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Citation for published version:

Murray, H & Robertson, AH 2019, 'Pliocene–Pleistocene sedimentary and geomorphologic development of the Vasilikos river catchment, S Cyprus, in relation to uplift of the Troodos ophiolite and climate-related changes', *Geological Magazine*, pp. 1-30. <https://doi.org/10.1017/S0016756819001134>

Digital Object Identifier (DOI):

[10.1017/S0016756819001134](https://doi.org/10.1017/S0016756819001134)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Geological Magazine

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1 **Pliocene-Pleistocene sedimentary and geomorphologic development of the Vasilikos river**
2 **catchment, S Cyprus in relation to uplift of the Troodos ophiolite and climate-related**
3 **changes**

4
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14 **Abstract**

15 The Pleistocene development of the Vasilikos River exemplifies the interaction of focused,
16 tectonically-induced surface uplift and climate-influenced changes. The resulting sediments
17 are well exposed in Vasilikos Quarry and in the main river catchment farther east. An
18 important erosional surface incises the highest-level (oldest) fluvial conglomerates, down into
19 Late Pliocene-Early Pleistocene open-marine mudrocks (Nicosia Formation), allowing
20 integration with the circum-Cyprus sedimentary-geomorphic development (F1-F4 stages). To
21 determine where the quarry deposits lie in relation to the Vasilikos river catchment, the fluvial
22 deposits were mapped and valley profiles were constructed, revealing four main episodes, each
23 associated with incision and distinctive fluvial deposition. Source lithology strongly influenced
24 channel morphology, infill and adjacent slope-sediment (colluvium) composition. Paleosols,
25 particularly red-brown terra rossa, developed on abandoned fluvial terraces and adjacent
26 hillslopes, especially overlying F3 surfaces. The combined evidence allows close correlation
27 of the Vasilikos river and quarry deposits. Relatively coarse (chalky conglomerate/breccia) and
28 fine-grained colluvium (calcareous silt--Cyprus harvara) developed especially on lower
29 hillslopes following incision (mainly above F2 and F3 surfaces). Based on regional
30 comparisons, overall sediment aggregation ended during the Early Pleistocene. The F1-F2
31 surfaces and deposits are inferred to be Middle Pleistocene, the F3 ones later Middle
32 Pleistocene and the F4 ones near the Middle-Late Pleistocene boundary. Geomorphology and
33 deposition were tectonically forced during strong, focussed Early-Mid Pleistocene surface
34 uplift. Coarse clastic ruff-off and paleosol development (terra rossa) and related sediment
35 aggradation are inferred to have increased during warm, humid periods. Late Pleistocene
36 geomorphology and deposition were more influenced by climatic change, with semi-perennial

37 stream flow, rapid sediment aggradation and paleosol (terra rossa) development during warm,
38 humid periods (interglacials). Cooler (glacial) periods enhanced fluvial incision, sediment
39 bypassing and hillslope colluvial processes (e.g. frost shattering, downslope creep and mass
40 flow) when sediment transport (by-passing) exceeded sediment supply. Neotectonic faulting
41 affected the catchment but did not greatly affect geomorphology or sediment supply. Although
42 climate/climate change (and eustatic sea-level change) had an important influence tectonics is
43 interpreted as the fundamental driver of geomorphological development and fluvial
44 sedimentation, with implications for other areas, regionally to globally.

45

46

47 *Key words: Troodos Massif, river terraces, alluvium, colluvium, paleosols, fluvial processes*

48

49

50 1. Introduction

51 The processes and timing of orogenic uplift in relation to clastic sedimentation and slope
52 development are topics of fundamental geological importance (Blum & Törnqvist, 2000; Allen,
53 2008; Bridgland & Westaway, 2008; Whittaker, 2012; Jamieson & Beaumont, 2013; D'Arcy
54 & Whitaker, 2014; Jia *et al.* 2015). The Eastern Mediterranean region is very well suited for
55 such studies (Maklin *et al.* 2002) because major uplift has taken place during the last 3 Ma,
56 notably within and around Anatolia (Glover & Robertson 1998; Maddy *et al.* 2008; Seyrek *et*
57 *al.* 2008; Cosentino 2012; Schildgen *et al.* 2012, 2014; Duman *et al.* 2017; Fig. 1). Cyprus is
58 of particular interest because of the rapid uplift of both the Troodos Massif in the centre and
59 the Kyrenia Range in the north of the island, mainly during the Pleistocene (McCallum &
60 Robertson, 1990; Poole & Robertson, 1991; Kinnaird *et al.* 2011; Weber *et al.* 2011;
61 Palamakumbura *et al.* 2016; Palamakumbura & Robertson, 2016a). A range of proximal to
62 distal, continental to marine facies are exposed around the periphery of the Troodos Massif
63 (Poole *et al.* 1990; Poole & Robertson, 2000) (Fig. 1, inset), which is a key area for the study
64 of clastic sedimentation and geomorphology related to uplift (Poole & Robertson, 1998; Main
65 *et al.* 2016). The Troodos Massif is widely accepted to have been located in a supra-subduction
66 ('fore-arc') setting during Neogene time related to diachronous continental Collision of the
67 African and Eurasian plates (Robertson, 1990; Anastasakis & Kelling, 1991; Zitter *et al.* 2005;
68 Kinnaird & Robertson, 2013), although other tectonic models have been proposed (Sage &
69 Letouzey, 1990; Harrison *et al.* 2004; Calon *et al.* 2005).

70 A key requirement for uplift-related geomorphological and sedimentological studies is a
71 good understanding of the geology and structure of the Troodos Massif. Previous studies
72 indicate that the main uplift of the Troodos Massif was focussed on Mount Olympos, resulting
73 in overall radial drainage and clastic sediment distribution, as indicated by paleocurrent data
74 (Poole & Robertson, 1998, 2000). Because the Troodos ophiolite is well mapped
75 (Constantinou, 1995), sediment provenance in many areas around the Troodos Massif can be
76 related to specific outcrops, with known erosional properties (e.g. chert vs. basalt) and
77 predictable distances of transport. Fluvial and marine terraces have been traced generally
78 around the Troodos Massif without marked disruption or abrupt changes in height, suggesting
79 that the Troodos Massif was uplifted essentially as a coherent structural unit (Poole *et al.* 1990;
80 Harrison *et al.* 2013). Some other fore-arc settings, in contrast, are highly fault-segmented. For
81 example, in the fore arc of the Island of Crete, Pleistocene sediments are offset by major
82 margin-parallel, high-angle extensional faults which have created syn-tectonic sedimentary

83 basins (Caputo *et al.* 2010; Gallen *et al.* 2014). Similarly, the adjacent Messenia Peninsula, SW
84 Peloponnese, is also strongly fault segmented (Kourampas & Robertson, 2000; Fountoulis *et*
85 *al.* 2014).

86 Although the Troodos Massif has risen as a relatively coherent entity, this has been modified
87 by neotectonic faulting in some areas. The most notable of these is the Polis graben of west
88 Cyprus, which has continued to be highly active during Late Miocene to Recent time
89 (Robertson, 1977a; Payne & Robertson, 1995; Balmer *et al.* 2017). In addition, coastal SE
90 Cyprus is cut by numerous high-angle *c.* E-W faults that are related to regional strike-slip
91 faulting (Soulas, 2002; Soulas & Geoter Consortium, 2005; Kinnaird, 2008; Harrison *et al.*
92 2013; Kinnaird & Robertson 2013). Neotectonic faulting could therefore have significantly
93 affected the geomorphology and sedimentation in some areas.

94 In this paper, we specifically consider the example of the Vasilikos river catchment in
95 southern Cyprus (Fig. 2). This is a classic area for study because geomorphic terraces, slopes,
96 fossil soils (paleosols) and fluvial deposits are all well developed in successive stages during
97 the Pleistocene. Pleistocene fluvial deposits, termed Fanglomerate, were initially mapped along
98 the southern margin of the Troodos Massif (Morel, 1960) and interpreted as alluvial fans
99 derived from the Troodos ophiolite and its sedimentary cover (Bagnall, 1960). Gomez (1987)
100 identified four terrace levels within the Vasilikos river valley and suggested that younger
101 terraces are located at progressively lower topographic levels as a result successive incision.
102 The Vasilikos river valley is known to have been affected by neotectonic faulting in some areas
103 (Soulas 2002; Kinnaird & Robertson, 2013). This raises the question as to whether such
104 faulting could have had a significant effect on the geomorphology of the river catchment and
105 thus on clastic sediment supply.

106 Around the Troodos Massif as a whole the oldest Pleistocene fluvial sediments have been
107 successively incised by younger fluvial sediments as surface uplift proceeded (Poole *et al.*
108 1990; Poole & Robertson, 1991). This resulted in four main stages of fluvial accumulation, that
109 were termed F1 (oldest) to F4 (youngest), as identified in many areas (Poole & Robertson,
110 2000; Main *et al.* 2016).

111 On the other hand, a detailed study of the much-visited, large Vasilikos Quarry (Fig. 2) near
112 the SW periphery of the lower Vasilikos river catchment has been described and interpreted,
113 alternatively as an essentially two-phase, *aggrading* fluvial succession (Waters *et al.* 2010).
114 The sediments in the quarry are very well exposed, allowing individual depositional units (e.g.
115 fore-set bedding; channels) to be observed in three dimensions (Waters *et al.* 2010). The
116 present interpretation of the facies exposed in the quarry contrasts with the evidence of

117 successive down-cutting during the Pleistocene, as inferred in many other areas (Poole *et al.*
118 1990; Poole & Robertson, 1991; Main *et al.* 2016). Waters *et al.* (2010) inferred that alluvial
119 fan deposits, dominated by conglomerates and sandstones, lie disconformably above open-
120 marine silty mudstones of the Late Pliocene-Early Pleistocene Nicosia Formation. The base of
121 this alluvial fan above the Nicosia Formation is located at c. 50 ASL (above sea level). A
122 caliche sample from the upper part of the alluvial succession yielded a U-series age of c. 59 ka
123 (Waters *et al.* 2010), which implies remarkably rapid uplift since that time, averaging 84 cm/ka.
124 The authors concluded that a major alluvial fan aggraded during the late Pleistocene over c.
125 120,000 years, generally equivalent to MIS (marine isotope stage) 5 to MIS 1. This compares
126 with uplift rates of ~24 cm/ka for the Early to Mid-Pleistocene and ~5 cm/ka for the Late
127 Pleistocene time periods, based on dating of south-Cyprus coastal marine terraces using
128 solitary coral (Poole *et al.* 1990).

129 The apparent discrepancy in inferred uplift rates between coastal southern Cyprus generally
130 and Vasilikos Quarry specifically raises the question as to whether the quarry could have been
131 strongly uplifted by neotectonic faulting (and any other related neotectonic processes; e.g.
132 folding), which if valid, could have also had a major effect on the geomorphology and clastic
133 sediment supply in the adjacent Vasilikos river catchment. Neotectonic faulting is known to
134 have affected the Vasilikos river catchment (Soulas, 2002; Soulas & Geoter Consortium, 2005;
135 Kinnaird, 2008; Kinnaird & Robertson 2013; this study-see below). However, it is uncertain
136 whether this faulting significantly affected uplift rates in any part of the Vasilikos river
137 catchment. Alternatively, the reported c. 59 ka caliche age might not be correct.

138 To test the existing alternative interpretations, it is necessary to correlate the sedimentary
139 record in the Vasilikos Quarry with the combined geomorphological and sedimentary
140 development of the adjacent Vasilikos river catchment within the regional temporal
141 framework.

142

143 Here, we report new field evidence of a hitherto unknown, major angular discontinuity within
144 the Pleistocene succession in the Vasilikos Quarry. As a result, the local fluvial stratigraphy
145 can be re-interpreted as recording successive phases of downcutting, as reported elsewhere
146 around the Troodos Massif (Poole *et al.* 1990; Poole & Robertson, 1991; Main *et al.* 2016).
147 During the present work, fluvial terraces within the Vasilikos river valley were found to be
148 much more extensive than previously documented, allowing three-dimensional relationships
149 to be determined through time. Successive phases of development (from the coast up-
150 catchment for c. 15 km) can be recognised by an integration of geomorphological and

151 sedimentological evidence related to successive fluvial incision. This allows the Vasilikos river
152 valley and the adjacent quarry sediments to be correlated for the first time. This has wider
153 implications for other areas of Cyprus and the Eastern Mediterranean region, including the
154 relative role of local neotectonic faulting compared to more regional-scale uplift in controlling
155 geomorphology and related sedimentation. In addition, climatic change (and potentially sea
156 level change) have also had an important influence on the geomorphology and sediment
157 deposition within the Vasilikos river catchment, as elsewhere in Cyprus, and an attempt is
158 made to unravel the relative roles of these processes.

159

160 **2. Methods and nomenclature**

161 To understand the facies and facies distribution, detailed field observations and sedimentary
162 logs were made within and around Vasilikos Quarry, and also within the adjacent Vasilikos
163 river catchment (mainly south of Vasilikos Dam), where possible (Fig. 2). River terraces within
164 the catchment were mapped by using a combination of topographic maps, Geographical
165 Information Systems (GIS) (using ArcGIS 10.1) and Google Earth satellite imagery. Ten-metre
166 contours were taken from the 1:25,000 Geological Survey Department map of the area
167 (Pantazis, 1966), converted to a digital elevation matrix (DEM), and used to generate a series
168 of cross-sectional valley profiles that highlight geomorphological surfaces. The overall
169 Pleistocene development of the Vasilikos river catchment was then determined using the
170 combined geomorphological and sedimentary evidence, in turn allowing a detailed correlation
171 with the logged sequences in Vasilikos Quarry. In addition to fluvial sediments, paleosols,
172 colluvium and secondary deposits (e.g. caliche) shed light on climate and climatic change.
173 Many studies focus on individual facies, whereas here we have been able to establish a
174 developing geomorphological framework as a basis to interpret the inter-relations of the
175 different sediment types as large-scale uplift and incision have proceeded during the
176 Pleistocene.

177 In this study, we follow the nomenclature of Poole & Robertson (1991), in which the
178 topographically highest of the non-marine conglomerates (Fanglomerate Group) is termed F1
179 (i.e. Fanglomerate 1). Topographically lower conglomerates are correspondingly termed F2,
180 F3 and F4. However, no relative ages were initially assumed. Each of these conglomerates
181 form the four main terrace levels within the Vasilikos river valley that were originally identified
182 by Gomez (1987). Elsewhere in the Kyrenia Range, N Cyprus where marine and non-marine
183 terraces are thicker and more extensive the geomorphological surfaces underlying the

184 overlying the deposits have been identified and classified separately (Palamakumbura et al.
185 2016 a, b; Palamakumbura and Robertson 2016 a). However, within the Vasilikos river
186 catchment the fluvial terraces are mainly restricted to thin, discontinuous remnants of valley
187 fill (of similar heights above sea level) and thus a single F1-F4 classification suffices.

188 Any interpretation of sedimentation in and around the Vasilikos river catchment must also
189 take account of several types of associated finer-grained deposits, of both primary and
190 secondary origin, two of which have local Cyprus names:

191 First there is harvara, a term used in Cyprus for surficial (primary) sedimentary deposits
192 (Bellamy & Jukes-Brown, 1905). Harvara is a form of colluvium related to hillslope
193 adjustment. Unconsolidated calcareous sediment predominates, with variable amounts of
194 detrital material, locally including rock clasts (Pantazis, 1967, 1973). Harvara is commonly
195 interbedded with brownish grey to reddish-coloured paleosols, some of which correspond to
196 the widespread Mediterranean terra rossa (Schaetzl & Andreson, 2005).

197 Secondly, the fluvial terraces are commonly capped by a calcareous crust of secondary origin
198 termed kafkalla (Pantazis, 1967, 1973). Kafkalla is preferentially developed above carbonate
199 rocks and sediments. Two types commonly occur; first, calcrete, a cemented surface with or
200 without clasts and secondly, caliche which is typically nodular or pipe shaped. Although
201 preferentially developed above carbonate rocks and sediments, caliche and calcrete can also
202 occur within and above ophiolite-derived sandstone and conglomerate.

203 Kafkalla (calcrete and caliche), harvara (colluvium) and paleosols (e.g. terra rossa) encode
204 important geomorphological and climatic information and therefore play an important role in
205 understanding of the Vasilikos catchment.

206

207 **3. Vasilikos Quarry and adjacent natural exposure**

208 Below, we focus on the successive sedimentary events that can be inferred from the Vasilikos
209 Quarry. However, we begin by outlining the upward sedimentary passage from the Pliocene
210 than can be inferred from an adjacent natural escarpment.

211

212 *3.1. Exposures in the vicinity of Vasilikos Quarry*

213 Key sedimentary information comes from within and adjacent to Vasilikos Quarry (Fig. 2). An
214 overall Late Pliocene-Early Pleistocene succession is well-exposed along a WNW-ESE
215 trending topographic escarpment, c. 1.8 km northwest of the quarry (Fig. 3 a, b). Localised
216 exposures of Pliocene-Pleistocene sediments in this area have been referred to as the Mari basin

217 (JE McCallum, unpub. PhD thesis, Univ. Edinburgh, 1989). The local succession begins with
218 Messinian evaporites (locally gypsum breccias) that are exposed near the Limassol-Nicosia
219 highway to the west (Fig. 3 a). The evaporites are unconformably overlain by a relatively thin
220 (c. 60 m) succession of marine mudrocks of the Nicosia Formation (Henson, 1949; Ducloz,
221 1964; JE McCallum, unpub. PhD thesis, Univ. Edinburgh, 1989). The base of the succession
222 includes clastic intervals and is followed by marine silts of Early Pliocene age, in which
223 ostracod fauna suggest open-marine shelf-depth accumulation (JE McCallum, unpub. PhD
224 thesis, Univ. Edinburgh, 1989). This is followed by a lenticular body of coarse clastic
225 sediments (termed the Vasilikos Formation by JE McCallum (unpub. PhD thesis, Univ.
226 Edinburgh, 1989) (Fig. 3 b), which have been interpreted to represent the overall progradation
227 of a fan-delta towards the SE (JE McCallum, unpub. PhD thesis, Univ. Edinburgh, 1989; p.
228 179-182). A series of braided streams and gravelly, to sandy bars, was inferred and related to
229 tectonically-driven fluvial incision. The conglomeratic facies occurs between the Pliocene-
230 Early Pleistocene Nicosia Formation and the Pleistocene Fonglomerate Group, suggesting an
231 Early Pleistocene age for these deposits (JE McCallum, unpub. PhD thesis, Univ.
232 Edinburgh, 1989).

233 The overall upward transition from fine to coarse-grained sediments was studied during this
234 work to facilitate facies comparisons with the Vasilikos Quarry and the adjacent river valley.
235 Marine mudrocks are overlain by four-main laterally persistent units of sand/conglomerate,
236 which become generally coarser and more laterally extensive upwards (Fig. 3 a, b). Interbedded
237 marls become more sand-rich upwards and contain reworked oyster shells (mostly
238 fragmentary). The conglomerates are lenticular (up to 2 m thick by up to 10 m wide) and are
239 matrix-supported. Clasts are mainly well-rounded and were mostly (c. 70-80%) derived from
240 the Paleogene chalks of the Lefkara Formation that overlie the Troodos ophiolite. Other clasts
241 were mainly derived from ophiolitic diabase, which is relatively resistant to breakdown during
242 erosion and fluvial transport. The Lefkara Formation chalk clasts are, on average, distinctly
243 larger (up to c. 1 m) than the ophiolite-derived ones (10s of cm) in any given conglomerate
244 depositional unit. The finer-grained conglomerates (pebblestones) are more matrix-rich and
245 include localised, poorly developed clast imbrication which is variably orientated. Locally
246 measured northerly paleoflow hints at the presence of meandering streams. The thicker more
247 laterally continuous conglomerates that occur towards the top of the marine succession (Fig. 3
248 b) exhibit patchy reverse clast grading, irregularly distributed outsized clasts (mostly chalk)
249 and variable matrix abundance, features that indicate accumulation by high-energy mass-flow
250 processes. In addition, these conglomerates are relatively rich in diabase clasts, together with

251 a few gabbro and ultramafic rock clasts, indicating an increased contribution from the relatively
252 far-removed intrusive rocks of the Troodos ophiolite. The above conglomeratic sediments
253 accumulated in small channels within a shallow-marine fan delta.

254 Upwards, there is a relatively abrupt change (over < 10 cm) to more laterally continuous,
255 less matrix-rich, clast-supported conglomerates. The abundance of ophiolite-derived clasts
256 increases further to c. 50%, with the remainder still being chalk from the Lefkara Formation.
257 The conglomerate includes 'floating' intraclasts, up to 2 m in size, that are composed of sandy
258 and silty sediments, as exposed within the underlying marine succession. Sandy sediments
259 directly beneath these conglomerates in places exhibit extensive soft-sediment deformation,
260 including disharmonic folding. These conglomerates include reworked oyster shells and are
261 therefore likely to be still shallow-marine in origin. These conglomerates are interpreted as
262 having accumulated along a rapidly prograding delta front with erosion and disruption of
263 underlying finer-grained material. There is then a break in the succession owing to downcutting
264 by later-Pleistocene non-marine deposits (F2 unit; see below). The highest levels of the
265 escarpment (above the level of Fig. 3 a,b) are made up of very coarse conglomerates, similar
266 to those exposed in the highest topographic levels of Vasilikos quarry (F1 unit; see below),
267 capped by a well-developed calcretised surface. In terms of facies and topographic height
268 above sea level, these conglomerates also correlate with the F1 fluvial conglomerate, as
269 exposed on ridges to the northeast of the Limassol-Nicosia highway (see below).

270 The lower, marine, channelised part of the succession in the escarpment (Fig. 3 a, b) is
271 similar to the marine fan-delta system (Kakkaristra Formation), which transitionally overlies
272 the Nicosia Formation in the Mesaoria Basin, north and northeast of the Troodos Massif
273 (McCallum & Robertson, 1995). The laterally persistent, non-marine conglomerates which
274 form the highest levels of the succession are correlated with the F1 conglomerate Group, as in the
275 Mesaoria Basin (Ducloz, 1964; McCallum & Robertson, 1995). In the Mesaoria Basin, there
276 is an intervening unit of fluvial conglomerates (Apolos Formation) which is very thin (several
277 metres) or absent in the escarpment, which is suggestive of relatively rapid marine regression.

278

279 *3.2.Exposures within Vasilikos Quarry*

280 The exposures in the escarpment (Fig. 3 a, b) can be traced southeastwards through
281 abandoned quarries and correlated with the succession in the southwest face of Vasilikos
282 Quarry (Fig. 4).

283 Within the quarry, the lowest exposed deposits (Fig. 5, face A) are fine-grained, grey/light
284 brown, silty calcareous mudrocks of the Nicosia Formation (Fig. 5, faces A-C). These are fine-
285 grained, grey/light brown, silty calcareous mudrocks that dip gently towards the east (10/126°,
286 08/104°, 10/113°, 07/080°). These sediments have been dated as Late Pliocene-Early
287 Pleistocene using planktonic foraminifera (*G. inflata* Biozone; i.e. c. 1.8-2.1 Ma) (Waters *et al.*
288 2010). The mudrocks also contain abundant shallow-marine shell fragments including
289 abundant gastropods and bivalves (averaging 3 mm in size), and also small (<1 cm) intraclasts
290 of Nicosia Formation mudrock. *Thalassinoides* trace fossils (c. 1 cm wide elongate traces) are
291 well-developed. Upwards in face A (Fig. 6, log A), lenses of unconsolidated conglomerate
292 appear, mainly comprising small (c. 1 cm), well-sorted ophiolite-derived clasts (99% of the
293 total), in a matrix of medium to coarse-grained sand. These conglomerates can be correlated
294 with the lower level of the coarse shallow-marine facies (Kakkaristra Formation equivalents)
295 in the escarpment described above (Fig. 3 a, b).

296 Upwards in the succession, there is a clearly defined sedimentary contact with an interval of
297 clast-rich, matrix-supported lenticular conglomerates, c. 10 m thick (Fig. 6, log A; mid part).
298 The matrix of these conglomerates is fine to medium-grained, dark brown/yellow sand. The
299 clasts are sub-rounded, larger than those beneath (> 4 cm), and again mainly ophiolite-derived
300 (> 85% of the total). Gabbro and diabase clasts are conspicuous (up to 15% of the total),
301 together with chalk and chalk-chert clasts, mainly from the Lefkara Formation. Overall, the
302 clasts are moderately sorted and increase in relative abundance upwards. Conglomerate lenses
303 become thicker and more numerous compared to finer-grained intercalations. The
304 conglomerates are characterised by large-scale cross-bedding (up to 1 m in amplitude).
305 Paleocurrent indicators (cross-bedding and clast imbrication) indicate flow towards the SE.
306 There are also lenses of medium-grained sand (up to c. 50 cm thick) that generally thin
307 southwards (Fig. 5, face B), suggesting the existence of channel margins in this direction.
308 Where present, intercalated mudrocks contain scattered clasts that have a vague alignment
309 parallel to bedding (orientated 09/102°, 10/114°). No fossils were noted in the above
310 conglomeratic interval and non-marine deposition is likely, broadly equivalent to the (much
311 thicker) Apolos Formation in the Mesaoria Basin (McCallum & Robertson, 1995).

312 The succession in the southwest face of the quarry (Fig. 6, log A; upper part) terminates with
313 very coarse conglomerates that can be correlated with the F1 unit (Fanglomerate Group) at the
314 top of the escarpment section. The F1 conglomerate in the quarry ranges from very poorly
315 sorted to moderately-sorted and is predominantly matrix-supported (Fig. 7 a). However, clast-
316 supported lenses (> 80% of the clasts) are also widespread. Overall, the clasts are subangular

317 to angular and vary in size from < 1 cm to > 100 cm (average 6 cm). Individual conglomerate
318 lenses vary in clast size and composition. Chalk clasts vary from 15-45% of the total. The
319 remainder of the clasts are ophiolite-derived, mostly gabbro and diabase, and are generally
320 more rounded than the chalk clasts. Progradational (Gilbert-type) foresets (0.5-2 m thick), are
321 locally well-developed in the southwest corner of face C (Fig. 7 b). Large-scale cross-bedding
322 and associated clast imbrication indicate paleoflow towards the SE. The uppermost c. 4 m of
323 the conglomerate, beneath the modern erosional surface, is heavily calichified.

324 A key finding is that the F1 conglomerate is abruptly terminated by a laterally persistent,
325 inclined erosion surface that is reported here for the first time. This surface dips eastwards at
326 up to c. 40° (Figs. 6, sections; 7 c). Crucially, this surface can be traced across quarry faces C
327 and D to the base of face E, where it cuts into the Nicosia Formation; i.e. over a vertical height
328 of c. 40 m from the unconformable contact with the Nicosia Formation to the top of the
329 Pleistocene exposure (Fig. 5). The succession that unconformably overlies the Nicosia
330 Formation in the northerly part of the quarry (Fig. 5 faces C and D) does not therefore represent
331 the oldest part of the Pleistocene succession but rather the result of later-stage large-scale
332 incision. The presence of an erosional unconformity explains the unexpectedly abrupt contact
333 between the Nicosia Formation mudrocks and Pleistocene conglomerates, which contrasts
334 strongly with the actual marine, to non-marine facies transition that is exposed both in the west
335 of the quarry (Fig. 6, log A). The probable reason why this key inclined erosion surface
336 (unconformity) was not reported before is that it is not clearly visible from the access track in the
337 east.

338 The inclined erosion surface forms the base of a composite conglomerate and sand-
339 dominated sedimentary package, which being the second oldest after the F1 conglomerate, is
340 termed the F2 conglomerate. Within this interval, the base of the local succession decreases in
341 angle of dip over several tens of metres away from the unconformity (towards the NE) and the
342 clast size decreases (Figs. 4, 6 (section and inset 1)). Ophiolite-derived clasts, mostly diabase,
343 predominate near the unconformity, with a higher percentage of Lefkara Formation chalk clasts
344 farther away. Many of these clasts appear to have been reworked directly from the F1
345 conglomerate. Compared to the underlying F1 conglomerates, which contain little matrix, the
346 F2 conglomerates have a buff to pinkish, silty to sandy calcareous matrix.

347 The F2 sedimentary package is made up of three distinct depositional intervals from the
348 base upwards: a predominantly conglomeratic interval, a sandier unit, and then another mostly
349 conglomeratic interval (Figs. 5, 6 (section and inset 1), 6 (log B, lower part) and 7 d-f).

350 The lower, predominantly conglomerate interval, as well exposed at the base of face D; Fig.
351 5) is c. 5 m thick and made of a clast-rich, clast-supported conglomerate, in which a coarse-
352 grained matrix is locally present. Although still large, the average clast size (average 10 cm) is
353 less than that within the F1 conglomerate. This lower interval of the F2 conglomerate is poorly
354 sorted, with mainly sub-angular clasts that indicate imbrication, and thus paleoflow, towards
355 the SE, in agreement with Waters et al. (2010). The majority of the clasts are gabbro (40%),
356 chalk (35-40%) and diabase (20%), with a small percentage (< 5%) of plagiogranite. Diabase
357 clasts tend to be relatively small (4 cm) and subrounded, whereas associated chalk clasts are
358 larger (c. 10 cm) and commonly tabular (elongate in outcrop).

359 Above the lowest conglomerate interval in the F2 deposit there is a relatively sharp
360 transition (tens of cm) to a second conglomerate-dominated interval (Fig. 6 section, 7d) that
361 can be observed in both long-profile (Fig. 5, face E) and cross-section (Fig. 5, face D). Along
362 face E, sand and conglomerate are interbedded (Fig. 7 d). Medium to coarse-grained, lenticular
363 sands, with lithic fragments (<1 mm), increase in relative abundance towards the south (from
364 10-20% to 80%). Where the sand is dominant, the intercalated conglomerate lenses extend
365 laterally for 2-15 m, vary in thickness (commonly 20-30 cm) and pinch out locally. Within
366 these conglomerate lenses, the clasts are moderately well-sorted by size and composition. The
367 clasts are predominantly ophiolite-derived (60-80%), with gabbro and diabase clasts being
368 particularly dominant. Paleocurrent data (clast imbrication and cross bedding) within the
369 conglomerate and sand lenses again indicate flow towards the SE. Planar-dipping foresets (50
370 cm-scale) occurs towards the top of Fig. 5, face E. On face D, the same interval reappears as
371 discontinuous lenses of conglomerate (1-2 m thick x up to c. 4 m long), within a background
372 of medium to coarse-grained sand. The clasts there are small (1-2 cm), subrounded, well-sorted
373 and fine upwards, with an increasing percentage of matrix upwards (i.e. between the individual
374 coarse-grained lenses). Towards the northwest, on Fig. 5 face C, this sand-conglomerate
375 interval is in direct erosional contact with the Nicosia Formation mudrocks beneath.

376 The contact between the second interval and the upper more laterally continuous,
377 predominantly conglomeratic interval is highly irregular, including a 3-4 metre-deep, scoured
378 channel (Fig. 7 f) that is located on Fig. 5, face E. This upper conglomeratic interval is
379 dominated by disorganised, clast-supported conglomerate, with poorly to moderately sorted,
380 subrounded clasts (average 5 cm; maximum > 46 cm), again demonstrating imbrication
381 towards the SE. Overall, c. 80% of the clasts are ophiolite-derived (mainly gabbro and diabase)
382 and c. 20% chalk. However, the individual conglomerate lenses contain different proportions
383 of clast lithologies. The clast size and relative clast abundance gradually decrease upwards,

384 with a corresponding increase in coarse-grained sandy matrix, as exposed along Fig. 5 faces C
385 and D. Towards the west, the upper conglomerate package transgresses the Nicosia Formation
386 with a sharp, irregular contact that can be traced upwards towards the south until an erosional
387 contact with the F1 conglomerate (Fig. 6, section).

388 The above mainly coarse-grained package (F2) is followed by a sharp (several cm) but
389 undulating change to a strongly contrasting, sub-horizontal-stratified finer-grained sedimentary
390 interval (Fig. 6, section). The lower few metres of this are dominated by buff-coloured
391 calcareous sands and silts (Fig. 6, log B; see also supplementary material for photographs).
392 Above this, sandy sediment is intercalated with occasional conglomerate lenses (1-5 m thick)
393 that contain moderately to well-sorted, subrounded clasts, set in a sandy matrix. Higher in the
394 succession, the sediments change to dark brown/grey. Clasts diminish and then disappear.
395 Above, there is a westward-thickening interval that is dominated by brownish to reddish layers
396 (c. 17 m thick) that are interpreted as paleosols. These sediments alternate with pale grey/buff-
397 coloured, calcareous silts (Fig. 6, log B; see also supplementary material for photographs). The
398 paleosols contain occasional small (< 1 cm) chalk clasts, charcoal fragments (up to 5 cm long
399 x 3 cm thick) and roots/rootlets (up to 4-5 cm long x 2-3 cm thick), particularly in the
400 stratigraphically higher layers. The uppermost paleosol interbed (2-3 m thick) is very dark
401 brown/red and intensifies in colour upwards to the present-day erosion surface (Fig. 6, Log B;
402 see also supplementary material for photograph). This deposit is unusually coarse-grained,
403 poorly sorted, and contains subangular to subrounded clasts (maximum 4.6 cm by average 2
404 cm). These clasts are randomly orientated, irregularly distributed and made up of 60% chalk
405 and 40% ophiolitic rocks.

406 Within the paleosols as a whole (along Fig. 5, face C), the relative size (0.5 cm to 8 cm) and
407 abundance (<5% - c. 65%) of clasts relative to brown-coloured matrix increases for over 120
408 m laterally towards the SW. The clasts are predominantly ophiolite-derived (75-80%),
409 moderately sorted, vary from rounded to angular, range in size from < 1 cm to 40 cm, and
410 generally fine upwards. In contrast, the interbedded pale grey/buff-coloured intervals are
411 generally thicker (> 1m) and finer-grained than the brownish/reddish paleosols and contain
412 occasional small (< 1 cm) clasts and roots (up to 6 cm long x 6 mm wide), together with
413 common caliche nodules (see supplementary material).

414 Of particular note, the lowermost brown paleosol, which grades upwards into fine to
415 medium-grained grey/buff-coloured silt (c. 20 cm thick), includes well-developed caliche
416 nodules towards the top, one of which was dated at 59 ka using the U-Series whole-rock method
417 (Waters *et al.* 2010). The caliche nodules are fine-grained, hard, and contain numerous small

418 black specs of inferred organic matter, up to c. 3 mm in size (average c.1 mm). The caliche
419 also contains detrital grains of quartz, calcite, basic igneous rocks and bioclastic material
420 (reworked) within a very fine-grained brown, muddy matrix, as seen in thin section.

421 In summary, Vasilikos Quarry and the adjacent escarpment document a Late Pliocene-Early
422 Pleistocene aggrading marine succession (marine fan delta), passing upwards into thin, only
423 locally exposed, non-marine conglomerates (non-marine fan delta). These sediments are
424 overlain by very coarse fluvial conglomerates representing the major fluvial package (F1). This
425 is, in turn, strongly incised into by a major lenticular conglomerate-sandstone package (F2),
426 which is, in turn, directly overlain by grey/buff-coloured calcareous silts and reddish to
427 brownish paleosols. Evidence from the Vasilikos river valley, discussed below, allows all of
428 these deposits to be correlated throughout the catchment.

429

430 **4. Vasilikos river catchment**

431 The geomorphology of the Vasilikos river valley (Fig. 8) is first outlined to provide a
432 framework for the description and interpretation of the associated Pleistocene sediments.
433 Several geomorphological surfaces within the Vasilikos river catchment can be identified as
434 sub-horizontal features that vary in width, length and altitude, referred to here as terraces.
435 Although discontinuous, both down-catchment and in cross-profile, some of the terraces can
436 be correlated throughout the catchment, allowing the identification of four main
437 geomorphological surfaces. These terraces are associated with locally preserved F1, F2, F3
438 and F4 deposits, with F1 being the highest and F4 the lowest, closest to the modern-day
439 Vasilikos river course. However, correlation with the F1-F2 units exposed in Vasilikos Quarry
440 is not initially assumed but will be demonstrated in the Discussion.

441

442 *4.1. Geomorphology of Vasilikos river catchment*

443 From its source at c. 1200 m ASL (above sea level), Vasilikos River flows approximately
444 southeastwards over the Troodos Sheeted Dyke Complex for c. 7.8 km, and then turns east for
445 c. 4.5 km (Fig. 2). The river flows over the Arakapas Fault and then sub-parallel to the
446 lithologically variable Arakapas Fault Zone (South Troodos Transform Fault Zone) for c. 6
447 km. This highly tectonised ophiolitic belt (Fig. 9 a) includes serpentinitised ultramafic rocks
448 (e.g. dunite, websterite, wherlite), gabbro (layered and massive), sheeted dykes, basaltic pillow
449 lavas and small volumes of volcanoclastic rocks (Pantazis, 1966; MacLeod and Murton, 1993).
450 In its lower reaches (as defined here) the river flows SSE over ophiolite extrusive rocks, near

451 very localised Fe-Mn sediments (umbers) and radiolarites (Perapedhi Formation), and then
452 over extensive outcrops of chalk, marl and chert of the Maastrichtian-Oligocene Lefkara
453 Formation (Robertson, 1976, 1977b). The river then flows over soft-weathering marl, chalk
454 and Messinian-aged gypsum of the Miocene Pakhna and Kalavastos Formations, and finally
455 mudrocks of the Pliocene-Early Pleistocene Nicosia Formation (Pantazis, 1966) (Figs. 2, 8).

456 Topographic profiles (Fig. 10) of the present-day valley were constructed to help indicate
457 the distribution of geomorphological surfaces. The profiles were constructed from near the
458 south coast for c. 10 km northwards as far as Vasilikos Dam (Fig. 8). Geomorphological
459 surfaces cannot be traced directly northwards beyond this because there is an abrupt change
460 to an area of immature dendritic drainage with little evidence of preserved terraces (Figs. 8, 9
461 a). However, mature erosional surfaces and related sediments (e.g. conglomerates and
462 paleosols) reappear closer to the river source, especially within the Arakapas Fault Zone. The
463 northward change from an immature to a more mature drainage pattern suggests the presence
464 of one or more northward-retreating knick points which have yet to reach the E-W-trending
465 Arakapas Fault Zone (although this will not be considered further here).

466 For descriptive purposes, the stretch of the valley that was studied in detail (south of
467 Kalavastos Dam; i.e. lower reaches) is here subdivided into three distinctive geomorphological
468 segments, namely the *upper reaches* (Fig. 10 a-d), the *middle reaches* (Fig. 10 e-f), and the
469 *lower reaches* (Fig. 10 g-j) of the Vasilikos river catchment. Profiles a-c (Fig. 10) indicate that
470 the valley is wide in the upper reaches (over c. 5 km), with moderately steep slopes. Three
471 geomorphological surfaces are separated, vertically by a total of c. 100 m. Further south, the
472 channel narrows with the Asgata Potamos tributary coming in from the NW (Fig. 10 d). In the
473 middle reaches, including Kalavastos village (Figs. 8, 10 e, f), the river channel passes through
474 a steep gorge (c. 70 m high x up to 800 m wide). This narrowing corresponds to the river passing
475 through the relatively resistant chert-bearing interval of the Paleogene Lefkara Formation,
476 suggesting a lithological control on fluvial incision (see Discussion). Geomorphological
477 surfaces within the gorge are restricted to narrow (several metre-wide) low-amplitude (several
478 metre-high) benches or ribs. In the lower reaches, south of Kalavastos village (Fig. 10 g-j), the
479 active channel cuts into relatively soft Miocene Pakhna Formation chalks and marls and the
480 valley widens greatly (to c. 1,200 m wide). Three to four major geomorphological surfaces in
481 this interval are separated, vertically by 10s of metres. However, small slope irregularities
482 locally exist between these marked surfaces, suggesting a complex and variable incision history
483 (e.g. Fig. 10d, f for F3; a for F2).

484 Overall, four distinct types of geomorphological surface are identified, as shown on the
485 same-scale topographic profiles with terrace conglomerates added (Fig. 11). Where sediments
486 are present, the terrace surfaces correspond to the tops of the sedimentary infills of incised
487 fluvial channels.

488 The upper reaches are dominated by three terrace levels at c. 300, 200, 75 m ASL (Fig. 11 a-
489 d). On its southwest side, the highest level of the valley locally corresponds to the F1
490 geomorphological surface with rare preserved conglomerates (Fig. 8). However, on the
491 northeast side of the valley the F1 surface is marked by a break in slope at c. 310 m ASL
492 without preserved fluvial conglomerates. There are hints of an older (unstudied) remnant
493 surface above this (Fig. 11a).

494 Below the remnant F1 surface, hillslopes are initially steep but shallow downwards into
495 sub-horizontal surfaces, with a marked break in slope, corresponding to a distinct surface at c.
496 220 m ASL (Fig. 11 a). This second surface is associated with coarse conglomerates, defined
497 as the F2 terrace, which are semi-continuous on the western slopes of the catchment for > 3 km
498 (Figs. 8, 11 a-d). Colluvial deposits (i.e. slope-related unconsolidated sediment) are very well
499 developed at topographic heights between the F2 terrace and the F3 terrace (around 150 m
500 ASL), especially in the upper and middle reaches, between Kalavassos and Vasilikos Dam (Fig.
501 9 c).

502 Directly southeast of Vasilikos Dam (Fig. 8), the modern river channel lies within a narrow
503 (c. 20 m-wide), steep-sided (c. 20 m-deep) gorge (Fig. 11 b). Above the gorge, the topography
504 broadens out greatly, with a narrow (< 20 m) but well-defined terrace on the southwest side of
505 the valley and a much wider (c. 500 m) undulating, discontinuous terrace on the northeast side
506 of the valley. This extensive surface represents the F3 terrace at c. 75 m ASL. Unlike the F2
507 terrace, the F3 terrace is in places laterally continuous for > 100-200 m, particularly on the
508 northeast side of the valley, where it is dissected by small tributary channels (Figs. 8, 9 b).

509 Within the upper reaches, the F3 terraces can also be traced from the Vasilikos Valley, near
510 Kalavassos, northwestwards for several kilometres up the adjacent Asgata Potamos tributary
511 valley (Figs. 8, 10 d). The highest elevations in this segment of both valleys (c. 270 m ASL)
512 correspond to a series of ridges that are correlated with the F1 terrace. Major breaks in slopes
513 occur at the same heights (c. 200 and c. 140 m ASL) in both valleys and are associated with
514 similar geomorphological surfaces which are correlated with the F2 and F3 surfaces. On the
515 floor of Asgata Potamos valley, a series of narrow (<15 m wide), sloping surfaces occur 5-6 m
516 above the active channel and are continuous up-valley for c. 2 km. These localised surfaces
517 correlate with lower, wider (c. 200 m), gently sloping, better-developed surfaces in the main

518 Vasilikos valley. These features, which first appear at c. 130 m ASL and are continuous down-
519 catchment, are interpreted as the F4 surface, which becomes progressively better developed in
520 the lower reaches. This overall evidence suggests that the two paleovalleys, despite differing
521 lengths and source lithologies underwent a similar geomorphological and sedimentary
522 development.

523 In the middle reaches (Figs. 8, 11 e-f), the overall valley height decreases from c. 180 m to
524 c. 135 m ASL. The F2 is the highest preserved surface (c. 120 m ASL) on the eastern side of
525 the valley (Fig. 11 f). Between the upper and middle reaches, the valley narrows from c. 3 km
526 to c. 1.5 km and as a result the F1 and F2 surfaces are much closer together than in the upper
527 reaches.

528 Near Kalavassos, the valley is constricted, steep-sided and retains only localised remnants of
529 the F3 and F4 terraces (Figs. 9 d, 10 e). F2 deposits are rarely preserved as a narrow,
530 discontinuous rib on the west side of the valley (Fig. 8). F3 and F4 terraces are more widely
531 preserved but lack identifiable geomorphological surfaces on both sides of the valley. The F4
532 surface is well preserved as a continuous feature (c. 150 m wide) on the western margin of the
533 valley, although it decreases in width from c. 150 m to < 20 m towards Kalavassos as the channel
534 narrows (Figs. 8, 10e). Beyond where the river leaves the confinement (Figs. 8, 11 f), the F3
535 terrace re-appears as a well-preserved feature (c. 70 wide) on the western side of the valley.
536 The F3 terrace is also present there as a narrow (c. 20 m), upward-sloping remnant on the
537 valley's eastern side (c. 100 m ASL) (Figs. 8, 10 f). The F4 terrace is only locally preserved on
538 the western side of the valley, increasing to c. 75 m in width.

539 The lower reaches of the Vasilikos Valley are broader and flatter (Fig. 10 g-j). The F1 surface
540 is patchily preserved as a remnant surface on the western side of the valley, above Mari village
541 (c. 115 m ASL) (Figs. 8, 10 h). Although discontinuous (Fig. 9 e), the F2 remnant terrace forms
542 the highest surface within the valley in the vicinity of Tenta (c. 95 m ASL) (Fig. 10 g). In
543 contrast, the F3 terrace is increasingly well-preserved down-catchment, enlarging from
544 remnant surfaces at Tenta (Figs. 8, 10 g), to wide (c. 65 m in the east vs. c. 600 m in the west),
545 gently-dipping terraces near Mari, at c. 50 m ASL (Fig. 10 i). The upper surface of the F3
546 terrace is generally characterised by a series of paleosols, which overlie F3 clastic deposits,
547 culminating in dark red/brown paleosols on both sides of the valley (Fig. 11 i-j). The position
548 of the top of the upper terraces on the west side of the valley (Fig. 10 j) is indeterminate owing
549 to quarrying. The extensive paleosols on the F3 surfaces are very similar to those exposed in
550 Vasilikos Quarry (see above). None of the other surfaces expose similar reddish-

551 coloured paleosols although reddish to brownish paleosols occur at several different level in
552 the paleo-valley including the late Pleistocene, intercalated with harvara (colluvium).

553 In the wide lower reaches (Figs. 9 f, 10 g-j), the F4 terrace is well-established near the
554 valley floor, c. 4-5 m above the present-day channel on both sides of the valley. In this segment,
555 there is a marked change in slope gradient from sub-horizontal to steeply dipping between the
556 F3 and F4 terraces (Fig. 11 f). The present-day channel meanders in the lower reaches.

557

558 *4.2. Vasilikos river deposits*

559 The sequential river deposits are classified according to the geomorphological surface that they
560 overlie, conformably and are illustrated on the geological map (Fig. 8), same-scale simplified
561 topographic profiles (Fig. 11a-f) and photographs (Figs. 13, 14).

562

563 *4.2.1 F1-related facies*

564 Deposits associated with the F1 terrace are limited to the middle reaches, close to Kalavasos.
565 NW of Kalavasos (Fig. 12.F1 a), the F1 (c. 4.5 m thick x c. 20 m across) is conglomerate with
566 poorly sorted, sub-angular clasts, set in an abundant fine-grained (calcretised) matrix. The
567 conglomerate occur as very small (unmappable) discontinuous lenses, up to 3 m long x 40 cm
568 thick (Fig. 13 a). The clasts are small (average c. 1-2 cm) and become better-sorted upwards.
569 Larger clasts (maximum 8 cm) mainly occur near the base of individual lenses. The clasts
570 exhibit weakly developed imbrication towards the SE. Most of the clasts are ophiolite-derived
571 (c. 70%), with the remainder (c. 30%) being chalk from the Lefkara Formation. The
572 sedimentary clasts are usually relatively small (average c. 1 cm), elongate and angular.

573 The F1 terrace deposits SW of Kalavasos (Fig. 11 f), although restricted to the western
574 margin of the Vasilikos River (on either side of distributaries) are more extensive (c. 3-4 m
575 thick x 35 m across), and differ in facies from the conglomerates farther northwest. The contact
576 between the Lefkara Formation bedrock and the conglomerate is locally steep and highly
577 irregular, indicating fluvial incision into bedrock. (1-2 m thick) (Fig. 13 b). The overlying
578 conglomerate is covered by prograding foresets (c. 30 cm thick) that vary from matrix to clast-
579 supported and are calcrete-cemented. The dip locally steepens towards the bedrock. The clasts
580 are poorly to moderately sorted, sub-angular to rounded, and coarsen upwards (< 1 cm at the
581 base vs. > 10 cm at the top). Individual lenses vary in size and composition, with typically 65-
582 70% ophiolite-derived clasts and c. 30% Lefkara Formation clasts. Clast imbrication is absent,
583 although occasional large clasts (up to c. 47 cm) are aligned parallel to bedding. On the

584 hillslope, c. 20 metres below intact exposures, large (up to 2 m-thick), steeply inclined bodies
585 of calcrete-cemented conglomerate are interpreted as slip-blocks from the terrace above (Fig.
586 13 c). The F1 fluvial deposits were therefore incised into bedrock in some places and the fluvial
587 deposition was strongly influenced by the stream-bed topography.

588

589 4.2.2. *F2-related facies*

590 Preservation of the F2 terrace deposits increases down-catchment. In the upper reaches, the
591 deposits are restricted to near Vasilikos Dam, exemplified by a thin (c. 80 cm), localised
592 exposure on the southwest side of the valley (Fig. 11 a). This conglomerate comprises well-
593 cemented clasts (70%) within a white chalky matrix (30%), and includes small (average 1 cm;
594 maximum 3 cm), angular, predominantly (c. 95%) ophiolite-derived clasts. At the equivalent
595 height on the northeast side of the valley there is a contrasting, thicker poorly sorted
596 conglomerate (up to 20 m thick), which is dominated by chalk clasts (>c. 95%) within a very
597 fine-grained chalky matrix. This deposit overlies weathered pillow lavas with an irregular,
598 undulating contact. Lenticular bedding is visible (c. 30 cm scale), with subangular to angular
599 clasts (< 0.5 cm to > 10 cm). Similar-sized clasts are concentrated within individual
600 conglomerate lenses. This chalk-rich conglomerate is interpreted as a texturally immature
601 colluvial deposit which overlies an inward-sloping erosional surface (see below).

602 Lower on the hillside, indistinctly bedded, clast-poor (30%) conglomerate is exposed 30 m
603 in altitude below the colluvium mentioned above (Fig. 12.F2 a, 13 e). This dips towards the
604 SW (15/195°, 14/201°, 15/198°) and has a smaller proportion of chalk clasts (75%) versus
605 ophiolite-derived clasts (25%), compared to the colluvium. The clasts are relatively large (4-5
606 cm maximum 57 cm), poorly to moderately sorted, subangular to angular, and locally
607 imbricated towards the SW.

608 In the middle reaches, both north and south of Kalavassos (Fig. 12.F2 b), the F2 deposit is a
609 represented by conglomerate, up to 18 m thick, with a calcretised upper surface. This
610 conglomerate overlies the Lefkara Formation with a gently undulating, steep-sided contact
611 (Fig. 13 d). The clasts fine upwards, from an average of c. 4 cm at the base, to c. 2 cm at the
612 top, although oversized clasts (up to 30 cm) are present throughout. The base of the
613 conglomerate is clast-supported, with a fine-grained, grey, silty matrix that increases in relative
614 abundance upwards. The clasts are subrounded, to rounded, and poorly to moderately sorted,
615 with weakly developed imbrication towards the SE. The clasts were derived from the ophiolite
616 (c. 65%) and from the Lefkara Formation (c. 35%).

617 In the lower reaches, near Mari, F2 conglomerates (c. 5 m thick), cemented by calcrete,
618 directly overlie the Pliocene-Early Pleistocene Nicosia Formation (Fig. 12.F2 c). The
619 conglomerate is irregular downslope, forming undulations (1-3 m in amplitude). Clast-
620 supported near the base, this conglomerate becomes increasing matrix-supported upwards. The
621 clasts are poorly to moderately sorted and grade upwards, with smaller (1-2 cm) than average-
622 sized clasts (c. 6 cm), towards the top of the deposit. Smaller clasts (c. 3 cm) infill depressions
623 in the bedrock, whereas larger ones (maximum 38 cm) are distributed randomly throughout the
624 conglomerate.

625

626 4.2.3. F3-related facies

627 The F3 deposits, up to 40 m thick, are well-preserved within all three reaches of the Vasilikos
628 river catchment. In the upper reaches, the basal contact with the underlying ophiolitic pillow
629 lavas undulates gently (Fig. 12.F3 a) and steepens towards the northeast margin of the
630 exposure. This conglomerate varies from clast-supported to matrix-supported. The matrix is
631 grey, medium-grained sand with lithic fragments. Increasingly clast-supported intervals occur
632 both towards the base and the top of the deposit. The clasts are poorly, to moderately sorted,
633 fine upwards (average 18-20 cm at the base versus 1-3 cm at the top) and are imbricated
634 towards the SE. The uppermost conglomerate contains well-developed caliche (c. 3 m thick).
635 In the upper reaches the deposits occur at several topographical levels along the eastern side of
636 the valley, but these are man-made (agricultural) benches within the same F3 deposit.

637 A small tributary channel on the western side of the valley is infilled with typical F3
638 conglomerate (Fig. 8, just NE of profile c). The lower levels (1.5 m) of the deposit are similar
639 to those on the opposite, eastern side of the valley (Fig. 14 a, lower unit). Large (average 5-6
640 cm; maximum 17 cm), subangular to angular chalk clasts (5-10%) are locally concentrated in
641 the uppermost c. 40 cm of the deposit. The uppermost levels (c. 1 m-thick) of this deposit
642 contains > 95% chalk clasts, which are small (4 cm; maximum 28 cm), subangular to angular,
643 and poorly sorted, within a fine-grained chalky matrix, together with occasional much larger
644 ophiolite-derived clasts that are likely to be reworked (Fig. 14 a, upper unit). The proportion
645 of chalk clasts increases laterally from to east to west, away from the valley axis (from 90-
646 15%).

647 Within the middle reaches (e.g. east of Kalavassos), the basal contact of the F3
648 conglomerate undulates. The conglomerate, which is up to c. 40 m-thick, is clast-rich and
649 matrix-supported. The matrix is fine-grained, silty, lithic fragment-rich and increases upwards
650 within individual depositional units. Clasts are generally poorly sorted, to moderately sorted,

651 and imbricated towards the S or SE. The clasts fine upwards (c. 7 cm at base versus. c. 2 cm at
652 the top), and change from rounded to subangular on average upwards. The uppermost
653 conglomerate (c. 5 m) is rich in caliche, as seen on the west side of the valley south of
654 Kalavastos (Fig. 11f). There is general increase in chalk and chalk-chert clasts (Lefkara
655 Formation) in the middle reaches (Fig. 12.F3 b-c), averaging 30% to 45%, compared to the
656 upper reaches.

657 Also, within the middle reaches, the F3 conglomerates are typically overlain by colluvial
658 deposits. These are weakly bedded (5-10 cm scale), made up of c. 95-100% chalk clasts, with
659 the addition of occasional gypsum clasts downstream of the *in situ* outcrop (Fig. 12.F3 b-c).
660 The chalk clasts vary in size (0.5 cm to > 10 cm), are randomly orientated, mostly highly
661 angular, poorly to moderately sorted, and set within a fine-grained, sandy, silty or chalky matrix
662 (Fig. 14 d). Weak clast imbrication towards the SW is locally developed near the base of the
663 deposit (Fig. 12.F3 b). West of Kalavastos, colluvium near the underlying F3 fluvial
664 conglomerate contains subangular to subrounded ophiolite-derived clasts that increase in size
665 (up to 6-7 cm) and relative abundance (up to 40%) towards the east (axially).

666 A small slope-cut of relatively fine-grained colluvium (harvara; see below), together with
667 reddish brown palaeosol (poorly developed terra rossa) was previously studied by Schirmer
668 (1998) and later by Kinnaird et al. (2013) along the SW edge of Kalavastos village (c. 150 m
669 south of the village church). The sampled section is c. 5 m high, up a track off the main road
670 through the village (GPS UTM 34°46'.08''N; 33°17.47''E). The site is c. 30 m above the valley
671 floor where the slope toe begins to flatten. Re-examination of the exposure indicates that it
672 begins with brownish recessive-weathering paleosol (Gondéssa soil) from which a radiocarbon
673 age of 31.970 ka was determined. An OSL (optically stimulated luminescence) age estimate of
674 29.82 ± 2.11 ka was obtained from this paleosol (Kinnaird et al. 2013). This is followed, with
675 a transition over several centimetres, by buff-white harvara (c. 2.9 m thick) with poorly-sorted
676 angular clasts (< 5 cm in size), mainly chalk. Scattered clasts of chert (formed by replacement
677 of chalk) are also present, up to 15 cm in size and a few rounded basalt pebbles (< 4 cm in
678 size). Transitionally above (over several centimetres) there is then a second paleosol (Lower
679 Tsiáko Soil), which is distinctly brown with smaller clasts than the paleosol beneath, followed
680 by a second harvara (up to 80 cm thick) with scattered relatively large clasts (up to 35 cm in
681 size), and then a third (laterally discontinuous) paleosol (Upper Tsiáko Soil). Further harvara
682 follows (up to c. 1.5 m thick), from which charcoal near the base was radiocarbon dated at
683 $27.44 \text{ ka} \pm 1.6 \text{ ka}$ (Schirmer, 1998). Reworking of organic matter from the directly underlying
684 paleosol can be considered although this would not significantly change the depositional age.

685 The section ends with redeposited paleosol and harvara with a caliche capping.

686 In the lower reaches, the well-cemented F3 conglomerate (10 m thick) is matrix-supported,
687 although with clast-supported lenses (Fig. 12.F3 d). The matrix is fine to medium-grained sand,
688 with lithic fragments. Most clasts are poorly to moderately sorted. Clasts of similar size and
689 composition are sorted into lenses (c. 2-3 m long x c. 20 m high), with better sorting in the
690 clast-supported lenses. Clasts vary in size (averaging 4-6 cm), but generally fine upwards from
691 a maximum (38 cm) near the base. Exposures near Mari contain 60-70% ophiolite-derived
692 clasts and 30-40% chalk clasts, which are imbricated towards the SE. Downstream, the
693 proportion of ophiolitic versus chalk clasts decreases (to c. 50%), with south-directed clast
694 imbrication (Fig. 14 c). The calichified top of the F3 deposit forms an extensive sub-horizontal
695 geomorphological surface which underlies modern-day agricultural fields.

696 The F3 conglomerates near Mari are overlain by highly distinctive paleosols on both sides
697 of the valley (Figs. 6 inset 2). Where best developed on the east side of the valley (Figs. 12.F3
698 d, 14b), the contact between the F3 deposit and the paleosols above is irregular and locally
699 undulating due to erosion. The paleosols are locally intercalated with lenticular conglomerates.
700 Dark brown to grey, fine-grained, poorly consolidated paleosol alternate with paler,
701 white/yellow fine-grained silts (Fig. 14b, upper part). The silts contain numerous small (< 1
702 mm) lithic fragments and occasional caliche horizons. Relatively large clasts (> 1 cm) are
703 scattered through both the darker and paler-coloured deposits. Clasts of similar size,
704 composition and angularity characterise specific horizons. The uppermost horizon is a very
705 dark brown/red fine-grained paleosol which continues downstream above caliche-rich
706 conglomerate.

707

708 *4.2.4. F4-related facies*

709 In the upper reaches, the F4 (and/or younger) deposits are restricted to clasts within the modern
710 channel. F4 deposits in the middle and lower reaches are largely fine-grained, grey to light
711 brown silt which supports rich farmland. Where they first appear widely, directly south of
712 Kalavassos (Fig. 12.F4 a), the silts include small (average 1-2 cm; maximum 8 cm), scattered,
713 subrounded to subangular clasts, mostly chalk (Fig 14 e). The relative abundance and size of
714 the clasts increases southwards (Fig. 12.F4 b), averaging 2-3 cm opposite Tenta. Larger clasts
715 (maximum 25 cm) tend to be concentrated in lenses towards the top of the deposit. The clasts
716 are sub-angular, moderately to well-sorted, and have localised imbrication towards the S-SE.
717 Excavated pits in the lower Vasilikos Valley have revealed 3-5 layers (each several cm-thick),
718 composed of silt with intercalated calcareous layers (Gomez, 1987).

719 The F4 deposits in the lower reaches (Fig. 12.F4 c) comprises two distinct intervals, a lower
720 (c. 80 cm-thick) clast-rich muddy, matrix-supported conglomerate, and an upper (c. 70 cm
721 thick) fine-grained, muddy paleosol that is similar to the F4 deposits farther up-valley. Clasts
722 within the lower unit (Fig. 14 f) are small (average 3 cm), but with occasional outsize clasts
723 (up to 47 cm). The clasts are poorly, to moderately sorted and sub-angular, to sub-rounded,
724 with weakly developed imbrication towards the SE.

725 The axis of the F4 channel was incised downwards by up to c. 6 m, followed by alluvial
726 deposition between 5400 and 5010 B.C. (Gomez, 1987). Downcutting to within 2 m of the
727 present floodplain took place during post-Byzantine times, as documented elsewhere in
728 southern Cyprus (Gifford, 1978).

729 In summary, the combined geomorphological and sedimentary evidence demonstrates four
730 main stages of Pleistocene geomorphological and sedimentary development (F1-F4) which can
731 now be compared with those recognised in Vasilikos Quarry.

732

733 **5. Discussion**

734 *5.1. Correlation of the Vasilikos quarry and valley deposits*

735 The two independently determined stratigraphic schemes can be correlated based on three
736 main related lines of evidence.

737 1. Geomorphology. The top of the F1 terrace, as seen in Vasilikos Quarry represents the highest
738 preserved geomorphological surface, as does the F1 throughout the Vasilikos river catchment
739 (Figs. 10, 11). These F1 surfaces can be visually correlated from the escarpment c. 1.8 km NW
740 of the quarry (Fig. 3 b), across a topographic depression that is occupied by the Limassol-
741 Nicosia highway, to the northward-rising topography (towards Kalavassos). The F1 surfaces in
742 both areas are heavily calcretised, representing prolonged subaerial exposure during which
743 erosional and depositional processes mainly took place at lower topographic levels.

744 2. Stratigraphy. Of the four stages of development in the Vasilikos river valley (F1-F4), two of
745 these (F1 and F2) can be recognised on lithological grounds in Vasilikos Quarry. However, the
746 F3 and F4 conglomerates are not developed at Vasilikos Quarry. This reflects post-F2 fluvial
747 incision which located these younger deposits at lower topographic levels near the modern
748 river channel (c. 1 km to the east). The river channel is likely to have migrated eastwards after
749 the F2 deposition as no equivalent of the relatively thick F2 conglomerates is preserved on the
750 opposing eastern margin of the modern river channel.

751 3. Sedimentology. The F1-F3 deposits show many similar features in both the lower reaches
752 of the river valley and the quarry. The F1 deposits in both areas are sheet-like, extensively
753 distributed at relatively high topographic levels and include, on average, the largest clasts,
754 mainly of ophiolite-derived rocks. The incised F2 deposits in both areas also show marked
755 similarities in both areas, including erosive bases, lenticular (channelised) morphology,
756 sedimentary structures, clast size, clast maturity, matrix type and relative abundance. The
757 intense brown to dark reddish-coloured paleosols are highly distinctive and occur only on the
758 F3 fluvial deposits in Vasilikos Valley and also positionally *above* the F2 conglomerates in
759 the quarry. The occurrence of these paleosols in the quarry above the F2 conglomerates is at
760 first sight anomalous because F3 deposits (with overlying paleosols) are incised into F2
761 conglomerates in the river valley. However, this can be explained by accumulation of the
762 paleosols on the upper, westerly slopes of F3-related paleovalley (Fig. 8), well away from the,
763 then active channel. Fluvial material derived from the main river channel is absent, and the
764 material accumulated as soils on a weathering and eroding landscape. Similar-coloured
765 paleosols developed on valley slopes adjacent to the F3-aged river channel, especially in the
766 mid to upper reaches of Vasilikos catchment, especially north of Kalavassos.

767

768 *5.2. Geomorphological development of the Vasilikos river catchment*

769 In general, the valley profiles have deepened and narrowed through time, especially in the
770 middle and upper reaches (Fig. 10), representing successive stage of incision. However, the
771 channel generally widened and shallowed in the lower reaches, down to the modern coast,
772 largely reflecting the relatively soft rheology of the underlying mudrock (Nicosia Formation).

773 The geomorphological development of the headwaters of the Vasilikos river catchment to
774 the north of Vasilikos Dam was not studied in detail. However, for > 1 km north of the dam
775 the F1-F4 terraces are replaced by a young dendritic drainage pattern (Figs. 8, 9 a). This feature
776 could represent the development of markedly steeper slopes above relatively resistant
777 ophiolitic rocks (e.g. diabase/gabbro) with correspondingly increased incision and erosion of
778 pre-existing terrace deposits. Structural control (relative uplift) could have a similar effect
779 although there is no direct evidence of this (see below). Farther northwest, within the Arakapas
780 Fault Zone (Fig. 2), the Vasilikos River flows down more gentle slopes, possibly isolated above
781 one or more knick points (although this remains to be tested). Within the Arakapas Fault Zone,
782 well-developed erosional surfaces re-appear close to the present-day Vasilikos River.
783 Morphologically, these are similar to the F3 surfaces south of Vasilikos Dam. The associated

784 deposits are mainly thin (< 5 m) ophiolite-derived conglomerates with a reddish sandy matrix,
785 covered by distinctive, reddish terra rossa paleosols.

786 South of Vasilikos Dam, the dominant control on the geomorphology within the upper,
787 middle and the lower reaches is interpreted to be lithology, as supported by the geological map
788 (Fig. 8) and the topographic profiles (Figs. 10, 11). The upper reaches (Fig. 11 a-c) are
789 underlain by the Lower Pillow Lavas of the Troodos ophiolite near Kalavassos Dam, and by the
790 Upper Pillow lavas towards Kalavassos (Pantazis, 1966). The Lower Pillow Lavas are
791 predominantly massive and pillowed flows with much fragmental material (lava breccia and
792 hyaloclastite) that erodes readily. The F3 deposits directly overlie the Lower Pillow Lavas on
793 the east side of the valley, where they have been largely removed by small tributary channels.
794 In contrast, the F3 deposits are better preserved on the west side of the valley where the bedrock
795 is more resistant to erosion. The Upper Pillow Lavas, although composed of comparable
796 extrusive lithologies, are generally more indurated in this area as a result of hydrothermal
797 alteration and sea-floor weathering and support locally steeper valley slopes (Pantazis, 1966),
798 as reported from the north-Troodos Akaki river catchment (Main et al. 2016).

799 In the middle reaches (Fig. 11 e-f), the bedrock is dominated by chinks of the latest
800 Cretaceous-Oligocene Lefkara Formation (Fig. 2). The Vasilikos river valley gradually
801 narrows southwards culminating in a pronounced constriction (just south of Kalavassos), which
802 is coincident with erosionally resistant bedded and nodular chert making up the Middle Lefkara
803 Formation (Pantazis, 1966). Incision of this highly resistant interval resulted in steep channel
804 margins, leaving only a narrow preserved rib of F2 deposits on the steep westerly slope and a
805 thin strip of F3 deposits on the lower eastern valley slope, without a preserved F3 terrace. The
806 local development of the F4 terrace on the lowest west side of the valley is interpreted as the
807 inner bend of a small meander within the previously incised valley, where locally reduced
808 stream velocities resulted in the fluvial aggradation.

809 The lower reaches (Fig. 11 g-j), where the valley broadens and shallows, are underlain,
810 initially by the soft-weathering limestones, marls, chinks and local evaporites of the Miocene
811 Pakhna Formation, and farther down-catchment by mudrocks and marls of the Pliocene-Early
812 Pleistocene Nicosia Formation. Asymmetrical topographic profiles contrast with further
813 upstream (Fig. 11 a, b, c, e). This, and the marked variation in the width of the preserved F4
814 terraces points to meandering of the river channel in this area.

815

816 *5.3. Fluvial processes*

817 Poorly to moderately sorted, clast-rich, matrix-supported conglomerates with outsized clasts
818 (> 1m) are best represented by the F1 conglomerates (Fig. 7 a), which are interpreted as very
819 high-energy mass-flow accumulations; i.e. debris-flows and hyperconcentrated-flow deposits
820 (Harvey *et al.* 2005; Waters *et al.* 2010). Spasmodic flash floods introduced packages of
821 similar-sized clasts of similar composition, although individual depositional units vary (see
822 'Provenance', below). Such flash floods were highly erosive, as inferred from their irregular,
823 eroded basal contacts (Fig. 13 b). In the Vasilikos river catchment bedrock chinks were locally
824 scoured into to form depressions that were infilled by foresets, marking the base of high-energy
825 conglomerates. North of Kalavassos, (Fig. 13 a), clasts in the F1 conglomerates are relatively
826 small, well-sorted and lenticular, with some clast imbrication. These conglomerates were
827 deposited from a weaker flow with a higher degree of traction current activity compared to the
828 coarser deposits preserved farther south. The finer chalk-rich conglomerates are likely to have
829 accumulated in a relatively marginal position where stream energy was reduced.
830 Conglomerates, which are relatively well-sorted and show clast imbrication, generally to the
831 S-SE, represent the accumulation from sustained traction-flow processes (Collison, 1996;
832 Waters *et al.* 2010). Locally developed tabular foresets, mainly in the F1 and F2 conglomerates
833 (Fig. 7 e) are indicative of foreset progradation during short periods of high-energy, sustained
834 flow when clasts rapidly infilled local accommodation space (Miall, 1996). Sorting, clast size
835 and imbrication commonly decrease upwards within individual depositional units (Fig. 7 f,
836 12.F3 a), pointing to waning flow, particularly in the upper levels of the F3 fluvial deposits
837 within the Vasilikos river valley. The fluvial processes previously identified within Vasilikos
838 Quarry (Waters *et al.* 2010) are also largely applicable to the equivalent-aged river valley
839 deposits (and so will not be discussed again here).

840

841 *5.4. Alluvial settings*

842 Most of the margins of the F1 channels are not preserved owing to extensive erosion of the
843 older terrace deposits. However, discrete conglomerate-filled channels are locally preserved
844 within the F2 deposits, and more commonly within the F3 and F4 deposits (Figs. 8, 11). These
845 are all interpreted as relatively marginal facies because the coeval channel axis sediments were
846 mostly eroded during subsequent incision events. The sedimentary structures and lithologies
847 of the conglomerates are generally indicative of braided or semi-braided stream accumulation
848 (Miall, 1996; Jones *et al.* 2001), including the F1 and F2 deposits in Vasilikos Quarry (Fig. 6).
849 Paleocurrent evidence (mainly clast imbrication) from the F1-F3 deposits indicates consistent

850 flow to the S/SE and does not confirm meandering flow in our F2 conglomerate in Vasilikos
851 Quarry (cf. Waters *et al.* 2010). On the other hand, geomorphological differences on either
852 side of the channel in the southern reaches of the Vasilikos River, as far north as near Kalavassos
853 (Figs. 10, 11) suggest that some of the F4 deposits are likely to have accumulated from a
854 meandering river. The relatively well-sorted silts, especially the thin, laterally extensive F4
855 sheet-like deposits in the lower reaches can be interpreted as overbank deposits related to
856 channel avulsion (Nichols & Fisher, 2007).

857 The aggrading F2 succession in Vasilikos Quarry is of particular interest (Figs. 5, 6). This is
858 interpreted as a remnant of a relatively wide and deep channel that was cut into the F1
859 conglomerates. The eastern part of this channel is not preserved owing to subsequent F3
860 downcutting and relocation of the active channel to the east. The dipping erosional surface
861 (Figs. 5, 6, 7 c) represents a section through this F2 channel western margin. The steep,
862 undulating nature of the basal (near axial) contact resulted from erosion into the Nicosia
863 Formation. Following this incision, three-phase aggradation took place (all within F2), two of
864 poorly sorted, clast-rich, clast or matrix-supported, lenticular conglomerates, and one of
865 medium to coarse-grained sands, interspersed with isolated conglomerate channels. The highly
866 erosive base of the upper conglomeratic unit (Fig. 6) is suggestive of a high-energy, flashy
867 mode of emplacement. Both of these conglomerate intervals exhibit stream-flow
868 characteristics, such as size sorting and clast imbrication, that suggest a strong component of
869 perennial flow during deposition (Waters *et al.* 2010). The two main conglomeratic intervals
870 are interpreted to have accumulated during periods of relatively high-magnitude stream-flood
871 events. The markedly lenticular nature of the sand and conglomerate lenses within both of the
872 conglomeratic packages (Fig. 6) resulted from the switching of channels within an overall
873 semi-braided setting. The decreasing clast size, clast imbrication and local tabular foreset
874 bedding point to less flashy, more sustained perennial flow in the upper levels of both of the
875 conglomeratic intervals. The stacked morphology of some isolated conglomerate channels,
876 mainly between the two conglomeratic intervals (Fig. 6), indicates repeated short-term cutting
877 and filling of relatively immobile channels. However, other adjacent similar-sized channels
878 were more mobile. The transition from the uppermost F2 unit to the overlying paleosols
879 (equivalent to F3) is interpreted to represent waning flow. The aggrading F2 unit in the quarry
880 demonstrates a variable flow evolution within a single major incised depositional package,
881 which is also likely to be applicable to the less well preserved terrace deposits within the
882 Vasilikos valley.

883 Coarse grained F3-aged sediments are well developed in the Vasilikos Valley, in contrast
884 to the Vasilikos Quarry where they are absent, owing to narrowing of the incision, resultant
885 channel abandonment and relocation of the active channel eastwards after F2 accumulation
886 ended. The irregular, undulating nature of the base of the F3 infill in the Vasilikos Valley (Fig.
887 12.F3 a-b) is indicative of erosional downcutting. The immature textures and lenticular
888 character (Fig. 12.F3 c-d) of the conglomerates are indicative of high-energy flash floods
889 interspersed with periods of during more sustained background flow. The smaller clasts
890 observed at the top of the infill (Fig. 12.F3 a-d) indicate decreasing energy during waning flow,
891 prior to channel abandonment.

892 The mainly silty, sheet-like infill of the F4 deposits mainly represent overbank deposits from
893 the axial channel that probably meandered, and was later incised to its present level in several
894 stages (Gomez, 1987). During and after F4 deposition large volumes of coarse material, as
895 exposed in the present-day river bed, continued to bypass the coastal plain and accumulate
896 offshore.

897

898 *5.5.Sediment provenance*

899 Around the western, northern and eastern peripheries of the Troodos Massif, the outcrops are
900 distributed in a broadly radial pattern, with increasingly higher-level units outwards
901 (Constantinou, 1995). As a result, for any given clast lithology (e.g. diabase; chert), in many
902 areas (e.g. Akaki river catchment; Main *et al.* 2016) the provenance of the clasts can be
903 specified based on lithology (i.e. minimum/maximum distance of transport). However, this
904 straightforward approach breaks down in the Vasilikos river catchment because the outcrops
905 of ophiolitic rocks to the north of Kalavassos Dam are variably distributed, owing to the highly
906 tectonised nature of the E-W-trending Arakapas Fault Zone and the Limassol Forest area to the
907 south (Fig. 2). Despite this limitation, the derivation of sedimentary rock clasts within the
908 Vasilikos river catchment can be related to the well-organised southward-younging
909 Maastrichtian-Pliocene stratigraphy (Bagnall, 1960; Pantazis, 1966) (Fig. 8).

910 Clasts of the same range of lithologies occur in all of the F1-F4 deposits, which suggests that
911 the source area exposures did not change significantly during the development of the Vasilikos
912 River. There is a higher proportion of ophiolitic clasts in the upper reaches, with chalk clasts
913 first appearing in the middle reaches, where the river starts to flow over the Lefkara Formation
914 (Fig. 8). There is variable mixing of relatively far-travelled ophiolite-derived clasts (mostly
915 diabase and microgabbro) and more locally-derived sedimentary clasts (Fig. 12). The ophiolite-

916 derived clasts are mostly well-rounded and smooth-surfaced (Fig. 14 c, f) compared to the
917 chalk clasts (Lefkara Formation) that are commonly subangular to angular, blocky, or elongate
918 (Fig. 14 c, d). These differences in textural maturity represent a combination of transport
919 distance, abrasion during overall transport and the tendency of some sedimentary rocks,
920 especially bedded chert, to erode into highly resistant angular-sided, tabular clasts (e.g. Fig. 14
921 c, top left). In agreement, studies of recent Cyprus beach conglomerates show that chert is
922 strongly over-represented (by volume) compared to source outcrops, indicating the very high
923 preservational potential of chert (Garzanti *et al.* 2000). Similar preferential chert preservation
924 is represented by the local abundance of chert clasts in some of the Vasilikos valley
925 conglomerates. In addition, there is some evidence of multi-cycle erosion and transport during
926 which some clasts from higher terraces were reworked into lower ones (e.g. in Vasilikos
927 quarry, Fig. 6 inset). This particularly results in anomalously large or well-rounded clasts of
928 ophiolitic rocks (mostly diabase) (e.g. Fig. 14 a), as also noted in the N-Troodos Akaki river
929 catchment (Main *et al.* 2016).

930 Clast counting of the F1 conglomerate in Vasilikos Quarry previously indicated a
931 predominance of diabase/microgabbro compared to basalt and sedimentary rocks, with only
932 minor basic intrusive rocks and negligible ultramafic rocks (Poole, 1992; Poole & Robertson,
933 1998). The F2 conglomerates, where previously sampled, comprised a more even distribution
934 of the above rock types (Poole, 1992; Poole & Robertson, 1998). Within the Vasilikos Valley,
935 diabase and microgabbro clasts dominate, together with rare gabbro, very rare ultramafic rocks
936 (weathered serpentinite) and rare, localised jasper (iron-rich chert) related to the Troodos
937 extrusive rocks (Fig. 13 f). The relative clast abundances reflect the widespread availability of
938 erosionally resistant diabase and gabbro from the higher reaches of the Vasilikos River, north
939 of Kalvassos Dam (Fig. 8). On the other hand, despite their widespread outcrop basaltic clasts
940 are sparse other than directly overlying the ophiolitic extrusive rocks. This reflects the tendency
941 of the basalt to weather mainly to fine-grained silt-sized material, as reported in the north-
942 Troodos Akaki catchment (Main *et al.* 2016). Despite the existence of a large outcrop of
943 serpentinitised rocks that begins c. 2 km NW of the dam site (Pantazis, 1967), ultramafic
944 ophiolitic rock clasts are notably sparse, reflecting alteration to soft-weathering serpentinite.

945

946 *5.6. Paleosol development*

947 Both the Vasilikos river valley and Vasilikos Quarry are characterised by widespread
948 development of brownish to reddish paleosols (Fig. 6; see also supplementary material). In the

949 Vasilikos Valley, strongly reddish terra rossa-type paleosols occur within and directly
950 overlying the F3 fluvial deposits (Fig. 14 b). Paleosols occur elsewhere in the relative
951 chronology (e.g. late Pleistocene) near Kalavassos (Schirmer, 1998; Kinnaird et al. 2013).
952 However, these are mainly brownish rather than reddish and less well-developed. The facies
953 similarities and position in the stratigraphy support a correlation of the very well-developed,
954 intensely red terra rossa paleosols in the quarry with the F3 deposition (and associated
955 geomorphical surfaces) in the valley. Similar terra rossa paleosols are reported from the same
956 relative stratigraphic level (equivalent to F3) in the north-Troodos Akaki canyon (Main *et al.*
957 2016) and the Kyrenia Range (Palamakumbura & Robertson, 2016a).

958 In the quarry, the transition between clastic deposition and paleosols (Fig. 6 log b; see also
959 supplementary material) is interpreted as the result of soil formation, alternating with fluvial
960 sand accumulation, prior to channel abandonment. Southward-thickening of the paleosols
961 suggests more extensive soil formation away from the river channel. In places, small (< several
962 metre-deep) steep-sided channels cut the paleosols and are infilled with a mixture of reworked
963 (rounded) ophiolite-derived clasts and locally derived (highly angular) Lefkara Formation
964 chalk clasts (see supplementary material). The uppermost, darkest red (most iron-rich) paleosol
965 is indicative of highly favourable conditions for soil formation and/or a relatively long period
966 of accumulation. The paleosols in the quarry developed on the very gentle upper slopes of the
967 F3 river channel that was by then located well to the east and at a lower topographic level.
968 Partially eroded F1 conglomerate to the southwest contributed texturally mature, ophiolite-
969 derived clasts (mostly diabase) to the locally overlying paleosol (Fig. 6, section, west end).
970 Elsewhere, clasts are scattered through the paleosols; these are randomly orientated and range
971 from well-rounded to highly angular. The clasts are likely to have been washed downslope
972 individually during wet periods, without sorting. Where present, localised small conglomerate-
973 filled channels within the paleosols in the quarry are interpreted as high-energy flash-flood
974 events, which mainly reworked clasts from the F1 or F2 conglomerates.

975 In general, local topography strongly influenced paleosol morphology and thickness, varying
976 from thin sheets on flat areas (e.g. lower reaches), to locally thickened lenses in some hillslope
977 areas (middle and upper reaches). The paleosols in the quarry are thicker (several metres) and
978 darker in colour (more iron-rich) compared to most of those overlying the F3 deposits and
979 related surfaces in the Vasilikos Valley; these are relatively thin (tens of cm), grey-brown to
980 reddish (Fig. 14 b). This is probably because a relatively long time was available for paleosol
981 formation in the distal valley slope after major channel abandonment (i.e. quarry),
982 uninterrupted by major fluvial input or mass-wasting processes. In addition, bright red

983 paleosols developed on correlative F3 surfaces including ophiolite-derived conglomerate in the
984 higher reaches of the Vasilikos river catchment, within the Arakapas Transform Fault Zone
985 (see supplementary material).

986 Paleosols are well known to be climate-influenced. Relatively, warm, moist periods
987 generally favoured the formation of brownish/reddish terra rossa-type paleosols (Kraus, 1999;
988 Schaetz & Anderson, 2005; Celma *et al.* 2015). The presence of roots/rootlets and charcoal
989 within the paleosols is indicative of a well-developed vegetation cover, with an increasing
990 number of root traces up-sequence as the soils became more developed (see supplementary
991 material). The terra rossa could include a significant proportion of aeolian dust as elsewhere in
992 the Mediterranean region (e.g. Mallorca, Spain; Muhs *et al.* 2010), although geochemical
993 analysis is needed to test this possibility.

994

995 *5.7. Colluvium formation*

996 Landscapes tend towards equilibrium stability (Hurst *et al.* 2012). As a result, material tends
997 to move from high to lower topographic elevations, particularly on valley sides. Hillslope
998 readjustment processes have therefore played an important role in the development of the
999 Vasilikos Valley, especially in the topographically steeper upper to middle reaches. The
1000 readjustment-related deposits are of two types, one associated with the F1 and F2 surfaces
1001 which is conglomeratic (e.g. Nemeč & Kazanži, 1999) and one with the F3-F4 surfaces, which
1002 is mainly composed of silt-sized material (harvara).

1003

1004 *5.7.1. Conglomeratic colluvium*

1005 Chalky conglomeratic or breccia-like colluvium (> 20 m thick) overlies the F2 erosion surface
1006 in the upper reaches near Vasilikos Dam (Fig. 15 b). This material was derived from the
1007 Lefkara Formation (Fig. 8) that is exposed on the upper, easterly slopes of the Vasilikos river
1008 catchment (c. 2 km away and > 100 m topographically higher). This colluvial conglomerate is
1009 matrix-rich (75%), poorly sorted and contains > 95% angular to subangular chalk clasts,
1010 without imbrication (Fig. 15 c). In places, the deposits fill depressions in the underlying
1011 extrusive igneous rocks, indicating that that they were crudely channelised.

1012 Chalky conglomeratic colluvium also forms exposures (up to c. 0.5 km across) above ophiolitic
1013 lavas elsewhere within the upper reaches of the Vasilikos Valley (Pantazis, 1967). This chalky
1014 conglomerate, like the exposure near the dam, appears to have mainly formed post-F2 incision
1015 but pre-F3 incision. In addition, comparable conglomeratic colluvium forms widespread

1016 exposures (up to c. 2 km across) on the southward-facing slopes of the Arakapas Transform
1017 Fault valley (c. 7 km N of the dam). In this area, source the Lefkara Formation chalks were
1018 subsequently eroded leaving thick (tens of metres) chalky conglomerates, isolated from their
1019 source outcrop.

1020 The chalky conglomerates and breccias as a whole accumulated in response to erosion of
1021 relatively soft-weathering chalk, followed by downslope movement by mass-flow processes.
1022 Erosive power was sufficiently strong to incise locally into basaltic lavas, although these likely
1023 to have been strongly weathered (Fig. 15 a). After incision of the F2 paleovalley, which
1024 increased sediment accommodation space, the higher valley slopes underwent mass wasting of
1025 chalk to form the clast to matrix-supported conglomerate/breccia which then accumulated on
1026 the F2 erosion surface. Remnants of this coarse colluvial material remain after later incision
1027 and erosion (F3, F4).

1028 Within the middle reaches of the Vasilikos Valley, the steeply-sloping margins of the incised
1029 F3 surface are mantled by fallen blocks of conglomerate that were locally derived from the
1030 topographically higher F2 terrace. In many places, for example, southwest of Kalavassos, there
1031 is a clear change in slope beneath the F2 surface, which is initially steep and then flattens out
1032 downwards. The slope change corresponds to the occurrence of numerous irregularly-
1033 distributed conglomerate blocks (up to 10 m long x < 5 m thick). The blocks are lithologically
1034 similar to the F2 conglomerate that is locally preserved above. These F2 conglomerates were
1035 armoured by calcrete, incised (related to F3 downcutting), and then locally collapsed
1036 downslope as detached blocks. Mass-wasting of blocks of lithified conglomerate have therefore
1037 played a role in slope adjustment, at least locally.

1038

1039 5.7.2. *Silty and marly colluvium*

1040 Sloping F3 surfaces are commonly mantled by variably dipping, variably stratified, impure
1041 marls and silts (harvara), which are locally interbedded with matrix-supported conglomerates
1042 and/or grey to brown paleosols (Fig. 15 d). These deposits are very widespread, especially on
1043 the western side of the valley, in the middle reaches. The deposits range from thin (typically
1044 several metres), irregular veneers, especially on upper slopes, to lenticular slope cones (tens of
1045 metres thick) where valley re-entrants merge with valley floors. Downslope and axially, the
1046 colluvial deposits are increasingly mixed with fluvial conglomerate. The broad, sloping F3
1047 valley surfaces were particularly well-suited to harvara accumulation and were preserved from
1048 Holocene erosion related to their topographic position above the modern-day river channel.

1049 The harvara formed preferentially on carbonate-rich bedrock (Schirmer, 1998). However, it
1050 can also be reworked downslope onto other lithologies, as seen in the Vasilikos Valley near
1051 the dam, where it overlies ophiolitic rocks. Harvara commonly forms debris cones at the toes
1052 of valley slopes (< 10 m thick), although can also occur as thin sheets or lenses on more gently
1053 inclined surfaces.

1054 Individual stratified harvara deposits, as well exposed at Kalavasós Márkou (see above),
1055 begin with calcareous silt with rock fragments, interpreted to represent unstable slopes with
1056 limited binding vegetation. The presence of scattered relatively large, angular clasts in some of
1057 the harvara points to ‘flashy’ coarse sediment supply. Harvara layers then fines-upwards into
1058 more homogeneous silty marl that is interpreted to have accumulated under more stable slope
1059 conditions.

1060 The paleosols in Vasilikos Quarry are interbedded with thicker intervals of pale calcareous
1061 silts, commonly with rootlets and variably calichified (Figs. 6, 15 e). These sediments are
1062 interpreted as poorly developed paleosols, mixed with terrigenous material, that accumulated
1063 on a gently sloping land surface away from the active river channel.

1064 Harvara in Cyprus has been interpreted as mainly the product of slow periglacial mass
1065 wasting (solifluction), coupled with down-slope mass movement. Initially strong, but waning
1066 climatically-controlled erosion-redeposition characterised glacials, was followed by humic soil
1067 formation on a forested land surface during interglacials (Schirmer, 1998). During glacial
1068 periods, mechanical erosion (e.g. freeze thaw; frost shattering) provided a large amount of
1069 immature angular material, explaining the presence of relatively large (outsized) angular clasts
1070 (e.g. Lefkara Formation chalk) within the harvara, compared to generally smaller and more
1071 texturally mature (rounded) clasts within the overlying terra rossa when the landscape was
1072 more vegetated. Harvara therefore developed cyclically as climate changed, varying in
1073 thickness and facies according to the duration and intensity of climatic downturns and the
1074 prevailing slope conditions. A similar influence of vegetation on run-off is inferred from other
1075 areas including the Late Quaternary of the Sparta area, Greece (Pope & Wilkinson, 2005).

1076 During harvara accumulation hill slopes approached or exceeded 30°, which favoured
1077 sediment transport by dominantly non-linear processes such as mass flow and downslope
1078 creep. Sediments that moved downslope by such diffusive processes were shielded from
1079 chemical weathering that commonly affected subaerially exposed material.

1080 Aeolian processes are likely to have contributed to harvara formation (Schirmer, 1998),
1081 which is consistent with the abundance of Pleistocene aeolianites in adjacent areas (e.g. Israel
1082 coast plain) (Frechen *et al.* 2004). However, the Cyprus harvara is not necessarily equivalent

1083 to fine-grained colluvium in general, which is believed to have formed at various times and
1084 under varying climatic conditions (Nemec & Kazancı, 1999).

1085 Taken together, the chalky conglomerate/breccia and the finer-grained colluvium (harvara)
1086 were influenced by a range of processes including slope angle (and slope change), sediment
1087 accommodation space (related to incision), climate (and climate change) and source rock.
1088 Source rock was important especially the outcrops of Maastrichtian-Paleocene marly chalks
1089 which are particularly soft-weathering and supplied large volumes of chalky material.
1090 Relatively steep slopes were also important in concentrating colluvium in slope toes above
1091 terraces (especially F3). Chalks are also extensive in the NE-Troodos Akaki catchment (Main
1092 et al. 2016). However, there, chalky colluvium is minimal mainly because the adjacent slopes
1093 (e.g. F3) were much more subdued.

1094

1095 *5.8. Calcrete and caliche formation*

1096 The fluvial terraces are capped by a calcareous crust (kafkalla; see Nomenclature), which is
1097 generally thickest (up to several metres) and most pervasive on the topographically highest and
1098 thus older terraces (F1 and F2) (Fig. 13 c), reflecting prolonged subaerial (or near-subaerial)
1099 exposure. The uppermost levels of the conglomerate terraces are commonly cemented by
1100 calcrete (up to several metres thick), with or without a kafkalla capping. Beneath this, the
1101 matrix of the conglomerates at all levels commonly contains caliche nodules (see
1102 Supplementary material). Nodular caliche is widespread especially within the F3 and F4 finer-
1103 grained fluvial sediments.

1104 Caliche forms in a semi-arid climate with seasonal rainfall, similar to today (Arakel, 1982).
1105 Recent studies of other areas (e.g. Sorbas basin, Spain) suggest that suitable climatic conditions
1106 for caliche formation (similar to today) existed during several Pleistocene warm intervals, prior
1107 to the Holocene (MIS 1-5) (Candy *et al.* 2006; Candy & Black, 2009). Caliche is also reported
1108 from areas of high, but seasonal rainfall and relatively high temperate (Retallack, 2001). Given
1109 that caliche relates to fluid flow, precipitation and clastic sediment replacement it may form
1110 over a prolonged time period, and might even develop cyclically as climatic conditions change
1111 assuming that it remains within the seasonally affected profile. Whole-rock radiometric ages
1112 of caliche therefore need to be treated with some caution.

1113

1114 *5.9. Development of the Vasilikos catchment through time*

1115 Combined with the quarry exposure, the river valley geomorphology and deposits allow the
1116 progressive development of the Vasilikos river catchment to be reconstructed (Figs. 16, 17;
1117 Table 1).

1118 The scene was set during the early, focussed uplift of the Troodos Massif (Poole &
1119 Robertson, 1991). As a result, fully marine shelf deposition of the Pliocene-early Pleistocene
1120 Nicosia Formation (mud/marl) gave way to sand and conglomerate lenses, interbedded with
1121 bioturbated marine marls, rich in macrofossils. The interval records the progradation of a
1122 shallow-marine fan delta generally towards the SE (McCallum, 1989), although with hints of
1123 meandering streams. This was followed by a thin and probably short-lived interval of non-
1124 marine fan-delta accumulation. Each conglomerate lens is likely to represent a flash flood
1125 event, with the higher proportions of generally larger clasts representing deposition from the
1126 highest energy flows.

1127 The regionally distributed F1 conglomerate (Fanglomerate Group) accumulated during very
1128 rapid uplift of Troodos Massif. This background tectonic control coincided with a humid
1129 climate that facilitated major bedrock erosion, coarse clastic sediment supply and development
1130 of sheet-outwash fans, radially around the Troodos Massif (Poole and Robertson, 1991, 2000).
1131 Erosion and associated incision can be accentuated during times of climate deterioration and
1132 vegetation loss, as inferred in Mallorca (Spain) during the last 140 ka (Rose *et al.* 1999). Studies
1133 in other areas (e.g. Makran Range) suggest on the other hand that incision and terrace
1134 abandonment were accentuated during the transition to, and also during, warm, humid periods
1135 (Bridgland & Westaway, 2008, 2009; Wegmann & Pazzaglia, 2009; Kober *et al.* 2013).

1136 The F1 conglomerates, as in the Vasilikos Quarry and in the highest fluvial terraces in the
1137 Vasilikos river catchment, conform to the previously documented overall radial distribution
1138 pattern around the Troodos Massif (Poole & Robertson, 1991, 2000). The paleocurrent
1139 evidence, including the foresets in the F1 and F2 deposits of the quarry and the clast imbrication
1140 in all of the fluvial terraces studied indicate dominant flow towards the SE, which is in keeping
1141 with uplift and erosion centred on Mount Olympos (Poole & Robertson, 1991, 2000).

1142 The topography of the F1 fluvial distributary in the lower reaches is envisaged as a broad,
1143 shallow semi-braided channel, which transported very coarse material from the ophiolitic
1144 hinterland via a series high-energy traction and mass-flow events (Figs. 16 a, 17 a). The mid
1145 to higher reaches of the F1 distributary cannot be inferred owing to lack of sufficient deposits.

1146 The F2 deposits accumulated in a discrete, constrained channel that was incised into the
1147 F1 deposits or into bedrock (Figs. 16 b, 17 b). This is specifically demonstrated in Vasilikos
1148 Quarry, where the F2 conglomerates cut through the F1 conglomerates into Late Pliocene-

1149 Early Pleistocene marine marls/mudrocks of the Nicosia Formation (Figs. 5, 6). The F2
1150 conglomerates extend into the upper reaches of the Vasilikos river valley (Fig. 11), where the
1151 pre-existing, relatively broad F1 channel was incised by a narrower, steeper-sided channel.
1152 Further indications of the F2 channel-filling processes come from the quarry, where the lower
1153 of the two aggrading conglomeratic intervals (Figs. 5, 6) shows evidence of deposition near
1154 the threshold of a change between braided and channelled deposits. In some places, these
1155 conglomerates have similar depositional features to the F1 conglomerates, with lateral
1156 continuity for tens of metres or more and evidence of sandy and pebbly bars. However, in
1157 places conglomerates are strongly channelised and stacked vertically or obliquely.

1158 The F3 surfaces in the Vasilikos Valley record profound erosion which removed most of
1159 the pre-existing conglomerates, leaving only fringing fluvial deposits as terraces (Figs. 16 c,
1160 17 c). In the middle and upper reaches of the catchment, the F3 channel incised pre-existing
1161 channels. In contrast, in the lower reaches, above softer lithologies (Pakhna and Nicosia
1162 formations), the channel narrowed and deepened into bedrock. The western margin of the F2
1163 channel infill, represented by the quarry outcrop, was abandoned and covered by mainly fine-
1164 grained deposits in the form of alternating paleosols and pale calcareous silts.

1165 After F3 deposition, further incision created a range of geomorphologies and deposits (Figs.
1166 16 d, 17 d). A slot-like gorge was incised in the upper reaches, with minimal preserved
1167 sediment (Figs. 10, 11). A comparable, but deeper (c. 25 m) slot-like gorge formed during
1168 equivalent late-stage geomorphological development of the Akaki canyon, NE Troodos margin
1169 (Main *et al.* 2016), and has also been noted elsewhere around the Troodos Massif (unpublished
1170 data). The finer-grained F4 deposits of the mostly represent overbank deposits, probably from
1171 a meandering channels, which spilled over a broad, low-amplitude paleovalley in the lower
1172 reaches, south of Kalavassos. The modern-day channel in the lower reaches ranges from a
1173 shallow, well-constrained channel (south of Kalavassos) to a broader, less-constrained semi-
1174 braided channel towards the coast.

1175

1176 *5.10. Major controls of erosion and aggradation*

1177 Long-term tectonic uplift focussed on Mt. Olympos was the dominant control of
1178 geomorphology and fluvial deposition (Poole & Robertson, 1991). However, shorter term
1179 climatic changes (on Milankovitch time scales) also played a key role (Poole & Robertson,
1180 2000; Waters *et al.* 2010). Similar climatic influence is inferred for many other areas
1181 undergoing tectonic uplift, including Calabria (Massari *et al.* 2007) and south-central Australia

1182 (Quigley *et al.* 2007). Eustatic sea-level change is also likely to have played a role by lowering
1183 the base level of erosion, particularly at the near-coast quarry site (now c. 40-80 m ASL).
1184 Eustatic sea-level oscillations of up to c. 130 m took place during the last glacial maximum
1185 (19,000 and 30,000 years ago) (Lambeck *et al.* 2002) and presumably affected all areas of
1186 coastal Cyprus. The incised F4 channels, including the slot-like gorge in the upper reaches
1187 (south of the dam) could relate to northward retreat of a sea-level-change-induced nick point,
1188 similar to that suggested for the NE-Troodos Akaki river catchment (Main *et al.* 2016).
1189 Elsewhere in the Mediterranean, fan deposition on the Cabo de Gata coast, SE Spain is
1190 interpreted to have responded to base-level change with increased erosion and incision
1191 (Harvey, 2002).

1192

1193 *5.11. Timing of erosion and aggradation*

1194 Absolute age constraints on the direct age of the non-marine Pleistocene surfaces and deposits
1195 within the Vasilikos river catchment unfortunately remain very limited, restricted to two
1196 radiocarbon dates and three OSL ages estimates of palaeosols, together with supporting OSL
1197 age profiling (Kinnaird *et al.* 2013), and one whole-rock U-Series caliche age (Waters *et al.*
1198 2010) of debateable significance (see below). Despite these limitations, some older ages can
1199 be suggested for the earlier deposits mainly based on magnetostratigraphy of deposits in
1200 southern Cyprus and correlations with radiometrically dated shallow-marine, coastal
1201 carbonates.

1202 Paleomagnetic studies of Pleistocene fine-grained deposits from the western, southern and
1203 eastern periphery of the Troodos Massif indicate a normal magnetic polarity for both the fluvial
1204 and littoral-marine sediments as a whole (Kinnaird *et al.* 2011; Weber *et al.* 2011) (i.e. post-
1205 781 ka; Cohen *et al.* 2013). The F2 and F1 deposits (and by extension the associated surfaces)
1206 are not dated anywhere in Cyprus, largely owing to the absence of preserved aragonitic coral
1207 suitable for dating of correlative shallow-marine deposits. The older deposits (F1 and F2)
1208 originally inferred to be early-mid Pleistocene (Poole & Robertson, 1998, 2000) are now
1209 redefined as Middle Pleistocene age, following the reclassification of the Pliocene-Pleistocene
1210 boundary (from 1.806 Ma to 2.588 Ma to) (see Cohen *et al.*, 2013). However, it can be assumed
1211 that these two major incision-aggradation cycles correspond to major sea-level excursions prior
1212 to MIS 7, of mid-Middle Pleistocene age, potentially MIS 9, MIS 11 and possibly older (see
1213 Palamakumbura *et al.* 2016 b). Large-scale fluvial conglomerate accumulation (pre-F1, F1 and
1214 F2) therefore took place during Early-Middle Pleistocene time when the aggrading marine to

1215 non-marine fan-delta system is included. Although younger, the two correlative aggrading
1216 conglomerate intervals (F2) in the quarry are also inferred to be of mid-Middle Pleistocene age.
1217 The reported 59 ka (Late Pleistocene) whole-rock age (Late Pleistocene) of caliche from the
1218 upper level of these conglomerates (Waters et al. 2010) therefore appears to be too young, and
1219 is re-interpreted as a diagenetic age.

1220 The relative chronology of the F1-F4 deposits in the Vasilikos river catchment is similar to
1221 elsewhere around the periphery of the Troodos Massif (Poole & Robertson, 1998, 2000),
1222 notably the NE-Troodos Akaki river catchment (Main et al. 2016). In addition, similar stages
1223 of geomorphologic development have been established in the Kyrenia Range, north Cyprus
1224 (Palamakumbura *et al.* 2016 a, b; Palamakumbura & Robertson 2016 a, b). Shallow-marine
1225 terrace deposits, both around the periphery of the Troodos Massif and in the Kyrenia Range,
1226 have been radiometrically dated by means of U-series disequilibrium dating of *Cladocora*
1227 solitary coral, and then lithologically correlated with marine and continental deposits elsewhere
1228 around coastal Cyprus. Shallow-marine deposits that can be broadly correlated with the F3
1229 fluvial deposits in southern Cyprus have been dated at c. 185-192 ka, generally corresponding
1230 to MIS 7 (Poole *et al.* 1990), of later Mid-Pleistocene age. Comparable marine terraces in the
1231 Kyrenia range, N Cyprus have recently yielded more accurate ages of 243 and 131 ka
1232 (Palamakumbura *et al.* 2016 a), also within the age span of MIS 7. MIS 7 lasted for c. > 500
1233 ka, with at least two main internal excursions, implying > 60 m of eustatic sea-level change
1234 within this time interval (Cohen *et al.* 2013), with pronounced geomorphological and
1235 depositional effects.

1236 In many coastal areas, MIS 7 marine terraces are covered by a veneer (commonly tens of
1237 centimetres thick) of shallow-marine carbonate rock (Poole & Robertson, 2000;
1238 Palamakumbura & Robertson, 2016 b). These littoral deposits are dated generally at c. 116-
1239 130 ka and correlated with MIS 5e; i.e. related to the Last Interglacial (~129–116 ka) when
1240 sea levels are inferred to have been c. 6 m above modern day in many areas (Horton *et al.*
1241 2018). MIS 5 lasted for > 350 ka, with several high frequency oscillations (Cohen *et al.* 2013),
1242 which are again likely to be represented by small-scale geomorphological and depositional
1243 changes. For example, on the island of Mallorca (Spain), MIS 5e was associated with coastal
1244 erosion and eustatic sea-level rise (Rose *et al.* 1999). Comparable coastal erosion is seen around
1245 Cyprus, notably in the Larnaca area (Poole & Robertson, 2000).

1246 The long-lived, strongly fluctuating MIS 7 highstand (later Middle Pleistocene) facilitated
1247 extensive downcutting to form wide coastal terraces, as best developed in SW Cyprus (Poole
1248 & Robertson, 1991). The associated deep incision gave rise to a broad (but variable) valley and

1249 the accommodation space necessary for a wide range of clastic sediments, paleosols and
1250 colluvium, as observed throughout the Vasilikos river catchment. The similarly long-lived MIS
1251 5 highstand (Middle-Late Pleistocene boundary) was followed by incision of the narrow, steep-
1252 sided slot into the ophiolitic bedrock in the upper reaches and erosion of the broad shallow
1253 valley in the lower reaches (south of Kalavasos). In general, aggradation is likely to have
1254 occurred following strong incision, mainly during periods of high eustatic sea level
1255 (interglacials), as also inferred for the NE Troodos Akaki river catchment (Main et al. 2016).

1256 Charcoal from the paleosol in the lower part of the colluvium (harvara) at Kalavasós Márkou
1257 which overlies the F3 erosion surface yielded a radiocarbon age of $31,970 \pm 910$ a BP
1258 (Schirmer, 1998) and an OSL age estimate of 29.82 ± 2.11 ka (Kinnaird *et al.* 2013). Charcoal
1259 from a brown-grey discontinuous parting higher up ('charcoal streak') in this section yielded
1260 an age of 27.44 ± 1.6 ka (Schirmer, 1998). Paleosol from the lower part of a succession (c. 8
1261 m thick) of alternating paleosols and harvara in another section, c. 1.2 km north of Kalavasos
1262 gave an OSL age estimate of 9.97 ± 2.08 ka (Kinnaird *et al.* 2013). In addition, a sample from
1263 another section, which is located c. 200 m farther WNW (Vasilikos-Drapia) gave a
1264 significantly older age of 66.40 ± 4.07 ka. The sample was collected 2 m above the modern
1265 channel bed and at a slightly lower level than the younger sample.

1266 The Kalavasós Márkou harvara is similar to the widely distributed colluvium overlying the
1267 F3 surface (e.g. N of Kalavasos) which is therefore likely to be mainly late Pleistocene.
1268 However, the available stratigraphic and age evidence suggests that that harvara formed
1269 cyclically throughout the Pleistocene. The dated paleosols also formed at different times (> 65
1270 ka - < 10 ka), at different levels of the valley slopes, especially above the F3 and/or F4 erosion
1271 surfaces. The Eastern Mediterranean experienced relatively wet conditions during c. 6,000-
1272 5,400 BP, followed by drier conditions with short-lived more humid periods until the present
1273 day (Finné *et al.* 2011). Comparable results from SW Cyprus (Dhiarizos River) suggest that
1274 incision and subsequent alluvial aggradation took place synchronously in Cyprus over the last
1275 2000 ka (Deckers, 2005) and also elsewhere in the Mediterranean (Macklin *et al.* 2002).

1276

1277 *5.12. Influence of neotectonic deformation*

1278 Did neotectonic faulting played a significant role in Vasilikos Valley geomorphology and
1279 sedimentation?

1280 North of Kalavasos, the colluvium above the F3 surface exposes a local angular discordance
1281 which is likely to reflect contemporaneous fault-related tilting, followed by progradation of

1282 further colluvium (sub-horizontal) (Fig. 15 f). The fault-modified paleotopography in this area
1283 affected erosion and sediment deposition locally. However, there is little evidence that
1284 neotectonic faulting has had a significant regional influence on sediment supply or
1285 geomorphology in the Vasilikos river catchment, where instead, the development is similar to
1286 the periphery of the Troodos Massif as a whole. Most other faults deform units up to and
1287 including the Messinian deposits. Some faults in the area appear to have been reactivated in
1288 response to NW-SE compression, associated with c. E-W left-lateral strike-slip during
1289 Pleistocene-Recent time. Such transpressional effects can broadly related to the westward
1290 tectonic escape of Cyprus from the colliding African and Eurasian plates (Soulas, 2003,
1291 Harrison *et al.* 2004; Kinnaird & Robertson, 2013). However, there is no known structural
1292 evidence of major vertical fault offset which could have significantly affected the overall
1293 relative chronology of geomorphic terraces and deposits, including those in the Vasilikos
1294 Quarry.

1295

1296 5.13. *Wider implications*

1297 Much Quaternary research focuses on trying to identify and isolate specific features (e.g.
1298 fluvial deposits; geomorphological slopes) that can then be studied in terms of the processes
1299 involved, quantitatively where possible (e.g. stream power; mass-flow). However, there is also
1300 considerable merit in detailed case histories through time where every geomorphic surface and
1301 deposit has its place, allowing detailed comparisons of the processes involved. Global survey
1302 of such processes indicates a preference for climatic-related explanations, representing 55%
1303 of documented examples compared to tectonic-related explanations that make up only 5%
1304 (Schanz *et al.* 2018). In this regard, the Vasilikos river catchment is firmly in the ‘camp’ of a
1305 dominantly tectonic control at least during the Early-Middle Pleistocene when most of the
1306 geomorphological surfaces and sediments discussed here were formed. However, the processes
1307 of tectonic uplift (including timing and rate), climate (and climatic change) and eustatic sea-
1308 level change (especially in near-coastal areas) go hand-in-hand and interact to produce the
1309 landscape and deposits. The Vasilikos river catchment has the potential to emerge as a classic
1310 open-air laboratory for a wide range of related processes, especially if more accurate dating
1311 becomes possible in the future.

1312

1313 **6.1. Conclusions**

- 1314 1. The depositional and geomorphological setting of the isolated Pleistocene deposits
1315 exposed in the important (and much visited) Vasilikos Quarry in southern coastal Cyprus
1316 is resolved by establishing a stratigraphy within the quarry and also within the adjacent
1317 Vasilikos river valley, allowing an overall correlation of geomorphic surfaces and
1318 depositional units within the Vasilikos river catchment as a whole.
- 1319 2. The key to understanding of the stratigraphy of the deposits within Vasilikos Quarry is the
1320 discovery of a major angular unconformity which is incised through the highest-level
1321 (oldest) Pleistocene deposits into underlying fine-grained, open-marine Late Pliocene-
1322 Early Pleistocene deposits (Nicosia Formation).
- 1323 3. The construction of E-W geomorphological profiles over c. 10 km N-S within the Vasilikos
1324 river catchment (using ArcGIS) allows four main stages of valley development be inferred,
1325 mainly involving successive fluvial incision, coarse clastic deposition, colluvium and
1326 paleosol development.
- 1327 4. Fluvial conglomerates and associated sediments have been mapped through a large part of
1328 the Vasilikos river catchment in the form of patchily preserved, ribbon-like terrace deposits,
1329 which are indicative of four main successive cycles of fluvial aggradation (F1-F4) at
1330 progressively lower topographic levels.
- 1331 5. The quarry outcrop includes the distal, westerly margin of the F2-aged channelled fluvial
1332 deposits. The channel was abandoned related to incision to form a new channel (F3) farther
1333 east and at a lower topographic level.
- 1334 6. Mass-movement of calcareous material on sloping surfaces produced colluvial deposits
1335 ranging from chalky debris flows, mainly on a relatively high and thus old geomorphic
1336 surface (F2) to mainly lenticular calcareous silts (Cyprus harvara) which predominate
1337 above younger surfaces (mostly F3-aged), especially near slope bases.
- 1338 7. Correlation with comparable Pleistocene deposits elsewhere in Cyprus suggests that the
1339 pre-F1 (thin) fluvial deposits accumulated during the Early Pleistocene, the F1 and F2
1340 conglomerates during the Middle Pleistocene, the F3 conglomerate during the Middle
1341 Pleistocene (c. 219-185 ka) and the F4 conglomerate near the Middle-Late Pleistocene
1342 boundary (c. 141-116 ka).
- 1343 8. Initial, Early Pleistocene uplift focussed of the Troodos Massif was characterised by overall
1344 SE-progradation of a regressive shallow-marine fan-delta, exemplifying tectonically forced
1345 regression. The overlying coarse, immature and widely distributed F1 conglomerates
1346 accumulated during an inferred humid interval of high run-off of coarse clastic sediment.
1347 This climatic perturbation was coeval with ongoing rapid surface uplift that was focussed

1348 on the core of the Troodos massif (Mt. Olympos). The F2 conglomerates accumulated
1349 within paleovalleys that were mainly incised into the F1 deposits during another humid
1350 period when rapid surface uplift was still continuing. The F3 conglomerate and associated
1351 colluvial deposits (harvara) and paleosols (terra rossa) accumulated during, or after, a
1352 prolonged period (c. 219-185 ka) of fluctuating eustatic sea-level and related glacio-eustatic
1353 climate change when the climate was largely warm and humid and when surface uplift was
1354 still continuing (possibly at a reduced rate). The F4 conglomerates and extensive silty
1355 overbank deposits mainly accumulated within a wide, broadly incised paleovalley within
1356 the coastal plain. These sediments may have aggraded during a humid period of high
1357 eustatic sea level (c. 141-116 ka). Clastic sediment bypassing to the offshore continued
1358 throughout the Pleistocene, especially during the Early-Middle Pleistocene when surface
1359 uplift was most intense.

1360 9. Following incision episodes, channel infill took place during relatively humid periods by a
1361 combination of high-energy stream-flood events, creating poorly sorted, commonly chaotic
1362 conglomerates, and also by lower-energy sustained flow, producing more organised
1363 conglomerates (including local Gilbert-type foresets).

1364 10. The geomorphology of the Vasilikos valley was strongly influenced by lithology. Channels
1365 are wider and broader where incised into relatively soft extrusive igneous rocks (weathered
1366 basalt) and soft sedimentary rocks (marls and gypsum). Distinctive narrowing and
1367 confinement of the river channel at Kalavasos coincides with highly resistant chert layers
1368 within the Eocene interval of the Lefkara Formation. Slope evolution and colluvium were
1369 also influenced by lithology, with chalk liberating the largest volumes of colluvium (both
1370 fine and coarse-grained).

1371 11. The dominant control of catchment development was focussed tectonic uplift of the
1372 Troodos Massif, mainly during Early-Middle Pleistocene time (F1-F2 surfaces and fluvial
1373 deposits).

1374 12. The effects of surface uplift later waned, allowing climatic change and related glacio-
1375 eustasy to dominate the late Middle-Late Pleistocene (F3 and F4 surfaces and fluvial
1376 deposits).

1377 13. Neotectonic faulting in the Vasilikos river catchment had some influence on sedimentation
1378 and geomorphology but only locally on a small scale. Our new evidence is therefore
1379 consistent with the uplift of the adjacent Troodos Massif, essentially as one structurally
1380 coherent unit, in contrast to many other 'fore-arc' areas (e.g. S Crete) that were dissected
1381 by major high-angle faulting during the Pleistocene.

1382

1383 *Acknowledgements*

1384 The first author thanks Eric Fitton for acting as her field assistant during fieldwork in Cyprus,
1385 and also the School of GeoSciences for part-funding travel and subsistence. The second author
1386 acknowledges the John Dixon memorial fund for financial assistance with the fieldwork in
1387 Cyprus. Romesh Palamakumbura participated in early reconnaissance fieldwork. We thank
1388 Dick Kroon and Louis Kinnear for helpful discussion in the field. Hülya Alçiçek, Timothy
1389 Kinnaird and Louis Kinnear provided constructive comments on the manuscript.

1390

1391

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1744 Mediterranean from combined sidescan sonar and submersible surveys. *Deep-Sea Res.*
1745 *I* **52**, 457-475.
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1747 **Table caption**

1748 Table 1. Summary of the facies/stratigraphy, main field evidence, interpretation and age
1749 estimates of the primary deposits exposed in the Vasilikos Quarry and the adjacent Vasilikos
1750 river catchment. Material formed by secondary (diagenetic) processes (e.g. caliche) is
1751 excluded.

1752

1753 **Figure captions**

1754 Figure 1. Outline tectonic map of the Eastern Mediterranean region including the location of
1755 the Cyprus trench south of Cyprus (modified from Main *et al.* 2016). Inset: Outline map of
1756 Cyprus showing the location of the Vasilikos Valley.

1757

1758 Figure 2. Simplified geological map of the part of the southeastern Troodos Massif, the
1759 Limassol Forest area and the Vasilikos River (box). Based on the 1:250,000 Geological Map
1760 of Cyprus (Constantinou, 1995). Note also the locations of Vasilikos Quarry and Vasilikos
1761 Dam.

1762

1763 Figure 3. Sedimentary log and photograph of the Late Pliocene-Early Pleistocene succession
1764 exposed in a natural escarpment, c. 1.8 km northwest of Vasilikos Quarry. a, Sedimentary log
1765 from near the Nicosia-Limassol old highway in the north, to the approximately NW-facing
1766 escarpment shown in b (based on JE McCallum, unpub. PhD thesis, Univ. Edinburgh, 1989
1767 and this study). b, Transition from shelf-depth, Late Pliocene-Early Pleistocene fine-grained
1768 sediments (A) to Early Pleistocene coarse clastic sediments exposed in the escarpment above
1769 (B). Note the mainly planar-bedded to low-angle cross-bedded sands (pale), interspersed with
1770 lenticular conglomerates (C). Total thickness shown=c. 30 m. The line of section in a, is c. 80
1771 m west of the end of the photograph (beyond a bend in the outcrop).

1772

1773 Figure 4. Sketch map of Vasilikos Quarry showing the Pliocene and Pleistocene exposures.
1774 Based on Google imagery and observations during this work. Key features and areas mentioned
1775 within the quarry are indicated, including the key dipping erosion surface from the highest
1776 conglomerates in the SW, down into the Mid-Late Pliocene marls/mudrocks (Nicosia
1777 Formation).

1778

1779 Figure 5. Schematic fence diagram illustrating well-exposed faces in Vasilikos Quarry. The
1780 diagram shows five panels, A-E (the gap between D and E conceals a re-entrant in the quarry).

1781 Note the distribution of the sedimentary packages and the key dipping erosion surface (angular
1782 unconformity) cutting down through the F1 conglomerate into the Nicosia Formation to the
1783 NE, overlain by F2 deposits.

1784

1785 Figure 6. Details of the sedimentary successions exposed at the southern and northern margins
1786 of Vasilikos Quarry. Sedimentary logs: Log A (left). Upward succession from the Pliocene
1787 facies of the Nicosia Formation, through thin marine, to non-marine lenticular conglomerates
1788 (Early Pleistocene), into the relatively thick and coarse F1 conglomerate; Log B (right). Two
1789 lenticular F2 conglomerate intervals, separated by a sandy interval, and overlain by regular-
1790 bedded fine-grained silts and paleosols (F3 deposits). See Figs. 4 and 5 for locations. Sections
1791 SW-NE schematic section across part of the NE quarry face showing the Pliocene facies of the
1792 Nicosia Formation, overlain by F1 conglomerate and downcut by the major F2 channel; this
1793 was then infilled by the F2 clastic sediments and overlain by silts and paleosols (correlated
1794 with F3 deposits). Insets: Inset 1: detail of the erosional unconformity (channel margin)
1795 between the F1 and F2 conglomerates (clast size is exaggerated). Inset 2: Topographic profile
1796 of the entire Vasilikos Valley east of the quarry showing age-equivalent F2 conglomerates,
1797 overlain by fine-grained sediments, especially paleosols as in the quarry.

1798

1799 Figure 7. Field photographs of clastic sediments in Vasilikos Quarry. a, F1 conglomerate.
1800 Weakly stratified, poorly sorted, with near-randomly sorted clasts, including outsized blocks
1801 of ophiolite-derived diabase (A); SW face of upper quarry re-entrant; b, SE-prograding planar-
1802 bedded foresets (A) composed of relatively well-sorted pebbly conglomerate. Note the more
1803 extensive, relatively matrix-rich conglomerate above and below (B), as in a. NE face of same
1804 quarry re-entrant; c, F2 channel (A) eroded through F1 conglomerate (B) (see Fig. 6, enlarged
1805 inset). Note the pale, marly matrix and the poorly sorted clasts in the F2 deposit (C). Larger
1806 clasts are locally reworked from the F1 conglomerate; d, F2 channel infill; NE face of the
1807 quarry. The lower conglomeratic package (partly hidden by reeds) (A), is followed by a mainly
1808 sandy interval (poorly exposed) (B) and then by a higher, conglomeratic interval (C), as
1809 detailed below; total thickness of conglomerate=c. 16 m; e, Tabular cross-bedding (A) within
1810 pebbly conglomerate from the upper of the two aggrading intervals within the F2 deposits;
1811 viewed approximately at right angles to SE-directed palaeoflow; f, Conglomerate-filled small
1812 channel cut into fluvial silt (A). The silt was armoured by caliche before being incised. Note
1813 the weakly developed normal grading in the conglomerate infill (B); pen for scale; same unit
1814 as e.

1815

1816 Figure 8. Map of the Vasilikos river catchment (within c. 15 km of the coast) showing bedrock
1817 units, the distribution of Pleistocene sediments, the lines of geomorphological profiles (Figs.
1818 10, 11), and the locations of sedimentary logs. Geology based on Pantazis (1966).

1819

1820 Figure 9. Photographs of geomorphological features taken in the upper (a-c), middle (d) and
1821 lower (e-f) reaches of the Vasilikos Valley. Terrace levels are indicated. a, Terraces and
1822 surfaces are largely absent in the higher reaches above the dam because of the development of
1823 late Pleistocene dendritic drainage (A). View northwest towards the Arakapas Fault Zone
1824 (South Troodos Transform Fault Zone) with the Troodos mountains behind (B). b, Well-
1825 preserved F1 and F2 terraces in the upper reaches (A). In this area, the F3 terrace is dissected
1826 by younger streams (B). View southwest along profile c in Fig. 8). c, Landscape readjustment
1827 in the upper reaches. F1 is the highest elevation. The valley sides curve gently down to the F2
1828 terrace, representing the next break in slope. There is then a steeper break in slope between the
1829 F2 and F3 levels on both sides of the valley. The F4 is represented by the valley floor. Note the
1830 decreasing vertical distance between each of the F1 to F4 terrace levels. View north from
1831 Kalavassos at profile d in Fig. 8). d, Constriction of the valley south of Kalavassos (A)
1832 (intermediate reaches), followed by widening and flattening downstream (B). F1 is the highest
1833 level, with the F2 as the next break in slope. The F3 terrace is not well preserved around
1834 Kalavassos. The fields and houses lie on the F4 terrace. View south from above Kalavassos at
1835 profile e in Fig. 8). e, F2, the highest preserved terrace level (lower reaches) tapers out down-
1836 valley, merging with the F3 surface (A). F4 surfaces are well-developed on both sides of the
1837 modern channel (B) (fields). View from Mari looking east; between profile h and I in Fig. 8).
1838 f, F2 forms the highest terrace on the west side of the river valley (lower reaches). F3 forms a
1839 well- developed, wide terrace. The F4 terrace on both sides of the modern channel (A) is also
1840 well developed but narrower. View west along profile j in Fig. 8).

1841

1842 Figure 10. Same-scale topographic profiles derived from ArcGIS showing large-scale changes
1843 down-catchment (see Fig. 8 for locations). Note the locally preserved F1-F4 terraces (solid red
1844 lines) and extrapolations (dashed blue lines).

1845

1846 Figure 11. Comparative topographic profiles (the different scales highlight sediment
1847 abundances down-catchment); a-d upper reaches; e-f middle reaches and g-j lower reaches.
1848 The fluvial terrace deposits are marked as: (t) undifferentiated terraces; (d) Terraces associated

1849 with sediments; (s) Geomorphological surfaces without sediments; (r) Remnant or partially
1850 eroded terraces (r). See Fig. 10 for more detailed (same-scale) topographic profiles and Fig. 8
1851 for locations.

1852

1853 Figure 12. Sedimentary logs of terrace deposits in the Vasilikos river catchment. The logs are
1854 identified by F number (F1-F4) and by small letter for different logs of each terrace. Locations
1855 are marked in Fig. 8. See text for explanation.

1856

1857 Figure 13. Field photographs of key features of the F1 and F2 deposits in the Vasilikos river
1858 catchment. a, Thin F1 conglomerate consisting of small (1-2 cm), poorly sorted, sub-angular,
1859 predominantly ophiolite-derived clasts in a fine-grained matrix. The conglomerate forms
1860 discontinuous (3 m), thin (40 cm) lenses (A) which are heavily calcretised; above Kalavassos
1861 along profile e in Fig. 8. b, Relatively thick, well-bedded conglomerate (F2). The contact (A)
1862 between the conglomerate and the Lefkara Formation bedrock is steep and highly irregular as
1863 a result of fluvial erosion. As a result of local slope increase, the conglomerate accumulated as
1864 prograding foresets (1-2 m) (B). Clasts are poorly to moderately sorted, sub-angular to rounded
1865 and coarsen upwards (C). View along profile f in Fig. 8. c, Inclined (23°) blocks (up to 2 m
1866 across) of calichified conglomerate on the hillside (A). The blocks were reworked from the
1867 topographically higher F1 conglomerate terrace as a result of landscape adjustment processes.
1868 View c. 20 m downhill from b; along profile f in Fig. 8. d, Contact between the F2 conglomerate
1869 (A) and the Lefkara Formation bedrock (B), above Kalavassos. The uppermost chalks below
1870 are reworked as clasts in a fine-grained matrix, overlain, with a c. 45° contact, by moderately-
1871 sorted conglomerate with a mixture of subrounded to rounded, predominantly ophiolite-
1872 derived clasts (A); along profile e in Fig. 8. e, Matrix-rich, poorly to moderately-sorted,
1873 weakly-bedded conglomerate with c. 75% chalk clasts and c. 25% ophiolite-derived clasts. The
1874 beds dip (A) towards the southwest with local clast imbrication in this direction; east side of
1875 valley, just below the Kalavassos Dam; along profile a, Fig. 8). f, Matrix-rich, poorly sorted
1876 conglomerate with a marly matrix (A). The largest clasts (B) are ophiolitic diabase (e.g. near
1877 pen top), which were rounded and then, in some cases broken, prior to final deposition. The
1878 smaller clasts (C) are mainly silicified chalk (white) from the Lefkara Formation and jasper
1879 (D) related to the Troodos ophiolite. The clasts represent a concentrate of the most erosionally
1880 resistant lithologies; F2 conglomerate west of, and above, Kalavassos.

1881

1882 Fig. 14. Field photographs of key features of the F3 and F4 deposits in the Vasilikos river
1883 catchment. a, Two different conglomerates (contact marked by white dashed line). The lower
1884 conglomerate (A) (F3 terrace level) consists of subrounded, mostly ophiolite-derived clasts
1885 within a dark medium-grained sandy matrix. The upper conglomerate (B) is a more chalk-rich
1886 conglomerate containing subangular to angular chalk clasts within a fine-grained chalky
1887 matrix. Occasional oversized ophiolite-derived clasts (C) are likely to have been reworked from
1888 older terraces; small tributary in the upper reaches on the west side of the valley; profile c in
1889 Fig. 8. b, F3 conglomerate typical of the lower reaches (A) overlain by brown/reddish paleosols
1890 alternating with paler silty horizons interpreted as poorly developed cold-climate paleosols (B);
1891 west side of the valley, near Mari, profile I in Fig. 8. c, F3 conglomerate (lower reaches) made
1892 up of poorly to moderately sorted, subrounded clasts within a fine to medium-grained, lithic
1893 fragment-rich matrix. Clasts (c. 50% chalk and c. 50% ophiolite-derived) indicate paleoflow
1894 to the south; east side of the valley just below road; profile j in Fig. 8. d, F3 chalky colluvial
1895 deposit with c. 95% chalk clasts (middle reaches). The fabric is weakly stratified; clasts are
1896 subangular-angular, blocky, elongate and poorly to moderately sorted, with a fine chalky
1897 matrix; west side of the valley between Kalavastos and Tenta (see Fig. 8 for locations). e, Near-
1898 basal F4 conglomerate (middle reaches) close to the active channel. The conglomerate is mud
1899 matrix-rich with small subrounded clasts (mostly chalk) (A). Paleoflow is to the south based
1900 on weakly developed clast imbrication (B); southern outskirts of Kalavastos, in fields along
1901 profile f in Fig. 8. f, F4 conglomerate (lower reaches) made up of small, subrounded to
1902 subangular, poorly to moderately sorted, clasts within a fine-grained, muddy matrix; close to
1903 active channel along profile j in Fig. 8.

1904

1905 Figure. 15. Field photographs of calcrete (caliche), colluvium paleosol in the Vasilikos river
1906 catchment. a, Pillow lava (A) overlain by poorly developed palaeosol (B) and then by chalky
1907 talus (C) (talus); north of Kalavastos Dam. b, Pillow lava (A) overlain by lenticular, poorly
1908 stratified chalky talus (B) that overlies the F2 erosion surface; derived from the Lefkara
1909 Formation outcrop on the ridge above (to the NE); view from Kalavastos Dam. c, Unsorted
1910 talus rich in angular clasts of bedded chert and chalk; derived locally from the Lefkara
1911 Formation (above the F3 erosion surface) on the east side of the steep-sided valley opposite
1912 Kalavastos. d, Pebbly colluvium (buff-grey) (harvara) at the base (A), overlain by greenish
1913 pebbly lenticular alluvium (B), then laterally continuous reddish pebbly paleosol (C) and
1914 finally by additional pebbly colluvium (D); overlying F3 surface, NW of Kalavastos. e, Buff-
1915 coloured calcareous sandy silt (A), cut by rootlet (B); intercalation with reddish paleosol from

1916 the F3 unit in Vasilikos Quarry; upper NW face; interpreted as a poorly developed soil. f,
1917 Lower units of harvara (pale) and paleosol (brownish) (A), overlain by less steeply dipping
1918 harvara, paleosol and young superficial deposits (B). The probable explanation of the angular
1919 discordance is back-tilting, then transgression of similar material; above the F3 surface; W
1920 margin of paleovalley N of Kalavassos (outcrop since degraded).

1921

1922 Fig. 16. Interpretative maps showing the inferred stages of fluvial deposition in the Vasilikos
1923 River and its tributary. a, F1: broad, weakly channelized; b, F2 Incised narrower channels; c,
1924 F3 Further incised, narrower channels (only shown where known to have existed); d, F4:
1925 Narrow further incised channel (only shown where known to have existed).

1926

1927 Fig. 17. Block diagram showing the restored development of the Vasilikos River and its fluvial
1928 sediment infill. a, F1 Mid Pleistocene, broad semi-braided fluvial conglomerates; b, F2 Middle
1929 Pleistocene, confined semi-braided to locally channelized fluvial conglomerates; c, F3 late
1930 Mid-early Late Pleistocene, incised, confined fluvial deposits with marginal overbank deposits
1931 and paleosols; d, F4 Late Pleistocene; further incision, confined fluvial deposits and overbank
1932 silts.

1933

1934

1935

1936

Table 1

| Facies | Description | Interpretation | Age |
|--|---|--|-------------------------------|
| Kakkaristra Formation (Vasilikos Quarry and nearby escarpment) | Discontinuous lenses of well sorted, matrix supported conglomerate containing small clasts (c. 1 cm) and marine fossils. | Marine fan delta associated with first uplift of the Troodos ophiolite. | Pliocene-Pleistocene boundary |
| Apolos Formation (Vasilikos Quarry and nearby escarpment) | Clast rich, moderately sorted matrix supported conglomerate containing larger (up to 1 m) clasts and no marine fossils. | Conglomerates of fluvial origin associated with the shedding of the cover of the Troodos ophiolite during its early uplift. | Pliocene-Pleistocene boundary |
| F1 massive conglomerates (Vasilikos Quarry and valley, profile f)) | Poorly to moderately sorted, clast rich matrix supported conglomerate (with clast supported lenses) containing subangular, large clasts (c. 8 cm). Contains prograding foresets (0.5-2 m) and imbricate structures (SE paleoflow). Outcrops are heavily calcreted. | High energy mass flow accumulations, such as debris flows, produced by flash flood deposits. Highly erosive flows shown by undulating contacts and foresets infilling into accommodation space. | F1 |
| F1 conglomerate lenses (Vasilikos valley, profile e) | Discontinuous lenses of poorly sorted conglomerate containing small (1-2 cm) clasts with weakly developed imbrication towards the SE. | Weaker flow with a more sustained traction flow, likely accumulated in a marginal position or at a higher level in the flow. | F1 |
| F2 coarse conglomerate (Vasilikos Quarry and valley, profiles e and h) | Clast rich, clast supported conglomerate with a coarse grained matrix locally. Clasts are subangular to subrounded, poorly to moderately sorted, relatively large (averaging 6-10 cm) and grouped into lenses. Decreasing clast size up the intervals and deposits. | High energy mass flow accumulations, such as debris flows, produced by flash flood deposits. Highly erosive flows shown by undulating contacts. The lenses are produced through channel switching within a semi-braided setting. Graded bedding indicated waning energy of the flow towards the top. | F2 |
| F2 sandy interval (Vasilikos Quarry) | Interbedded sand and conglomerate lenses viewed in cross section (face D) and long profile (face E). Sand is medium to coarse grained containing small lithic fragments (<1 mm). Conglomerate lenses have a stacked morphology and are discontinuous with small (1-2 cm), subrounded, well sorted clasts. | Stacked morphology of the channels represents repeated cutting and infilling of channels into a sandy background. | F2 |

| | | | |
|--|--|---|----|
| F2 colluvium deposit | Chalk rich (90%) conglomerate within a fine grained chalky matrix. Clasts are poorly sorted and subangular to angular with lenticular bedding present | Texturally immature colluvial deposit formed as material moved downslope to readjust to steep valley sides. | F2 |
| F3 conglomerate (Vasilikos valley, profiles c, f, g and j) | Poorly to moderately sorted matrix supported conglomerate with clast supported lenses. Clasts are imbricated towards the SE-SW and decrease in size up each deposit. | Restricted to the Vasilikos valley indicating further erosion in the valley and channel abandonment in the quarry. Deposits are indicative of high energy flash flood with the imbrication suggesting a more sustained background flow. Decreasing clast suggest decreasing energy during the waning of the flow. | F3 |
| F3 paleosol (Vasilikos Quarry and valley, profile i) | Dark brown, red coarse grained paleosol containing small (2 cm), subangular to subrounded occasional clasts. The palaeosol intervals contain charcoal fragments and roots/rootlets (up to 4-5 cm long) | Formed during warm, wetter periods. Roots/rootlets indicated overbank environment increasing in dominance as the soils became more developed. Clasts are likely to have moved downslope from higher conglomerate levels during wet periods. | F3 |
| F3 harvara(Vasilikos Quarry and valley, profile i) | Medium grained grey/buff coloured silts with well-developed caliche nodules. Caliche nodules are fine grained and contain detrital grains and organic matter (c. 1mm) | Soils formed during cooler periods. Caliche forms in semi-arid conditions with seasonal rainfall hence not contemporaneously. | F3 |
| F4 conglomerate (Vasilikos valley, profiles f, g and j) | Fine grained, grey to brown silt containing scattered subrounded to subangular clasts (c. 2 cm) | Silty, sheet like deposits represent overbank deposits which have then been incised to the level of the current channel. | F4 |

1939 **Supplementary material**

1940 Field photographs of paleosol and caliche/calcrete in the Vasilikos river catchment. a, Diabase-
1941 derived, matrix-supported conglomerate (A) from the headwaters of the Vasilikos River,
1942 Arakapas Transform Fault Belt (South Troodos Transform Fault Zone). The reddish matrix is
1943 interpreted as reworked paleosol (B). b, F2 conglomerate (A) transgressed by well-stratified
1944 alternations of reddish paleosols (B) and pale grey/buff calcareous silts (C). Both units are cut
1945 by small conglomerate-filled channels (D); F3 unit in Vasilikos Quarry; upper NW face. c,
1946 Detail of palaeosol (A) (same cutting as b), interbedded with grey/buff-coloured calcareous
1947 sandy silt (B). Small fluvial lenses occur in paler-coloured material. D, uppermost, exposed
1948 paleosol (terra rossa) (A) cut by small conglomerate-filled channel (B). Many of the clasts
1949 (mostly diabase) were initially rounded then broken, consistent with redeposition from the
1950 topographically higher F1 conglomerate by a flash flood. E, Serpentine with caliche-filled
1951 fissures; north of Kalavassos Dam. F, F1 Conglomerate cemented by calcrete; clasts are mostly
1952 gabbro and diabase; as a result, the cemented uppermost levels of, especially the older fluvial
1953 terraces were relatively resistant to erosion; upper west margin of catchment S of Kalavassos.