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Fluvial sediments of the Algeti River in southeastern Georgia — An archive of Late Quaternary landscape activity and stability in the Transcaucasian region

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Abstract:

In order to obtain information about landscape activity and stability during the Late Quaternary in the Transcaucasian region, fluvial sediments of the lower Algeti River in SE-Georgia were studied by means of geomorphologic, sedimentologic and geochronologic methods. These investigations show that sediments aggraded by the Late Pleistocene braided Algeti River were strongly incised around the Pleistocene/Holocene transition, and subsequently a small-scale pattern of diachronous fluvial terraces deposited by the now meandering river developed in the new valley during the Holocene. Prior to ca. 3 cal. ka BP, active phases of river channel aggradation and overbank sedimentation about 6 cal. ka BP and 3.4–3.2 cal. ka BP can be linked with climate-driven vegetation changes, i.e. stronger fluvial dynamics with sedimentation occurred during more arid and colder periods whereas the Caucasian Holocene climate optimum between 6 and 3.4 cal. ka BP was characterized by stable geomorphologic conditions. After 3 cal. ka BP, strongly increased human impact documented by former pollen studies is reflected by the fluvial dynamics as well, i.e. an activity phase of strong overbank sedimentation 2.7–2.1 cal. ka BP occurred during a period when forests in the Lesser Caucasus were burnt down. Two subsequent activity phases with fluvial sedimentation can be linked with historic events that probably both influenced vegetation distribution of the region, i.e. a period of flourishing of Georgia during the Middle Age and a time of large-scale destruction of the country due to a Persian invasion at the end of the 18th century AD, respectively. Thus, whereas no influence of tectonic events or fluctuations of the Caspian Sea level on the fluvial dynamics could be detected, SE-Georgia shows its fragile character with respect to climate- and human driven vegetation-changes similar to other semi-arid landscapes of the Mediterranean region.

1. Introduction

During the past decades, fluvial archives from temperate regions were often used as recorders of Late Pleistocene and Holocene environmental changes (e.g. Houben et al., 2006; Howard et al., 2004; Wolf et al., 2013; Zielhofer et al., 2008). However, interpreting the sedimentary pattern of a river is never simple since different factors can influence its dynamics as there are climate, tectonic and anthropogenic activity, as well as internal factors of a river causing a change of its sedimentation pattern without any external trigger (Charlton, 2008; Leopold et al., 1964). Thus, a careful study of past changes of incision and aggradation along a longer part of a fluvial system is obligatory. Furthermore, these data have to be compared with information from other fluvial systems and/or paleoenvironmental archives, in order to identify external
triggers of changes of the fluvial dynamics. On the other hand, an advantage of fluvial archives is that rivers average the effects of external factors affecting their catchment area. Thus, their sediments can give valuable information about phases of landscape activity and stability on a regional scale (Faust et al., 2004; Rohdenburg, 1970; Zielhofer et al., 2008).

In the southern Caucasian region between the Black and Caspian Seas (Fig. 1), only a limited number of Late Pleistocene and Holocene paleoenvironmental studies mainly based on lacustrine deposits and peat bogs was carried out during the last years (e.g. Connor & Kvavadze, 2008; Kvavadze & Connor, 2005; Messager et al., 2013; Wilkinson et al., 2007). Likewise, apart from first investigations during the Soviet period (cf. Maruashvili, 1971; Tsereteli, 1966) there exists only a handful of studies dealing with fluvial systems from that region, often showing only rough chronologies (Arslanov et al., 2007; Dzhanelidze, 2007; Ollivier & Fontugne, 2013). However, significant environmental changes as e.g. shrinking or disappearance of glaciers in the Greater and Lesser Caucasus (Gobejishvili, 2004; Messager et al., 2013) or fundamental changes of the vegetation cover (Connor & Kvavadze, 2008) occurred in the southern Caucasian region during the Late Quaternary. Furthermore, Neolithic agriculture was introduced to southeastern Georgia already about 8 cal. ka BP, making this region one of seven centers of early agriculture in the Near East (Kiguradze & Menadbe, 2004; Lordkipanidze, 2002). Additionally, the area is characterized by very active tectonic processes (e.g. Matcharishvili et al., 2013). Altogether, this indicates a relatively high landscape sensitivity level in the southern Caucasian region during Late Pleistocene and Holocene, and highlights the need for comprehensive studies about morphodynamic changes by means of thorough investigations of paleoenvironmental archives. Furthermore, especially floodplains of the region are often densely populated and highly vulnerable to the forthcoming climate change (Keggenhoff et al., 2011). Thus, studies of the past dynamics of fluvial systems can be used to understand their behavior under changing global boundary conditions in the future.

This paper presents results of geomorphologic, sedimentologic and geochronologic investigations carried out along the lower course of the Algeti River in SE Georgia, showing several phases of aggradation and incision during Late Pleistocene and Holocene. These results are compared with other paleoenvironmental archives as well as archeological and historic sources from the region, in order to identify triggers of changes of the fluvial dynamics linked with phases of landscape activity and stability during the Late Quaternary.

2. Study area

The 118 km long Algeti River in the SE-part of the Republic of Georgia rises in the Lesser Caucasus Mountains at 1900 m a.s.l., and flows into the Kura (Mtkvari) River at about 300m a.s.l. The catchment area of 768 km² is mostly characterized by folded Paleogene and Neogene flysch and molasse as well as by volcanic deposits (Gamkrelidze, 2003, GIDROMETEOIZDAT, 1974). After leaving the Lesser Caucasus the river flows through the Marneuli depression, a tectonic basin with an extension of 10 × 25 km filled with ca. 135 m of loose Cenozoic sediments (Maruashvili, 1971; Fig. 1). To the south and west, the depression is limited by the Lesser Caucasus Mountains with altitudes >2000m consisting of Mesozoic and Cenozoic volcanic rocks and folded flysch and molasse deposits. To the north, uplifted and folded Cenozoic flysch and molasse deposits show several glacis surfaces with maximal altitudes of about 760 m (e.g. Yagludzha Ridge) (Gamkrelidze, 2003), whereas east of the Kura (Mtkvari) River the low-lying Kura depression is extending. In the north and the center of the Marneuli depression an elevated sedimentation level originating from the Late Pleistocene forms a predominantly flat surface, slightly dipping toward the east with a slope of 0.2–0.3%. This surface is limited from the southern Khrami and the eastern Kura valley by a steep scarp of 20–60 m (Fig. 1). Recent rivers as the Algeti are incised into that former surface up to tens of meters, and show different younger morphological terrace levels along their courses. The study area extends along the last 12 km of the course of the Algeti before its confluence with the Kura River (Figs. 1, 2). Here, the river has a meandering character (sinuosity 2.05) and an average slope of 0.24%.
The climate of the Marneuli depression is semi-arid with precipitation values of 300–500 mm/a, rising up to 800 mm/a in the upper catchment of the Algeti River in the Lesser Caucasus Mountains (Geographic Institute W. Bagrationi Tbilisi, unpublished precipitation map). Most precipitation falls in spring and early summer during convective events. Accordingly, the discharge maximum of the river during May is dominated by snowmelt in the Lesser Caucasus and the concomitant precipitation maximum, and discharge can reach up to 3.6 times the average value for that month of 7.36 m$^3$/s (data between 1938 and 1985; http://rda.ucar.edu/data/ds553.2/fsu2; cf. Fig. 1 inset). Average annual temperature is 13.4 °C (station Marneuli: http://de.climatedata.org/location/21591). The vegetation of southeastern Georgia is part of the Irano-Turanian group: The Marneuli depression is characterized by lowland steppes and semideserts. Surrounding slopes are covered by strongly anthropogenically influenced foothill hemixerophytic shrublands (Shiblyak) and by devasted Quercus–Carpinus forests, both dominating along the middle course of the Algeti River. The upper catchment of the river is covered by mixed deciduous and coniferous forests, and a small part with species-rich subalpine steppe grasslands (Connor et al., 2004).

3. Methods

3.1. Spatial measurements of fluvial terrace levels

Relative heights of fluvial terrace levels above the recent river bed were measured with a differential GPS (Magellan ProMark3). Data processing was carried out using the software GNSS solutions 2.00.03. In total, 287 points were measured, and measurements had a vertical error b10 cm (manufacturer information).

3.2. Investigations of sedimentary sections

We investigated the stratigraphy of 15 sedimentary accumulation sections along the lowest 12 km of the Algeti River with heights between 2.1 m and 11.0 m above the recent river bed, as well as two strath (erosional) terraces (I and II; Fig. 2). The basal parts of the sections, however, were often not accessible so that only their upper parts could be studied.

3.3. Sedimentary analyses

Paleosol horizons are important indicators for the past fluvial dynamics, since they indicate periods of stable geomorphological conditions without significant fluvial sedimentation. To discriminate in-situ paleosols from soil sediments vertical patterns of sedimentologic proxies through possible paleosol horizons were used, assuming decreasing carbonate and pH-values and increasing C$_{org}$ and $\chi_{fd}$ from bottom to top as signs of in-situ pedogenesis (cf. Zielhofer et al., 2009, see Fig. 3). In total, 42 samples of ca. 150 g were analyzed from all layers in question.

Furthermore, to compare properties of sediments deposited during different sedimentation periods 59 samples from loamy and clayey sedimentary layers not associated with in-situ soils were taken, and analyzed for contents of carbonate and C$_{org}$.

**Carbonate contents** were determined using the method of Scheibler: 1–10 g of material was filled into an Eijkelkamp Calcimeter apparatus, and 4 N HCl was added continuously until the reaction ceased. Calculation of carbonate content was based on the volume of CO$_2$ produced during the reaction.

The content of **organic carbon** was determined by measuring C$_{total}$ with a Vario EL cube elemental analyzer, with subsequent subtraction of inorganic carbon (taken from carbonate measurements) from C$_{total}$.
To determine pH with a pH-meter 196 (WTW) 20 g of sample material was mixed with 50 ml of 0.1 M KCl, and pH was measured after 2 h of soaking.

Measurements of frequency dependent magnetic susceptibility ($\chi_{fd}$) were done using a Bartington MS3 magnetic susceptibility meter equipped with a MS2B dual frequency sensor. After softly grounding the material and densely packing it into plastic boxes, volume magnetic susceptibility was measured with low (0.465 kHz, $\kappa_{(LF)}$) and high (4.65 kHz, $\kappa_{(HF)}$) frequencies. Frequency dependent magnetic susceptibility $\chi_{fd}$ indicates the presence of mineral grains at the single domain/superparamagnetic border (<30 nm) mostly formed by pedogenesis (e.g. Torrent et al., 2007), and was calculated with the formula:

$$\chi_{fd} = (\kappa_{(LF)} - \kappa_{(HF)})/\kappa_{(LF)} \times 100$$

### 3.4. Micromorphology

From Section Algeti 5 three oriented samples were taken for micromorphological analyses (Fig. 3c). The blocks were air dried, impregnated with Viscovoss and sliced into 9.0 × 6.0 cm thin sections following Beckmann (1997). Samples were analyzed using the terminology after Stoops (2003).

### 3.5. Numerical dating

15 charcoal pieces were sent for $^{14}$C-dating to the laboratory in Poznan. $^{14}$C-ages were calibrated using the program Calpal_A, the calibration program of the Cologne radiocarbon lab (applying the Hulu 2007 curve).

9 samples taken for luminescence dating during night were packed into lightproof bags, and processed under subdued red light ($\lambda = 640 \pm 20$ nm) in the Bayreuth luminescence laboratory. After sieving with 200 and 90 µm mesh-width we destroyed carbonate using 10 and 30% HCl, and organic matter using 10 and 37% H$_2$O$_2$, respectively. Since due to bad mineral properties quartz was not suitable for luminescence dating, K-feldspar was separated using sodium metatungstate monohydrate with densities of 2.58 and 2.53 g/cm$^3$. Obtained coarse feldspar grains were mounted on aluminum cups (diameter 12 mm) using silicone oil. Due to rather dim luminescence intensities, aliquots were produced using a 3 mm-mask. Measurements were carried out on a Risø-Reader TL/OSL-DA-15 combined with a Thorn-EMI 9235QA photomultiplier and a $^{90}$Sr/$^{90}$Y β-source, applying the single aliquot regeneration protocol of Murray & Wintle (2000). Stimulation was with infrared LEDs (IRSL), and detection at 390–450 nm. Since no dependence of the equivalent dose with preheat temperature was found during tests, a preheat temperature of 270 °C was chosen for equivalent and regenerated doses, and a cut-heat of 200 °C for the test dose. The first 1.5 s of the signal were used for analysis of the luminescence signal, and the signal of the last 100 s served as background. A recycling ratio larger ±10% was taken as a rejection criterion for individual aliquots. For correction of anomalous fading following Huntley & Lamothe (2001) using the R-package “Luminescence” (Kreutzer et al., 2012), g-values of three samples were measured using 4 aliquots for each sample, respectively.

In parallel with the luminescence samples, material was taken to measure the dose rate with low-level gamma spectrometry at the Felsenkeller-laboratory of the VKTA Rossendorf/Germany. All gravimetrically measured in-situ water contents were between 0.5 and 13.5%. However, since the natural outcrops had been open for an uncertain period causing the desiccation of the sediments, we used the grain size distributions of the samples and the resulting middle pore volume to estimate potential minimal and maximal water contents of a sample (cf. Fuchs, 2001). Since all samples are dominated by sandy and silty grain sizes, we estimated a water content of 15 ± 10% for samples L-43 and L-39 located close to the recent water-table of the river during September (monthly discharge of the river see Fig. 1, inset), and a value of 10 ± 10% for the remaining samples. These values should encompass the average values of the samples throughout the burial
period. We assumed an internal K-content of 12.5% (Dütsch & Krbetschek, 1997), and an a-value of 0.07 ± 0.02 (Preusser, 2003).

4. Results

4.1. Measurements of terrace heights

D-GPS-measurements show that the elevated Late Pleistocene surface was deeply incised by the recent Algeti valley. Subsequently, numerous terrace levels developed along the recent lower Algeti River with different heights that were summarized to three levels (2–4 m, 4–8.5 m, >8.5 m) (Fig. 4). Sedimentary bodies <2 m were included into the recent floodplain. A more resolved spatial pattern of fluvial terrace heights can be found in Menz et al. (2013, but note different numerations of sections in that publication). All investigated accumulation sections apart from Sections 1 and 2 belong to terrace levels that are much lower than the elevated Late Pleistocene surface of the Mameuli depression and are thus clearly younger than the latter. Furthermore, it can be seen that the incision depth of the recent valley increases toward the confluence with the Kura River where also the highest accumulation terraces are found (Fig. 4).

4.2. Stratigraphy of the sections, supported by sedimentological analyses and micromorphology

Locations of the sections are shown in Fig. 2. Descriptions and detailed drawings of the sections with the results of sedimentary analyses for the identification of paleosol horizons, geographic coordinates, locations of micromorphological and sediment samples from non-pedogenetic sediment layers and dating results are found in the Supporting online material (Figs. SOM 1–5).

Two investigated sedimentary accumulation sections crop out the elevated Late Pleistocene surface level (Sections 1 and 2), whereas Sections 3–15 crop out lower terrace levels developed inside the incised Algeti-valley. Most gravel bodies occur in basal but occasionally also in higher positions, and are generally overlain by sandy to clayey overbank fines (see exemplary sections in Fig. 3). Several Holocene overbank sediments contain pieces of charcoal and sometimes snails or snail fragments, and deeper parts of the sections often show Fe and Mn-stains.

Sedimentological parameters helped to identify reddish-brownish and clayey-loamy palaeosol horizons in nine sections, often showing a sharp upper and a transgressive lower boundary. For the exemplary paleosol in Section 5 micromorphology supports this interpretation (for location of the samples see Fig. 3c): Sample MM-2 - taken from the clayey–loamy soil horizon (Fig. 5a) shows a blocky to angular-blocky microstructure without any bedding or horizontal layering, caused by pedogenetic processes like alternating swelling/shrinking and bioturbation that lead to the formation of soil aggregates and destroyed original layering or bedding of the sediment (Stoops & Schaefer, 2010). Furthermore, a stipple speckled b-fabric and almost no micritic nodules are found here. In difference, numerous small micritic nodules and a crystallitic b-fabric (characteristic for calcareous material) occur in underlying sediments (sample MM-3, not shown), demonstrating the decalcification of the soil and enrichment of secondary carbonates in underlying sediments (cf. Pietsch & Kühn, 2009). Partly or completely filled channels related to bioturbation disturbed in someparts the banded microstructure of the underlying sediment, demonstrating a minor to absent influence of pedogenic processes except of bioturbation there.

Some potsherds in the sections indicate human activity in the floodplain at least since the Bronze period (oral communication Prof. Nodari Bakhtadze, Tbilisi). This is supported by some charcoal-rich bands in sediment layers younger 2.7 cal. ka BP, indicating short-time paleosurfaces potentially linked with human activity as e.g. the paleosurface developed in loamy sediments overlying the paleosol in Section 5 (location see Fig. 3c).
Here, below a thin layer with numerous finely dispersed charcoal fragments in micromorphological sample MM-1 (Fig. 5b) a banded microstructure is visible as brown fragments mainly consisting of fine material (Fig. 5c). This microstructure can be related to physical stress perpendicular to the surface of the layer so that it may be interpreted as an occupation layer, i.e. as a walking-horizon (cf. Thiemeyer, 2008).

Sediments found in terraces I and II partly contain specimen of the shell Unio pictorum and also show some other features typical for material that forms the elevated Late Pleistocene surface of the Marneuli depression, outcropping along the steep scarps along Kura and lower Khrami River. Thus, they were classified as strath terraces. Due to their similar height above the recent river bed (13.4 vs. 13.9 m, respectively) they belong to the same erosional level, i.e. they are paired terraces.

4.3. Numerical dating

Results of radiocarbon datings of charcoals are found in Table 1, and ages vary from Middle (max. 6.47 ± 0.12 cal. ka BP) until Late Holocene (min. 0.15 ± 0.1 cal. ka BP). As seen from the stratigraphic context, one age (sample Algeti 3, Poz-40494) is obviously overestimated due to the “old wood effect” (cf. Schiffer, 1986).

Results of luminescence datings are found in Table 2, and ages vary from Late Pleistocene (59.4 ± 14.5 ka) until Late Holocene (1.5 ± 0.8 ka). All samples show radioactive equilibrium. Some samples have broad equivalent dose (De) distributions (σ > 40 Gy), demonstrating bad bleaching prior to deposition that probably leads to age overestimations (samples L-30, L-35, L-39; cf. Table 2). This phenomenon is often observed in fluvial environments (Rittenour, 2008). Additionally, due to rather dim luminescence signals 3 mm- aliquots were used. Here, the luminescence signals of several hundred individual feldspar grains are averaged (cf. Heer et al., 2012), enhancing the possibility that samples with large standard deviations of their De-distributions overestimate the true burial age of the material. Furthermore, the applied fading correction after Huntley & Lamotho (2001) generally only works for Holocene samples, and several studies report failure of this technique (e.g. Buylaert et al., 2008, Reimann et al., 2011). Averaging our three measured g-values from the sequences and using that average for calculating the remaining ages introduces a further bias to our IRSL-datings. Consequently, especially Late Pleistocene ages have to be regarded more as coarse age ranges rather than as precise numerical ages, and have to be discussed in the stratigraphical context of all sections and not only based on individual ages.

4.4. Compiled chronostratigraphy of the fluvial record — fluvial dynamics

Combining stratigraphy and chronology of the individual sections allowed the build-up of a compiled fluvial chronostratigraphy for the lower Algeti River. Although due to incomplete bleaching some IRSL-samples overestimate the sedimentation age of the material and one 14C-sample is overestimated due to the “old-wood-effect”, using further stratigraphic information as well as the intensity of soil formation these sediments could, however, be classified into certain fluvial phases. For direct comparability with calibrated 14C-ages Holocene IRSL-ages were also referred to 1950 AD in Table 2. After Late Pleistocene braided river sedimentation and subsequent incision, according to the obtained ages five Holocene fluvial sedimentation phases could be identified (Fig. 6). These are separated from each other by periods without significant sedimentation (Fig. 7a–i). Terraces of different heights are located very close to each other, and sediments of different ages are found at similar heights. This can be explained by strong lateral migration of the Holocene meandering channel in the rather narrow recent valley during a period when the erosion base did not change significantly. Doing so, the river totally or partly removed older terrace levels and deposited new sediments so that a small-scale pattern of diachronous terraces was formed (Fig. 4).
In the following, the individual fluvial phases are described (see Fig. 7a–i):

a) Late Pleistocene sedimentation and incision

Late Pleistocene sediments of a braided river are found in the lower/middle part of Section 1 and in total Section 2 (Fig. 6), both outcropping the former elevated sedimentation surface of the Marneuli depression (Figs. 2, 4). Although IRSL-dating of Algeti sediments shows rather large uncertainties (see above), lower IRSL-ages in Section 1 (L29: 46.5 ± 13.8 ka) and 2 (L30: 59.4 ± 14.5 ka, but being somewhat overestimated as indicated by a large standard deviation of its De-distribution, see Table 2) and the upper IRSL-age in Section 1 (L31: 29.3 ± 8.3 ka) indicate that these originate from the period between ca. 50 and 30 ka (Fig. 6). Subsequently, these sediments were deeply incised at least until the level of the recent river bed, forming one strath terrace level (terraces I and II) during a (short) interruption of incision. The limit of the elevated Late Pleistocene surface toward the recent valley shows large paleomeanders that were created by the Late Pleistocene incising river (Fig. 4), demonstrating much stronger discharge during that period compared with the Holocene river. Following, Late Pleistocene sediments underwent pedogenesis (pedogenetic phase I) (Figs. 6, 7a).

b) Sedimentation around 6 cal. ka BP

Although no Early Holocene sediments were found it is well possible that they were swept out by a subsequent phase of strong lateral erosion (e.g. Wolf et al., 2013). Furthermore, due to dating uncertainties first Holocene sedimentation could only roughly be determined to have occurred around 6 cal. ka BP (Figs. 6, 7b). Sediments from this phase are found in the lower parts of Sections 13 and 14, as well as in the upper part of Section 1. Due to a medium pedogenetic intensity of the paleosol in Section 5, i.e. much lower when compared with paleosols of Pleistocene age, underlying sediments in this section were also classified into this earliest Holocene period. The same holds for sediments in the lower part of Section 11, where no hiatus is recognizable between basal gravels and the overlying paleosol. Since that paleosol is also much less intensively developed than typical Pleistocene paleosols, and the medium standard deviation of the De-distribution of the IRSL-sample giving an age of 12.2 ka (L27, see Table 2) does not exclude the possibility of age overestimation, these sediments were classified into this oldest Holocene sedimentation period as well. The $^{14}$C-age of 0.87 cal. ka BP (Poz-40485) from the overlying paleosol originates from a piece of charcoal that was brought into the soil during pedogenesis, and thus only gives a maximum age for the beginning of the next sedimentation rather than an age of previous sedimentation. The same holds for the $^{14}$C-age of 0.84 cal. ka BP (Poz-40481) from the paleosol in Section 14. As seen by gravel beds in the lower parts of Sections 11 and 14 and by gravelly sediments in the upper part of Section 1, fine overbank sedimentation during this phase was accompanied by strong aggradation of the river bed (Figs. 7b, 8).

c) Incision and pedogenesis between 6 and 3.4 cal. ka BP

As seen by basal gravels close to the recent river bed that originate from the next sedimentation period d) (Fig. 6), during this period the river-channel was incised at least until the level of the recent river bed. Pedogenesis occurred on sediments of the previous sedimentation phase b) (pedogenetic phase II) (Fig. 7c).

d) Sedimentation between 3.4 and 3.2 cal. ka BP

Gravely sediments of this period are found in the lower parts of Sections 9 and 12 (Fig. 6). In the former section, a large standard deviation of its De-distribution indicates that the IRSL-age of 5.8 ka (=5.7 cal. ka BP; L39, see Table 2) is somewhat overestimated, whereas the $^{14}$C-age of 1.9 cal. ka BP (Poz-40483) from the overlying paleosol only shows mixing of a piece of charcoal during pedogenesis and thus the maximum age for the beginning of the next sedimentation. Furthermore, fine sediments below the middle paleosol in Section 13 possibly originate from that period as well. Since gravely sediments are found up to a height of 5.5 m above the recent river bed, fine overbank sedimentation was accompanied by strong aggradation of the river channel (Figs. 7d, 8).

e) Incision and pedogenesis between 3.2 and 2.7 cal. ka BP
As seen by sediments close to the recent river bed that originate from the next sedimentation period f) (Fig. 6), the river channel was incised at least until the level of the recent river bed during this period. Pedogenesis occurred on sediments of the previous sedimentation phase d) (pedogenetic phase III) (Fig. 7e).

**f) Sedimentation between 2.7 and 2.1 cal. ka BP**
Sediments from this phase of intensive fine overbank sedimentation, obviously without significant aggradation of the river bed (Figs. 7f, 8), occur in the lower parts of Sections 4 and 6, in the upper part of Section 5 as well as in the whole outcropped part of Section 15 (Fig. 6). Fine sediments below the uppermost paleosol in Section 14 probably originate from this phase as well. Subsequently, sediments from this phase underwent pedogenesis (pedogenetic phase IV, Fig. 7g).

**g) Sedimentation between 0.77 and 0.72 cal. ka BP (1180–1230 AD)**
Sediments from this phase of strong overbank sedimentation, but without significant aggradation of the river bed (Figs. 7g, 8), are found in the upper parts of Sections 4 and 6, in whole Section 8 and probably also in the upper parts of Sections 9 and 11 (Fig. 6). In Section 14, the upper part of the underlying paleosol gave a \(^{14}\text{C}\)-age of 0.84 cal. ka BP (Poz-40481) as a maximum age for the start of this sedimentation phase. Furthermore, a large standard deviation of its De-distribution indicates that the IRSL-age of 7.1 ka (= 7.0 cal ka BP; L-35, Table 2) in sediments from Section 13 that can optically be correlated with this phase must be overestimated. Thus, the uppermost sediments of Sections 13 and 14 also originate from this phase. Subsequently, sediments from this phase underwent pedogenesis (pedogenetic phase V, Fig. 7h).

**h) Sedimentation between 0.2 and 0.15 cal. ka BP (1750–1800 AD)**
This last phase of Holocene river sedimentation (Fig. 7h) is found in whole Sections 7 and 10, and due to a hardly developed recent soil on top of the upper sediments in Section 3 they must originate from this period as well. Thus, the \(^{14}\text{C}\)-age of 2.6 cal. ka BP (Poz-40494) in these sediments must be overestimated, also confirmed by the younger IRSL-age of 1.5 ka (= 1.5 cal. ka BP; L-43, Table 2) in underlying sediments that are separated from the upper part by a paleosol. Taking into account a maximal height difference of 1.5 m between the recent river channel and corresponding gravel beds, gravels found until 2 m above the recent river bed in Section 10 indicate that fine overbank sedimentation during this phase was possibly accompanied by slight aggradation of the river bed (Fig. 8). Very slight pedogenesis is visible on sediments from this phase (pedogenetic phase VI, Fig. 7i).

**i) Today**
Until today the river-channel was obviously incised again. Slight overbank sedimentation of previous phase h) still continues, since according to local farmers in rare cases the river inundates terrace levels up to 5 m above the recent river channel. However, the fact that slight initial soils are developed on the surfaces of phase h) indicates that recent inundations and thus sedimentation are weaker than during period h) (Fig. 7i).

### 5. Discussion

As mentioned above, interpreting a fluvial record in terms of paleoenvironmental change is never simple since changes of its dynamics can be caused by different triggers. Thus, its combination with independent paleoenvironmental data is obligatory. For instance, fluvial aggradation or incision can either be caused by a change of the ratio stream power/bedload influenced by climatic factors (change of runoff either directly by changes of precipitation and/or temperature, or indirectly by changes of the vegetation cover), or by anthropogenic activity (land use change and thus of runoff and sediment availability) (Charlton, 2008; Leopold et al., 1964). On the other hand, aggradation or incision can be triggered by tectonics (adjustment of the river section to tectonic perturbations, e.g. Holbrook & Schumm, 1999). Furthermore, the fluvial style
Thus, in the following we discuss and compare changes of the fluvial dynamics of the Algeti River with other paleoenvironmental and archeological studies, and with historic sources:

a) Late Pleistocene sedimentation, and subsequent incision

Late Pleistocene braided river aggradation due to variable discharge and abundant sediment supply caused by active glacial/periglacial processes in higher altitudes was observed in other river systems of the Mediterranean area and of Minor Asia as well. For instance, Wolf et al. (2013) describe this kind of sedimentation for Central Spain, Woodward et al. (1995) for northern Greece, Collins et al. (2005) for rivers of the Pasinler Basin in eastern Anatolia (ca. 300 km SW of the Marneuli depression), and Dogan (2010) for the latest Pleistocene in Central Anatolia. A similar situation is likely for the Algeti River, having its source in the Lesser Caucasus Mountains that were glaciated during the Weichselian Glacial (Messager et al., 2013). Incision of the Algeti River into these older sediments, interrupted for at least one (short) period possibly with reduced discharge as demonstrated by the strath terrace level, occurred after ca. 30 ka (cf. Section 2). Much larger paleomeanders of the Late Pleistocene river compared with the Holocene meander belt (cf. Fig. 4a) indicate much stronger discharge during that time than during the Holocene. Unfortunately, there is no datable fluvial material on the strath terraces so that the exact timing of incision could not be determined. However, ca. 40 km downstream the Kura River in Azerbaijan Ollivier & Fontugne (2013) dated an analogous strong incision event between 13.5 cal. ka BP and the Early Holocene, and a similar timing of erosion can be assumed for the Algeti as a part of the Kura catchment as well. Similarly, several studies of rivers from different parts of the world as e.g. from the northeastern Tibetan Plateau (Hetzel et al., 2006), southern Romania (Howard et al., 2004); Belgium (Vandenberghhe et al., 1984) or Great Britain (Bridgland & Westaway, 2008) also show strong fluvial incision at the end of the last glaciation. Due to that incision, with the exception of Section 1 located at the most upstream position where incision of the recent valley was not as deep as further downstream (cf. Figs. 4, 6), Late Pleistocene sediments were not flooded any more so that pedogenesis occurs on this material until today (pedogenetic phase I). No systematic lowering of the bases of Holocene terraces with time was observed, and they are all oriented along the recent level of the valley floor. Thus, major incision must have occurred prior to 6 cal. ka BP, although a recent incision trend due to a W-shift of the Kura river (i.e. the erosion base) is demonstrated by the active scarp between the Late Pleistocene elevated surface of the Marneuli depression and the Kura River (cf. Fig. 2; von Suchodoletz et al., 2011).

With 768 km² the catchment area of the Algeti River is rather small so that climatic signals should be suppressed by human signals after onset of Neolithic agriculture in southeastern Georgia about 8 cal. ka BP. However, human influence on landscape and vegetation cover was only of minor importance during the first millennia of human presence, and significantly increased only after 5 cal. ka BP (Connor & Sagona, 2007) before becoming dominant after 3 cal. ka BP (Connor & Kvavadze, 2008). Thus, also climate-driven vegetation changes in its catchment should be reflected by the Algeti River at least during the Middle Holocene:

b) Sedimentation around 6 cal. ka BP

Comparing the sedimentation phase around 6 cal. ka BP with pollen-based paleotemperature records from the Lesser Caucasus (Connor & Sagona, 2007) and the Holocene precipitation master-curve for Georgia (Connor & Kvavadze, 2008), it appears that this phase occurred during a period of relatively low temperatures and low precipitation (Fig. 8). Generally, semiarid landscapes as that of southern and eastern Georgia show decreased flooding during more humid periods when the landscape was stabilized by vegetation, and stronger floods with soil erosion during arid phases when the vegetation cover was weakened (Zielhofer & Faust, 2008). First afforestation of the Lesser Caucasus, the source area of the Algeti River, started between 11 and 8.3 cal. ka BP (Connor & Sagona, 2007; Messager
et al., 2013). However, only after 6 cal. ka BP also the driest regions of southern and eastern Georgia as e.g. the foothills of the Lesser Caucasus were afforested (Connor & Sagona, 2007, Fig. 8), a region where the middle Algeti is flowing through. Thus, sedimentation around 6 cal. ka BP occurred during a more arid and still relatively cool phase just before the slopes in a large part of the Algeti-catchment were intensively forested and thus stabilized. However, it is possible that the onset of this period was already significantly earlier since intensive vegetation in the catchment was missing, but that all those sediments were swept out during a later phase of fluvial erosion.

c) Incision and pedogenesis between 6 and 3.4 cal. ka BP
The following geomorphologically stable phase without fluvial sedimentation but soil formation is coincident with the warm and humid Holocene climate optimum in Georgia. During this period southern and eastern Georgia were mostly covered by forests, probably reducing runoff and stabilizing the slopes. However, in parts of the Lesser Caucasus human activity caused a change toward an oak/pine savanna from ca. 5 cal. ka BP (Connor & Sagona, 2007; Fig. 8).

d) Sedimentation between 3.4 and 3.2 cal. ka BP
In addition to human activity in the Lesser Caucasus starting ca. 5 cal. ka BP, the climate of Georgia became drier from ca. 4.5 cal. ka BP and also colder from ca. 4 cal. ka BP, leading to a shift of the vegetation belts in the Lesser Caucasus (Connor & Sagona, 2007, Fig. 8). These human and naturally-triggered changes of the vegetation cover probably destabilized the slopes and enhanced sediment availability, a possible cause of the sedimentation phase that could be documented at least between 3.4 and 3.2 cal. ka BP but was possibly somewhat longer.

e) Incision and pedogenesis between 3.2 and 2.7 cal. ka BP
External causes for this rather short geomorphologically stable phase cannot be derived from existing paleoenvironmental or archeologic data.

f) Sedimentation between 2.7 and 2.1 cal. ka BP
Anthropogenic impact on vegetation distribution in Georgia strongly increased from ca. 3 cal. ka BP. More specifically, at the Tsalka plateau close to the headwaters of the Algeti River in the Lesser Caucasus anthropogenic burning of the tree cover started from 2.9 to 2.5 cal. ka BP, finally leading to its recent treeless character (Connor & Sagona, 2007). Together with rising precipitation (Fig. 8) these activities probably increased runoff and destabilized slopes, possibly delivering material for the fluvial sedimentation phase 2.7–2.1 cal. ka BP. With rising precipitation and temperature starting between 3 and 2 cal. ka BP vegetation cover and slopes were obviously finally stabilized again so that no fluvial sediments were deposited between 2.1 and 0.77 cal. ka BP (Fig. 8).

The last two sedimentation phases (h) (0.77–0.72 cal. ka BP, i.e. 1180–1230 AD) and (i) (0.2-0.15 cal. ka BP; i.e. 1750–1800 AD) can be linked with historic events in Georgia:

g) Sedimentation between 0.77 and 0.72 cal. ka BP (1180–1230 AD)
This phase occurred during a period of flowering of Georgia, characterized by strong inland colonization with a maximal population density (Maruashvili, 1971; Lordkipanidze, 2002, Fig. 7). Although no special events are known from historical sources about the Algeti region (oral communication Prof. Nodar Bakhtadze, Tbilisi), we assume that forest clearance in the Algeti catchment during that period could have caused higher runoff leading to increased flooding, as well as stronger soil erosion increasing sediment delivery to the river.

h) Sedimentation between 0.2 and 0.15 cal. ka BP (1750–1800 AD)
Sediments originating from this phase were deposited during a period when Georgia was attacked by the army of the Persian king Aga Mohammed Khan in 1795, causing large-scale destruction of cities and agricultural land and subsequently a very low population density (Maruashvili, 1971; Lordkipanidze, 2002, Fig. 8). Abandonment of arable land could have led to soil erosion causing enhanced sediment delivery to the river, possibly explaining the deposition of sediments along its course. The time-lag of ca. 50 years between the older charcoal-dating in Section 7 (Poz-40487), i.e.
the apparent start of this phase and the Persian attack can easily be explained by a small “old wood effect”.

The dominant impact of anthropogenic activity on the landscape since at latest 3 cal. ka BP (Connor & Kvavadze, 2008) (Fig. 8) is furthermore underlined by results of sedimentological analyses from non-pedogenetic layers of the Algeti sections (Fig. 9): High carbonate values in sediments ranging from the Late Pleistocene until sedimentation phase d) (3.4–3.2 cal. ka BP) are strongly reduced in sediments from later phases. Conversely, very low C_{org}-values in Late Pleistocene sediments increase in sediments from first Holocene sedimentation phases b) and d) indicating stronger Holocene pedogenesis, but show a further strong rise starting from phase f) (2.7–2.1 cal. ka BP). Accordingly, in difference to preceding sedimentation periods especially phases f) and g) saw the accumulation of mighty fine and organic-rich overbank sediments that was not accompanied by significant gravel accumulation (cf. maximal heights of overbank sediments and of the river bed in Fig. 8). Fine sediments rich in C_{org} and depleted in carbonate were also deposited during phase h), although also gravels were accumulated during this period (Fig. 8). These observations demonstrate that the Late Holocene river mostly transported decalcified and organic-rich fine-textured soil material, probably due to increased anthropogenic soil erosion from ca. 3 cal. ka BP. For the study area itself increased human activity along the Algeti River is also seen by intensified findings of potsherds and the occurrence of walking horizons in sediment layers younger than 3 cal. ka BP, i.e. starting from phase f) (2.7–2.1 cal. ka BP) (Fig. 6).

Finally, we cannot rule out that intrinsic evolution of the river was responsible for at least a part the observed fluvial sedimentation phases (Erkens et al., 2009; Schumm, 1977). However, that fact that all phases but phase d) are found in different sections distributed along several km of the river course reduces the possibility that small-scale internal river processes as e.g. meander cutoffs were responsible for observed sedimentation phases. On the other hand, aggradation of the river bed during phase d) was so significant that local internal river processes seem unlikely as a cause for this sedimentation phase as well (Figs. 2, 6).

6. Conclusions

For the first time, this study of fluvial sediments of the Algeti River in SE-Georgia allows insights into the reactions of the semi-humid to semi-arid landscapes of its catchment area to Late Quaternary natural and anthropogenic influences.

In summary, the following conclusions can be drawn from our investigations:

- In difference to the Holocene meandering river, the Algeti had a braided character during the Late Pleistocene. This was certainly caused by high sediment load due to glacial/periglacial processes in its catchment in the Lesser Caucasus, combined with high peak discharges during snowmelt in spring. Similar to other regions, strong fluvial incision into these sediments occurred at the Pleistocene–Holocene transition.

- During the Holocene, changes of vegetation cover were obviously the dominant trigger for the fluvial dynamics of the Algeti River. Although agriculture was introduced to southeastern Georgia already about 8 cal. ka BP, human influence was only of minor importance on the landscape during the following millennia so that natural factors still dominated the vegetation cover and thus the fluvial dynamics of the Algeti. It appears that sedimentation phase b) (around 6 cal. ka BP) occurred during a colder and more arid phase with a rather sparse vegetation cover in large parts of the Algeti catchment, whereas the following geomorphologically stable phase until (latest) 3.4 cal. ka BP is coincident with the Georgian climate optimum with dense vegetation cover. Sedimentation phase d) (between 3.4 and 3.2 cal. ka BP, although probably somewhat longer) occurred during a cold and dry period as well, but since human impact significantly increased after 5 cal. ka BP natural vegetation
changes were probably amplified by human influence on the vegetation cover. Sedimentation phase f) (2.7–2.1 cal. ka BP) also occurred during a colder and in the beginning also more arid period, but in accordance with strongly intensified human impact on the landscape since 3 cal. ka BP anthropogenic activity obviously dominated during this and subsequent fluvial phases. This is in agreement with Zielhofer & Faust (2008) who state that fragile semiarid landscapes in the Mediterranean area show decreased flooding during more humid periods when the landscape was stabilized by vegetation, and stronger floods with soil erosion during more arid phases with a weakened vegetation cover.

- Youngest sedimentation phases g) (0.77–0.72 cal. ka BP) and h) (0.2–0.15 cal. ka BP) can be linked with periods of Georgian history. As already reported by Hsü (2000), periods of economic prosperity such as the flourishing Georgian Middle Age, as well as periods of social crises such as land devastation following the Persian attack in Georgia at the end of the 18th century can have similar geomorphic effects, i.e. increased fluvial sedimentation due to destabilization of vegetation and slopes.

- Although located in the Caucasian area showing high tectonic activity, the connection of fluvial phases with known climatic and human phases indicates that there was no significant tectonic influence on the Holocene fluvial dynamics of the Algeti River. Likewise, this indicates that there was no influence of the Caspian Sea-level on the Holocene fluvial dynamics, in contrast to Ollivier & Fontugne (2013) who assume a Caspian influence on the fluvial dynamics of the Kura some km downstream from its confluence with the Algeti River.

Altogether, these results show the high potential of fluvial sediments as archives of geomorphic activity and stability due to paleoenvironmental change and anthropogenic activity in the southern Caucasian area during the Late Quaternary. However, due to the generally discontinuous character of fluvial sediments, but also due to the relatively small catchment of the Algeti River this research has to be complemented by further investigations of other fluvial systems from the region, in order to get a more comprehensive picture of landscape activity and stability.

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.catena.2014.06.019.

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http://dx.doi.org/10.1029/2005JF000352.


### Table 1

Results of radiocarbon datings.

<table>
<thead>
<tr>
<th>sample number</th>
<th>section and depth</th>
<th>(\delta^{13}C) (%)</th>
<th>(^{14}C)-age (ka BP)</th>
<th>calibrated (^{14}C)-age (cal. ka BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poz-40490</td>
<td>Algeti 1, 2.1 m</td>
<td>-46.0</td>
<td>5.67 ± 0.10</td>
<td>6.47 ± 0.12</td>
</tr>
<tr>
<td>Poz-40494</td>
<td>Algeti 3, 1.2 m</td>
<td>-35.8</td>
<td>2.51 ± 0.04</td>
<td>2.6 ± 0.09</td>
</tr>
<tr>
<td>Poz-40492</td>
<td>Algeti 4, 1.1 m</td>
<td>-25.4</td>
<td>0.82 ± 0.03</td>
<td>0.74 ± 0.03</td>
</tr>
<tr>
<td>Poz-40493</td>
<td>Algeti 4, 5.4 m</td>
<td>-27.3</td>
<td>2.09 ± 0.03</td>
<td>2.06 ± 0.05</td>
</tr>
<tr>
<td>Poz-40491</td>
<td>Algeti 5, 0.8 m</td>
<td>-50.2</td>
<td>2.49 ± 0.14</td>
<td>2.55 ± 0.16</td>
</tr>
<tr>
<td>Poz-40583</td>
<td>Algeti 6, 0.5 m</td>
<td>-26.4</td>
<td>0.79 ± 0.03</td>
<td>0.72 ± 0.03</td>
</tr>
<tr>
<td>Poz-40488</td>
<td>Algeti 6, 2.5 m</td>
<td>-31.3</td>
<td>2.58 ± 0.04</td>
<td>2.69 ± 0.06</td>
</tr>
<tr>
<td>Poz-40487</td>
<td>Algeti 7, 2.1 m</td>
<td>-26.4</td>
<td>0.20 ± 0.03</td>
<td>0.2 ± 0.09</td>
</tr>
<tr>
<td>Poz-40486</td>
<td>Algeti 8, 1.6 m</td>
<td>-23.7</td>
<td>0.85 ± 0.03</td>
<td>0.77 ± 0.04</td>
</tr>
<tr>
<td>Poz-40483</td>
<td>Algeti 9, 1.1 m</td>
<td>-25.3</td>
<td>1.90 ± 0.03</td>
<td>1.85 ± 0.04</td>
</tr>
<tr>
<td>Poz-40484</td>
<td>Algeti 9, 5.3 m</td>
<td>-22.7</td>
<td>3.21 ± 0.04</td>
<td>3.42 ± 0.03</td>
</tr>
<tr>
<td>Poz-40482</td>
<td>Algeti 10, 1.5 m</td>
<td>-28.5</td>
<td>0.11 ± 0.05</td>
<td>0.15 ± 0.1</td>
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<tr>
<td>Poz-40485</td>
<td>Algeti 11, 0.7 m</td>
<td>-23.6</td>
<td>0.96 ± 0.03</td>
<td>0.87 ± 0.05</td>
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<tr>
<td>Poz-40481</td>
<td>Algeti 14, 1.3 m</td>
<td>-24.9</td>
<td>0.91 ± 0.03</td>
<td>0.84 ± 0.06</td>
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<tr>
<td>Poz-23664</td>
<td>Algeti 15, 5.9 m</td>
<td>-25.1</td>
<td>2.36 ± 0.03</td>
<td>2.38 ± 0.05</td>
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</table>
Table 2
Measurement parameters and results of luminescence datings.

<table>
<thead>
<tr>
<th>sample number</th>
<th>section</th>
<th>U-activity (Bq/kg)</th>
<th>Th-activity (Bq/kg)</th>
<th>measured total aliquots</th>
<th>Dc (Gy)</th>
<th>standard deviation of Dc distribution (Gy)</th>
<th>uncorrected age (ka)</th>
<th>g-value</th>
<th>corrected age (ka)</th>
<th>corrected age, related to 1950 AD (= cal. ka BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L29</td>
<td>Algeti 1, 7.0 m</td>
<td>14.1 ± 1.6</td>
<td>14.8 ± 0.6</td>
<td>407 ± 21</td>
<td>24/29</td>
<td>59.72 ± 6.21</td>
<td>32.5</td>
<td>23.7 ± 3.2</td>
<td>5.16 ± 0.8**</td>
<td>46.5 ± 13.8</td>
</tr>
<tr>
<td>L30</td>
<td>Algeti 2, 8.7 m</td>
<td>17.2 ± 1.6</td>
<td>14.4 ± 0.7</td>
<td>399 ± 21</td>
<td>29/36</td>
<td>53.76 ± 3.62</td>
<td>42.2</td>
<td>21.2 ± 1.9</td>
<td>6.65 ± 0.53*</td>
<td>59.4 ± 14.5</td>
</tr>
<tr>
<td>L31</td>
<td>Algeti 2, 1.2 m</td>
<td>29 ± 4</td>
<td>20.7 ± 1.3</td>
<td>410 ± 40</td>
<td>27/37</td>
<td>42.2 ± 1.4</td>
<td>27.1</td>
<td>15.2 ± 1.7</td>
<td>5.16 ± 0.8**</td>
<td>29.3 ± 8.3</td>
</tr>
<tr>
<td>L33</td>
<td>Algeti 3, 2.6 m</td>
<td>15.9 ± 1.2</td>
<td>14.1 ± 0.6</td>
<td>437 ± 22</td>
<td>23/36</td>
<td>2.28 ± 1.33</td>
<td>12.0</td>
<td>0.88 ± 0.5</td>
<td>5.16 ± 0.8**</td>
<td>1.5 ± 0.8</td>
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<tr>
<td>L39</td>
<td>Algeti 9, 7.5 m</td>
<td>14.1 ± 1.5</td>
<td>15.5 ± 0.7</td>
<td>443 ± 23</td>
<td>28/32</td>
<td>8.17 ± 1.81</td>
<td>45.5</td>
<td>3.2 ± 0.8</td>
<td>5.16 ± 0.8**</td>
<td>5.8 ± 1.7</td>
</tr>
<tr>
<td>L27</td>
<td>Algeti 11, 4.8 m</td>
<td>21.5 ± 2.2</td>
<td>16.8 ± 0.8</td>
<td>403 ± 22</td>
<td>42/46</td>
<td>17.22 ± 1.17</td>
<td>31.7</td>
<td>6.6 ± 0.7</td>
<td>5.16 ± 0.8**</td>
<td>12.2 ± 2.7</td>
</tr>
<tr>
<td>L36</td>
<td>Algeti 12, 2.3 m</td>
<td>13.8 ± 1.9</td>
<td>13.5 ± 0.7</td>
<td>443 ± 15</td>
<td>39/45</td>
<td>4.96 ± 1.69</td>
<td>36.6</td>
<td>1.9 ± 0.44</td>
<td>5.16 ± 0.8**</td>
<td>3.3 ± 0.9</td>
</tr>
<tr>
<td>L35</td>
<td>Algeti 13, 1.4 m</td>
<td>25.6 ± 2.2</td>
<td>19.9 ± 1</td>
<td>443 ± 24</td>
<td>29/40</td>
<td>10.37 ± 0.42</td>
<td>62.7</td>
<td>3.7 ± 0.4</td>
<td>5.2 ± 0.67*</td>
<td>7.1 ± 1.2</td>
</tr>
<tr>
<td>L34</td>
<td>Algeti 14, 2.3 m</td>
<td>30.5 ± 2.7</td>
<td>19.4 ± 0.9</td>
<td>419 ± 23</td>
<td>28/32</td>
<td>9.34 ± 1.17</td>
<td>36.6</td>
<td>3.4 ± 0.5</td>
<td>5.16 ± 0.8**</td>
<td>6.0 ± 1.4</td>
</tr>
</tbody>
</table>

* Based on the selection criterion of a recycling-ratio smaller/equal ±10%.

b To allow direct comparability with calibrated 14C-ages.

** Measured g-value used.

** Averaged g-value used (averaged from g-values of L-30, L-35 and a further sample taken from Algeti material but not shown here with a g-value of 3.32 ± 0.69).
Figures

Figure 1

Morphologic situation of the Marneuli depression. The elevated Late Pleistocene surface in the depression is indicated with hatching, and the working area (in detail shown in Fig. 2) with a gray rectangle. Inset left: Mean monthly discharge of the Algeti River 1960–1985. Source: http://rda.ucar.edu/data/ds553.2/fsu2. Inset right: Overview of the Caucasian region. The Marneuli depression is marked with a gray rectangle, and the catchment of the Algeti River with hatching.
**Figure 2**

The study area in detail. Sedimentary accumulation sections (1–15) are indicated with Arabic letters (1–15), whereas strath terraces are marked with Latin letters (I and II). The elevated Late Pleistocene surface wherein recent rivers are cut up to several tens of meters is shown in gray.
Figure 3

Exemplary Sections 1, 3 and 5 with results of pedological analyses used for paleosol-identification and numerical ages.
Figure 4

Terrace levels developed along the lower Algeti River based on D-GPS-measurements. a) Map of the terrace levels. b) Longitudinal profiles of the terrace levels along the left and the right bank.
Figure 5

Results of micromorphological analyses from Section 5 (for sample-locations see Fig. 3c). a) Paleosol horizon with well-developed pedality (subangular blocky to blocky peds); weakly developed stipple speckled b-fabric indicates carbonate-free material - crossed polarizers, sample MM-2; b) scan of thin section MM-1 (2 × 3.5 cm) with finely dispersed charcoal fragments (arrows show peds with charcoal enrichment); c) banded microstructure. Bands have a thickness of around 300 μm becoming thicker with depth - plane polarized light, sample MM-1.
Figure 6

Compilation of fluvial accumulation sections (1–15) and strath terraces (I and II) of the Algeti River. For location of the sections see Fig. 2.
Figure 7

Fluvial phases of the Algeti River during Late Pleistocene and Holocene.
Figure 8

Comparison of Holocene fluvial phases of the Algeti River with regional paleoenvironmental and archeologic/historic data for the last 9 ka. For fluvial phase numbers according to Fig. 7 are given. The concept of maximal heights of overbank sedimentation and river bed during different fluvial periods is adapted from Faust & Zielhofer (2002). a = Connor & Kvavadze (2008), b = Connor & Sagona (2007), c = Messager et al. (2013), d = Lordkipanidze (2002).
Figure 9

Average values and standard deviations for carbonate and C\textsubscript{org}-values from non-pedogenetic sediment layers originating from different sedimentation periods. Sampling positions are indicated by crosses in exemplary Fig. 3 and in the figures in the Supporting online material (Late Pleistocene (a): 11 samples; ca. 6 cal. ka BP (b): 14 samples; 3.4–3.2 cal. ka BP (d): 3 samples; 2.7–2.1 cal. ka BP (f): 14 samples; 0.77–0.72 cal. ka BP (g): 6 samples; 0.2–0.15 cal. ka BP (h): 11 samples).
Suchodoletz et al. – Algeti: Supporting Online Material

SOM-figures 1 – 5 show section drawings with geographic coordinates, ages, results of sedimentologic analyses to identify palaeosols, and sampling positions for micromorphology and layers without pedogenesis.

Furthermore, detailed stratigraphic explanations of the individual sections are given.

SOM- Figure 1

Stratigraphy of sections 1, 2 and 3.
Stratigraphy of sections 4 and 5.
Stratigraphy of sections 6, 7, 8, 9 and 10.
SOM- Figure 4:

Stratigraphy of sections 11, 12 and 13.
SOM- Figure 5

Stratigraphy of sections 14, 15, I and II.
Section 1

In the lowest outcropped part, a lenticular gravel body interstratified with several sand bands between 810 and 600 cm gives a luminescence age of 46.5 ±13.8 ka (Fig. SOM-1a). This gravel discordantly cuts into ocherous-yellowish silty loam with clear signs of Fe/Mn-dynamics as e.g. small concretions. Until 300 cm the gravel is overlain by ocherous-yellowish sand containing singular pebbles and several silty lenses, as well as carbonate concretions in the lower part. Laterally, this sand passes into a lenticular gravel body that includes several sand bands. This lower part of the section indicates a braided river regime. Between 300 and 200 cm, the gravel is overlain by ocherous-yellowish silty sand that includes singular pebbles and grades into a brown and slightly clayey layer with 20 cm thickness. This layer has a distinct upper limit, contains some small pieces of charcoal and a potsherd and is underlain by a zone of intensive carbonate concretions. The $^{14}$C-age of a charcoal-piece is 6.47 ± 0.12 cal. ka BP. Carbonate and pH-values are lower in this layer compared with the underlying material, whereas C$_{org}$ is somewhat elevated. Altogether, morphology and sedimentary proxies of this layer evidence a palaeosol, indicating geomorphic stability after overbank sedimentation proximal to the river. Above the palaeosol until the surface the material changes between ocherous-yellowish sandy loam or sand, and brownish clayey loam. Several bands of pebbles and singular pebbles occur, as well as snail shells immediately above the soil. Also this upper layer indicates overbank sedimentation proximal to the river. In the uppermost 20 cm the brownish clayey recent soil is developed, underlain by a layer of carbonate concretions.
Section 2

The lowest outcropped part until 900 cm contains light-brown clayey loam, overlain until 850 cm by sandy-pebbly material with a luminescence age of 59.4 ± 14.5 ka (Fig. SOM-1b). A brown sand layer follows until 830 cm, overlain by ocherous clayey loam including some carbonate concretions until 750 cm. A sequence of interbedded fine sand and silty loam with some carbonate concretions is developed until 690 cm. Brownish-reddish clayey loam follows until 560 cm, showing Fe-dynamics in the lower and the upper part as well as some carbonate concretions between 560 and 600 cm. Until 505 cm the material gets more silty and ocherous and contains some carbonate concretions and Fe-/Mn-stains. A fine sand layer including some carbonate concretions follows until 490 cm, overlain until 440 cm by ocherous silty loam with some carbonate concretions in the lower part. Starting with silty-clayey material, a light-brown fine-sandy/silty layer containing carbonate-concretions follows until 380 cm, overlain by ocherous-brownish loam and clayey loam until 330 cm. Brownish and ocherous sandy-pebbly layers intercalate with loamy and clayey loamy layers until 250 cm, followed by ocherous loam and ocherous-brownish sandy loam until 140 cm. The overlying gravel-bed developed until 95 cm includes several sand lenses, giving a luminescence age of 29.3 ± 8.3 ka. The gravel is overlain by ocherous fine-sandy loam with singular pebbles. From 35 cm to the surface the recent brown clayey soil is found, underlain by numerous carbonate concretions at about 70 cm.

Most parts of the section are interpreted as overbank sediments deposited proximal to the river-bed, and the upper gravel as a river channel facies.
Section 3

From the base until 210 cm a gravel body interstratified with several sand lenses occurs, giving a luminescence age of 1.5 ± 0.8 ka (Fig. SOM-1c). The gravel is overlain by brown sand until 190 cm, fining until 160 cm into ocherous-yellowish silty flood loam containing intensive Fe-/Mn-stains and some carbonate concretions. Here, the flood loam grades into a brownish clayey layer with a distinct upper limit at 140 cm and many interspersing carbonate mycelia. Carbonate values get lower towards the top of this layer, whereas C$_{org}$ and $\chi_{fd}$ continuously increase. Although different from a typical soil section pH-values increase upwards, morphology and other sedimentological proxies identify this layer as a palaeosol that indicates stable geomorphic conditions. The palaeosol is overlain by ocherous-brownish silty flood-loam including some thin brown clay bands. Several carbonate mycelia, Fe-/Mn-stains, carbonate concretions, broken snail shells and pieces of charcoal are found here. $^{14}$C-dating of a charcoal-piece gave an age of 2.6 ± 0.09 cal. ka BP. A very weak brown loamy soil horizon is developed in the uppermost 5 cm. The sequence is interpreted as a pebbly river channel facies overlain by overbank sedimentation that was interrupted by a period of geomorphic stability.
Section 4

The base until 675 cm is taken by a gravel body (Fig. SOM-2a). This is overlain by grey sand that passes into grey clayey loam until 550 cm, showing intensive Fe-/Mn-stains and charcoal in its upper part. This is discordantly overlain by layered yellowish-ocherous sandy loam that passes into clayey loam until 470 cm, with singular carbonate mycelia in the upper and charcoal-pieces in the lower part. Greyish-reddish marbling indicates Fe-dynamics. $^{14}$C-dating of a charcoal-piece from the base of this layer gave an age of 2.06 ± 0.05 cal. ka BP. This lower part of the section with the two fining up-sequences is interpreted as overbank-sedimentation proximal to the river bed. Until 330 cm an intercalation of greyish-reddish sandy and silty bands follows, showing an increasing density of carbonate mycelia until the top. Between 375 and 335 cm two clayey greyish-reddish layers including many charcoal-pieces are found, probably representing former short-time palaeosurfaces. Between the upper palaeosurface and 290 cm greyish-brownish sandy loam containing singular reddish Fe-stains and carbonate mycelia occurs. At 290 cm this material grades into greyish aggregated clayey loam containing many charcoal-pieces, carbonate mycelia and several carbonate concretions and ending abruptly at 210 cm. Carbonate and pH-values decrease towards the top of this layer whereas C$_{org}$ and $\chi_{fd}$ increase. Together with its morphology this demonstrates a palaeosol that represents a period of geomorphic stability. Above the palaeosol ocherous-greyish silty, sandy and clayey layers are developed, showing partly strong Fe-stains in the lower part. At 100 cm this package is overlain by a greyish layer containing many charcoal-pieces, interpreted as a very short-time palaeosurface. $^{14}$C dating of a charcoal-piece gave an age of 0.74 ± 0.03 cal. ka BP. This surface is overlain by greyish sandy loam containing singular carbonate mycelia as well as some snails. The recent soil is developed within the upper 50 cm, characterized by grey clayey loam, aggregation and sporadic occurrence of snails. This upper part of the sequence can be interpreted as overbank sedimentation interrupted by three very short (palaeosurfaces) and one longer (palaeosol) period of geomorphic stability.
Section 5

The base of the outcropped part from 395 cm to 120 cm consists of layered ocherous-beige silty loam with several carbonate mycelia and carbonate concretions (Fig. SOM-2b). Singular pieces of charcoal occur at 300 cm, and 180-170 cm a thin band of beige-brown clayey loam is found. This band is covered by ocherous-brownish layered silty sand with some carbonate mycelia until 130 cm. Until 100 cm brown clayey loam follows, containing singular pieces of charcoal and some carbonate/gypsum concretions. Whereas the upper boundary of this layer with many charcoal-pieces is distinct, it grades into the underlying material. Carbonate contents in this layer are lower compared with the underlying material, and $C_{org}$ and $\chi_{fd}$ increase from the base to the top. Together with its morphology this demonstrates that this layer is a palaeosol, representing a period of geomorphic stability. This interpretation is also supported by micromorphology (see main paper, chapter 4. “results”). Up to 95 cm the palaeosol is buried by layered silty loam with numerous charcoal pieces at its top. This layer was interpreted as a very short-time palaeosurface, i.e. as an occupation layer (also confirmed by micromorphology; see main paper chapter 4. “results”). Until 85 cm the palaeosurface is overlain by brownish-greyish sand that is covered by alternating layers of sandy loam and brownish slightly clayey loam. The latter contain carbonate mycelia and few charcoal fragments, whereof $^{14}C$-dating yielded an age of $2.55 \pm 0.16$ cal. ka BP. The upper 15 cm comprise a greyish-brownish soil horizon, characterized by a well aggregated slightly clayey loam containing snail shells and charcoal-pieces. The complete sequence can be interpreted as an overbank-sedimentation interrupted by one longer and one very short time of geomorphic stability.
Section 6

At the base of the section until 315 cm a gravel body is found, including lenses of sand with some Fe-/Mn-stains (Fig. SOM-3a). Partly, the gravel is underlain by clayey loam. Until 260 cm the gravel is overlain by brown sand with some pebbles in its lower part. Between 260 and 255 cm a thin band of grey silty loam with some pieces of charcoal is developed. Until 220 cm the sediment changes between brownish fine sand and ocherous silty loam including Fe-spots and some charcoal pieces in its lower part, whereof $^{14}$C-dating gave an age of 2.69 ± 0.06 cal. ka BP. This package is overlain by a brown sand band with a thickness of 5 cm. Until 150 cm the sand is followed by reddish-ocherous sandy loam, with decreasing sand towards the top and some pieces of charcoal in its upper part. This layer grades into partly aggregated brown strongly clayey loam with Fe-/Mn-stains. Its upper limit at 110 cm is distinct, and carbonate and pH-values decrease in this layer compared with the underlying material whereas $C_{org}$ and $\chi_{fd}$ increase. Altogether, this pleads for a palaeosol indicating a period of geomorphic stability. Until 60 cm the soil is overlain by reddish-yellowish sand, followed by a band of silty loam with some carbonate concretions and showing Fe-dynamics. This is covered by ocherous silty fine sand. Greyish silty loam is found until 50 cm, overlain by brownish-greyish sandy loam with some charcoal-pieces in its lower part. $^{14}$C-dating of one charcoal gave an age of 0.72 ± 0.03 cal. ka BP. The greyish-brownish recent soil starts at 10 cm. This section is interpreted as quite proximal overbank-sedimentation interrupted by a period of geomorphic stability.
Section 7

At the base of the section until 270 cm a gravel body is found that includes several sand lenses (Fig. SOM-3b). Until 215 cm this gravel is overlain by greyish/brownish middle to coarse sand that contains singular pebbles and shows some Fe-stains. Above until 205 cm a small band of greyish fine-sandy loam is found that shows Fe-stains and contains some pieces of charcoal. $^{14}$C-dating of one charcoal gave an age of $0.2 \pm 0.09$ cal. ka BP. Brownish sand with singular pebbles follows until 165 cm. Until 150 cm, brown silty sand containing pieces of charcoal as well as Fe-/Mn-bands is found, overlain by 5 cm of brown sand with Fe-stains. Silty layers with different percentages of clay are developed until 120 cm that partly show Fe-stains. These are overlain by a small sand band with singular pebbles until 115 cm, followed by greyish-brownish loamy sediments with Fe-/Mn-stains that contain charcoal at 105 cm. The upper 20 cm are taken by the recent initial soil, characterized by greyish clayey loam that contains many snail shells. The whole section is interpreted as quite proximal overbank-sedimentation.
Section 8

The base of the section until 190 cm is taken by a gravel body that includes some sand lenses (Fig. SOM-3c). Until 130 cm this gravel body is overlain by greyish mostly fine sand with pebbles, showing some Fe-stains. Around 150 cm pieces of charcoal are found, whereof $^{14}$C-dating gave an age of 0.77 ± 0.04 cal. ka BP. A band of clayey loam with Fe-stains follows until 125 cm, overlain by a brownish sand layer until 110 cm. Ocherous-greyish silty and partly clayey layers showing Fe-stains occur until 85 cm, overlain by greyish-brownish fine sand until 75 cm. Above, silty loam with fine sand lenses in its lower part is found until 50 cm, overlain by greyish-brownish fine sand until 35 cm and ocherous silty loam with some Fe-stains until 25 cm. The latter contains some pieces of charcoal. The upper 25 cm are taken by the recent brownish initial soil. The whole section is interpreted as quite proximal overbank-sedimentation.
Section 9

The lowest outcropped part until 570 cm is taken by a gravel body that includes some sand lenses and shows Fe-/Mn-stains (Fig. SOM-3d). Luminescence dating of a sand lense in its lower part yielded an age of 5.8 ± 1.7 ka. Until 520 cm this gravel is overlain by intercalating small sandy and silty layers, the former containing some pebbles. Around 540 cm pieces of charcoal are found, whereof $^{14}$C-dating yielded an age of 3.42 ± 0.03 cal. ka BP. Until 400 cm ocherous silty loam follows, showing some Fe-stains and bleached parts and containing a fine sand lense. A brownish-greyish fine sand band with some Fe-/Mn-stains is developed until 385 cm, containing some pieces of charcoal. This is followed until 320 cm by ocherous silty loam with some Fe-stains at the base and charcoal-pieces in the middle. This lower part of the section is interpreted as a river-channel facies overlain by proximal overbank sedimentation. Above the loam until 240 cm a gravel body occurs that includes lenses of coarse sand. Until 220 cm this gravel is overlain by a sequence of brownish-ocherous sand partly showing Mn-stains, followed by ocherous silty loam with increasing clay contents towards the top and carbonate mycelia until 170 cm. Until 140 cm ocherous silty fine sand is found, followed until 90 cm by ocherous-yellowish sandy loam that contains carbonate mycelia and singular carbonate concretions. Here, the transition towards a brownish clayey aggregated layer is found. In this layer, singular snails and many carbonate mycelia and -stains covering aggregate surfaces are found, and its transient upper limit is located at 55 cm. $^{14}$C-dating of a charcoal-piece from this layer gave an age of 1.85 ± 0.04 cal. ka BP. Carbonate content increases and pH-values slightly decrease in this layer compared with the underlying material, whereas both $C_{org}$ and $\chi_{fd}$ increase. Based on its morphology and the latter three proxies, this layer is interpreted as a palaeosol indicating a period of geomorphic stability. Higher carbonate values in the soil can easily be explained by secondary calcification from overlying layers, also indicated by carbonate mycelia and -stains found here. The palaeosol is overlain by greyish-brownish sandy loam with increasing sand contents towards the top, containing singular carbonate mycelia and large dead roots. The upper 10 cm are taken by the recent greyish-brownish loamy soil, showing slight aggregation. This upper part of the section is interpreted as a river channel facies overlain by overbank sediments, where sedimentation was interrupted during a longer period as indicated by the palaeosol.


Section 10

The base of the outcropped part until 205 cm is taken by a gravel passing into sand, overlain until 190 cm by greyish coarse sand containing singular pebbles and showing some Mn-stains (Fig. SOM-3e). Until 130 cm an intercalation of greyish-brownish silty and clayey loam with Fe- and Mn-stains follows. At 150 cm, this package contains some pieces of charcoal whereof $^{14}$C-dating yielded an age of $0.15 \pm 0.1$ cal. ka BP. Overlying, silty loam with singular sandy bands is found that contain Fe-/Mn-stains. The upper 10 cm are taken by the initial recent soil that is underlain by singular carbonate mycelia. The whole section is interpreted as a silting-up-facies above gravelly channel-sediments of a palaeomeander.
Section 11

The base of the section until 650 cm is taken by a gravel body that includes several lenses of coarse sand (Fig. SOM-4a). The gravel is overlain by ocherous-greyish middle to fine sand that laterally grades into a gravel body until 460 cm, and luminescence dating of the sand at 480 cm yielded an age of 12.2 ± 2.7 ka. The sand is followed by a layer of brownish fine-sandy loam that extends until 430 cm. Until 380 cm ocherous-greyish middle to fine sand is found, showing Fe-stains and bleached spots in its upper part. A greyish layer of silty loam found until 320 cm contains some clay in its lower part. This is separated by a thin ocherous fine sand layer between 320 and 315 cm from a greyish-brownish silty loam that extends until 235 cm. The latter shows some clay in its lowest and highest parts, as well as several carbonate concretions, bleached spots and charcoal fragments at 265 cm. Until 190 cm this is overlain by brownish-greyish sand that shows some bleached spots and carbonate concretions. Up to 160 cm ocherous silty loam with carbonate concretions is developed, overlain by brown sand that extends until 145 cm. Above, ocherous-yellowish silty sand containing some carbonate/gypsum mycelia is found, passing into dark-brown aggregated clayey loam at 110 cm. The latter contains many carbonate mycelia and some small pieces of charcoal, and has an accentuated upper surface at 70 cm. $^{14}$C-dating of a charcoal-piece yielded 0.87 ± 0.05 cal. ka BP. Carbonate and pH-values in this layer are reduced compared with the underlying material, whereas $C_{org}$ and $\chi_{fd}$ increase towards the top. Together with its morphology, these proxies demonstrate that this layer is a palaeosol that indicates stable geomorphic conditions. The palaeosol is overlain by yellowish-ocherous sandy loam that contains some carbonate/gypsum concretions. The uppermost 25 cm of the section are taken by the recent soil, characterized by aggregated, light-brown and slightly clayey loam and containing some broken snail shells. The whole section is interpreted as quite proximal overbank sedimentation above a gravelly river bed facies, interrupted by a period of geomorphic stability.
Section 12

The base of the outcropped part until 175 cm is formed by a mighty stratified gravel bed intercalated with layers of stratified sand (Fig. SOM4b). The whole package shows intensive Fe-/Mn-stains and bleaching spots. Luminescence dating of a sand layer at 2.3 m yielded an age of 3.3 ± 0.9 ka. Until 150 cm, the gravel is overlain by stratified sand with singular pebbles containing Fe-/Mn-stains. Above until 105 cm ocherous sandy loam is found, showing Fe-/Mn-stains as well. Until 20 cm brownish loam occurs, containing broken glas and potsherds. The upper 20 cm are taken by the recent brownish-greyish and silty soil that contains broken glas, remains of bricks, potsherds and singular pebbles. The whole section is interpreted as quite proximal overbank sedimentation above a gravelly river channel facies.
The base of the outcropped part until 265 cm is taken by yellowish-ocherous fine sand that contains some carbonate/gypsum mycelia (Fig. SOM-4c). Until 245 cm aggregated light-brown and slightly clayey loam with carbonate/gypsum mycelia is found, overlain until 235 cm by ocherous-yellowish sandy loam with slight carbonate-stains of aggregate surfaces. Until 210 cm, aggregated light-brown and slightly clayey loam with carbonate/gypsum mycelia follows. Ocherous-yellowish sandy loam with slight carbonate-stains of aggregate surfaces is found until 200 cm, and above until 160 cm another aggregated brownish slightly clayey loam with carbonate/gypsum mycelia occurs. Potsherds of Bronze age (oral communication Prof. Nodari Bakhtadze, Ilia State University Tbilisi) and large pieces of charcoal are found at the surface of the latter layer. Carbonate and pH-values decrease in the two upper brownish layers (160-200 cm, 210-235 cm), whereas carbonate slightly decreases but pH-values are indifferent in the lowest brownish layer (245-265 cm). However, since $C_{\text{org}}$ and $\chi_{\theta}$ increase all three brownish layers compared with their underlying materials, respectively, they can be interpreted as three stacked palaeosols that indicate three periods of geomorphic stability. Until 140 cm the palaeosol is overlain by brownish-greyish loam that contains singular carbonate/gypsum concretions as well as carbonate mycelia. OSL-dating in a depth of 1.4 m yielded an age of $7.0 \pm 1.2$ cal. ka BP. Between 140 and 130 cm a small band of brownish fine-sandy loam is developed, followed until 30 cm by brownish-greyish loam that contains singular carbonate/gypsum concretions and carbonate mycelia. The upper 30 cm are taken by the recent brownish, loamy and aggregated soil. The sequence is interpreted as overbank sedimentation that was interrupted by three periods of geomorphic stability, as indicated by the three-phased palaeosol.
Section 14

The base of the outcropped part until 650 cm is taken by a gravel body, overlain until 600 cm by ochrous silty loam (*Fig. SOM-5a*). Until 525 cm an intercalation of ochrous-greyish silty and sandy layers is developed, including Fe-stains and bleached spots. Carbonate concretions are found in the middle part of this package. This intercalation is overlain by ochrous-brownish clayey loam that grades into fine sand at 465 cm. Between 460 and 430 cm ochrous-yellowish silty loam is found, overlain by a thin sand band with 5 cm thickness. This is followed until 390 cm by ochrous-brownish silty loam that is overlain by a thin sand band until 385 cm, the latter containing many pieces of charcoal. Until 365 cm ochrous-yellowish silty loam with some carbonate mycelia occurs, grading until 340 cm into fine sand. Overlying, ochrous silty loam is found until 295 cm that contains carbonate concretions and some charcoal between 330 and 320 cm. The ochrous cross-bedded sand layer developed until 270 cm contains carbonate concretions and shows some Fe-stains. Above, brownish-yellowish slightly clayey loam occurs, becoming sandier towards the top until 220 cm. This layer contains carbonate/gypsum mycelia as well as singular pebbles, and luminescence dating at 230 cm yielded an age of 6.0 ± 1.2 ka. At 220 cm this layer passes into brownish aggregated sandy-clayey loam that has an accentuated upper limit at 130 cm. This brownish layer contains carbonate/gypsum mycelia and small carbonate concretions in its lower part, and shows carbonate stains at its aggregate surfaces. In its upper part pieces of charcoal are found, whereof $^{14}$C-dating gave an age of 0.84 ± 0.06 cal. ka BP. Carbonate and pH-values decrease towards the top of this layer compared with the underlying material whereas $C_{org}$ increases. The behaviour of $\chi_{fd}$ is indifferent, although highest values are found at the top. Together with its morphology this pleads for a palaeosol indicating stable geomorphic conditions. This is confirmed by optical correlation of this soil with the three stacked brownish palaeosols of the neighbouring section Algeti 13. Above the soil until 30 cm ochrous-yellowish silty sand follows, containing carbonate mycelia and in the upper part carbonate concretions. Above 30 cm the recent brownish, loamy and aggregated soil is developed. The whole section is interpreted as quite proximal overbank sedimentation above a gravelly channel bed facies that was interrupted by a period of geomorphic stability.
At the base until 555 cm ocherous-greyish clayey loam is found, showing Fe-stains and bleached spots (*Fig. SOM5b*). \(^{14}\)C-dating of a charcoal layer at 590 cm gave an age of 2.38 ±0.05 cal. ka BP. A band of ocherous clayey loam including carbonate concretions and Fe-stains follows until 540 cm. This is overlain by greyish-brownish clayey loam that extends until 490 cm, containing carbonate concretions and Fe-stains in the upper part. Ocherous-brownish silty loam follows until 435 cm that contains small carbonate concretions and Fe-stains in the lower part. The greyish-brownish clayey loam following until 350 cm contains broken snail shells, and is overlain until 240 cm by ocherous silty loam. Above until 280 cm reddish-greyish clayey loam occurs, containing broken snail shells as well as some pebbles in the lower part and pieces of charcoal at 320 cm. Until 230 cm ocherous silty loam with more sand towards the top is found, containing carbonate concretions in its upper part. This is followed by reddish-brownish clayey loam until 200 cm, overlain by ocherous silty loam until 180 cm. A thin layer of reddish-ocherous clayey loam between 180 and 170 cm is followed by ocherous silty loam extending until 95 cm. The latter layer contains carbonate concretions and carbonate mycelia above 110 cm, as well as a charcoal layer at 130 cm. A thin ocherous fine-sand band until 90 cm is overlain by ocherous silty loam until 25 cm. The upper 25 cm are taken by the recent brownish aggregated soil that contains potsherds as well as charcoal. The whole section is interpreted as a sequence of overbank sediments.
**Strath terrace I**

The base of the outcropped part of strath terrace I until 585 cm is taken by ocherous silty fine sand containing some carbonate concretions, followed until 400 cm by ocherous fine-sandy loam showing bleached spots and Fe-stains (Fig. SOM-5c). Ocherous silty fine sand containing some carbonate concretions and Fe-stains occurs until 310 cm, overlain until 300 cm by ocherous fine sand with carbonate concretions, Fe-stains and bleached spots. This is followed until 210 cm by light-grey clayey loam containing some fossil shell fragments (*unio pictorum*), these latter also occurring in the overlying light-grey silty loam that extends until 10 cm. The upper 10 cm are taken by the recent brownish humic soil.
Strath terrace II

At the base of the drilled part of strath terrace II ocherous silty sand is found until 170 cm, containing some carbonate mycelia in the whole layer and carbonate concretions in its upper part (Fig. SOM5-d). At 170 cm this layer passes into a greyish clayey soil with a sharp upper boundary at 130 cm. The soil is overlain by ocherous-greyish silty sand with singular pebbles, obviously a recent colluvium overlying the original terrace level. Thus, the latter has its upper boundary at 13.9 m above the recent river bed.