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When is a terrace not a terrace? The importance of understanding landscape evolution in studies of terraced agriculture

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Abstract

Before the invention of modern, large-scale engineering projects, terrace systems were rarely built in single phases of construction, but instead developed gradually, and could even be said to have evolved. Understanding this process of landscape change is therefore important in order to fully appreciate how terrace systems were built and functioned, and is also pivotal to understanding how the communities that farmed these systems responded to changes; whether these are changes to the landscape brought about by the farming practices themselves, or changes to social, economic or climatic conditions. Combining archaeological stratigraphy, soil micromorphology and geochemistry, this paper presents a case-study from the historic and extensive terraced landscape at Konso, southwest Ethiopia, and demonstrates – in one important river valley at least – that the original topsoil and much of the subsoil was lost prior to the construction of hillside terraces. Moreover, the study shows that alluvial sediment traps that were built adjacent to rivers relied on widespread hillside soil erosion for their construction, and strongly suggests that these irrigated riverside fields were formerly a higher economic priority than the hillside terraces themselves; a possibility that was not recognised by numerous observational studies of farming in this landscape. Research that takes into account how terrace systems change through time can thus provide important details of whether the function of the system has changed, and can help assess how the legacies of former practices impact current or future cultivation.

Key words: terraces, archaeology, landscape evolution, agriculture, land management

1 Introduction

In common parlance the term 'agricultural terrace' is well understood, and it is well understood too that terraces can produce a range of benefits including limiting surface water run-off and reveting soils, thereby reducing soil erosion; increasing topsoil depth and water infiltration and retention, thereby increasing yields; improving drainage or redirecting excess water flows, thereby mitigating erosion, conserving water and protecting dry-adapted plants; as well as increasing soil temperatures, thereby promoting seed germinating. However, it should be clear even from this very short summary that no single terrace can perform all of these functions: a terrace could not be designed to both improve water retention and improve drainage, for example. This is not simply a question of engineering semantics (i.e. that the catch-all term 'agricultural terrace' encompasses a range of structures that are built in different ways to solve different problems) because a particular type of terrace such as the common cut and fill levelled bench terrace could be managed to perform different functions even within the same hillside: exposed to increased soil temperature in one location, while shaded and irrigated in another. Cost-benefit analyses reporting positive results for the construction of terraces in a given time and location (e.g. Bizoza and De Graaff, 2012; Tesfaye et al., 2016) must therefore be taken in context, and produce conclusions that cannot, of course, be readily transposed to a different time and place.

This point, though in some ways a statement of the obvious, is illustrated in the current paper by reference to archaeological and pedological research at the impressive terraced landscape in Konso, southwest Ethiopia; a landscape that was listed as a UNESCO World Heritage Site in 2011, includes some 40 historic walled towns surrounded by an estimated 200km^2 of dry-stone agricultural terracing (Kimura, 2006), and which is thought on the basis of genealogical evidence to have included terracing and perhaps supplementary irrigation approximately 500 years ago (Amborn, 1989). Whether or not this date is a true reflection of when terracing was first employed at Konso has yet to be confirmed archaeologically, but it is clear from early 20th-century accounts (e.g. Harrison, 1901) that the area was extensively terraced at this time, and it is thus reasonable to assume that the practice of building terraces began more than a century earlier. Attempts to date the terraces directly are underway, but regardless of the exact date of inception it would be a mistake to assume that the whole of the 200km^2 of terraces were built simultaneously, and mere conjecture to conclude that the function of the terraces has remained constant: terraces constructed to produce high value tradable crops might have later been converted to grow staples for domestic consumption, for example. A long-term perspective can provide these answers (Hayashida, 2005), employing archaeobotanical methods to examine what crops were grown and consumed (the results of which for the current case-study are forthcoming), and employing archaeological stratigraphy combined with studies of soil formation to define the function of particular terraces and the consequences of their construction. This is because archaeological excavation is designed to discern the order in which sediments are deposited and the sequence in which structures are built, meaning that excavation is able to effectively 'reverse engineer' features such as agricultural terraces. This is important because doing so helps discern which of the priorities listed above a particular terrace was designed to fulfil, and can help assess how effective a particular terrace system was at achieving these.

Unsurprisingly, the use of archaeological excavation to map how terrace systems have changed through time has typically been applied to abandoned agricultural landscapes (e.g. Soper, 1996 and 2002; Stump, 2006; Widgren et al., 2016), but examining an extant system offers important opportunities for interdisciplinary studies. Indeed, this is particularly true for the current case-study, since Konso has long been a focus of anthropological research (e.g. Amborn, 1989; Amborn and Straube, 2009; Hallpike, 2008 [1st edition 1972]; Jensen, 1936 and 1960; Minker, 1986; Nowack, 1954; Straube, 1967), with the agricultural system itself subsequently studied by geographers (Watson, 2009) and by agronomists and others interested in the developmental lessons that might be learnt from studies of so-called ‘indigenous knowledge’ (e.g. Abate, 1992; Beshah, 2003; Demeulenaere, 2002; Förch, 2003; Tadesse, 2010). This offers clear advantages, because the social, cultural and managerial aspects of the operation of the agricultural system that would be hard or impossible to see archaeologically are well understood, at least for the late 20th and early 21st centuries. By examining historic terraces directly it is possible to extend this understanding back into the deeper past, but direct examination of structures and the soils within terraces that continue to be farmed can also be used to test the conclusions drawn by these observational studies. As the results outlined below illustrate, this ability can generate insights that both complement and extend those derived from other research techniques.

Importantly, this ability to examine the function, efficacy, construction sequence and environmental consequences of terrace systems strongly suggests that previous observational studies did not fully appreciate some elements of the Konso landscape by assuming that terraces were designed to conserve the original topsoil from erosion, and by underestimating the value of a particular type of agricultural ‘terrace’ (more properly described as a sediment trap or check dam) that are mentioned only briefly in previous published accounts (Amborn, 1989, citing Kuls, 1958; and Straube, 1967) or which were described as only existing in the far northwest of the landscape (Beshah, 2003). The argument here, therefore, is that assessments of the efficacy, sustainability or resilience of a system of environmental management are substantially strengthened by an understanding of its history; a point of direct relevance to Konso given that a report by the United Nations Food and Agriculture Organisation described the terrace system as offering important “lessons from the past” (FAO, 1990), and given that agricultural practices in Konso have been the subject of research by the British-based NGO FARM-Africa (see Hallpike, 2008 citing FARM-Africa 1993a and 1993b) which produced recommendations for large-scale irrigation projects in the area (Camacho, unpublished report), aspects of which were subsequently implemented. The research reported here helps place such interventions in their historical context, and serves to emphasize that there are many reasons why a community might choose to build or abandon agricultural terraces.

2 Study area. Topography and overview of previous research

The densest concentration of agricultural terracing in the Konso highlands centre on approximately 5°18’30” North / 37°23’30 East, with the entirety of the terraced landscape located within the Konso Special Woreda (district), one of the eight special woredas in the Southern Nations, Nationalities, and Peoples Region (SNNPR) of south-western Ethiopia (Figure 1). Ranging in height from 1400m above sea level (m asl) to 2100m asl, the Konso highlands extend for approximately 200 km^2, and are bounded by the river Sagan to the east and south, by the plains of Gumaide and Lake Chamo to the north, and the Gidole mountains and Woito river to the west. The climate is dry montane type, with rainfall ranging from between 300mm to 900mm per year (Förch, 2003). Rainfall follows a bimodal pattern: a long rainy season (the belg) occurring between March and May when c.70–80% of grain production is harvested, followed by shorter rains (the kiremt) from September to November (Watson, 2009). Rainfall can be erratic, however, with frequent intense storm events and common severe droughts (Förch, 2003; see also Messeret, 1990).

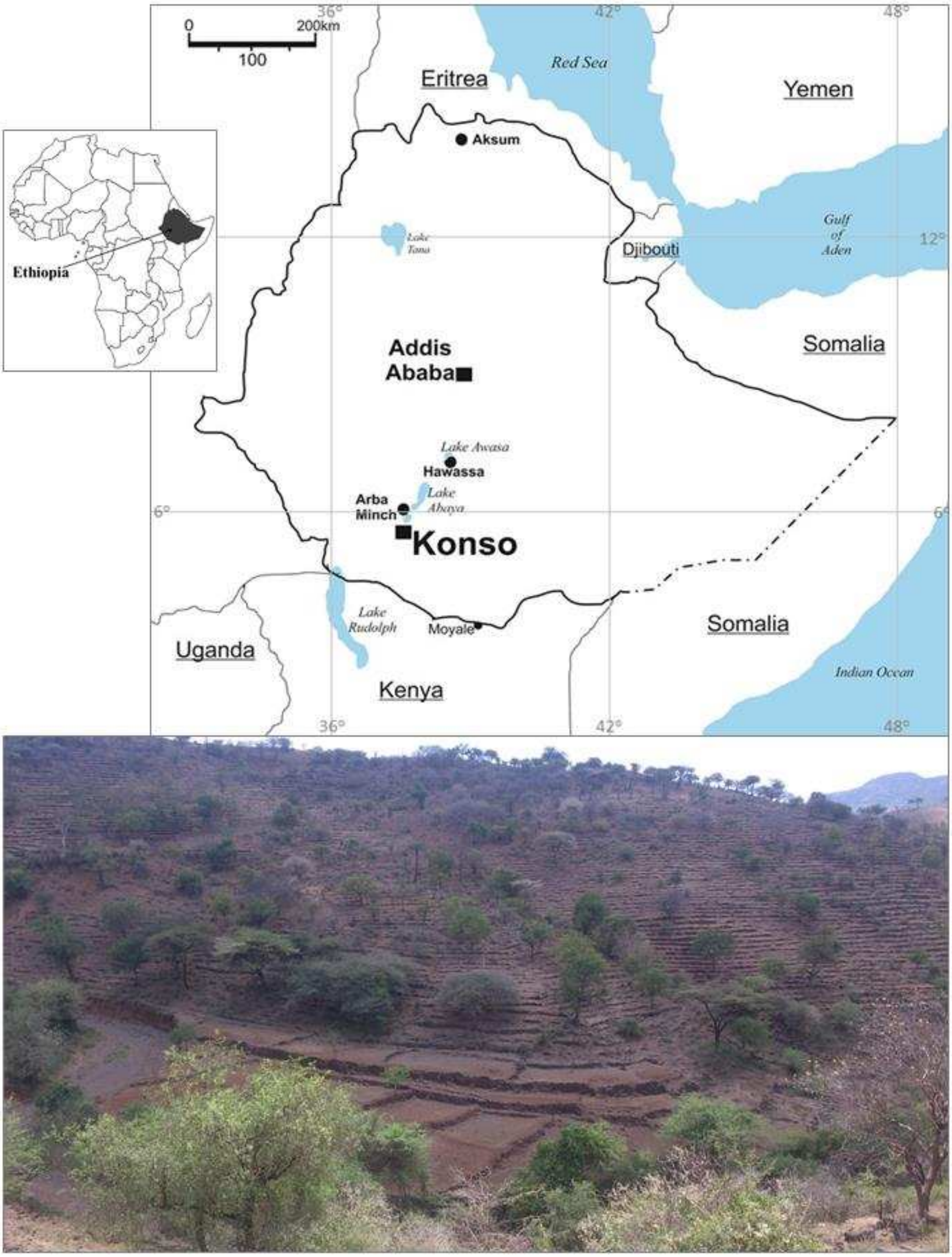

Figure 1. Above: location of Konso in relation to the administrative centre for the region (Hawassa). Below: hillside terraces (background) and yela sediment traps (foreground) in the Sahayto area, located in the northeast of the Konso highlands.

Highlands of this type are highly economically significant in Ethiopia, since nearly half of the country's total area and approximately 95% of the country’s cultivated land lies above 1500m asl (Krüger et al., 1996). This area is also the most populous, with estimates from the 1990s indicating that nearly 90% of the population lived above 1500m asl (Krüger et al., 1996) while approximately 60% of the country’s population live at altitudinal ranges similar to those in Konso: the cool, subhumid agro-ecological zone between 1500 and 2300m asl classified in Ethiopia as Woina Dega (Tadesse, 2010). With temperatures varying from 15 to 33°C these areas are potentially highly productive agriculturally, but are also highly susceptible to soil erosion; a problem considered to be a major threat to agricultural development and food security in highland Ethiopia (ITPS, 2015; Lemenih et al., 2005; Tadesse, 2001). Vertic and argic soils are frequent in stable topographical positions, but the steep topography and the high erodibility of edaphic materials have a major effect on the distribution of fertile soils, with shallow and stoney soils frequently found on hill slopes, thereby creating challenges in maintaining soil fertility.

The construction of terraces is of course a potentially highly effective way of mitigating these risks, and this has prompted - in Ethiopia as elsewhere - an interest in local systems of agricultural terracing that might act as models for erosion mitigation and/or agricultural intensification to maintain soil fertility and achieve higher crop yields (e.g. Bruins et al., 1986; Hogg, 1988; Reij et al., 1996). Given an estimate by the Ethiopian Environmental Protection Authority (EPA) that 80% of the cultivable land in Konso is terraced (EPA, 2004) it is unsurprising that the area has been a focus of interest by proponents of 'indigenous' soil and water conservation (e.g. Adams and Anderson, 1988; FAO, 1990 see also; Grove and Sutton, 1989; Watson, 2009). This having been said, much of the work at Konso that can broadly be categorized under the heading of 'indigenous knowledge' research has explored aspects of environmental and agricultural management other than terracing, including the maintenance of forests as sacred groves, fire breaks and as retreats during military raids (Demeulenaere, 2002); studies into the use of wild foods, particularly in times of drought (Addis et al.; Guinand and Lemessa, 2001); an examination of the value of the so-called cabbage tree (Moringa stenopetala), the leaves of which form an important part of the local diet (Jahn, 1991); as well as more general studies of the agricultural system as a whole (Forch, 2003); and an interview-based project that aimed to study how Konso farmers perceived both local and introduced soil and water conservation techniques (Beshah, 2003).

Importantly, these more recent works can also be contextualized by reference to earlier studies, including the work of six anthropological expeditions to the area carried out between 1934 and 1974 (e.g. Amborn and Straube, 2009 ; Jensen, 1936; 1960; Nowack, 1954; Straube, 1967), not all of which are published, but photographs, sketches, field notes and various versions of an unpublished Konso manuscript are held by the Frobenius Institute library. From this published and archival data it is clear that terraces have periodically been abandoned during the 20th century, and when compared with later sources provide significant data on how this agricultural system has changed through time. These changes include reductions in the level of stock held in Konso, changes in crops grown, and declines in the length and frequency of fallow periods. However, the records also show apparent continuity, for example repeated references to the best maintained and most intensively cultivated terraces being in the northeast of the Konso highlands, though even here there were evidently periodic short-term depopulations, such as the apparent large reduction of the population of villages by up to 75% in the early to mid-1950s attributed locally to droughts. It is argued here, therefore, that interdisciplinary research that compares historical data with modern observations are better able to assess the operation and future sustainability of terrace systems; a point returned to below.

This having been said, the main focus of the current paper is to demonstrate that physical data in the form of soil descriptions and geochemistry contextualized by stratigraphy can play a significant role in achieving this long-term perspective, and can provide pivotal details not recorded by other sources, even in comparatively well-studied locations like Konso. Indeed, it is perhaps surprising, given the amount of previous work drawing attention to the extensive terracing at Konso, that until the current study no previous work had looked at the construction of terracing directly. It is therefore assumed the landscape is comprised predominately by bench terraces(e.g. Förch, 2003; WOCAT, 2010); a reasonable conclusion given that some sources describe terrace construction as starting with the excavation of a 'foundation trench' (Beshah, 2003 uses the term "basement") into which the lower courses of a dry-stone wall are inserted, which is then followed by the dragging of soil from upslope to create a broadly level cultivation platform, with subsequent terraces being built progressively up the slope (cf Amborn, 1989; e.g. Beshah, 2003). Although this does indeed broadly describe one method of building a bench terrace (Figure 2), aspects of this account seemed questionable, particularly the function of the wall foundation cut. It is therefore worth attempting to confirm or refute this characterisation, especially given that Beshah's informants merely described this process, and noted that although old terraces are still maintained, no members of the community have participated in the building of new terraces.

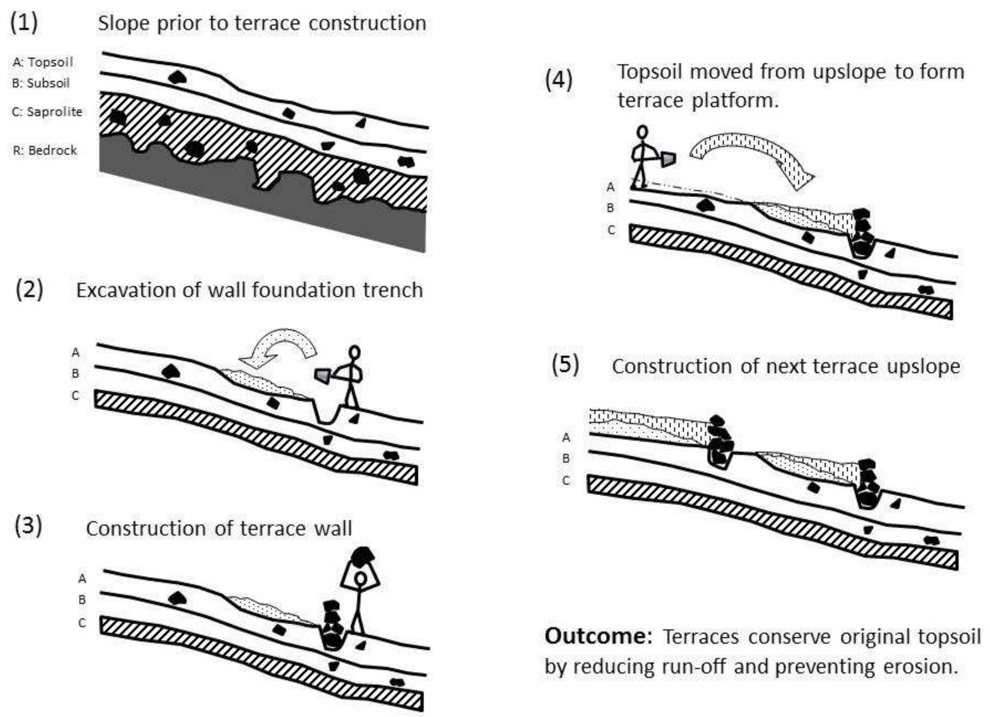

Figure 2: Schematic representation of the process of hillside terrace construction as described to Beshah (2003). Compare this schematic to that based on excavation, Figure 4.

3 Methods

The work reported upon here focused on terraces located on a west-facing hill slope above the Kilkilo river basin in the Sahayto area (Figure 1), with this area chosen for three reasons. Firstly, because the northeastern corner of Konso contains the highest concentration of historic walled towns, is said by some oral traditions to be the historic heartland of the Konso settlement, and is the area consistently described by visitors from the 1950s onwards as containing the densest and best maintained terraces. Secondly, the area contains both terraces that are currently cultivated and examples that are said to have remained uncultivated for 10 years or more. Finally, the area includes both hillside terraces and riverside sediment traps, in many places with these two types of fields physically abutting one another.

Prior to excavation, the geology and geomorphology of the catchment were surveyed, with these surveys including examinations of examples of terrace profiles exposed by gullies, as well as sediment trap profiles exposed within the sides of the river bank. These surveys noted land use, vegetation, parent material, erosion features, depth of sediment profile, macromorphological signals of horizonation and polycyclism (i.e. more than one cycle of soil formation within a soil profile) and the possibility of stratigraphic sequencing. From the results of the survey five locations considered representative of the different geomorphological positions and stratigraphic sequences were selected for excavation, with excavation comprising either the cutting back of faces of existing exposures to remove any potentially disturbed or contaminated deposits, or the excavation of trenches close to these exposures to enable the safe examination of undisturbed terrace walls and associated deposits. The resulting profiles were all at least two meters wide, are referred to here as 'sections', and the deposits within them assigned arbitrary numbers starting at 100 to distinguish these from investigations undertaken by a pilot study in 2010. Details of two of these sections are presented here as the most illustrative and informative, and comprise one examining a terrace in slope positions (Section 118), located at 5°19'44.3"N/37°27'22"E, and a second investigating a riverside sediment trap (Section 102) located at 5°19'33.1"N/37°27'24.4"E.

Studies of agricultural fields are generally controlled by comparison to uncultivated contexts. However, no representative non-terraced or uncultivated test plots were available, as in the study area essentially all land was either currently cultivated or had been in the past. Soils in two 'sacred forests' located on hilltops nearby were surveyed as a means to understand uncultivated pedogenesis and stratigraphy. However, these soil sequences are not suitable as control locations for this study, given that their geomorphological positions were not equivalent and they were not within the same catchment of our study area. The environmental conditions and the processes undergone by these soils were therefore probably different, and they are considered inadequate as a background setting. The presence of some relict pedogenetic features of the original dynamics below terraced layers in the surveyed slope soil profiles has nevertheless allowed this shortcoming to be partially addressed.

Stratigraphic methodology, soil sampling and laboratory methods are described in detail in the online supplementary material (SM1).

4 Results

4.1 Stratigraphy and soil descriptions

Section 118 stratigraphy and pedological features has been chosen among all the hillside locations excavated, since this is the most illustrative and is the only location to include unambiguous evidence of earlier terraces buried beneath the terrace walls that are currently visible at ground level. Its stratigraphic sequence (Figure 3) shows a layer of weathered saprolite above the fresh basaltic bedrock, assigned record number (265). This is physically beneath three later deposits: former terrace soils (267) and (272) and former dry-stone terrace wall (266). Stratigraphically, the sequence of deposition of these three deposits is ambiguous, but the most likely sequence is that wall (266) was built to contain terrace soil (267), and that the wall was subsequently buried on its downslope side by the deposition of (272). Importantly, former terrace soils (267) and (272) are distinct in terms of color, the presence of charcoal, and the sharpness of their boundaries to the underlying saprolite (see soil horizons descriptions in online supplementary materials, SM2), demonstrating that they are not two parts of the same deposit that has been truncated by the excavation of a foundation trench for the construction of wall (266).

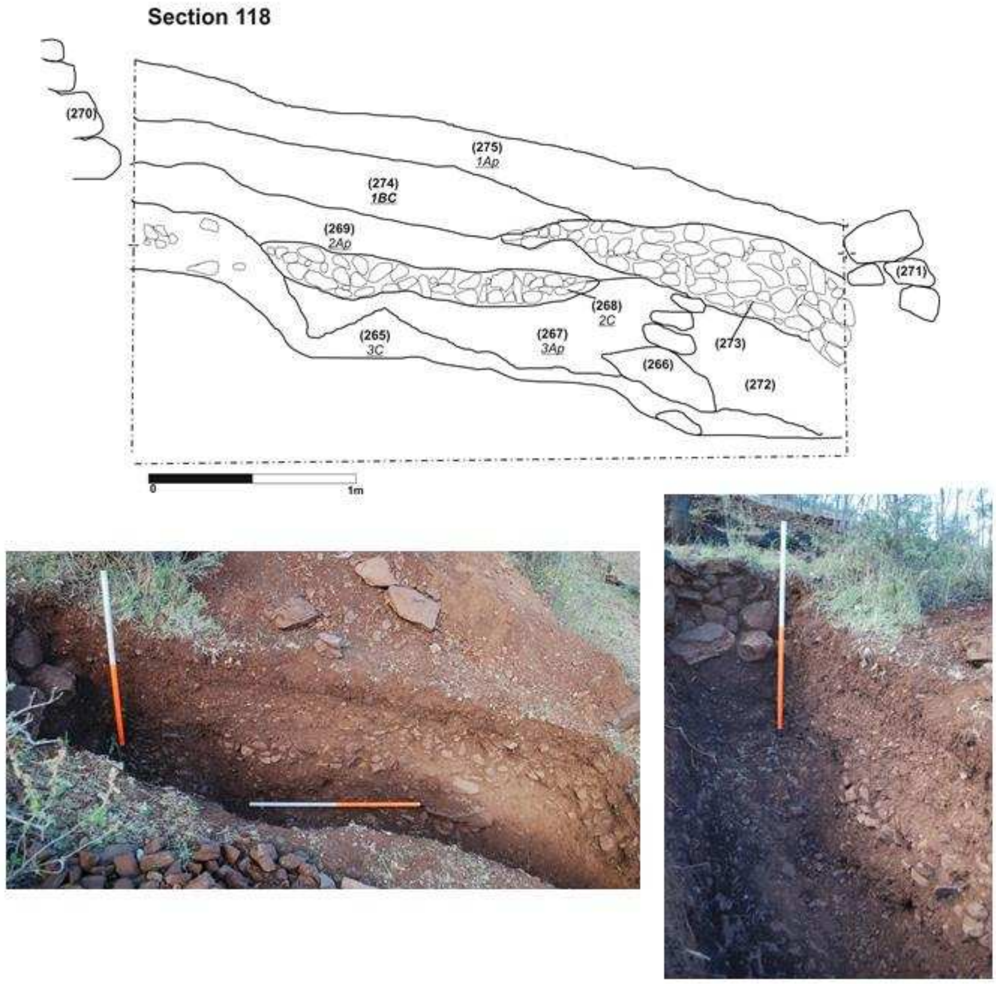

Figure 3: Scale drawings and photographs of hillside terrace deposits within Section 118. Photographic scales all 1m.

These observations have two significant ramifications. First, that wall (266) was built directly on to either exposed bedrock or exposed relic saprolite, meaning that the original topsoil and subsoil had been eroded away prior to the construction of this terrace wall. Second, the lack of a subsoil layer between saprolite (265) and the physically overlying terrace soils (267) and (272) demonstrates that these palaeosols have not developed in situ within the terrace, and instead have been deposited. Taken together this suggests at least two broad phases of erosion and deposition took place, with the first phase removing the topsoil and subsoil to expose the saprolite or bedrock, while a subsequent later phase incorporated material into the terrace formed by wall (266).

Thereafter terrace soil (267) was partially buried by stoney layer (268), which was in turn buried by terrace soil (269); a sequence of deposition that is later repeated by the deposition of stoney layer (273) and the overlying former terrace soil (274). Seen in relation to the downslope terrace riser wall (271) it is clear that the upper of the two stoney deposits is directly associated with the construction of wall (271), and it is therefore surmised that the earlier stoney layer and its overlying palaeosol also represent the remains of a constructed terrace; the (presumed) wall for which may have been removed when (273) and (271) were deposited. Construction of this terrace was then completed by the deposition of the layer that also forms the modern topsoil (275) which stratigraphically postdates palaeosol (274) and physically buries stoney layer (273), thereby creating a relatively stone-free cultivation layer. Although on the basis of stratigraphic data the upslope terrace wall (270) could have been built immediately after the deposition of former cultivation layer (269) it is equally possible that this wall sits within a trench cut that post-dates current topsoil (275); an interpretation that would fit with observations from other excavation sections, and which could be regarded as receiving support from the descriptions of terrace construction recorded by Amborn (1989) and Beshah (2003 105).

Section 118 thus shows the construction of three and probably four terraces: first the terrace associated with wall (266), then that represented by stoney layer (268) and the subsequent palaeosol (269), followed by the terrace bounded on its downslope side by riser wall (271), and finally by the construction of wall (270). In terms of pedegenic classification the deposits thus form a 1Ap, 1BC, 2Ap, 2C, 3Ap, 3C, R sequence. This is perhaps clearest if illustrated, and a simplified schematic of this sequence is presented in Figure 4.

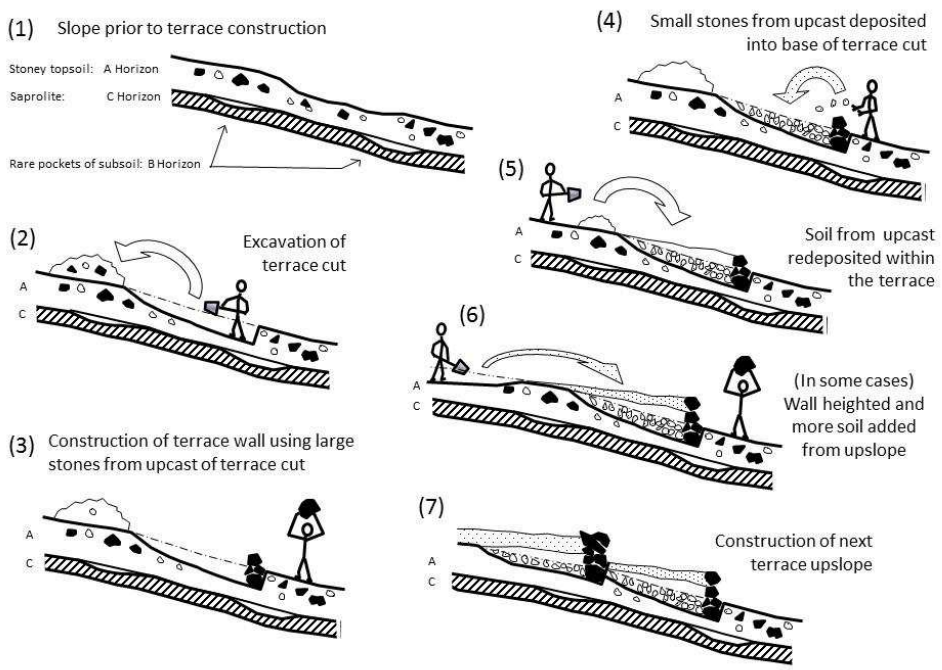

Figure 4. Sequence of hillside terrace construction as revealed by stratigraphy and soil descriptions, demonstrating loss of original topsoil and most subsoil prior to terrace construction, and suggesting that terracing was undertaken partially to reduce the number of stones in the upper rooting zone. Compare this sequence to that described during interviews shown in Figure 2.

Section 102 (Figure 5) is located immediately adjacent to a seasonal river, the bank of which was cut back to reveal the depositional sequence. Neither bedrock nor saprolite were revealed in this section, with the earliest deposit being a dark brown alluvial (i.e. water deposited) layer (157). Data confirming the alluvial origin of this deposit are presented below, but support for this conclusion is also provided by the stratigraphic relationships between the later walls and sediments within this profile. This is because the drystone walls all consist of a single line of facing stones backed by gravel packing, and are inclined at an angle of between 60 and 75˚, meaning that these walls are not self-supporting and rely on the deposits of fine material behind them for their integrity. Each wall is then subsequently buried by later deposits of fine material, which are themselves contained by inclined walls. The only process that accounts for these observations is if each wall is built incrementally by no more than three courses at a time, since this would seem to be the maximum number of courses that could be supported by the gravels placed behind and beneath the inclined drystone courses; these deposits of gravel typically extending for no more than 60mm behind the wall. Fine sediments entrained within running water are then captured behind the wall, permitting more drystone courses to be added and subsequent alluvial sediments to be captured. Once this manner of sediment accumulation had been identified, questions regarding this construction method were asked of local informants, who noted that this technique was now rarely used but that a field of this type is known as a 'yela'.

The earliest yela wall revealed in Section 102 immediately follows the deposition of the earliest sediment in the sequence: (157). This wall, (117), was supported by gravel packing layer (153), with both the drystone face of this wall and its associated packing periodically extended as alluvial layer (116) gradually accumulated. Following the accumulation of (116) a change is the depositional regime deposited the gravelly and pebbly deposit (155), which was followed by fine material (154), the latter very similar to the earlier deposits (116) and (157). These deposits all accumulated behind the earliest wall; the single course of stones marked on the section drawing at (100) being merely the surviving upper course of the wall that started life as (117). Thereafter, this pattern of sediments being deliberately captured behind drystone walls continued with the construction of wall (138) above former yela field deposit (154), and the accumulation of predominantly fine material against the face of wall (117)/(100): in chronological order (151), (150), (149) and (148). Following a period in which (148) was presumably farmed, a further batch of alluvial sediments were captured, starting with (144) and ending with (141), after which wall (137) was built along broadly the same orientation as the pre-existing but now almost entirely buried wall (138). Finally, the current topsoil (118) was deposited.

Stratigraphically, then, this one cross-section includes elements of six distinct yela fields (i.e. one field each side of the three walls), or seven if it is assumed the lowermost deposit (157) also accumulated in a yela for which the associated wall falls outside the limits of the excavation. However, based on the morphological characteristics of the soil core, it is possible to identify two main soil units. The upper one is represented by the reddish clays interspersed with gravel layers that postdate the completion of wall (117)/(100). The six soil horizons postdating the construction of wall (138) thus form the upper soil unit (in pedogenic terms: 1Ap, 1Bk, 2Ap1, 2Ap2, 2BkC, 3B1, 3B2) from 0 to 105 cm depth, differentiated mainly by textural changes and sometimes separated by gravel and stone lines, the most visible one being at 35 cm depth (143; a 2BkC horizon). The deposition of this layer appears to have been an event of sufficient force to scour a channel into the underlying sediment (144). Colour, structure and consistency are quite homogeneous in this upper soil unit.

Below this upper unit, and separated from it by a gravel and stone layer at 100-108 cm (4BkC; i.e. layer 155), there is a dark, clay rich, carbonated layer that extends from 105 cm to 200 cm depth, that accumulated during the process of (110)/(117) wall's construction. It has been identified as a former yela surface due to its clear and flat upper limit, and because it ends in a terrace wall. Two soil horizons have been identified in this unit. The upper one (5Ap1) is a black clay-rich horizon, with macroscopic carbonate precipitates. Underlying this there is a more reddish soil horizon (5Ap2), also clay rich and with some small Fe oxides nodules. An analogue sequence has been identified in other yela fields within the same catchment. Charcoal has been observed throughout the soil profile, although these fragments are below 1 mm in size and highly degraded, so could not be isolated, quantified, or used for anthracological identification.

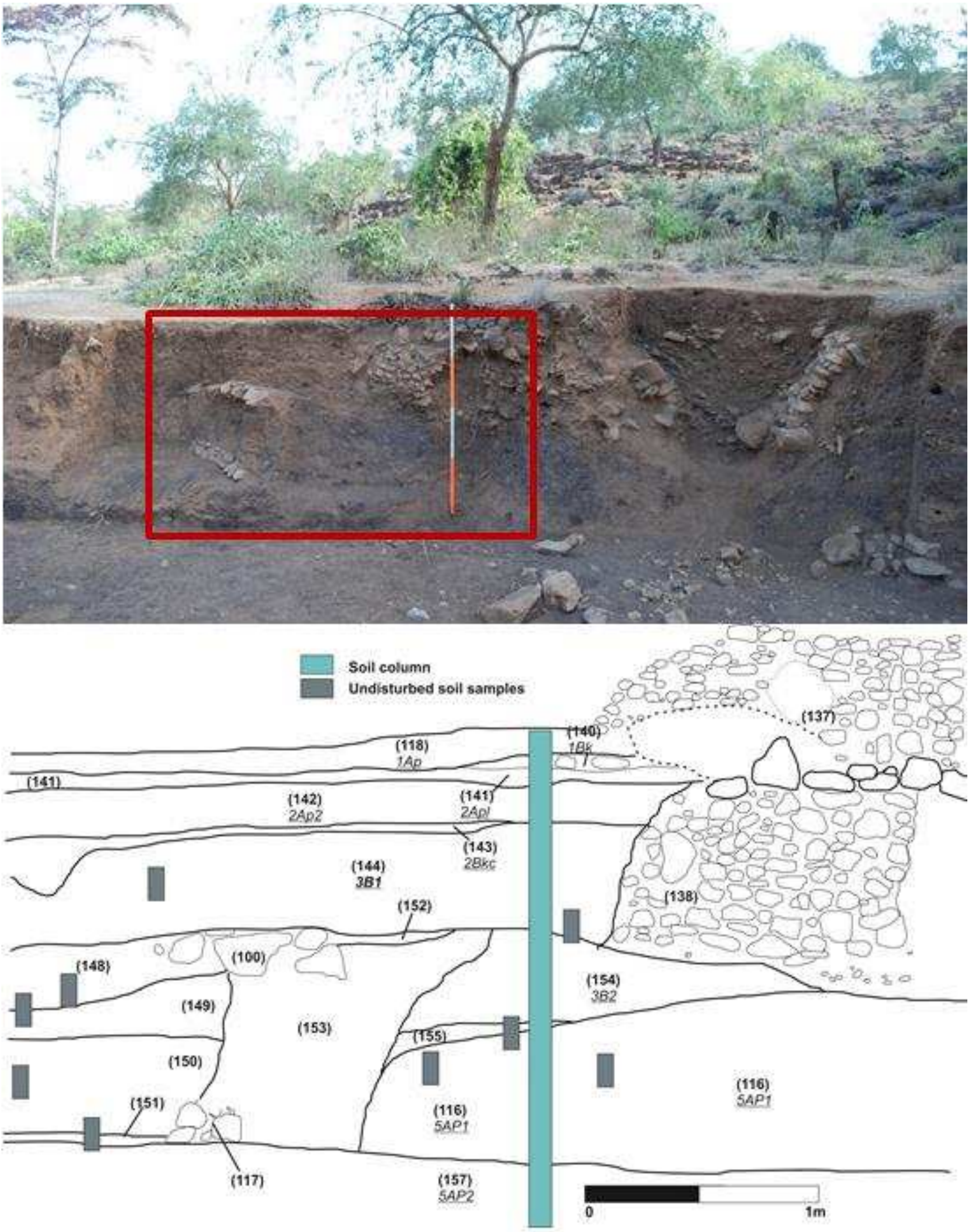

Figure 5: Photograph and scaled drawing of east-facing Section 102. The blue rectangle indicates the position of the soil sampling column, and the grey boxes mark the undisturbed samples collected for micromorphological analyses. Numbers in brackets indicate the depositional events as described in the field. Note that the drawing shows oblique segments of the drystone walls (137), (138) and (117) and the packing deposit behind wall (100)/(117): (153). The drawing does not show true cross-sections of these walls, therefore. The seasonal river at this location flows from north to south. Photographic scale 2m

The marked differences between the upper and lower soil units (see a list of characteristics by soil horizon of sections 118 and 102 in the supplementary material, SM2) suggest a change in the broader depositional conditions between the time that the lower and upper units were formed. To find out which processes caused these changes data provided by the soil micromorphology, geochemistry and soil organic matter composition were used.

4.2 Soil micromorphology

The basic coarse rock and mineral components identified in the thin sections (mainly basalt, feldspar and calcite) were consistent with the geological survey, macromorphological observations and the pXRF analysis. A summary of the main micromorphological features can be found in the online supplementary material information (SM3). Micromorphological differences within the Section 102 can best be expressed by the differences in the fine material (b-fabric), the presence of charcoal, the coloration and presence of the redoximorphic nodules, and the overall microstructure.

In general terms, Section 102 displayed subangular blocky peds separated by inter-pedal channels with intra-pedal chambers and vughs (SM3). Granular peds identified in several samples are thought to be artefacts of sampling and slide manufacture due to high levels of gravel causing poorly aggregated soils. Modern root material was observed in the upper deposits and identified due to the level of birefringence (Babel, 1975 454). At the bottom of the section (116) there is evidence of increased clay content, with the formation of both subangular and angular blocky peds, the latter separated by accommodated planes. Deposit (116) also contains unmistakable 'onion skin' formations around small fragments of sub-rounded, highly weathered basalt indicative of in situ weathering. Calcite inclusions (SM4: Figure 1A) were exhibited together with calcite coatings both on and within the degraded basalt (fine clay) of (116), however crystalline calcite coatings and inclusions were only observed in two deposits: (154) the final layer in the same yela field as (116), and in (150), an early deposit in the layer built immediately downstream of the yela containing (116) and (154). This suggests slower evaporation had taken place in deposits (150) and (154) and may relate to differences in temperature, thus effecting evaporation rates (Durand et al., 2010 116).

The appearance of dotted fine material under PPL indicates micro-charcoal (<50 µm) was present in all contexts and points to either a drier environment prompting wild fires or anthropogenic burning activity (Macphail and Goldberg, 2010). There was micro-charcoal present within the fine matrix; however it was not identified in the void structures, dusty coatings and calcite inclusions, indicating that it was incorporated prior to the deposition of sediments with the yela fields and is not a post deposition intrusion via soil water translocation. Larger fragments of charcoal (SM4: Figure 1D) were identified in the upper part of event (116), and at the diffused boundaries between events (154) and (155), indicating deposition during the later formation of (116) that continued during the subsequent deposition of (155). Furthermore, the diffuse boundaries between (116) and the subsequent depositional events (154) and (155) indicate that there have been both physical and chemical interactions. The b-fabric (XPL) indicates shrinking and swelling, due to wetting and subsequent drying activity, had occurred in events (154) and (116), with parallel striation (SM4: Figure 1E) evident in events (154) and (116), and grano-striations (SM4: Figure 1D) in (116) (Dalrymple and Jim, 1984). Striations and grano-striations are typical vertic features (Kovda and Mermut, 2010).

Soil features related to hydrological conditions were displayed in the form of redoximorphic nodules and hypo coatings (SM4: Figure 1B and C) throughout the soil profile. The development of these features are characteristic of Fe/Mn depletion and the reduction, translocation and precipitation of these elements within the fine material due to reduction/oxidation conditions occurring through repeated cycles of wetting and drying (Stoops and Eswaran, 1985); conditions that have been identified in irrigated field systems (Lee et al., 2014). However, layer (116) displayed a distinctly purple coloration, indicating an increase in manganese (Mn) concentration in the nodules. Mn reduces before Fe in redox conditions, this being based on Eh and pH of the soil solution, reducing from Mn^{4+} to Mn^{2+}. Similarly Fe precipitates out of soil solution before Mn in oxidizing conditions, thus larger amounts of Mn can translocate in prolonged waterlogged conditions (Lindbo et al., 2010). Fragmented dusty clay coatings substantiate the characterization of vertic soils in Section (102).

These were also identified in (154), (150) and (144) where fragmentation had occurred. According to Nettleton and Sleeman (1985) churning processes associated with vertic soils can cause the fragmentation of coatings.

4.3 Soil Geochemistry

The depth variations of the main physico-chemical soil properties and elemental composition recorded from the soil column at Section 102 are depicted in online supplementary materials (SM4: Figure 2). The proportion of gravel (grain size > 2 mm) in the column ranged from 9.3% (SM4: Figure 2A) in the deeper part of the soil - (157) and (116) - to 50.3% at 105 cm, coinciding with the (155) stone and gravel layer above layer (116). High gravel contents are also observed at 35 cm [47.6%, corresponding to deposit (143)] and at the soil surface (48.1%).

The soil within the Section 102 sample column is generally alkaline (SM4: Figure 2B), pH_w ranging from 7.9 at the soil surface to 8.7 at 105-110 cm. Below 110 cm, pH_w decreased again to 8.1-8.2, probably related to higher carbonate contents. The calcium carbonate is probably provided by irrigation water and had precipitated secondarily in the soil, producing Ca enrichments with respect to Sr and Al (Ca/Sr and Ca/Al molar ratios (SM4: Figure 3A and B), at 35-40 and 110-125 cm, were the carbonate content is larger probably as a result of a more prolonged irrigation and/or evapotranspiration. The total C content suggests also a higher abundance of calcium carbonate in this part of the soil. Carbon concentration ranges between 7.0 and 23.5 g kg^{-1} being the bottom part of the soil [110-200 cm, corresponding with (116) and (157)] deposition events as seen in SM4: Figure 2C) more C rich (19.7±3.4 g kg^{-1}) than the upper soil layers (9.0±1.9 g kg^{-1}). Total N is generally low, decreasing with depth from topsoil (1.0-1.3 g kg^{-1} in the upper 20 cm) to 70 cm (where the N contents are below the detection limit) and then progressively increases with depth (SM4: Figure 2D). The C and N content are correlated (r^2=0.70) in samples from topsoil to 105 cm depth [(155) deposit], but not in the bottom part (110-200 cm), where C is proportionally higher. Despite this evident $CaCO_3$ accumulation, crusts were not observed in the Section 102 soil. This could be due to the elimination of incipient carbonate crusts by cultivation or because of upward movement of the rooting depth as a consequence of deliberate annual sediment inputs. Other yela soils surveyed in this area, however, displayed cemented carbonate crusts, their formation perhaps suggesting abandonment periods, as discussed below.

The depth variation in the Ti/Zr ratio (SM4: Figure 3E) reflects that the parent material source(s) has changed through time, from a highly uniform composition within the deeper soil layers [(116) and (157)], to a more variable curve from 105 cm towards soil surface. This is in agreement with the changes in gravel content in the soil, and therefore probably reflects a higher proportion of basaltic unweathered materials in these upper soil layers. The K/Rb molar ratios (SM4: Figure 3F) depict a similar depth variation curve (r^2=0.67).

The Fe/Ti ratios show an irregular increase with depth from the soil surface to 105 cm (SM4: Figure 3C), therefore displaying translocation of Fe in this part of the soil, perhaps as a result of irrigation processes. The bottom part of the soil (110-200 cm), however, showed small variations for the Fe/Ti ratios, suggesting that Fe depletion due to redox processes is negligible. The bottom soil unit showed relatively high contents of Mn with respect to Ti concentrations (SM4: Figure 3D). Moreover, Mn and C concentrations are strongly correlated (r^2=0.87), suggesting that Mn abundance is driven by redox processes: Mn would be reduced and released from basalt due to weathering under temporarily water saturation conditions, combined with anaerobic microbiological activity and relatively high OM contents (Hylander et al., 2000; Kabata-Pendias, 2010). When the soil becomes drier and oxidizing conditions are re-established, Mn would precipitate as Mn oxides within the soil, because the drainage conditions are unfavourable to leaching. In agreement with this, the Fe content is strongly correlated ($r2=0.84$) to Mn concentrations in the upper part of the soil (0-110 cm) while not in the bottom part, indicating that Fe and Mn post-depositional dynamics are decoupled in (116) and (157) layers, likely as a result of different hydrological conditions.

4.4 Composition of the soil organic matter

The sum of the products that are most likely derived from pyrogenic organic matter (such as charcoal) in the Section 102 soil column; i.e. benzene, benzonitriles and naphthalenes (Kaal et al., 2009) show a marked increase around 110 cm depth, from 18.2 ± 7.0 % to 38.7 ± 7.5 % (SM4: Figure 4A). This coincides with a major decline in the relative proportions of products of degraded OM and OM of microbial origin (furaldehyde, phenols and N-containing products excluding benzonitriles; (furaldehyde, phenols and N-containing products excluding benzonitriles, as indicated by Buurman et al., 2007) from 26.2 ± 3.2 % to 16.7 ± 2.2 % (SM4: Figure 4B). Hence, the pyrolysis fingerprint allows identification of two different sections within the soil profile: a bottom layer where pyrogenic OM is relatively abundant and a top layer where OM composition is mostly controlled by microbial reworking. This boundary coincides more or less with the increase in C content at 110 cm depth, suggesting that the relatively high C content recorded in the (116) and (157) depositional events of Section 102 is related to the relatively recalcitrant nature of pyrogenic OM, or Black C (Goldberg, 1985; Schmidt and Noack, 2000). Indeed, the amount of pyrogenic OM is correlated to the C content ($r2=0.71$) in the samples below 110 cm. Furthermore, pyrogenic OM is known to be a very strong black pigment in comparison with other forms of soil OM, which is consistent with the Munsell colour data. Products of relatively intact plant-derived OM such as the guaiacols from lignin, indole from vegetable proteins or pyrans and anhydrosugars from polysaccharides (Abelenda-Suárez et al., 2011; Buurman et al., 2007) were scarce or absent, and concentrated in the top 40 cm of the profile (1.0 ± 0.2 % compared to 0.4 ± 0.3 % below that depth) which is indicative of a strong impact of OM degradation (SM4: Figure 4C).

5 Origin and evolution of the system: from valleys to slopes

The molecular signal of the OM and the information obtained from micromorphological analyses in Section 102 indicates that fires were frequent in the catchment at the time that the earliest layers of the Section 102 yela fields were deposited. According to previous studies of oral histories and traditions (Tadesse, 2010; Watson, 2009), settlement and ownership of land was established by the first settlers by igniting fire on the forested landscape, with the place where the fire stopped then claimed as the boundary of their land. Although this story forms part of the oral tradition and should not be taken too literally, it might indicate that forest clearance by fire was a feature of early settlement in this landscape. In fact, the black horizon at the bottom of earliest yela fields within Section 102 was not only observed at this location: during the visual survey of the area, similar black layers, albeit with different thicknesses, were observed in other yela fields upstream. This means that the burning was not a local event affecting the current site only, but a phenomenon that affected the whole catchment. From the low amount and small size of gravel in the bottom part of Section 102, it is deduced that the yela did not initially receive sediment directly from the adjacent hillside: only material that eroded into the watercourse and was then transported within the river flow was captured. Careful construction of artificial offtakes (dotatta) and channels (kaba) ensured that flow rates leading to yelas were kept low, and produced an efficient granulometric selection, allowing for sedimentation of only fine materials as identified by grain size analysis. The sedimentary material recorded in the earliest yela layers was thus composed mostly of clay and pyrogenic OM, lacking coarse fragments of transported geological materials.

As a result of extensive and/or repeated fires within the catchment it seems that the former vegetation was comprehensively removed, perhaps being today exemplified by the small areas of 'sacred forest' that still exist on hilltops. Removal of vegetation would have brought increased erosion and its associated risks (Figure 6), exacerbated by the lithology of the soils parent materials: weathering of basalts under fluctuating hydrological regimes and relatively warm temperatures producing high amounts of smectitic clay (Eggleton et al., 1987; Nyssen et al., 2000; Vingiani et al., 2004) which may provoke swelling and shrinking pressures and make slopes unstable. This would have contributed to destabilization of the slopes, increasing gully erosion and the risk of landslides (Frankl et al., 2012; Heshmati et al., 2013; Kerr, 1972). The (155) stone and gravel layer at 105 cm depth in Section 102 evidences a higher energy erosive event that contributed coarse material to the surface of the yela, in a process consistent with the dynamics of a deforested landscape, and likely would have caused damage to fields and crops (Figure 6). Other studies in East Africa have stressed the widespread incidence of land degradation processes due to human activities, particularly deforestation. These comprised soil erosion (Billi and Dramis, 2003), chemical soil degradation (FAO and ITPS, 2015; Lemenih et al., 2005) and the destabilization of the water budget (Legesse et al., 2003). In the north western Ethiopian highlands Zeleke and Hurni (2001) reported a serious trend of land degradation resulting from the expansion of cultivation on steep slopes at the expense of natural forests, and Bewket and Stroosnijder (2003) noted the problem of downstream sedimentation caused by upstream degradation resulting from land use/cover changes, that could create extensive flooding and damage on important agricultural lands when not properly managed.

Since the stratigraphic sequence of the investigated hillside terraces shows that the agricultural landscape expanded up the slopes from the valley bottom (Figures 3, 4 and 6), this suggests the earliest terraces would have been conceived specifically as a means of protecting the agriculturally important and irrigable yela fields. Furthermore, the stratigraphy of the excavated locations, illustrated by the sequence of Section 118, shows that most of the terraces surveyed in the catchment have been constructed directly on the saprolite, indicating that the original slope material was already eroded when the terraces were built. This supports the idea that yelas were the key agricultural resource in an early stage of the system, as they were constructed and heightened by capturing topsoil that was being eroded from the non-terraced slopes upstream.

It should be stressed that the existence of yelas is acknowledged in the existing literature, but it is noteworthy that they are devoted very little attention in the published accounts. Amborn (1989), for example, mentions fields in Konso "consisting of thick alluvium which is highly valued", and cites Kuls (1958) and Straube (1967) to conclude that "the alluvial deposition of minerals has a manuring effect"; an idea not specifically tested for in the geochemistry reported here, but one worthy of consideration in future studies examining the productivity and sustainability of the yela fields in particular, and of the Konso agronomy as a whole. Moreover, it seems clear that previous work did not consider how these yela fields came to exist, with Amborn (1989) noting that in these irrigable riverside plots the "ground is carefully levelled"; a statement that is both accurate but susceptible to misinterpretation: the fields are not laboriously levelled after the alluvium has been deposited, but are level as a consequence of the careful control of water and the sediments entrained within it. Beshah (2003), in contrast, does mention "flood harvesting" and note that alluvium is deliberately captured in some fields, but the existence of these sediment traps is only noted in the far northwest of the Konso landscape.

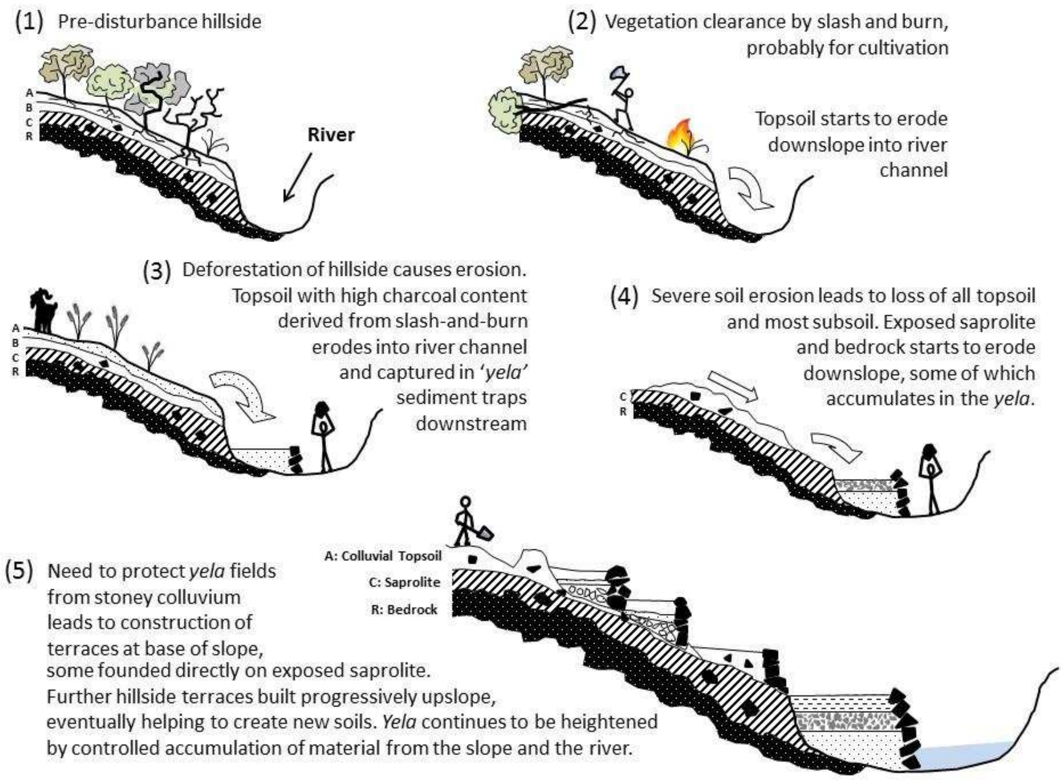

Figure 6: Schematic representation of the landscape development sequence in the Sahayto area, northeast Konso.

Having noted that the earliest hillside terraces were built to protect these yelas, terracing would have acted to stabilize slopes and helped to manage runoff and soil eroded from an upslope position; controlling deposition in the lower valley. The increase in the cultivable area would have come as a secondary benefit, as terraces provided stable surfaces, thus allowing the 'creation' of new soils. Furthermore, these new soils created on the slopes would act as a new, managed, sediment source for the yelas immediately below them. In this sense, Konso terraces constitute a sophisticated type of runoff farming: soil was grown, eroded and transported downslope in a controlled manner together with rainwater, and then harvested in yelas. Examples of analogous water and soil harvesting strategies can be found in other East African systems (see, e.g. Bruins et al., 1986; Reij et al., 1996; and Stump, 2006), and in archaeological and currently farmed sites worldwide, as shown e.g. in Ashkenazi et al. (2012) et al. for the Negev Desert; and Norton et al. (1998) and Sandor et al. (2007) for North American arid zones. An extensive review can be found in Barrow (2014).

In the upper part of the Section 102 yela sequence, above the stoney layer (155), the geochemical and micromorphological signal is quite different: pyrogenic OM is scarcer, and the amount of gravel increases progressively towards the soil surface. There is also evidence of a change in the sedimentary parent material, with a higher proportion of fresh basalt fragments. It seems that the hydrological regime of the yela had changed, displaying a Fe-oxides red coloration compared to the black coloration below, and exhibiting a decrease in C and Mn oxides. The increased amount, larger size and angular shape of the gravel in this part of the soil would indicate that the material would not solely have derived from the river, since the irrigation method prevents the transport of coarse rock fragments from the river into the yela, as commented above. Rather, by this period the yelas were also receiving material from the slopes due to runoff. Nonetheless, the lack of rock fragments bigger than 2-3 cm would point to an already controlled water runoff flow: the capture of predominately fine material in the yela indicates that the risk of direct inputs from the adjacent hillsides had been mitigated by this time, i.e. after the period in which hillside terraces were being constructed.

At 35 cm depth in Section 102 - depositional event (143) - a new stone layer indicates a further high energy erosive process, perhaps related to a deterioration of the terraces upslope, and could suggest a temporary abandonment of this agricultural land. This is in agreement with the polycyclic soil sequence of Section 118, in which clear morphological and stratigraphic evidence for the continued construction of new terraces above earlier examples were observed. In addition, the depth variation of the Ca content respecting to Sr and Al (Ca/Sr and Ca/Al molar ratios) in the Section 102 column sample showed higher values at 35-40 cm and 105-130 cm depth, coinciding with both stone layers and immediately underneath them, suggesting more prolonged or intense evapotranspiration periods. This might be in agreement with the conditions prompted by a temporary abandonment. However, if this abandonment did occur it cannot have spanned a prolonged period, as otherwise the absence of tilling and the concomitant slow recovery of vegetation would have led to the formation of cemented carbonate crusts (García-Ruiz and Lana-Renault, 2011; Lasanta et al., 2000) that are absent in the Section 102 soil. Hardened carbonate crusts were observed in other abandoned yelas during the visual survey and these were also identified in subsurface positions in currently farmed yelas.

6 Implications for land management

The anthropological, geographical and agronomic aspects of the Konso terraced system have been extensively studied in the last decades. In all this previous work, soil erosion has been named as the largest threat to agriculture development (Tadesse, 2001, WOCAT, 2010) and avoiding it has been said to be the main objective of terrace construction in the traditional system. However, the work presented here demonstrates that the system of hillside terraces for which the area is justly famous was not designed from the outset as an improved soil conservation strategy; instead it was created when the hillside soil resources had already been exhausted through erosion. Therefore, erosion has not only been the trigger for the inception of the Konso system but the foundation of its productivity: it was engineered for taking advantage of erosion by controlling it, first by harvesting soils that had washed into watercourses by capturing these within irrigable riverside sediment traps, and then by effectively 'repopulating' the denuded hillsides with new soils through the construction of hillside terraces. From this new perspective, soil erosion has been a necessary enemy which, while managed, has constituted an agronomic resource, the system having initially relied on soil erosion to be productive, and the community having apparently only begun the process of protecting the hillsides in order to protect the productive alluvial fields that were the legacy of that first phase of erosion.

It is thus noteworthy that modern studies and assessments have up to now focussed solely on the hillside terraces, which were assumed to be the key agronomic resource of the system, while yela fields, which have been demonstrated in this work to have been an essential resource in the past, have been mostly overlooked. That is because previous studies did not always recognise that the 'terraces' next to rivers and adjacent to streams in hillside valleys were distinct from the hillside terraces that surround them. It is stressed here, however, that this oversight is understandable, and indeed the only reason that the current project recognised the former – and possibly current – importance of the yelas was because it had the stated aim of understanding how the terrace system was originally designed to function, and because to do this it sought to understand how the system changed through time.

Future research into the productively and sustainability of the Konso system should thus certainly approach the yelas as a distinct field type and help design future management plans accordingly. It is conceivable, for example, that it may actually be beneficial to tolerate a certain amount of hillside soil loss in order to maximise their productivity; a position that would stand in marked contrast to projects designed to limit soil erosion through reforestation (e.g. Bishaw, 2001; Jagger and Pender, 2000; see also EPA, 2012; Watson, 2009; Yiman, 2011) or via the construction or maintenance of terracing or bunds (e.g. Liniger et al., 2011;WOCAT, 2010).

Fundamentally, this in essence also means recognizing that no one type of terracing is suited to all landscapes, and that all resource use strategies – including terrace systems - change through time. There are many ways that this could be illustrated through reference to the data presented here, but one way of doing so would be to note the apparent evidence of periodic abandonments – perhaps perceived locally as no more than extended fallows – within the sedimentary record of the investigated yelas. At present it is far too early to regard these as evidence of a failure to adequately maintain terraces, and although previous studies have regarded the level of terrace maintenance at Konso as a proxy for the health and sustainability of the system (Jones, 2009), it is equally possible that periodically prioritizing other areas of the landscape was – and perhaps remains – an informed decision by local farmers.

To return to the thus far rhetorical question that heads this paper: when is a terrace not a terrace? We can now respond with the answer: when it is a sediment trap. But we can also reformulate this question to one that is more relevant to the estimated 200 km^2 of hillside terraces: when is an erosion prevention terrace not simply an erosion prevention terrace? When it is not designed to prevent the loss of the original topsoil, but is instead designed to 'manufacture' new soils, in this case by capturing eroding colluvium, and by removing the frequent stones within this material to produce a relatively stone-free and more easily tilled terrace soil. To have done this over such an extensive area over an as yet unknown period is undoubtedly a remarkable achievement, but this is not the same as saying that the Konso landscape is self-evidently a paradigm of 'indigenous' soil and water conservation. More importantly, it is not in itself evidence that the system will continue to be highly productive or highly sustainable in the future.

This and other aspects of Konso history have still to be studied, and includes research that must be led by experts in modern agronomy and environmental management. Nonetheless, the evidence presented here has demonstrated that knowledge of past processes is important in understanding the mechanisms that drive a system's evolution, and is essential for assessing the opportunities and risks associated with their long-term maintenance.

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