefore older) terraces has been considerably modified by repeated decalcification and re-cementation; clasts

A

B

C

Fig. 2. The Upper Orontes valley, field photographs: A — Typical exposure of cemented gravel in the land surface beside a rural road (at BU 75492 26442), showing the subdued relief of the Upper Orontes terrace staircase (looking northwards); this deposit is ~520 m a.s.l. and is interpreted as forming part of the Tir Mala terrace (Fig. 4; Table 2). B — Section at Arjun, showing lower cemented gravel filling a channel cut in (much softer) Pliocene marl bedrock, overlain by calcified fine-grained fluvial sediments, with post-cementation solution structures. The calcreted channel gravel illustrated here was sampled for U-series dating (see online Appendix 2).C — Cemented gravels of the lowest (al-Hauz) terrace of the Orontes, exposed in the right bank of the river at the type locality, ~25 km south-west of Homs.

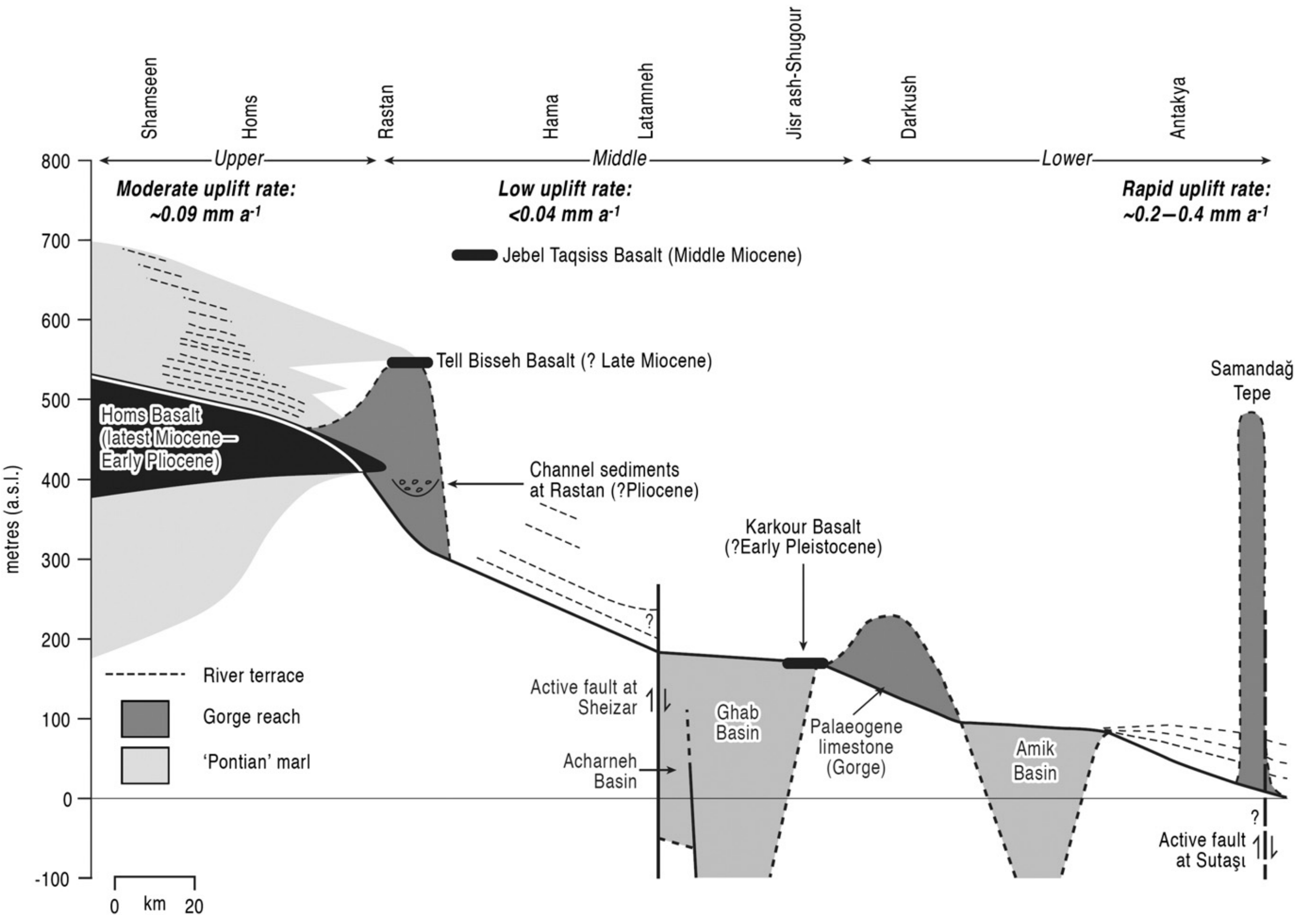


Fig. 3. Schematic long profile of the Orontes valley floor and its terraces in relation to gorge reaches, subsiding fluvio-lacustrine basins and basalt flows. Summaries of pos-Early Pleistocene histories of the terraced reaches are also shown (for explanation, see text).

(presumably calcareous ones) have been weathered out to leave cavities, sometimes partly filled with re-precipitated calcium carbonate. This means that the fluvial bedding structures are best preserved in the younger conglomerates, such as those forming the Arjun and al-Hauz terraces (Figs. 2C and 4).

Bridgland et al. (2003) reported Orontes terrace deposits at up to 130 m above the modern river (Table 2). They constructed an age model for this sequence, assuming climatically generated terrace formation in approximate synchrony with 100 ka (Milankovitch) climatic fluctuation (cf. Bridgland, 2000; Bridgland and Westaway, 2008a) and using a correlation, based upon height above the modern river, with the sequence in the Middle Orontes, for which there is vertebrate biostratigraphical evidence (see below). Further consideration of the palaeontological evidence, however, indicates that the age model used in 2003 was a significant underestimate (see below). Subsequent attempted U-series dating of the Arjun channel calcrete (see above) has provided an adjusted age pinning point for the Upper Orontes terrace staircase, albeit rather low in the sequence. Different U-series age estimates were obtained for the brown pebble coating s and the pinkish-grey interstitial cement: >350,000 years for the former and 157,000 ± 31,000 years for the latter (see online Appendix 2). The pebble coatings are interpreted as reworked older cement that was already present on clasts derived from older gravels within the sequence. It is considered, therefore, that the age of the interstitial cement is more representative of the channel gravel. It should be noted that channel calcretes form in active (semi-arid) fluvial environments, by infiltration of calcareous water into recently deposited underlying sediment, so there is every reason to believe that the cement was precipitated during the same geological episode as the gravel (cf. Nash and McLaren, 2003; McLaren, 2004).

The basal channel gravel at Arjun is thus attributed to Marine oxygen Isotope Stage (MIS) 6, rather than the MIS 4 age favoured by Bridgland et al. (2003). A comparison of the earlier 2003 and revised age models is provided in Fig. 4. An important implication of the revision is that uplift has been significantly less rapid than previously supposed: 85 m since MIS 22, instead of 97 m (see Fig. 4).

Fieldwork in 2002–3, reported here for the first time, has revealed that the Upper Orontes terrace staircase extends higher than was reported by Bridgland et al. (2003), the highest gravel remnants being found in cuttings along the Homs–Damascus motorway as it crosses the interfluve between the Orontes and its prominent tributary, the Wadi ar-Rabiya (Fig. 1). The oldest gravels occur in the vicinity of Shamseen (at BU 925240), the highest being south of the village (BU 2930 3821), ~700 m a.s.l. and ~180 m above the level of the modern Orontes (Fig. 4). Mapping of in situ fluvial conglomerates has revealed at least fifteen Upper Orontes terraces (Figs. 3 and 4), although the wider vertical gaps between the higher terrace remnants suggest that others await discovery or have been removed by erosion.

The Upper Orontes gravels are characterized by two main rudaceous components: (1) flint and/or chert, highly variable in character, and (2) limestone. The siliceous rocks are believed to have been derived both from the valley sides (from Cretaceous and Palaeogene flint-bearing strata) and from upstream in the Orontes catchment, whereas the limestone probably represents Cretaceous–Miocene occurrences in the wider region (e.g. Ponikarov et al., 1963a). The limestone component varies from approximately one third of the

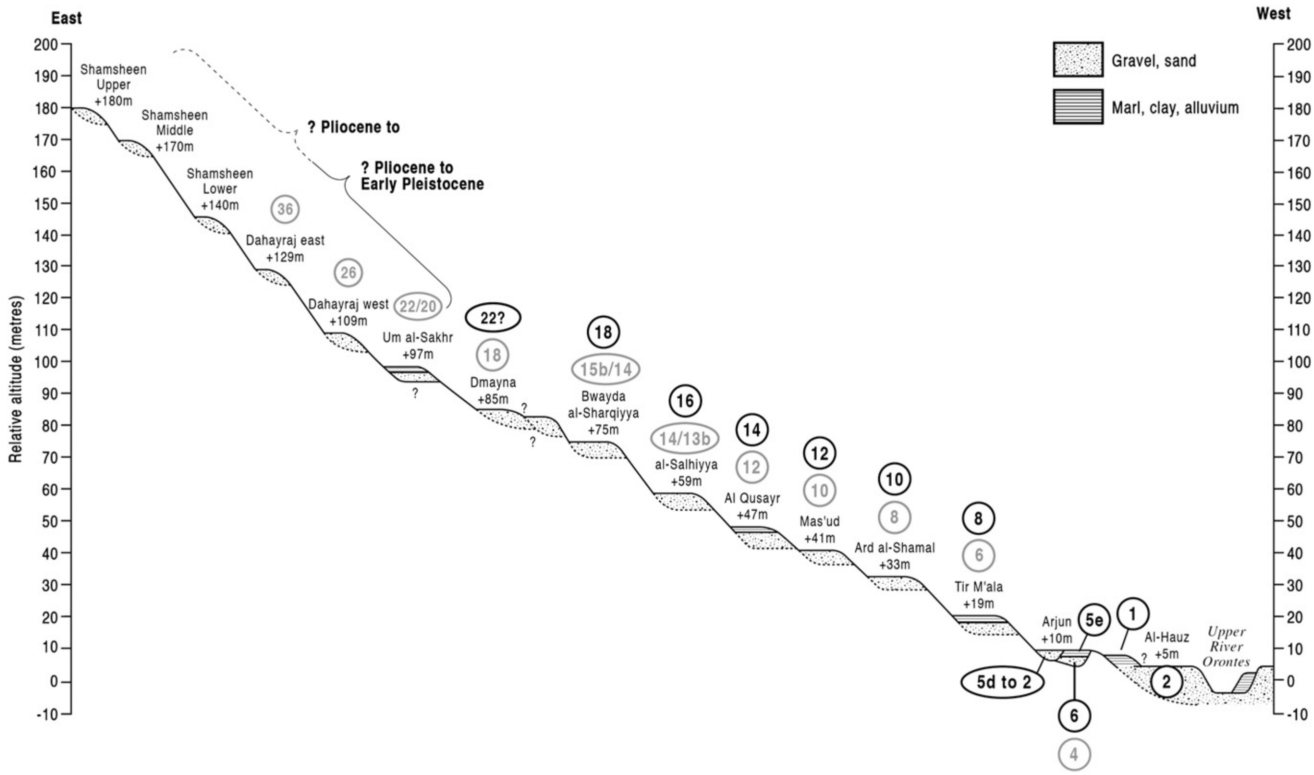


Fig. 4. Idealized transverse section through the terrace sequence upstream from Homs (after Bridgland et al., 2003, with modifications). MIS attributions suggested by Bridgland et al. (2003) are shown, together with correlations of the older terraces now suggested (see text).

(16–32 mm) total to nearly three-quarters (counting voids as limestone clasts removed by solution: see above and Table 1). Thus the siliceous lithologies never fall below 25% of the total count in those Orontes gravels analysed (Table 1). Substantial gravels have also been produced by the Wadi ar-Rabiya (Fig. 1); calcreted gravels, presumably from the last climate cycle, are well exposed in a wadi-floor quarry (BU 85311 19993). These wadi gravels, however, are invariably dominated by limestone clasts, although up to 14% flint/chert occurs in them (Table 1), presumably reworked from the older Orontes terraces, across which the tributary has flowed. Thus, clast analyses can be used as a means of distinguishing the deposits of the main river, with their larger siliceous component.

4. The Rastan Gorge

The gorge at Rastan reflects the lateral constriction of the river in its passage through the relatively resistant Homs Basalt. The puzzling disposition of the gorge close to the eastern margin of the basalt outcrop (Fig. 5) suggests that the course of the Orontes here has been superimposed from a valley originally developed in less resistant overlying marl. Indeed, the basalt is known from borehole data (Ponikarov et al., 1963a) to have an eastward inclination, which suggests that its exhumation from beneath overlying marl will have caused the cessation of the westward migration of the river exemplified by the distribution of terraces further upstream. Geological

Table 2
Upper Orontes terrace stratotypes and other key localities, numbered sequentially. To obtain accurate positioning, co-ordinates of sites were measured in the field using a portable GPS receiver, and are expressed as 8- or 10-digit grid references using the Universal Transverse Mercator (UTM) system. Height information has been obtained from dGPS and/or SRTM topographic imagery.

Terrace	Type locality (UTM coordinates)	Above river	Height a.s.l.	MIS 2003[1]	Revised MIS
al-Hauz	Right bank of the Orontes (BU 7345 2783)	5 m	506 m	2	2
Arjun	Quarry (BU 7458 2573)	10 m	512 m	5 d–2	6–2
Tir M'ala	Bluff exposure (BU 9023 5296)	19 m	471 m	6	8
Ard al-Shamal	Surface exposure (BU 7762 2598)	33 m	534 m	8	10
Mas'ud	Surface exposure (BU 7877 2570)	41 m	542 m	10	12
Al Qusayr	Surface exposure (BU 7918 2288)	47 m	551 m	12	14
al-Salhiyya	Surface exposure (BU 8209 2876)	59 m	552 m	14 or 13b	16
Bwayda al-Sharqiyya	Surface exposure (BU 8482 3052)	75 m	567 m	16 or 15b	18
Dmayna	Bluff exposure (BU 8512 2897)	85 m	580 m	18	?22
Um al-Sakhr	Quarry (BU 8673 3142)	97 m	584 m	22 or 20	–
Dahayraj West	Surface exposure (BU 8537 2249)	109 m	613 m	26	–
Dahayraj East	Surface exposure (BU 8846 2614)	129 m	625 m	36	–
Shamseen Lower	Surface exposure (BU 91260 28896)	~140 m	637 m	–	–
Shamseen Middle	Surface exposure (BU 92897 22448)	~170 m	689 m	–	–
Shamseen Upper	Surface exposure (BU 93026 21473)	~180 m	698 m	–	–

Notes: 1 — MIS correlations proposed by Bridgland et al. (2003). Information from more recent research suggests that ages have been underestimated (see revised MIS column).

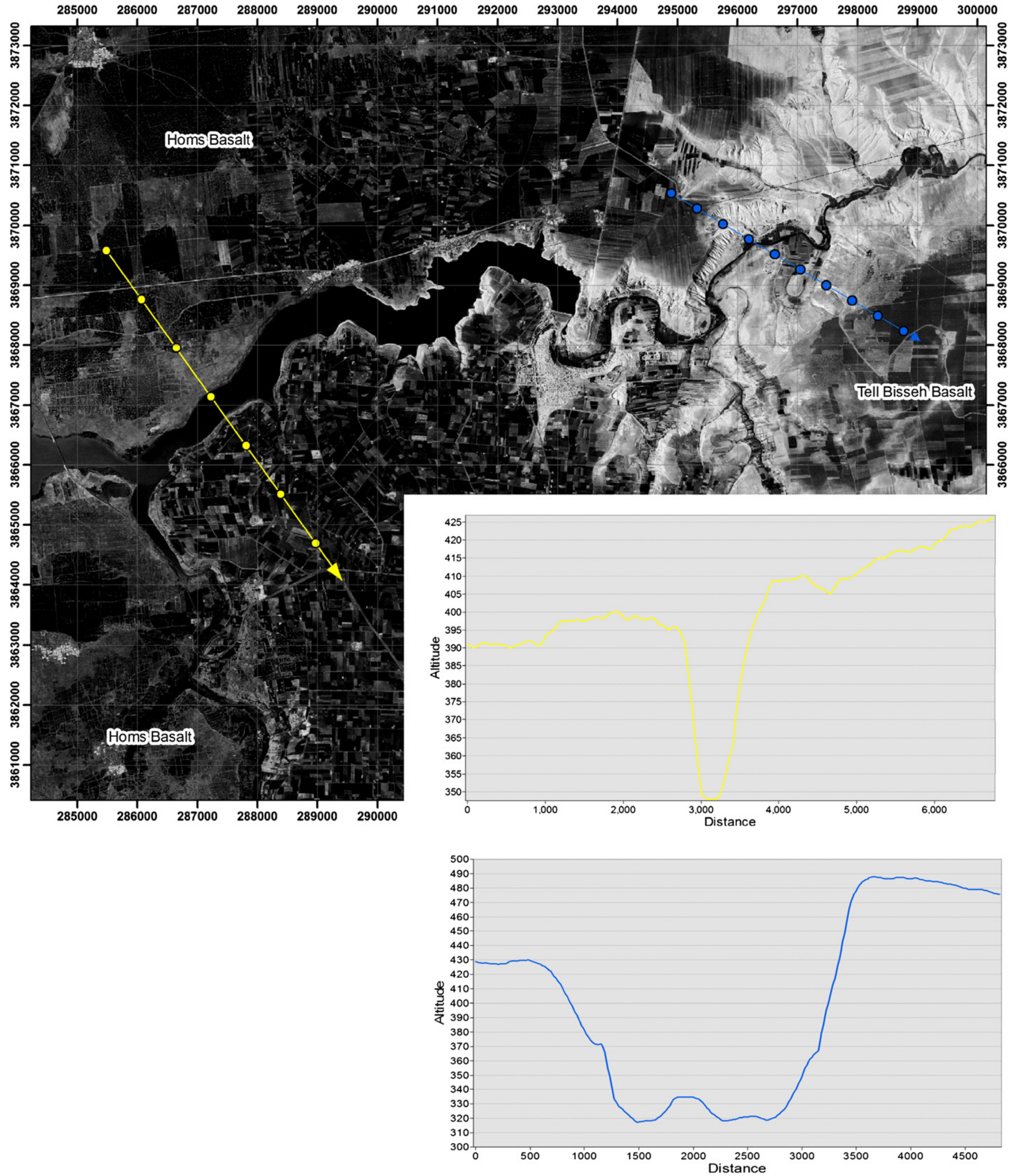


Fig. 5. The Rastan Gorge. This is a CORONA image from the 1960s, with derived transverse profiles (colour coded). Positions of the two basalts, of different age, are indicated (see text). The westernmost (upper) cross section is located on the Homs Basalt on both sides of the river, whereas the easternmost (lower) cross section shows the higher Tell Bisseh Plateau on the right bank of the river.

mapping (Ponikarov et al., 1963a) indicates that a flow unit of Homs Basalt reached the Rastan area from the main outcrop west of the Orontes valley. Its main outcrop, on the north side of the valley, reaches a location ~2 km north-east of Rastan (~ BU 940700), where its upper surface is ~420 m a.s.l., dying out just east of the point where the gorge is crossed by the Damascus–Aleppo motorway viaduct. A smaller basalt outcrop south of the river, also depicted on the 1963 geological map, reaches ~1 km west of Rastan (~BU

Fig. 6. Terraces of the Middle Orontes: A — View looking downstream from CU 02087 83210, a location on the inside of a meander loop on the left (west) side of the Orontes, ~10 km south-east of Hama. Landforms on this side of the valley hereabouts were mapped by the French as part of their numbered 'glacis' and terrace system but clearly developed in bedrock, rather than being a depositional features (see text). On the right skyline is a basalt-capped mesa (a volcano), which is ~10 km distant, with its summit at CU 034927. B — Surface exposure in cemented gravel at CU 09511 78980, ~410 m a.s.l. (>100 m above modern river level). The view is northward, looking across the valley of an Orontes tributary, the Wadi Kafat, towards the basalt-capped plateau in the distance, from a point ~3 km east of the modern river. C — Limestone fan gravels at the Khattab 2 locality (see also online supplement, Fig. A.1.4; see text for explanation). The gravels are exposed in the bluffs beneath the building on the skyline.

920680), where it is ~400 m a.s.l. This outcrop is both overlain and underlain by the 'Pontian' marl; however, the overlying marl is locally no more than a few tens of metres thick, although its above-basalt thickness increases southwards to ~100 m in the Homs area (Fig. 3), according to borehole data compiled by Ponikarov et al. (1963a). The larger outcrop on the north side of the valley is underlain by the marl, but any overlying marl has been lost to erosion. The Orontes is locally ~320 m a.s.l.; the ~100 m depth of the Rastan Gorge below the top of the basalt and overlying marl, determined from GIS data (Fig. 5), thus provides a measure for fluvial incision in the ~4–5 million years since the basalt eruption and cessation of marl deposition. Fluvial deposits reported by Bridgland et al. (2003) in the southern approach cutting to the Rastan motorway viaduct (online supplement, Fig. A.1.2) are at roughly the same height as the basalt south of the river and thus (rather than the early Middle Pleistocene age previously suggested) probably indicate the Early Pliocene level of the Orontes.

On the southern side of the river, ~4–12 km downstream of Rastan, an older basalt has been exhumed from beneath the marl to form the capping of the Tell Bisseh Plateau (Figs. 3 and 5), up to 550 m a.s.l.; it is mapped as Upper Miocene (Ponikarov et al., 1963a), although it has not been dated directly. Furthermore, higher-level basalts further downstream, in the Middle Orontes, have yielded Middle Miocene ages (Sharkov et al., 1994; see below).

5. Middle Orontes: Rastan to the Ghab Basin

For much of its length, the Middle Orontes forms a deep valley up to 400 m below a succession of flat-topped hills capped with basalt mapped as Upper Miocene (comparable with that capping the Tell Bisseh Plateau, noted above: Ponikarov, 1986); the highest of these, Jebel Abou Dardeh and Jebel Taqsiss, reach 682 and 685 m a.s.l., according to Besançon and Sanlaville (1993a). The river loops east of Jebel Taqsiss, north of Rastan, and then turns northwards, flowing to the west of other mesas in the area north and east of Hama (see Fig. 6A and B). Sharkov et al. (1994) obtained whole-rock K–Ar dates of 17.3 ± 0.6 and 12.8 ± 0.6 Ma for basalt samples from Jebel Taqsiss, implying eruption in the Middle rather than the Late Miocene, as well as 12.0 ± 0.5, 10.8 ± 0.3, and 7.8 ± 0.3 Ma for basalt samples from the area north-east of Hama. It is now apparent, however, that K–Ar dates of this whole-rock type frequently result in numerical ages that are significantly older than the true age of the volcanism, as a result of inherited argon in phenocrysts (Kelley, 2002); this problem, alluded to above in relation to the Homs Basalt (Westaway, 2011), raises doubts about the accuracy of the above ages. Nonetheless, it is apparent, from its relation with the Pontian lacustrine marl, that the Tell Bisseh Plateau Basalt is older than the latest Miocene–Early Pliocene Homs Basalt. It is also clear that the basalts capping Jebel Taqsiss and the mesas north and east of Hama (also mapped as Upper Miocene) belong to the older group, although determining whether they represent a single eruptive phase must await future dating. Bridgland et al. (2003) were thus incorrect in their correlation of the Jebel Taqsiss and Homs basalts, with the inference that the whole ~400 m of entrenchment of the Middle Orontes had developed since the Early Pleistocene. On the contrary, it is now clear that the Middle Orontes valley is of much greater antiquity, apparently dating back at least to the Middle Miocene, with the implication that fluvial incision has been correspondingly slower than was previously supposed. The basalt-capped mesas of the Middle Orontes valley are formed in Palaeocene–Eocene nummulitic limestones, lying to the north of the latest Miocene lacustrine basin (Van Liere, 1961).

The fluvial sediments of the Middle Orontes have been studied since the early 1930s (Burkhalter, 1933), although a major catalyst for research in this area was the discovery of an extensive mammalian fossil assemblage in gravel quarries ~1.5 km south of the village of Latamneh (Van Liere, 1960; Hooijer, 1961, 1965; Fig. 1; see below). This led to a series of excavations in which unabraded Lower Palaeolithic artefacts were recovered from fine-grained fluvial deposits overlying the gravels containing the vertebrate fauna (e.g., Modderman, 1964; Clark, 1967, 1968). Latamneh is the single major source of fossils in the Middle Orontes and provided the vertebrate biostratigraphical evidence used by Bridgland et al. (2003), by extrapolation upstream, as an age indicator for their Upper Orontes sequence (see above). In addition, a tooth of the ancestral mammoth *Mammuthus meridionalis* was reported from a gravel quarry at Sharia, east of Hama (Van Liere and Hooijer, 1961), in an area subsequently built over during the expansion of the city. This contrasts with the teeth of the more evolved mammoth *Mammuthus trogontherii* from Latamneh (e.g. Van Liere, 1960; Hooijer, 1961, 1965), ~25 km downstream of Hama (Fig. 1).

During the late 1970s and early '80s a team from the French Centre National de la Réchèrche Scientifique (CNRS) instigated a survey of Pleistocene deposits in the Middle Orontes valley in order to place the discoveries from Latamneh within a local chronostratigraphical sequence (Besançon et al., 1978a, b; Besançon and Sanlaville, 1993a; Copeland and Hours, 1993). This led to the discovery of Lower and Middle Palaeolithic artefacts at a number of localities and the identification of a sequence, above the valley-floor alluvium, of up to five terraces, as follows (from Besançon and Sanlaville, 1993a):

Qf0	Floodplain and Holocene alluvium of the valley bottom
QfI	Lowest Pleistocene terrace; ~10 m above river
Qf II	Second Pleistocene terrace; ~25 m above river
QfIII	Third Pleistocene terrace; includes Latamneh; 30–60 m above river
QfIV	Fourth Pleistocene terrace; ~80 m above river
QfV	Highest Pleistocene terrace

(Note: the 'f', for fluvial, as opposed to 'm' for marine, was not always used).

The CNRS team mapped these five terraces along the Orontes from the Rastan Gorge to the southern end of the Ghab Basin, with preservation distributed on both sides of the valley, although QfV was identified as an erosion surface that was devoid of fluvial sediments and QfIV was mapped as a 'glacis' with occasional (poorly documented) traces of fluvial conglomerate. Fieldwork during 2007 and 2009 has shown the CNRS feature mapping to be generally sound but, whereas the right-bank terraces are generally formed from fluvial gravels and floodplain silts, those on the left bank (including those below QfIV) are often 'glacis' type features formed in bedrock or slope deposits and incorporating valley-side fans and colluvial slope aprons (Fig. 6.A). It was also found that the terrace sequence in this reach extends higher above the river on the eastern side of the valley than had been realised previously, with a series of cemented gravels capping hills south–east of Hama and west of Salamiyeh (Figs. 1, 6B and 7). The highest level at which ancient Orontes sediments have been observed hereabouts is alongside its right-bank tributary, the Wadi Kafateh, which joins the main river some 8 km upstream of Hama (online supplement, Fig. A.1.3). These cemented gravels, which crop out widely hereabouts, can be confirmed as Orontes deposits from their flint content; in every respect, including their disposition within the landscape, they resemble the high-level conglomerates of the reach above Homs. There are several facets underlain by gravel, the highest reaching 410 m a.s.l. (Fig. 6B), with lower-level 'flats' down to a prominent level at ~370 m a.s.l., well developed around CU 08825 81661. The sequence thus ranges between 80 and 120 m above the modern level of the river (Fig. 7). Whether these are erosional facets or whether they mark 'cut-and-fill' events cannot be determined.

The height of these cemented gravels, in comparison with the fossiliferous deposits at Latamneh (see below), helps confirm the great antiquity of Orontes drainage in north-western Syria and their disposition implies westward migration of the river during the Late Cenozoic, helping to explain the absence of fluvial terrace deposits on the left bank of the river. On the basis of height above the river, bearing in mind the disposition of the fluvial deposits at Rastan (see above), an Early Pliocene age is tentatively estimated for these high-level deposits of the Middle Orontes.

In contrast to these new discoveries, the single locality at which the French workers recorded substantial gravels beneath their QfIV terrace, Khattab 2 (regarded by them as the type locality of the Khattabian Palaeolithic Industry: Copeland and Hours, 1993; location: BU 88795 96553), was visited in 2007 and found to expose a cemented limestone gravel of presumed local, perhaps alluvial-fan origin. It comprises mainly rounded limestone pebbles, although with large angular flints that have clearly not been subjected to significant fluvial transport. Thus, despite occurring in the flanks of a steeply incised reach of the Orontes, this deposit must be rejected at a product of that river, since all Orontes gravels in the Middle reach are strongly

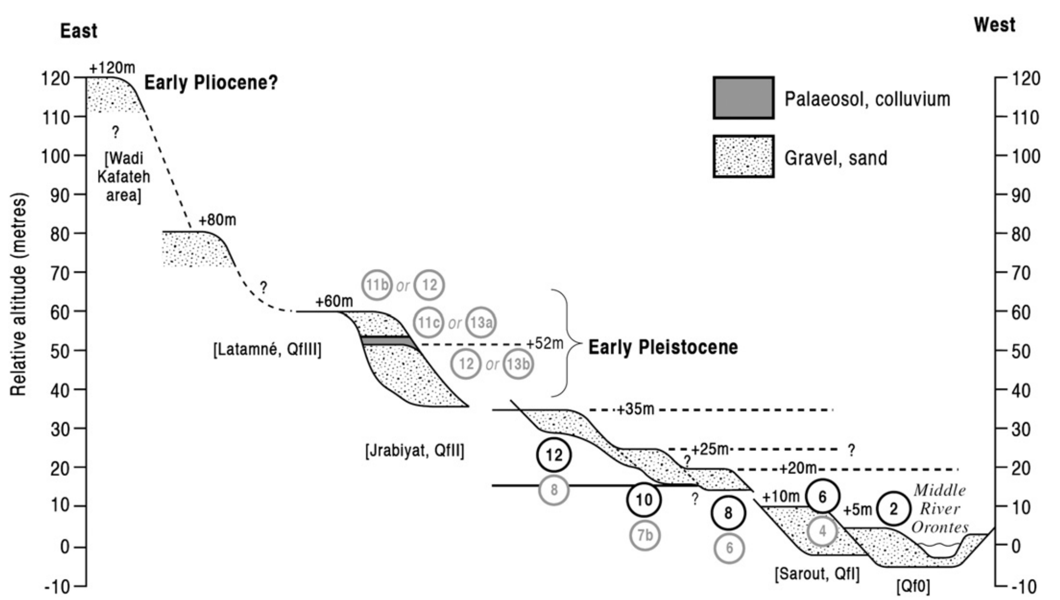


Fig. 7. Idealized transverse section through the terrace sequence of the Hama–Latamneh area, showing the MIS correlation suggested by Bridgland et al. (2003), now thought to be underestimated, and the greater ages suggested in this paper (see text). Uses data from Besançon and Sanlaville (1993a) and Dodonov et al. (1993); artwork modified from Bridgland et al. (2003).

dominated by subangular siliceous clasts. Indeed, the location of the cemented gravel adjoins a confluence with a tributary wadi (cf. Besançon and Sanlaville, 1993a, their Fig. 7A), which is the possible source of the material. This interpretation is supported by the poorly stratified nature of the deposit, more akin to fan gravel than a fluvial channel facies (Fig. 6C; online supplement, Fig. A.1.4). Besançon and Sanlaville (1993a) regarded the Khattab gravel as older than the QfIII deposits encountered at Latamneh and elsewhere, largely because the former is well-cemented, whereas the QfIII deposits of the Middle Orontes are not; its height, no more than ~30 m above the modern river, is not a basis for considering it as ancient. The cemented nature of the deposit, however, can probably be attributed to its limestone clast composition, since evidence from other reaches of the Orontes shows that in calcareous groundwater areas gravels can be cemented rapidly, as in the lowest terraces of the valley upstream from Homs (see above).

Copeland and Hours (1993) applied the name Khattabian to a series of artefact assemblages lacking handaxes that they considered older than those from handaxe-bearing QfIII terrace deposits such as at Latamneh. This material was reportedly from pockets of fluvial conglomerate on the QfIV terrace glacis, some of which were at much greater heights than the supposed type locality at Khattab. Recent re-examination of the artefacts from the type locality at Khattab (Shaw, 2008, in press) failed to identify any pieces unequivocally of human manufacture, nor indeed were any definite artefacts identified amongst the small collections from the five other 'Khattabian' findspots in the Orontes (Abu Obeida, Mahardeh 2, Ard Habibeh, el-Farcheh 1 and Khor el-Aassi). Not only is the age attribution of the Khattab 2 type locality suspect, therefore, but the status of a separate and earlier non-handaxe industry is also open to question, particularly since handaxes are known from the site at Ubeidiya, further south in the Levant, in deposits dating from the mid Early Pleistocene, ~1.4 Ma (Tchernov, 1987, 1999). The only one of these 'Khattabian' sites that is both at a relatively high level and, from the brief descriptions by Besançon and Sanlaville (1993a) and Copeland and Hours (1993), clearly in deposits of the Orontes, is el-Farcheh (~CU 045 850); at ~340 m a.s.l. it is ~55 m above the river. Being significantly lower, this is evidently younger than the gravels described above in the vicinity of the Wadi Kafateh; the deposits at el-Farcheh can be tentatively ascribed to the latest Pliocene–earliest Pleistocene.

The aforementioned Latamneh locality in fact constitutes a number of separate sites (Fig. 8) that were worked for gravel during the latter half of the 20th and into the present century, details of which have been reviewed recently by Shaw (2008, in press). Remote sensing data from different dates have now been used to determine the disposition of the sediments. In summary of these various findings, it has been concluded that the large extant quarry (online supplement, Fig. A.1.5) studied by the present authors is an expanded version of what was called Latamneh 2 by Copeland and Hours (1993); it is, however, a later working than was available in the 1960s, when most of the collections were made (Clark, 1966a, b; Van Liere, 1966; de Heinzelin, 1968) at localities 1–1.5 km to the south and east (Fig. 8). Much of the recorded mammalian material came from Latamneh Quarry 1 (Hooijer, 1961; Van Liere, 1966) and from two sondages (A and B) to the south. There were also finds from the working that Van Liere (1966) described as Quarry 2 (not the extant quarry) and from excavations (the 'Living Floor excavations') to the east of that quarry (Hooijer, 1965; Clark, 1966a, b, 1967, 1968; see Fig. 8C), although they represent a small proportion of the total. The thick gravel sequence exposed in the extant quarry, mapped as QfIII (see above), is disposed between ~260 m and ~280 m a.s.l., the upper level being ~55 m above the level of the modern River Orontes, with a further ~10 m of silt above the quarried levels. There is nothing to contradict the view that all the various sites have exposed the same set of mammal-bearing fluvial deposits, these being the 'lower gravels' within the thick aggradational sequence here (cf. Shaw, in press).

5.1. Biostratigraphical evidence from the Middle Orontes

The mammalian remains from Latamneh include *Crocuta crocuta*, *Hippopotamus* cf. *behemoth*, *Camelus* sp., *Giraffa camelopardalis*, *Praemegaceros verticornis*, *Bos primigenius, Bison priscus*, Bovidae 'de type antilope', gen. et sp. indet., cf. *Pontoceros* (?), *Equus* cf. *altidens*, *Stephanorhinus hemitoechus*, *Mammuthus trogontherii* and *Stegodon* cf. *trigonocephalus* (Guérin and Faure, 1988; Guérin et al., 1993). During the 2007 field season further vertebrate fossils were obtained from exposures in the large extant Latamneh quarry (see online supplement, Figure A.1.6), as follows:

1. Indeterminate bone fragment, white–pale yellow preservation, heavily weathered
2. Distal diaphysis of right humerus of fallow deer *Dama* sp. (probably *mesopotamica*)
3. Molar fragment (very crushed) of cf. *Stegodon* sp., encrusted with gravel
4. Left upper molar fragment of *Equus* sp.

These new discoveries contribute little to the list reported by Guérin et al. (1993); *Dama* cf. *mesopotamica* was recorded previously, along with *Camelus* cf. *dromedarius* and a molar tentatively attributed to *Gazella soemmering*, from the 'Living floor' excavations (Hooijer, 1965; Fig. 8C).

The Latamneh assemblage is of Lower–Middle Pleistocene affinity and combines mammoth and giant deer species that are unknown in Europe after the Elsterian (excluding the dwarf form of *M. trogontherii* that characterizes MIS 7 faunas: Lister and Sher, 2001) with a rhinoceros (*S. hemitoechus*) that first appears in Europe immediately after that glacial, in the Holsteinian. On that basis Bridgland et al. (2003) suggested correlation with MIS 13 or 11 (perhaps a MIS 12 refugial population would be equally likely), considering this to be an important pinning point for Terrace QfIII within the Orontes sequence and for their uplift–incision modelling. There are, however, reasons to doubt that interpretation, which owed much to the occurrence of *S. hemitoechus*. In a recent review of Early and Middle Pleistocene faunas and archaeological evidence in the wider region, Bar-Yosef and Belmaker (2010) have grouped Latamneh, despite the occurrence of *S.* cf. *hemitoechus*, with sites thought to represent the interval 1.2–1.0 Ma. In this they were influenced by the small-mammal assemblage, in which Mein and Besançon (1993) reported the arvicolid *Lagurodon arankae*, which is not thought to have survived into the Middle Pleistocene. Mein and Besançon (1993) noted that all the small-mammal genera at Latamneh are represented at Ubeidiya, but by different species or more primitive morphotypes. The most abundant species at Latamneh is a gerbil, *Meriones maghrebianus*, which is defined on the basis of North African material. The species recorded as *Arvicola jordanica* (now attributed to a different genus: *Tibericola jordanica* Haas 1966) is also present at Ubeidiya (Koenigswald et al., 1992) and Gesher Benot Yaaqov (Goren-Inbar et al., 2000), which, respectively, pre-date and post-date the supposed age of Latamneh (Bar-Yosef and Belmaker, 2010). *L. arankae* is indeed the most significant element, biostratigraphically; it first appeared in late Early Pleistocene Biharian faunas in eastern Europe but had disappeared by the early Middle Pleistocene (Markova, 2007), one of its last appearances being in the Karapürçek Formation in Turkey (Ünay et al., 1995, 2001; Demir et al., 2004), which is dated to ~0.9 Ma.

The location of the earlier discovery of a mandible, with teeth, of *M. meridionalis* at Sharia, near Hama (see above), also coincides with deposits mapped as QfIII by the CNRS workers, although in the original description Van Liere and Hooijer (1961) regarded it as

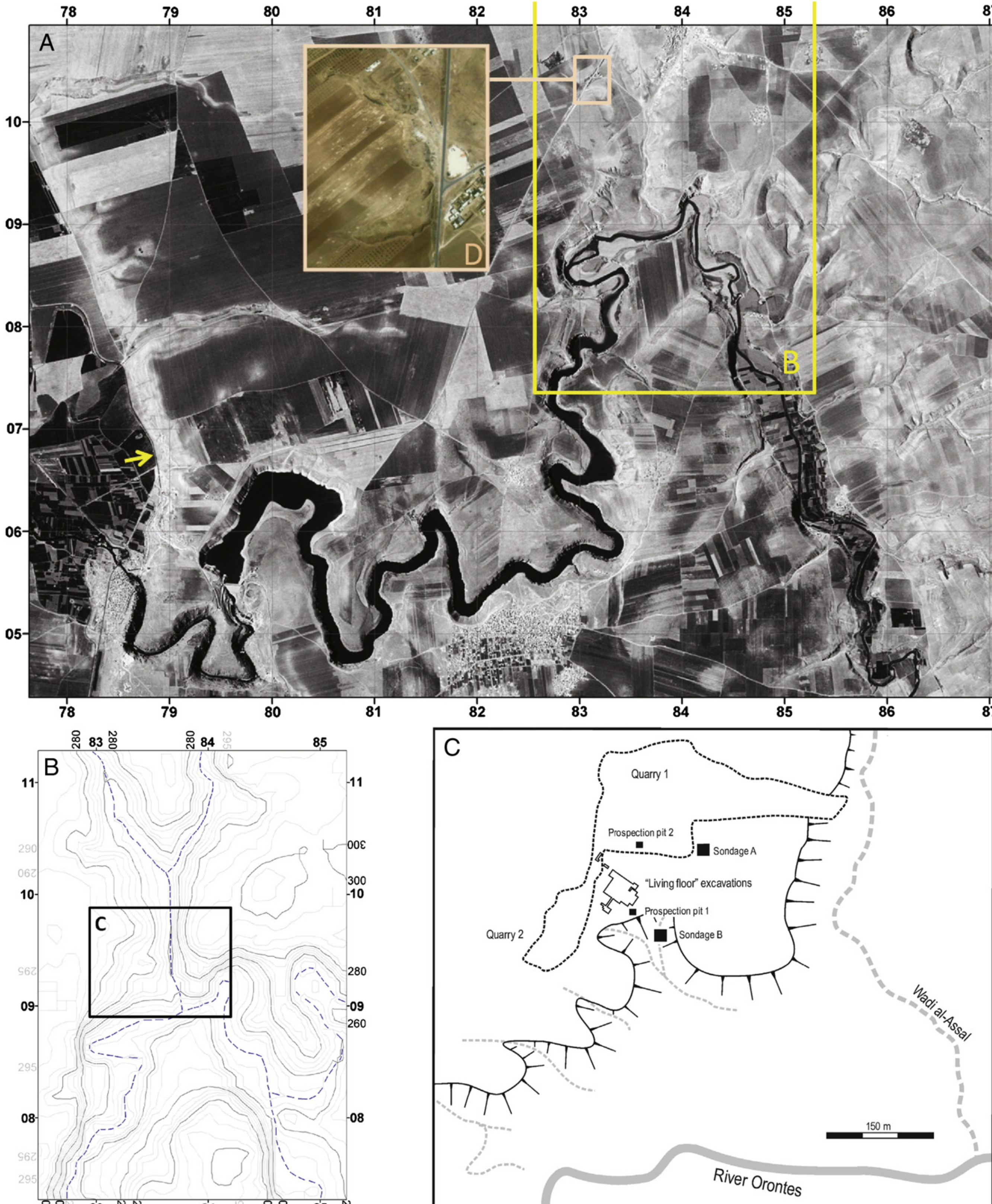


Fig. 8. The important archaeological and fossiliferous locality at Latamneh: A — CORONA image from the 1960s of the area between Latamneh and the Sheizar fault scarp, the latter being indicated with an arrow (top left); the southern part of Latamneh village is at the northern edge of this image, within the area of B. B — Contour map (5 m interval) derived from Shuttle Radar Topographic Mission (SRTM). C — Location of the earlier palaeontological and archaeological localities at Latamneh (from Shaw, in press).D — Inset showing a modern Google Earth view of the extant quarry at Latamneh, to the north of the earlier localities depicted in C.

older. This would seem to relate, at least in part, to the fact that Van Liere (1966) underestimated the height of the deposits at Latamneh. Artefacts were also discovered but the assemblage is too small for the absence of evidence for handaxe making to be meaningful. This leaves a conundrum in that ancestral mammoths of different types, and presumed to be at different evolutionary stages, are recorded in deposits that have been attributed to the same Orontes terrace. In an attempt to resolve this problem, the photographs of mammoth teeth provided for Sharia by Van Liere and Hooijer (1961) and for Latamneh by Hooijer (1965) were re-examined. This confirmed that the single R m3 tooth from Latamneh figured by Hooijer (1965) is consistent with an identification of *Mammuthus trogontherii*. Sixteen plates are apparent on the image but there has been a limited amount of wear at the front of the tooth so this should be regarded as a minimum count. Early Pleistocene *M. meridionalis* is characterized by low hypsodonty and a mean of 10–14 plates in the third molar, whereas *M. trogontherii* is more hypsodont, with between 16 and 22 plates (Lister and Sher, 2001). The published images of the Hama tooth allow confirmation of its identification as *M. meridionalis*, implying a greater age than the Latamneh fauna.

Consultation of SRTM imagery (Fig. 9) has confirmed that the deposits at Sharia (≤10 m thick) are aggraded to ~40 m above the modern river, as originally suggested by Van Liere and Hooijer (1961), placing them within the height range of the sequence at Latamneh and making the attribution of both sites to QfIII seem entirely reasonable. Possible differences in uplift history between the two localities cannot be ruled out however, which could explain the apparently older mammalian remains at Sharia. Indeed, Van Liere (1966) suggested that an older set of deposits, equivalent to those at Sharia, occurred at Latamneh and that the fossiliferous and handaxe-bearing sediments had subsequently been incised into them, although no later descriptions have confirmed a sequence of this sort.

The various biostratigraphical evidence thus requires the reattribution of the QfIII terrace, as represented at Latamneh and Sharia, to an age in the region of 1.2–0.9 Ma. This has a significant implication for the age model established for the Orontes by Bridgland et al. (2003; see above), which is confirmed as underestimated. Revised suggestions for the ages of terraces in the Hama–Latamneh area are indicated in Fig. 7. The ~40 m height of the Sharia deposit suggests a significantly younger age than the aforementioned el-Farcheh site; the somewhat greater height of the deposits at Latamneh, notwithstanding the younger age, is attributed to a component of localized uplift in the vicinity of the adjacent Sheizar Fault (see below and Fig. 8A). Given this revision, it is no longer tenable to consider the Middle Orontes terraces as representative of formation in response to 100 ka Milankovitch climatic forcing (cf. Bridgland and Westaway, 2008a).

6. The Ghab Basin

About 5 km downstream of Latamneh (along the valley axis) the Orontes leaves the incised part of its middle reach and enters the Acharneh Basin (located to the east of the southern part of the larger Ghab Basin: Fig. 1, inset), passing through a well-marked west-facing scarp slope close to the town of Sheizar (Fig. 8A). Further downstream the valley widens out within the Acharneh Basin to form a large flat plain and all but the lowest Pleistocene terraces disappear. These lowest terraces are represented on the maps of Besançon and Sanlaville (1993a, b) by widespread glacis, mostly forming apparent fans that extend westwards from the scarp; a few of the highest fragments of these are mapped as QfIII, although QfI and QfII dominate and extend along the course of the river downstream to Acharneh, beyond which they too cease to be represented (Fig. 10). Sections beneath the glacis surfaces in the latter area reveal them to be formed on lacustrine sediment of the Acharneh Basin (Devyatkin et al., 1997), probably Neogene in age, that have been slightly uplifted. Downstream of Acharneh the river resumes its northward course, flowing above the stacked infill of the Ghab Basin (Fig. 3); this has been widely interpreted as an actively developing pull-apart basin (Devyatkin et al., 1997; Brew et al., 2001; Westaway, 2004b, 2010) the formation of which was probably broadly synchronous with the comparable Hula Basin further south, the initiation of the latter being reliably dated to ~4 Ma from its associated volcanism (Heimann and Steinitz, 1989; Heimann et al., 2009). These structures thus reflect the development of the present geometry of the DSFZ, which came into being around that time, at ~3.7–3.6 Ma (Westaway, 2004b, 2010; Seyrek et al., 2007). The fact that fluvial aggradational terraces occur only upstream of the Sheizar scarp implies that the latter has formed in response to Pleistocene dip-slip (down-to-the-west) movement of a fault at this location (Figs. 3 and 8A). This interpretation was suggested by de Heinzelin (1966) but was overlooked by later workers; indeed, de Heinzelin envisaged that the succession at Latamneh (see above) was deposited before this fault became active, at a time when much of the present relief of the area did not exist. Movement on this fault can be presumed to account for the lack of fluvial incision in the area downstream and the greater-than-expected height (give their biostratigraphical age) of the deposits at Latamneh, ~5 km upstream.

Much work was carried out in the Ghab by Russian scientists during the Soviet era, as reviewed by Domas (1994) and Devyatkin et al. (1997), who described a mixed lacustrine and fluvial Pliocene infill that, from geophysical evidence, attains a maximum thickness of 0.8–1.0 km. According to Devyatkin et al. (1997), the maximum sediment thickness occurs in the central–southern part of the basin, thinning to <200 km in the north (Fig. 1, inset). They also reported a lacustrine fill of up to ~300 m in the Acharneh Basin. A longitudinal section through the northernmost part of the Ghab, based on borehole evidence (Besançon and Sanlaville, 1993b), shows the majority of the infill, proved to a maximum thickness of 40 m (but unbottomed), to be Pliocene shelly clay, with interbedded sands, volcanic ash and, at the northern end of the basin, basaltic lava (Fig. 11B). This lava, erupted from poorly preserved cones to the north and east of the downstream limit of the Ghab, has been attributed to the Pliocene (Ponikarov et al., 1963b; Ponikarov, 1986; Domas, 1994), although it has yielded K–Ar dates as young as 1.1 ± 0.2 and 1.3 ± 0.9 Ma (e.g. Devyatkin et al., 1997).

It is unclear whether the Ghab has been continuously occupied by a lake throughout the Pleistocene or whether there were periods when the Orontes flowed across a dry lake floor, as at present (following anthropogenic drainage). As it approaches the northern end of the Ghab, the modern Orontes channel becomes increasingly deeply incised, partly, perhaps, as a result of the artificial drainage during the 1950s of what was, in historical times, a wetland (Besançon and Sanlaville, 1993b). In part, however, this is likely to be a consequence of the river cutting into the basalt barrier as it passes from the subsiding basin interior into an area that has clearly been uplifting. There is evidence for uplift of the basalt barrier during the Quaternary, in the form of inset low-level river terrace gravels that border the course of the Orontes along the northernmost 15 km of the Ghab (Domas, 1994). These deposits are well exposed at Karkour, near the northern end of the basin, where Quaternary gravel was recorded by Van Liere (1961) and Besançon and Sanlaville (1993b, their Fig. 19). Two gravel exposures were recorded during fieldwork in 2007, both in the incised banks of the Orontes. First, at Karkour sluice (BV 57282 59073; ~168 m a.s.l.), 1–2 m of cemented medium–fine gravel was exposed, capping an unconsolidated sequence of shelly silts and fine sands above a lower clayey gravel–pebbly clay and culminating in fine gravel with an argillaceous matrix; the basal cemented gravel reveals cross bedding indicative of northward palaeoflow (Fig. 11A; online supplement, Fig. A.1.7). Analysis of the cemented gravel, carried out in the field (as in the Upper Orontes), showed that it comprises >95% flint/chert (Table 1), the only other constituent being

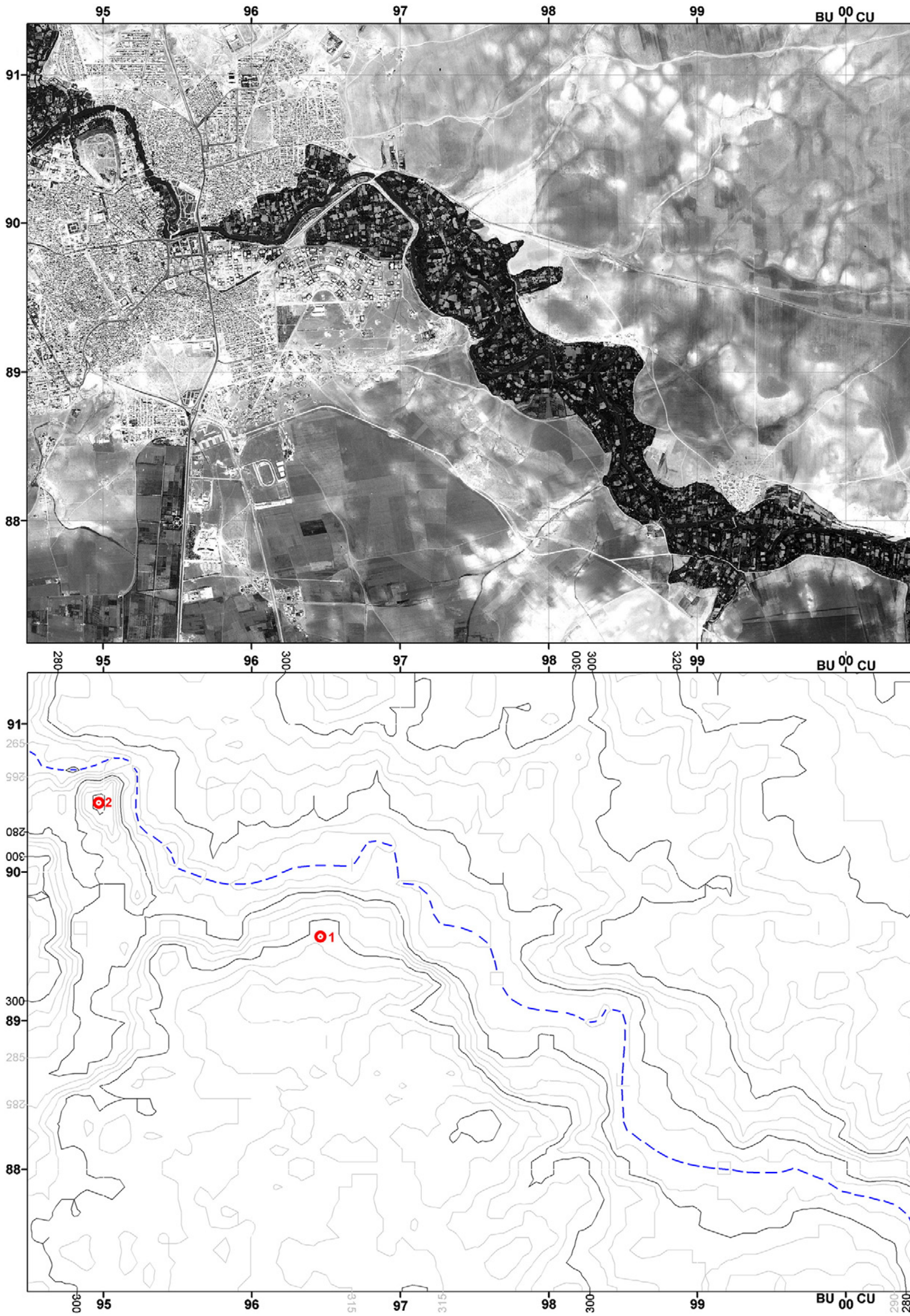


Fig. 9. Paired images showing the *M. meridionalis* locality at Sharia, Hama: upper — GAMBIT image, taken in 1967; lower SRTM-derived contour image, with selected 5 m interval contours labelled and the Sharia locality indicated, centre left (as Point 1) in what was in 1967 the south-eastern edge of the Hama conurbation (UTM coordinates: BU 965 896). Point 2 is the ancient citadel in the centre of Hama. Coordinates are marked for 1 km grid squares.

Fig. 10. Fossiliferous sites in the Ghab Basin: 1960s CORONA image showing the location of (from north to south) the Karkour railway bridge and Karkour sluice sites at the northern end of the Ghab; note that the railway was under construction, with the bridge not yet in place. Insets show the location of sample points from present-day Google Earth. Coordinates are marked for 1 km grid squares, although the image shows a 0.5 km grid.

limestone, which has presumably been introduced from the sides of the basin. Some 2.5 km further north, at the Karkour railway bridge (BV 57306 61493; 165 m a.s.l.), a second gravel exposure was observed. The deposit here, which overlies the basalt that gives rise to the knick point at the northern end of the Ghab, is much coarser than that further south, containing large weathered basalt clasts. It is ~3 m thick, has a variable argillaceous matrix and contains shells, including large gastropods (see below; online supplement, Fig. A.1.8). It also yielded a well-preserved handaxe (Fig. 11C) and a butt fragment from a larger handaxe. The flint/chert reaching Karkour has evidently been transported from the Middle Orontes upstream of Sheizar, avoiding deposition as part of the thick stacked succession in the Ghab Basin. Analysis of samples from the two Karkour sites has shown that the sediments contain ostracods as well as molluscs.

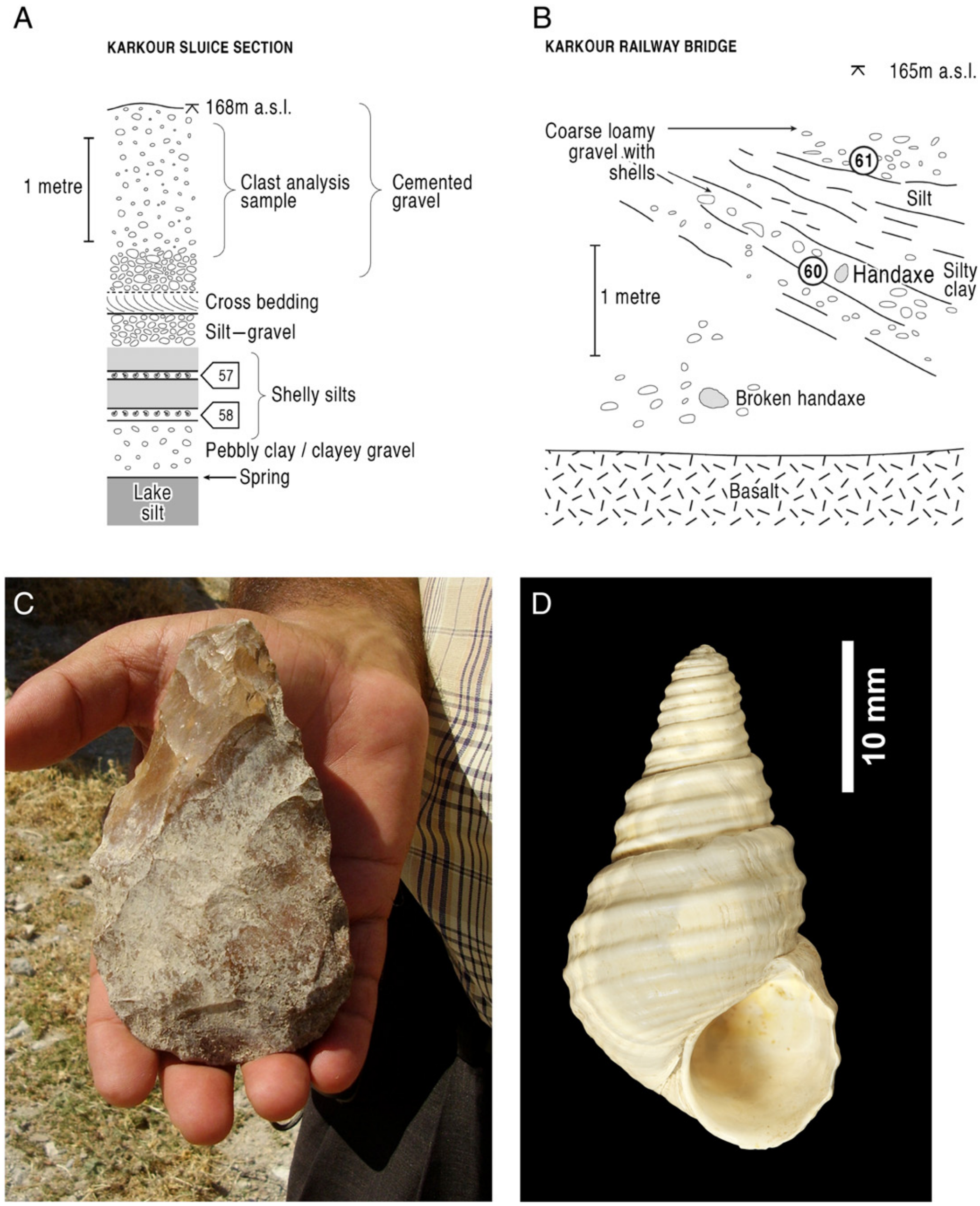


Fig. 11. Karkour, northern Ghab Basin: A — Section log from the Karkour sluice locality; B — Section log from the Karkour railway bridge locality; C — hand axe from the Karkour railway bridge section; D — *Apameaus apameae* from the Karkour railway bridge section. This species is named after Apamaea, a Roman site in the Ghab.

6.1. Palaeontology of the Ghab sediments

Mollusca were analysed from both Karkour exposures (Table 3). Samples 57 and 58, from silty deposits beneath the cemented gravel at Karkour sluice, yielded assemblages dominated by *Dreissena bourguignati* (~95% of the total). Samples 60 and 61, from Karkour railway bridge, also yielded well preserved shells, the most distinctive being the large viviparid gastropod *Apameaus apameae* (formerly *Viviparus apameae*; Fig. 11D; cf. Sivan et al., 2006). Previous authors have described other fossiliferous exposures in this general area (cf. Schütt, 1988; Devyatkin et al., 1997; see online Appendix 3).

First described by Blankenhorn (1897) based on shells from the Orontes, *A. apameae* is best known from the Jordan valley, where it has been used as an index fossil to define the 'upper freshwater series' or '*Viviparus* Beds' of the Benot Ya'aqov Formation at Gesher Benot Ya'aqov (Picard, 1963; Tchernov, 1973; Goren-Inbar and Belitzky, 1989; Bar-Yosef and Belmaker, 2010), noted above as being somewhat more recent than the Latamneh deposits. As at Karkour, *A. apameae* is found in direct association with handaxes at Gesher Benot Ya'aqov (Goren-Inbar and Belitzky, 1989; Goren-Inbar et al., 1992). The species became extinct in the Jordan Valley at ~240 ka, on the basis of U-series dating (Kafri et al., 1983; Moshkovitz and Magaritz, 1987; Heller, 2007). Its first appearance there followed the eruption of the Yarda Basalt, in the vicinity of the Sea of Galilee, and of the Hazbani Basalt, which flowed from southern Lebanon into the Hula Basin in the northernmost Jordan valley. Although dating of these basalt eruptions has been attempted using the K–Ar method, this has not resulted in reliable age-determinations (e.g. Schattner and Weinberger, 2008). Given the data currently available, probably the best guide to the age of the Hazbani Basalt and of the stacked succession in the Hula Basin is from the biostratigraphical and oxygen isotope calibration by Moshkovitz and Magaritz (1987),

Table 3
Molluscan faunas from exposures at Karkour (for locations, see Fig. 10; for details see text).

	Sample			
	57	58	60	61
Theodoxus jordani (Sowerby)	+	+	+	+
Theodoxus orontis Schütt				+
Apameaus apameae (Blanckenhorn)			+	+
Melanopsis blanckenhorni Schütt	+	+	+	+
Melanopsis unicincta Blanckenhorn				+
Melanopsis bicincta Blanckenhorn				+
Melanopsis cylindrata Blanckenhorn				+
Lymnaea (?Radix) sp.	+			
Gyraulus piscinarium Bourguignat			+	+
Planorbis carinatus				+
Planorbis sp.		+	+	+
Valvata saulcyi Bourguignat	+	+	+	+
Semisalsa longiscata (Bourguignat)	+	+		
Bithynia applanata Blanckenhorn	+	+		+
Syrofontana fossilis Schütt	+			+
Falsipyrgula rabensis (Blanckenhorn)	+	+		+
Falsipyrgula ghabensis Schütt	+	+		+
Potomida kinzelbachi Schütt			+	+
Unio terminalis Bourguignat			+	+
Dreissena bourguignati Locard	+	+	+	+

based on borehole evidence. They recognized glacial-to-interglacial termination IX (the MIS 20–19 transition) at a depth of ~160 m in the Hula Basin fill, which implies that *A. apameae*, which occurred between depths of 67 and 168 m in the studied borehole, had appeared by MIS 21. If it is assumed that the occurrence of this gastropod in the Ghab was synchronous with its presence in the Jordan, then it can be concluded that the sediments at Karkour railway bridge are Middle Pleistocene.

Samples 57 and 61 were also examined for ostracods, Sample 57 yielding the most abundant and diverse fauna of seven species (Table 4), amongst which the most common was *Cyprideis torosa*. The assemblages appear to include reworked and indigenous components, indicated by differential preservation; the reworked material might be as old as Pliocene (see online Appendix 3). Pliocene–Pleistocene ostracod faunas from the Levant region have been poorly documented, making this an important record, particularly since these crustaceans are extremely valuable palaeolimnological indicators (Holmes, 1996; Battarbee, 2000). For example, *C. torosa* generally occurs in brackish water, developing noded valves in salinities below ~6‰, but can also tolerate hypersaline conditions in lakes and water bodies prone to desiccation. The indigenous component from the Karkour samples, presumed to be Pleistocene, comprises both brackish (*C. torosa* and the loxoconchids) and freshwater elements (*Candona neglecta*, *Ilyocypris* spp. and an unnamed *Heterocypris*).

The analysis of these two faunal groups thus supports a Pleistocene age for the sediments at both Karkour sites, with reworked ostracods from earlier, possibly Pliocene sediments within the Ghab Basin. It is worth highlighting the close similarities between the palaeontological and archaeological material from the Ghab deposits at Karkour and the Benot Ya'aqov Formation in the Jordan Valley; these records, coupled with the suggested contemporaneity of the Ghab and Hula basins, permit a tentative broad correlation to be suggested. This and the above-mentioned K–Ar dates for the basalt at the northern end of the Ghab imply an age range from the latest Early Pleistocene to Middle Pleistocene for the sedimentary succession at Karkour, rather than the Pliocene age previously suggested (cf. Ponikarov et al., 1963b), making it therefore somewhat younger than the deposits at Latamneh.

Table 4
Ostracod faunas from faunas from exposures at Karkour (for locations, see Fig. 10; for details see text).

	Sample	
	57	61
Cyprideis torosa (Jones)	+	+
Ilyocypris cf. *inermis* Kaufmann	+	
Ilyocypris sp. (spinose form)	+	+
Loxoconcha spp.	+	
Candona neglecta Sars	+	
Candona sp. (juveniles)		+
Heterocypris salina (Brady)		+
Herpetocypris sp.	+	

7. The Orontes Gorge north of Jisr ash-Shugour

The town of Jisr ash-Shugour is situated at the downstream end of the Ghab Basin, north of which the Orontes enters a gorge, ~100 m deep (although within a wider, deeper feature up to 300 m deep) and ~25 km long (along its sinuosity; see Fig. 12; online supplement, Fig. A.1.9), that it has cut through Palaeogene limestone. At the northern end of the gorge is the town of Darkush, only 3 km upstream of the border with Hatay Province (Turkey).

Where this gorge could be accessed it was, unsurprisingly, found to contain no fluvial terraces, only a basal gravel ~0.3 m thick, beneath ~0.2 m of sand with gravel seams and capped by ~1.0 m of silty overbank deposits. This valley-floor sequence was observed and sampled at Hammam ash Sheykh Isa, where the gravel (126 m a.s.l.) proved to comprise mainly limestone (>99% of a somewhat undersized sample: Table 1). This demonstrates that the bedload of the Orontes has been recharged with limestone from the local Palaeogene outcrop, this having greatly diluted the flint/chert clasts that accounted for >95% of the gravel at Karkour.

8. The Amik Basin, Hatay Province

The meandering Orontes channel north-west of Darkush forms the border between Syria and Hatay for a (straight-line) distance of 23 km. To the north the river enters a second subsiding lacustrine basin, formerly occupied by Lake Amik. In this case the lake has disappeared during the last half century, having (along with its associated wetlands) occupied 53.3 km^2 in 1972 (Figs. 1 and 13) but been eliminated completely by 1987 as a result of drainage for agriculture (Kiliç et al., 2006; Çalışkan, 2008; for notes on its earlier history, see Wilkinson, 1997; Yener et al., 2000). It was also known as the Lake of Antioch, the ancient city of that name (modern Antakya) being situated on the south-western extremity of the Amik Basin, the flat-topped infill of the latter giving rise to the Antioch/Amik Plain. The lake was drained by an artificial channel (the Balıkgölü Canal) into the Orontes, which flows along the southern edge of the basin without reaching the former site of the lake (Fig. 13).

Extending NNE (upstream) from the Amik Basin is the valley of the River Karasu, which follows the alignment of the DSFZ as it trends in that direction, passing into the East Anatolian Fault Zone (e.g. Westaway, 2004b; Westaway et al., 2006; Fig. 1). The nature of faulting in this region was for many years a subject of debate, in relation to controversy concerning the geometry of the DSFZ in western Syria. Yurtmen et al. (2002) showed that the evidence was consistent with active faulting along the Karasu valley continuing southward into the DSFZ, with no requirement for any other large-scale faulting extending offshore to the south-west, as others had previously inferred. In this view, the Amik Basin can be interpreted as marking a leftward step in the faulting, from the Amanos Fault, which runs along the western margin of the Karasu valley, to the DSFZ segment further south, which Westaway (2004b) called the Qanaya–Babatorun Fault. Subsequent analyses (e.g. Seyrek et al., 2007, 2008; Westaway et al., 2008) have confirmed this general interpretation. The Amik Basin can therefore be interpreted as another pull-apart basin within the DSFZ, comparable with the Ghab. Although they have yet to be

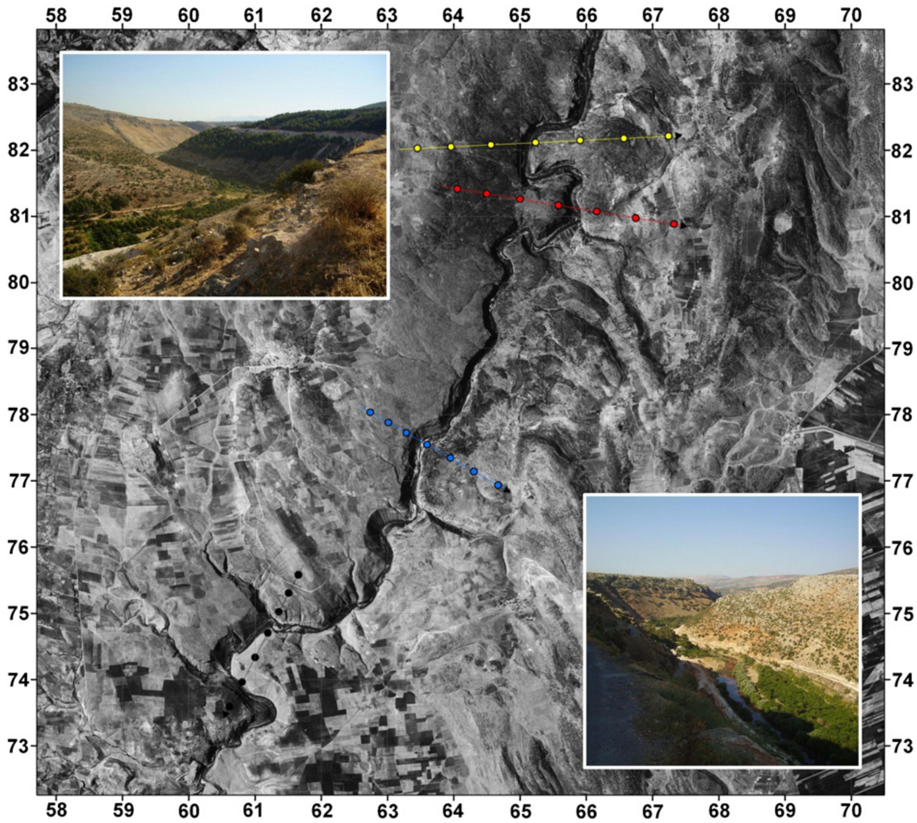


Fig. 12. The gorge between Jisr ash-Shugour and Darkush: 1960s CORONA image of the gorge (for location, see Fig. 1); dotted lines show locations of derived cross sections (see online supplement, Fig. A.1.9). Coordinates are marked for 1 km grid squares. Insets show photographic images of the gorge: A — looking SSW (upstream) from BV 63205 76708, about 5 km east of Qanaya. The mountains visible in the far distance are part of the Jebel Nusayriyah range along the western side of the Ghab Basin.; B — Looking northwards, downstream along the valley, from BV 63234 76771. The gravel sample locality at Hammam ash Shaykh Isa is ~400 m to the north of the viewpoint, accessed from the nearer part of the valley-floor platform in the middle distance. Both photographs show features that might represent early river levels, although other explanations would be possible and ground-truthing has not been practicable.

mapped in detail, the existence of active faults in the region is corroborated by records of numerous large historical earthquakes (e.g. Akyuz et al., 2006). The Karasu valley is the site of extensive eruptions of Quaternary basalt; offsets of dated basalt flows, where they cascade into the main valley along tributary gorges, have provided the principal method of measuring slip rates on faults in this region (e.g. Yurtmen et al., 2002; Seyrek et al., 2007).

It is difficult to study the Orontes to the south-east of the Amik Basin because of the political sensitivity of the Syria–Hatay border, with which it coincides in this area. Once downstream of the border, the river channel can readily be observed as it meanders extravagantly across the Amik Plain. Simple measurements at intervals demonstrate that the bed of the river becomes progressively incised below the surface of the plain as the outlet from the basin, near Antakya, is approached. The Orontes channel was measured as declining from ~3.5 m below the Antioch Plain at BA 54539 18533, ~2.5 km upstream of Alaattin, to ~9.5 m on the northern outskirts of Antakya (BA 48448 15139), over a (straight-line) distance of ~7 km (see Fig. 13, points 4 and 5).

Thin cobble-gravel, interbedded with floodplain silt, cropping out in the river bank (north side) ~2 m above the Orontes, ~1 km south of Alaattin Köyü (~86 m a.s.l.; Fig. 13, point 2; the source of a clast analysis sample: Table 1), was found to contain pottery, demonstrating a mid–late Holocene age, as well as freshwater mussel shells. Flint/chert from the Middle Orontes has increased in frequency in the river's bedload here (~10%), in comparison with the Darkush Gorge sample locality ~50 km upstream, despite the much greater distance from its source outcrops than from the Palaeogene limestone (which has fallen to <75%: Table 1). This change can be attributed to the relative hardness and resistance to abrasion of the siliceous clasts, which persist into the gravels of the Lower Orontes, whereas the limestone disappears (see below; Table 1). The Amik Basin sample also contains a fresh input of crystalline material, notably local basalt (>10%), as well as coarser mafic rocks and traces of quartzitic, schistose and amphibolitic rocks. The coarse mafic rocks are likely to be from the latest Cretaceous Hatay ophiolite, whereas the other constituents are probably derived from the Precambrian/Palaeozoic succession exposed in the Amanos Mountains, west of the Karasu, by way of its right-bank tributaries. All such material is exotic to the Orontes valley upstream of this point.

Also exposed in the incised channel sides of the Orontes in the Amik Basin are horizontally laminated fine sands and silts, interpreted as fluvio-lacustrine sediments of Neogene–Quaternary age. They were observed in a river-bank section, ~1 km south of Alaattin (Fig. 13, point 1). Comparable deposits, although rather more indurated and gently tilted, were also observed in quarry sections in low hills standing above the Amik plain at Alaattin Köyü (Fig. 13, point 3). These would appear to represent upfaulted blocks of Neogene basin fill; at ~125 m a.s.l., the deposits have been uplifted ~40 m above the general level of the plain. The same upfaulted ridge reaches 159 m a.s.l. to the north-west of Alaattin Köyü (Fig. 13, point 6). The absence of any other high ground suggests that this area has been a subsiding sedimentary depocentre for most of recent geological history and certainly since the present geometry of the DSFZ in this region came into being, in the Mid Pliocene (~3.6–3.7 Ma: e.g. Seyrek et al., 2007; Westaway et al., 2008). A seismic reflection profile published by Perinçek and Çemen (1990) indicates that the sedimentary fill in the Amik Basin reaches a maximum thickness of ~1 km.

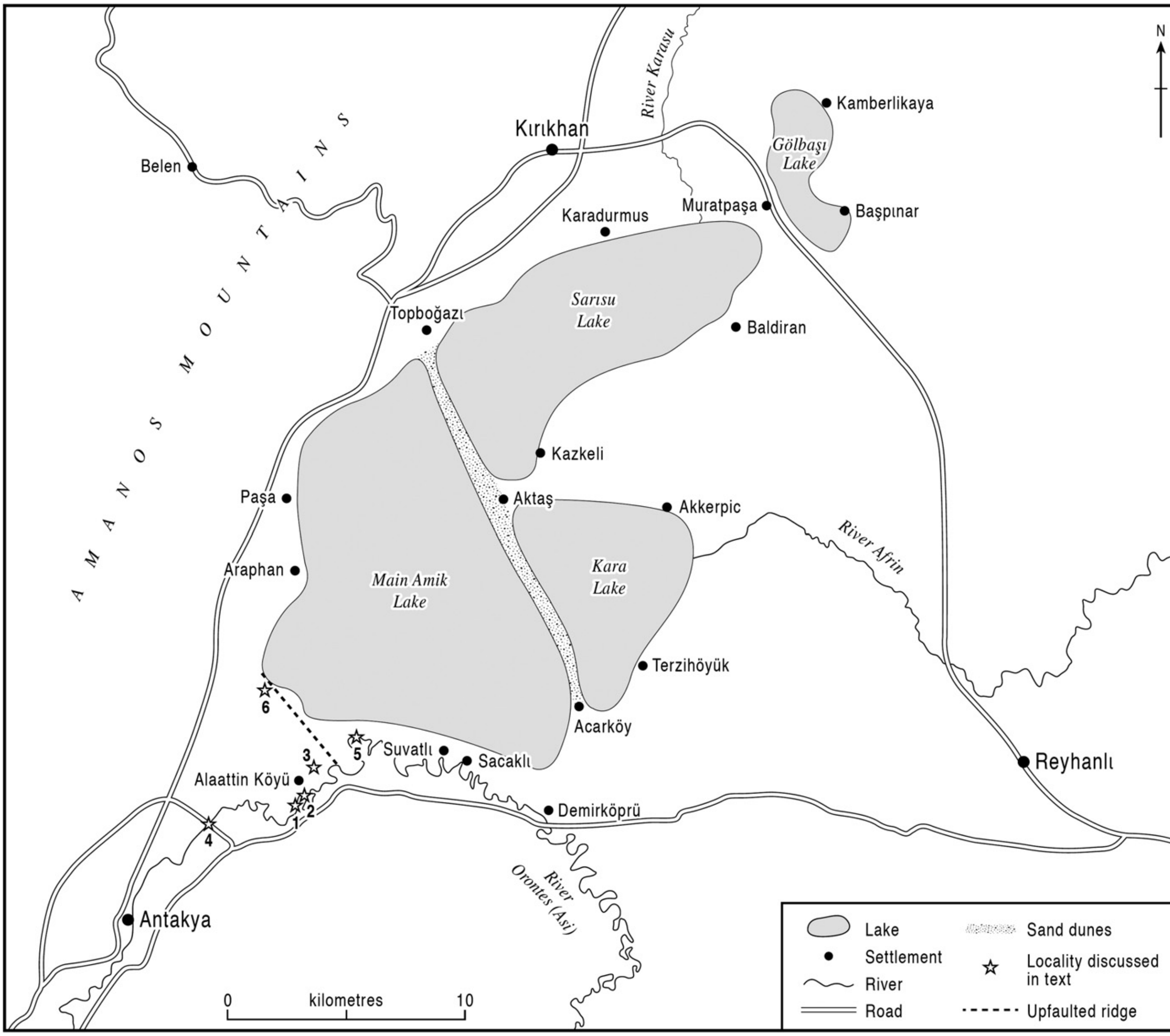


Fig. 13. The Amik basin showing the extent of the former Lake Amik (modified from Çalışkan, 2008). For location, see Fig. 1. Field localities are numbered as follows (see text): 1, the Alaattin Köyü clast analysis locality (see Table 1); 2, river-bank Section 1 km south of Alaattin Köyü (BA 52477 15506); 3, quarry section in upfaulted basin sediments at Alaattin Köyü (BA 52626 16772); 4 and 5, downstream and upstream limits of measurement fluvial entrenchment beneath the Amik Plain (at BA 48448 15139 and BA 54539 18533, respectively); 6, spot-height in the upfaulted sediment observed at 3, at 159 m a.s.l. (~BA 508 200).

9. The Lower Orontes, downstream of Antakya

Flowing south-westwards from Antakya, the Orontes again enters a high-relief area in which river terrace deposits are preserved sporadically along its incised course (Erol, 1963), before entering the most spectacular of its three gorges, more than 400 m deep, cut into resistant latest Cretaceous ophiolitic rocks (Figs. 1 and 14). This incised valley makes a dramatic contrast with the low relief in the area of the Amik Plain. Between Aknehir and Sutaşı (BA 30927 97820), for a distance of ~8 km, the Orontes follows a particularly deeply entrenched gorge between the Ziyaret Dağı mountain range to the south–east and the isolated Samandağ Tepe hill (summit 479 m a.s.l.) to the north–west. The abruptness of its downstream end (Fig. 14), where the Orontes flows out of a major escarpment that was recognized by Erol (1963), raises the possibility that it is caused by localized slip on an active dip-slip fault (Figs. 3 and 14). A fault in this location, near the village of Sutaşı, was indeed indicated by Tolun and Erentöz (1962). Recent interpretations of the regional kinematics (e.g. Westaway, 2004b; Gomez et al., 2006; Seyrek et al., 2008; Abou Romieh et al., 2009) require a component of crustal shortening in the crustal blocks alongside the active left-lateral faults forming the northern DSFZ. It is thus probable that any dip-slip fault in the Antakya area, away from the main left-lateral faulting, would be a reverse fault (cf. Fig. 3) rather than a normal fault. Heights and tentative ages for the marine terraces on the Mediterranean coastline were reported by Erol (1963) and were used by Seyrek et al. (2008) to infer a typical uplift rate of ~0.2 mm a^{-1} during the latter part of the Middle Pleistocene and the Late Pleistocene. The rate of localized uplift in the supposedly fault-bounded gorge reach may well be significantly higher than this already-high estimate of the regional uplift rate (cf. Demir et al., 2012-this issue).

In this gorge reach the Orontes falls 50 m in 16 km to the sea south of Samandağı. Former dock-side masonry of ancient Seleucia Pieria (the former port of Antioch) can be observed today within agricultural land (at YF 63841 00704), demonstrating relative sea-level fall in this area in the past two millennia. Relative sea-level decline has

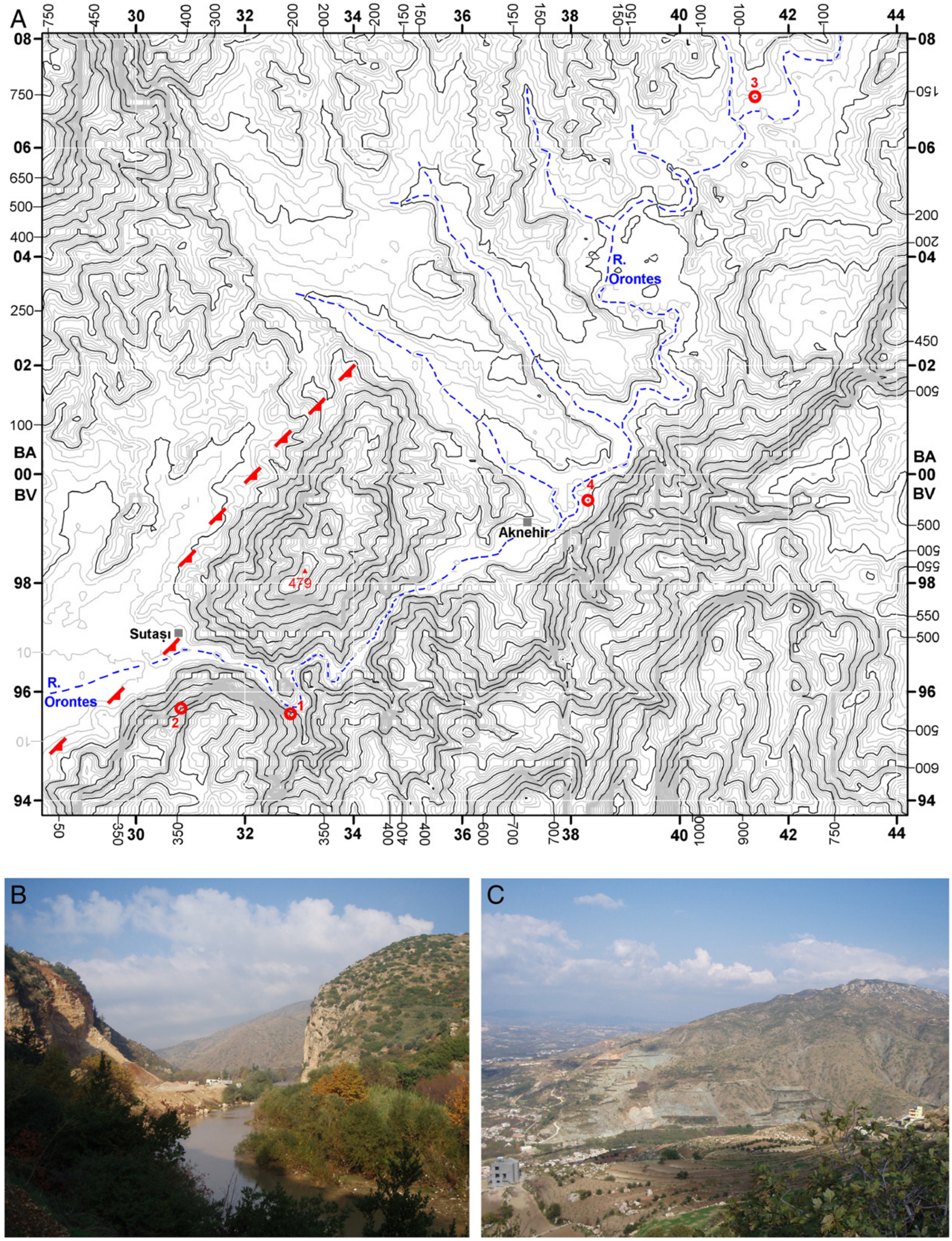


Fig. 14. The Lower Orontes Gorge, Hatay Province, Turkey: A — Synthetic contour map generated from SRTM data showing the Orontes valley downstream of Antakya (for location, see Fig. 1). Faint contours are at 10 m intervals, with dark contours at 50 m intervals, the latter omitted where the relief is too steep. Note the contrast between the broad valley upstream of Aknehir and the gorge reach between there and Sutaşı. The Sutaşı fault is marked, with ticks on the hanging wall. The summit of Samandağ Tepe is marked by its ~479 m spot height. Numbered localities denote the following: 1, viewpoint for Fig. 14B; 2, viewpoint for Fig. 14C; 3, Bostancık Köyü (Antakya western bypass) clast analysis locality; 4, the Şahin Tepesi clast analysis locality.B — Looking north-west (downstream) from BV 32785 95604 along the entrenched gorge reach shown in A. C — Looking NNE from BV 30827 95697 across the exit of the Orontes gorge at the village of Sutaşı, where the river emerges from what is interpreted as a locally uplifted fault block, the margin of which also creates the abrupt escarpment below the viewpoint.

also been documented from the levels on the quayside masonry of borings by marine molluscs, at up to 0.75 m above modern sea level, and has been linked to historical earthquakes, notably one in AD 551 (Pirazzoli et al., 1991).

Study of gravel exposures in this Lower Orontes reach reveals a further input of the crystalline rocks first seen in the Amik Basin sample. For example, a sample collected near Bostancık Köyü (Fig. 14), from an Orontes terrace gravel exposed on the western side of the Antakya western bypass (76 m a.s.l.; ~25 m above the river), contained ~30% basalt and >50% coarser basaltic lithologies, both including badly weathered examples (Table 1). Highly weathered ophiolitic rocks were also encountered (14.4%), as well as quartzose lithologies and kaolinized rocks (Table 1). Only a single flint/chert clast was recorded in this sample, which was devoid of limestone. In contrast, a sample collected from a bluff on the left bank of the Orontes at Şahin Tepesi, ~25 m above the river (therefore probably representing the same terrace), yielded 1.7% flint/chert and 7% limestone, the latter assumed to be locally derived (from the Cretaceous marine succession onto which the Hatay ophiolite has been emplaced; e.g. Tolun and Erentöz, 1962) rather than transported from Syria. It was comparable with the previous sample in that it was dominated by basalt and coarser basaltic rocks, together with ophiolite and a trace of quartzitic lithologies (Table 1). Erol (1963) included the terrace deposits here as part of his Orontes Terrace II, which is the lowest of the terraces depicted in Fig. 3 (his lowest terrace being too close to the river to show at this scale). He correlated this fluvial terrace with his Marine Terrace II, which Seyrek et al. (2008) concluded to be of last interglacial (MIS 5e) age. A direct correlation between fluvial and marine terraces, and Erol's (1963) resulting age assignment of this fluvial terrace to the 'Riss–Würm Interglacial', is unlikely to be tenable, given that current wisdom generally attributes river terrace gravels to cold-climate episodes (e.g. Bridgland, 2000; Bridgland and Westaway, 2008b; Bridgland et al., 2008). The reported heights of Erol's (1963) five Orontes terraces in the reach between Bostancık Köyü and the upstream end of the Samandağ Tepe gorge, 5–7, 15–25, 40–50, 70–80, and 90–100 m above the modern river, are indicative of a regular pattern, suggesting terrace formation in response to 100 ka climatic cycles, as in other parts of the world (cf. Bridgland, 2000; Bridgland and Westaway, 2008a). The reported terraces can perhaps be correlated with MIS 12, 10, 8, 6 and 2. Uplift rates in this reach of the river during this span of time would thus approach 0.2 mm a^{-1}, far higher than in localities further upstream. Like in the Ceyhan valley through the Amanos Mountains further north (Seyrek et al., 2008), and in the lower reaches of the Nahr el-Kebir near Latakia in north–west Syria (Bridgland et al., 2008), the absence of any earlier record in this reach of the Orontes can be attributed to the rapid uplift; the resulting high relief and the associated rates of slope processes have led to low probabilities for preservation of older river terrace deposits.

10. Discussion: possible age and relation to climatic fluctuation

Unlike other nearby rivers in Turkey and Syria (Sharkov et al., 1998; Bridgland et al., 2007; Demir et al., 2007, 2012-this issue; Seyrek et al., 2008; Westaway et al., 2009b), there are no Pleistocene lava flows interbedded within the Pleistocene terrace sequence of the Orontes to provide marker levels for dating, although the Homs Basalt provides a maximum age for the start of incision by the upper river below the level of the Late Miocene–Early Pliocene lake bed onto which this lava erupted. It has been thought, therefore, that the best indication of age within the sequence comes from the mammalian assemblage from the Middle Orontes (see above). Indeed, Bridgland et al. (2003) previously used the Latamneh terrace deposits as a pinning point for correlation between the Middle and Upper Orontes terrace sequences, having also modelled the latter (see also Bridgland and Westaway, 2008a) using the technique applied widely to terrace systems elsewhere (Westaway, 2004a; Westaway et al., 2002; see above). They attributed the formation of comparable terrace sequences in both the middle and upper reaches of the Orontes to cyclic climatic forcing of fluvial sedimentation and erosion with progressive incision in response to regional uplift. The similarity of these records to those in rivers elsewhere, notwithstanding proximity to plate boundaries (as in the case of the Orontes) or otherwise (as in rivers in NW Europe with similar uplift histories) was also noted (Bridgland et al., 2003; Bridgland and Westaway, 2008a). The consistent pattern of uplift, seen widely and calibrated in systems with optimal dating control, records acceleration at around 3 Ma, followed in many cases by renewed acceleration around 2 Ma, then by decrease during the Early Pleistocene and a further acceleration at around the 'Mid-Pleistocene Revolution', when the 100 ka climate cycles began (Bridgland and Westaway, 2008b; Westaway et al., 2009a). Each of these phases of uplift is well developed in fluvial sequences within the Arabian Platform, notably that of the River Euphrates (e.g. Demir et al., 2007, 2008; Westaway, 2010). This pattern of persistent uplift is seen, however, only in areas of post-Early Proterozoic (i.e. non-cratonic) crust, older crust being colder and more stable and showing either intermittent uplift and subsidence (Early Proterozoic crust) or, in the case of Archaean cratons, little vertical movement at all during the Late Cenozoic (Westaway et al., 2003, 2009a; Westaway, 2012-this issue). Subsiding areas of sediment accumulation are further exceptions to the standard pattern; not necessarily fault bounded, their subsidence is presumed to be a response to sedimentary isostasy. Examples of substantial subsiding regions of this type are the Lower Rhine, beneath the Netherlands (Brunnacker et al., 1982; Ruegg, 1994), and the Great Hungarian Plain (Gábris and Nádor, 2007; Kasse et al., 2010). Smaller areas of subsidence are also recognized within the Rhine, such as the Neuwied Basin, where a substantial stacked sequence of fluvial deposits floors a downfaulted block (Meyer and Stets, 2002). The Ghab and Amik Basins compare closely with the last-mentioned European example, as they also occupy small subsiding fault-bounded blocks.

It is apparent from the disposition of fluvial gravel terraces in both the Upper and Middle Orontes that the river in both these reaches has migrated westwards during the Pleistocene, although throughout that time it flowed between them through the fixed and entrenched Rastan Gorge. The close coincidence of the modern Orontes course and the eastern margin of the Homs Basalt outcrop can be explained as the result of this westward migration being prevented once the river encountered the resistant basalt, with forms an eastward-inclined interbed within the 'Pontian' lacustrine marl.

The previous use of the Latamneh deposits as a dating level within the Orontes sequence must now be open to question, since, as noted above, the mammalian assemblage from that locality includes elements that date back to the late Early Pleistocene and would seem to imply an age in the region of 1.2–0.9 Ma. This revision (Fig. 7) effectively doubles the supposed age of the QfIII terrace at Latamneh, with the clear implication that uplift there has been at half the rate previously supposed. Account must also be taken of the contradictory indications from the occurrences of different mammoth species within deposits mapped as Terrace QfIII at Latamneh (*M. trogontherii*) and Sharia, Hama (*M. meridionalis*), the latter being potentially an older indicator than even the arvicolid *L. arankae* at Latamneh. It is also now evident that the Latamneh locality is within a few kilometres of an active fault, at Sheizar, that has experienced significant movement during the Pleistocene. It is thus possible that the deposits there might provide a less-than-reliable indication of the regional uplift rate in the Middle Orontes valley, which could explain the indication that older deposits occur at a lower height relative to the modern river in the Hama area. The deposits in the latter area are ~30 km upstream of the faulting and can be assumed to provide a genuine indication of the regional uplift. It is nonetheless clear that the deposits of Middle Orontes Terrace QfIII are significantly older than was suggested in previous publications (cf. Sanlaville, 1988; Bridgland et al., 2003).

The reinterpretation of the Middle Orontes record raises the possibility that it is comparable with that from other parts of the Arabian Platform, further east in Syria and to the north-east in Turkey, where it has been discerned from the terrace sequence of the River Euphrates. Evidence from the Euphrates points to relatively slow uplift and to a brief period of subsidence in the late Early Pleistocene, during which the valley was partly backfilled with fluvial sediment (Demir et al., 2007, 2008, 2012-this issue). The resultant thick aggradation, culminating at about MIS 22, has yielded numerous handaxes, although the Euphrates sediments are generally devoid of fossils. It is tempting, therefore, to suggest a correlation with the deposits at Latamneh, which also indicate thick sediment accumulation, have an age (from biostratigraphy) close to the Early–Middle Pleistocene boundary and contain numerous handaxes. The comparable localities in the Euphrates, indicative of subsidence in the late Early Pleistocene, include sites such as Ain Abu Jemaa, near Deir ez-Zor, Syria (Demir et al., 2007), and Birecik and Karababa, in south–eastern Turkey (Demir et al., 2008, 2012-this issue). A physical mechanism for the reversals in vertical crustal motion that are implicit in this interpretation is suggested by Westaway (2012-this issue). The subsequent increase in regional uplift rates that caused a switch from aggradation back to incision in these rivers can be attributed to the Mid-Pleistocene Revolution, with the more severe cold stages that occurred within the subsequent 100 ka climate cycles leading to enhanced climatic forcing and a positive-feedback enhancement of erosional isostasy. At Latamneh this effect might well have been accentuated by the component of vertical slip on the Sheizar Fault (cf. de Heinzelin, 1966). Indeed, it is conceivable that increased rates of vertical motion in opposite senses (i.e. faster uplift in the Middle Orontes and faster subsidence in the southern Ghab Basin) following the Mid-Pleistocene Revolution affected the state of stress in the region, resulting in initiation or reactivation of slip on the Sheizar Fault (cf. Westaway, 2006).

There is scant evidence that late Early Pleistocene subsidence occurred further upstream in the Orontes. Recalibration of the ages of the Upper Orontes terraces (cf. Fig. 4) generally suggests that the Bridgland et al. (2003) age model underestimates their ages by a single Milankovitch (100 ka) cycle, given that the number and spacing of the terraces remain suggestive of formation in approximate synchrony with these glacial–interglacial cycles. The more rapid uplift, in comparison with the Middle Orontes, that is implicit in this interpretation is in keeping with the evident post-Pliocene uplift of the 'Pontian' lacustrine basin (cf. Fig. 3).

The dating of river gorges is, in general, difficult and typically relies upon projection of terraces from upstream and downstream (cf. Fig. 3). The Rastan Gorge is, in fact, an exception, since its incision can also be constrained by the ages of the Homs and Tell Bisseh basalts. In particular, the well-constrained age of the Homs Basalt provides an upper limit on the ages of the oldest terraces, comparable in height above the river (Fig. 3), of ~4–5 Ma. It is much more difficult to be clear about the age of the Darkush Gorge, since it is isolated from well-dated terrace sequences, falling between the subsiding Ghab and Amik basins.

In contrast to the Upper and Middle Orontes catchment, much higher rates of vertical crustal motion are indicated in coastal parts of the study region. Setting aside any local effects of active faulting, as already noted, the disposition of the Orontes and marine terraces downstream of Antakya indicates an uplift rate of ~0.2 mm a^{-1}, roughly an order-of-magnitude faster than estimates for the Middle Orontes, where the inferred ~120 m of incision in the Hama reach since ~4 Ma (Early Pliocene) equates to a rate of ~0.03 mm a^{-1}, although if the deposit at Sharia, ~40 m above the modern river, is as young as ~1 Ma it indicates an accelerated rate of ~0.04 mm a^{-1} during the last million years. This estimate of the regional uplift rate can be compared with an independent estimate of ~0.4 mm a^{-1} further north in the Amanos mountain range, based on the terraces of the River Ceyhan, which are capped by datable basalt flows (Seyrek et al., 2008). The uplift rate is also ~0.4 mm a^{-1} further south, in the Latakia area of north-west Syria, on the basis of marine and fluvial terraces in the region of the Nahr el-Kebir estuary (Bridgland et al., 2008), the latter river draining a catchment that lies entirely seaward from the course of the Orontes (Fig. 1, inset). Seyrek et al. (2008) reported on a modelling study that attempted to establish the cause of the high uplift rates in these coastal regions, which lie close enough to the DSFZ for it to be possible that they are affected by the distributed crustal shortening (as well as localized faulting) that is required given the orientation and slip sense of this fault zone. However, they found that this process is unlikely to be the main cause of the rapid regional uplift observed, concluding instead that this is primarily the isostatic response to erosion. They envisaged a complex sequence of events, with positive feedback effects, following the elevation of the coastal mountain ranges as a result of plate motions (once the modern geometry of the plate boundary zone was established at ~4 Ma). Once some initial topography had developed, orographic precipitation would have been initiated in this coastal region, as a result of westerly winds from the Mediterranean. The resulting rainfall in turn triggered erosion, and, given the physical properties of the underlying crust (cf. Bridgland and Westaway, 2008a, b), the resultant unloading drove the observed uplift isostatically. Conversely, sediment loads, triggered by the same combination of processes, may well have driven the observed subsidence in depocentres such as the Ghab and Amik basins. It thus appears likely that both plate motions and climate have contributed to the pattern of vertical crustal motions in this coastal region, whereas parts of the arid interior hinterland that are well away from any active faults, such as the Hama area, have experienced much slower uplift, reflecting the lower rates of erosion.

The difference between the ~0.2 mm a^{-1} uplift estimated for the lower Orontes downstream of Antakya and the ~0.4 mm a^{-1} rates in the other coastal regions may result from a significant part of the deformation in the former area being accommodated by local reverse faults, such as that at Sutaşı (see above; Figs. 3 and 14), whereas in the regions traversed by the Ceyhan and Nahr el-Kebir it is accommodated entirely by distributed crustal deformation. It is thus possible that the spatial average of the uplift rates in the terraced reach of the Lower Orontes downstream of Antakya and in the gorge reach in the hanging wall of the Sutaşı Fault equates to ~0.4 mm a^{-1}. However, there is no way of estimating directly the local uplift rate in this gorge reach to facilitate such a comparison.

In the Upper Orontes the uplift rate appears to be significantly higher than in the Middle Orontes; the age model in Fig. 4 indicates a time-averaged rate since the Mid-Pleistocene Revolution of ~0.09 mm a^{-1}, more than double the upper bound of ~0.04 mm a^{-1} for the Middle Orontes over a similar interval, based on the supposed age of the Sharia deposits (see above). This difference may possibly reflect the relative erodability of the 'Pontian' marl substrate in the Homs area (i.e., faster erosion is resulting in a faster isostatic uplift response). Alternatively, much of the study region south of Homs adjoins the NNE end of the Anti-Lebanon mountain range and the western end of the Palmyra Fold Belt (Fig. 1). It is thus possible that localities in this region are affected by components of localized deformation (possibly arising from slip on blind reverse faults beneath anticlines; cf. Demir et al., 2012-this issue). Abou Romieh et al. (2009) indeed noted localized deformation of Euphrates terraces where the Palmyra Fold Belt crosses this river valley in NE Syria, and inferred significant rates of deformation in more westerly parts of this deforming zone. Demir et al. (2012-this issue) have shown that the heights of Euphrates terraces in SE Turkey vary laterally because rates of localized deformation on active faults and folds can be significant compared with regional uplift rates.

11. Conclusions

The work on the Orontes, reported here, testifies to the value of a pragmatic approach, using multiple techniques and taking account of data from all relevant sources, in this case field and GIS survey of terrace morphology and sediments (assisted by dGPS), the use of fossil and artefact content as indicators of age for particular terrace formations, of clast analysis to identify the deposits of this river (as opposed to tributaries) and mathematical modelling, to provide a broad impression of likely ages, calibrated by pinning points and other constraints.

The variable Quaternary record from different reaches of the Orontes underlines the roles of crustal properties and climate in controlling landscape evolution within particular regions. Although less well dated than sequences in nearby catchments in Syria and Turkey, it is possible, using the starting point of the Homs Basalt eruption and the limited biostratigraphical and geochronological constraint (the last from the U-series dating reported here for the first time), to erect tentative age models for the sequences in the key reaches. This can be compared with those applicable to neighbouring catchments, in particular the slowly uplifting interior of the Arabian Platform (transected by the Euphrates), to which the Middle Orontes can be likened, and the rapidly uplifting coastal area that extends both north and south of, as well as including, the lowermost Orontes (cf. Fig. 3). The repeated changes along the course of the river between uplifting crustal blocks (with either terraces or gorges, according to the relative resistance of the bedrock) and subsiding ones is the major contribution of active Quaternary crustal deformation; otherwise the disposition of terraces in those reaches where they have formed is comparable with regions of post-Archaean crust elsewhere in the world (Bridgland and Westaway, 2008a, b; Westaway et al., 2009a). The contrasting record from the different reaches of this single river thus provides valuable insight into the contrasting types of records from rivers elsewhere that are wholly within individual crustal blocks.

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Appendix A. Supplementary data

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