Geoarchaeological survey and soil/sediment analyses of the lower slopes and floodplain zones of the Embobut-Kerio Rivers confluence, Tot, Kenya

Charles French

McBurney Geoarchaeology Laboratory, Department of Archaeology & Anthropology, University of Cambridge

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Introduction

A preliminary field-trip and survey to the Marakwet and Pokot areas of northern Kenya organised by Prof H Moore and Dr M Davies during December 2013 enabled a geoarchaeological evaluation survey of the landscape character of this region and some initial soil/sediment sampling of exposed stratigraphic profiles through the colluvial slope below the Elgeyo escarpment and the alluvial floodplain areas of the Embobut River valley to its confluence with the Kerio River. Particular attention was paid to three areas: first the farm compounds, fields and slope off-take irrigation system occupying the lower slopes to the northwest of the village of Tot; second the River Embobut valley at the base of the slope over a distance of about 4km eastwards; and third the wider valley floor to the southeast-east of Tot and the main River Kerio floodplain and low terrace area towards Pokot where the Canadian Red Cross has extensively cleared land for a new irrigation system and multiple field plots over an area of some 250 hectares.

The main profiles that were recorded and sampled in the field are found in Appendix 1.

Results are presented below of this first geoarchaeological survey and soil/sediment analysis. In addition, some initial suggestions are made on land-use and landscape change as well routes to future necessary analysis and research to combine the stories of landscape development and the ethnographic records of the recent past and present farming regime and community around Tot.

Observations

The lower slopes north of Tot

The River Embobut descends rapidly from the Elgeyo escarpment to the northwest of Tot at *c*. 2,600 metres above sea level. From about the 1,100 metre level down-slope there is an extensive series of irrigation ditches or ‘furrows’ defined by stone and concrete or earth walls that follow hillside contours down-slope to feed a variety of house/farm platforms and associated small plot fields (Davies 2008, 2012) (Fig. 1). The water flows year-round as it is fed by the rain- and spring-fed system on the escarpment above. The furrows require constant repairs because of collapse and erosion factors on the relatively steep slopes (*c*. 20-45 degrees), as well as regular cleaning out of the substantial and rapidly accumulating fine sand deposits in every furrow. This system is managed at the household and communal levels.

In addition, a new irrigation system has been built with funding from the Canadian Red Cross which includes a new concrete and stone spillway structure to take a proportion of the water from the River Embobut at the *c*. 1,100 metre level via a 30cm diameter pipe to the Kerio floodplain about 2-3km distant (Fig. 2). Significantly after one rainy season, the spillway was observed to already be about half-full of re-deposited fine-medium sand material, even though it was not yet fully operational. It will certainly require regular flushing/cleaning out, as well as maintenance of all the pipes and pumping/stand-pipe stations in the floodplain area.

The lower slope zone at about 800-600 metres is characterised by thick, gently undulating, lobate zones of red fine sandy-silt colluvial material. These 'colluvial fan' areas are extensively cropped today. One east-west erosion gully named Lagam, has revealed significant incision of over 3.75m that has occurred since 2007 (Nelson, pers. comm.) (Fig. 3; Table 1). This gully cut revealed a probable thin (*c*. 12-15cm) buried soil at its base that was composed of brown fine sandy silt loam developed on highly weathered mica-rich basaltic hard-rock. Above this were three thick units of hillwash accumulation: reddish brown, gravel free, fine sandy silt; reddish brown medium-coarse sand with abundant fine gravel; and an increasingly stoney/gravelly but similar reddish brown medium-coarse sand; all below about 70cm of modern, brown, fine sandy silt topsoil and large stone cobbles of the present day field system. The main horizons of this profile were spot sampled for micromorphological and geo-chemical analyses, which are further described below.

The Embobut-Kerio River valley and floodplain

From the base of the slope by the main road bridge for a distance of *c*. 4km eastwards the River Embobut and its exposed riverbed profiles were fieldwalked and six profiles were recorded and two were spot sampled for micromorphological and geo-chemical analyses (R Pr 1 and R Pr 6) (Table 1), the results of which are described below.

Profile R Pr 1 was located about 300m southeast of the road bridge beyond the foot of slope (Fig. 4). Here there was a large embayment of over 4.25m in depth which local farmer informants say began to become incised from *c*. 1978 (Nelson, pers. comm.). This profile revealed a basal *c*. 50cm thick alluvial soil beneath a *c*. 0.85m accumulation of alluvially derived organic sandy silt loam interrupted by discontinuous lenses of fine gravel deposits, with almost 3m of hillwash derived material above composed of mottled brown to reddish brown fine sandy silt with abundant fine gravel pebbles, all probably re-worked by water at the floodplain edge.

Within about half a kilometre to the east from the foot of the hill-slopes this colluvium over alluvium profile ceased to be evident and was replaced by profiles that were consistently composed of riverbed coarse sands/cobbles alternating with fine sandy to silty clay alluvial materials. In addition, the *c*. 3-4m of incision was now stepped in most places to reveal two distinct terraces, the lower one at about 1.5-2m above the present day river-bed, and the second, *c*. 1.5-2m higher terrace on the outer edges of the river valley, extending to the undulating hard rock geology some 100-200 metres distant to the east and west (Fig. 5). These terraces are regularly under (cash) crops today; there is just the risk of loosing the crops to high rainfall/flash flood events.

The lower river terrace deposits are consistently composed of greyish to yellowish brown, fine sandy/silt loam and fine gravels which reach a thick (*c*. 40-50cm) stabilisation zone at a depth of *c*. 1/1.5m below the present day highest valley ground surface (or top of the second, later terrace) (Fig. 5). The upper surface of the first terrace is a dark greyish brown, organic sandy loam with some columnar to blocky structure evident, and has the appearance of a considerable period of stability with minimal seasonal alluvial aggradation.

Alluvial and riverine deposition again resumes to form the make-up of the second/higher terrace, but now with more variable and greater flow energy evident. This is comprised of multiple alternating horizons of mottled orange silt, pale yellowish white medium to coarse sand, fine sandy silts and bedded fine gravels over a thickness of *c*. 1-1.5m.

This two terrace alluvial and riverbed deposit sequence was sampled near Mr Atomic's first valley farm at profile R Pr 6 (Fig. 6). As evident at profile R Pr1, there is a *c*. 50cm thick, well structured, silty clay alluvial soil at the base of the sequence, which exhibits frequent amorphous iron mottling. The latter is suggestive of a former wet, marshy, muddy alluvial soil in the valley bottom with common *in situ* standing vegetation.

The River Kerio floodplain

The present day muddy River Kerio is well incised to a depth of *c*. 3.5-4m through the reddish brown, fine sandy silt alluvial material of the floodplain. River-edge profiles were too overgrown to record properly, at least at this time, but the alluvial topsoils visible were predominantly fine-medium sandy loams. There is an extensive floodplain zone of at least 500-1000m to either side, which is the subject of the Red Cross irrigation scheme. At least 225 hectares have just been cleared of acacia scrub and the irrigation pipes have been laid every *c*. 100m along the long axis of the floodplain, with plans to double the area of this scheme (Fig. 7).

Soils of the Tot region

Field observations suggest that there are two main types of soils present in the Tot area: ferallitic and sandy alluvial floodplain soils. Primarily, the soils of the Tot area on the footslope, lower slopes and parts of the Embobut floodplain are ferallitic soils. These are thick, freely draining, weakly acidic soils dominated by iron and aluminium sesquioxides with quartz sand and kaolinite clays, with the silica removed from the clay, in an oxic B horizon (Bridges 1978, 82-3). These soils are characterised by their strong red colours and cementation with amorphous iron oxides. Depending on the degree of vegetation cover and leaching (related to rainfall and humidity), these soils typically have little or no reserve of weatherable minerals and consequently usually exhibit low fertility. They are characterised by a low organic and nutrient content, especially lacking in phosphorus and nitrogen, with some secondary nutrients such as calcium and magnesium. They contain few primary minerals, except for quartz and aluminium, but do have abundant iron oxides, often 'cemented'. All these characteristics of ferallitic soils are significant with respect to crop choice, growth and production, and certainly problematic without irrigation and nutrient replenishment by fertilisation and conservation-minded land management practices.

Sampling and laboratory methods

A series of samples of soil/sediment were taken for pH, magnetic susceptibility and multi-element geo-chemical analyses (Tables 1-3) (Avery and Bascomb 1974, 20; Clark 1996, 99-117; Oonk *et al*. 2009; Wilson *et al.* 2005, 2008) and micromorphological analyses (Tables 1 & 4) from three main profiles, one from Lagam Gully and two from the Embobut River floodplain (Bullock *et al*. 1985; Murphy 1986; Stoops 2003). Multi-element analysis (or ICP-AES using the 35 element Aqua Regis ICP-AES method) (www.alschemex.com) was used throughout. This recovers a full suite of included elemental composition data including phosphorus (or total phosphate) and a number of other elements which often indicate human activities in soils (e.g. Ba or barium, Ca or calcium, Fe or iron, K or potassium, Mn or manganese, Cu or copper, Sr or strontium, Zn or zinc). The multi-element results are described below and in Table 2, with the soil micromorphological data summarised in Table 4 and the detailed thin section descriptions in Appendix 2.

Sample number	Location	Field description
Embobut River Profiles:		
1/1, 380-390cm	base of slope/floodplain margin in recently cut (*c*. 1978) Embobut River embayment, equating to the upper terrace	basal alluvial ? soil of fine sub-angular blocky, dark greyish brown sandy clay loam
1/2, 410-420cm	as above	alluvial soil of fine sub-angular blocky, dark greyish brown sandy clay loam
1/3, 300-310cm	as above	alluvial aggradation of irregular small blocky, brown/reddish brown mottled, fine sandy silt loam
1/4, 360-370cm	as above	alluvial aggradation of reddish brown, organic sandy silt loam interrupted by fine gravel lenses
1/5, 270-280cm	as above	colluvial aggradation of irregular small blocky, reddish brown, fine sandy silt loam and abundant fine gravel intermixed in all orientations
6/1, 200-208cm	lower terrace on the Embobut floodplain	alluvial aggradation of mottled orangey brown, fine irregular blocky, silt loam
6/2, 230-240cm	as above	alluvial aggradation of mottled orangey brown, fine irregular blocky, silt loam
6/3, 240-252cm	as above	alluvial soil of columnar to large blocky, pinkish to reddish brown, silty clay loam with many plant pseudomorphs
6/4, 280-290cm	as above	base of alluvial soil of columnar to large blocky, pinkish to reddish brown, silty clay loam with many plant pseudomorphs
Lagam Gully Profile:		
1/1, 350-359cm	erosion gully through lower hillslope area on the northeastern edge of Tot village	transition from base of colluvium to old land surface
1/2, 359-369cm	as above	brown fine sandy silt old land surface and buried soil
1/3, 315-325cm	as above	colluvial aggradation of reddish brown fine sandy silt
1/4, 205-215cm	as above	colluvial aggradation of reddish brown loamy sand with abundant fine gravel

Table 1: Sample locations and field descriptions

Physical and elemental analyses

The pH of all the deposits sampled whether hillwash or alluvial deposits, was calcareous to highly calcareous in the range of 7-9 (Table 2). The Embobut River profile 1, the weathered bedrock and termite mound material exhibit the highest pH values. The loss-on-ignition organic carbon values were relatively high in both river floodplain profiles, probably reflecting the amount of eroded former topsoils in their make-up. The Lagam Gully samples were by contrast much lower, and therefore not indicative of the inclusion of organic matter nor being eroded topsoils. On the other hand, the magnetic susceptibility values are much more variable, but are noticeably enhanced in the Lagam Gully profile, with similar values to the weathered bedrock material. These magnetic susceptibility values along with the low organic total component suggests that the make-up of this profile is more likely to be derived from lower parts of the soil profile and weathered bedrock rather than the eroded topsoils observed in the alluvial profiles in the Embobut River valley (and see micromorphology below).

The multi-element analysis results (Table 3) were largely unremarkable, except for the moderately enhanced Fe or iron component and the moderately enhanced P or phosphorus (equating to total phosphate) values, especially in the modern topsoils and the Lagam Gully profile. The relatively high iron content is reflected in the amorphous sesquioxides present in most thin sections and particularly in sample 6/1 of the River profile. The higher loss-on-ignition values are coincident with the horizons exhibiting a higher organic carbon content (Table 2), and together with the phosphorus values probably indicate modern manuring practices adding household refuse and manure from domesticated animals to today's topsoils and in the hillwash deposits composing the Lagam Gully profile.

Profile/sample	pH	Magnetic susceptibility (SI)	Loss-on-ignition (%)
R Pr 1/1	8.53	100.9	5.36
R Pr 1/2	8.94	73.6	3.87
R Pr 1/3	8.04	145.1	4.88
R Pr 1/4	8.34	94.0	3.96
R Pr 1/5	7.81	117.2	3.17
R Pr 1/6 (topsoil)	7.99	171.8	4.52
R Pr 6/1	7.12	143.2	6.05
R Pr 6/2	7.07	156.4	4.2
R Pr 6/3	7.24	104.6	4.29
R Pr 6/4	7.25	105.1	4.45
LG 1/1	7.73	532.1	1.57
LG1/2	7.91	364.2	1.34
LG 1/3	7.42	273.4	1.57

LG 1/4	7.57	492.4	1.03
Weathered bedrock	8.87	493.2	1.446
Termite mound material	8.26	374.6	3.27

Table 2: pH, magnetic susceptibility and loss-on-ignition analyses (G. Marriner)

Sample	Ba	Ca	Cu	Fe	K	Mg	Mn	P	Sr	Zn
R Pr 1/1	310	0.58	41	4.28	0.6	0.83	1010	520	103	84
R Pr 1/2	330	0.69	38	4.46	0.59	0.87	1060	410	96	74
R Pr 1/3	310	0.69	38	4.19	0.62	0.65	931	860	67	74
R Pr 1/4	240	0.8	31	3.88	0.53	0.62	702	670	72	59
R Pr 1/5	230	0.48	36	4.21	0.56	0.53	1070	410	45	64
R Pr 1/6	260	0.68	43	3.58	0.63	0.62	933	1090	55	76
R Pr 6/1	400	0.48	50	4.52	0.63	0.68	835	1090	50	101
R Pr 6/2	330	0.45	34	4.25	0.63	0.59	1190	860	47	92
R Pr 6/3	240	0.37	31	4.07	0.57	0.52	859	700	35	85
R Pr 6/4	310	0.42	36	4.61	0.65	0.6	709	730	41	96
LG 1/1	260	0.56	40	2.77	0.48	0.58	450	1490	30	49
LG 1/2	290	0.61	43	3.15	0.48	0.64	604	1430	35	58
LG 1/3	310	0.57	51	3.08	0.55	0.78	550	1190	35	61
LG 1/4	240	0.64	45	3.14	0.45	0.61	472	1770	31	49
Bedrock	400	0.66	30	2.82	0.56	0.62	621	570	45	45
Termite mound	470	0.62	41	2.89	0.51	0.76	405	430	56	54

Table 3: Selected multi-element analysis results (ALS Chemex, Seville)

Micromorphological analysis

Three sets of samples for micromorphological and physical/elemental analyses were taken: from the colluvial toeslope area (Lagam Gully profile), the base of slope position where the Embobut River emerges into the floodplain margin (River Profile 1), and from the lower floodplain terrace about 1.5km downstream (River Profile 6) (Table 1).

Micromorphological descriptions

Embobut River Profiles

Profile 1

The basal samples (1/1 and 1/2) are composed mainly of a small to irregular blocky, reddish brown sandy/silty clay loam dominated by dusty or impure clay in the groundmass (Fig. 8a). They both exhibit very strong impregnation with amorphous sesquioxides resulting in a consistent reddening of the fabric and a considerable presence of humified organic matter making the fine fabric very dark, almost black (Fig. 8b). Dusty clay, ranging from slightly to strongly dusty (i.e. with included micro-contrasted particles of silt and organic matter) predominates in the groundmass, often as striations, as well as composes the lining of most of the void spaces (Fig. 8b). The basal sample (1/2) is interrupted by a thin (*c*. 7-10mm thick) lens of fine sandy silty clay loam with common infills of amorphous calcium carbonate. (Fig. 8c), and the upper transition to this lens is marked by fine humic laminae (Fig. 8d). Very fine charcoal fragments and punctuations were evident throughout the groundmass of both samples (Fig. 8e).

Sample 1/4 above was predominantly composed of three superimposed, similar horizons of reddish brown, sub-angular blocky sandy/silty clay loam overlying a basal unit of laminar silty clay alternating with fine sandy/silty clay, all strongly impregnated with amorphous sesquioxides (Fig. 8f). This laminar zone also exhibited thin surface crusts of amorphous sesquioxides and common irregular void infills with amorphous calcium carbonate.

Sample 1/3 contains two units. The lower unit is essentially similar to the fine blocky sandy/silty clay loam of sample 1/4 below, with its upper part being a much darker brown, indicative of a greater amorphous humic staining (Fig. 8g).

Sample 1/5 of a vughy and fine channelled, reddish brown, fine sandy/silty clay loam with abundant pure to dusty clay coatings and infills of fine channels (Fig. 8h).

Profile 6

The basal sample 6/4 is composed of a reddish brown sandy/silty clay loam exhibiting a weakly developed blocky structure with a few zones and concentrations/lenses of brown silt with occasional fine laminar infills of vughs with dusty clay (Fig. 9a). Sample 6/3 above was more of an heterogeneous mixture of silt and very fine quartz with a vughy fine sandy/silty clay loam, all strongly impregnated with amorphous sesquioxides (Fig. 9b & c).

Sample 6/2 comprised four units of ostensibly similar amorphous sesquioxide impregnated, reddish brown, fine sandy/silty clay loam marked by very thin planar voids, with the transition to the different units characterised by a slightly denser groundmass, greater/lesser porosity, greater/lesser impregnation with amorphous sesquioxides, and/or denser fine quartz components (Fig. 9d).

Sample 6/1 is composed of three units of amorphous sesquioxide impregnated, reddish brown, porous fine sandy/silty clay loam interrupted twice by horizontal lenses of dark brown silt with slight amorphous sesquioxide ‘crusting’ top and bottom of the lens (Fig. 9e & f).

Lagam Gully Profile

This profile exhibited a 3.6m depth of eroded soil material overlying a possible old land surface and buried soil at its base, all developed directly on bedrock. The two basal samples LG 1/2 and 1/1 are composed of a golden to reddish brown, poorly sorted, bridged grain to granular, sandy loam (Fig. 9g). Coarse/medium/fine and very fine quartz predominates (*c*. 50-65%) with the other half to one-third of the fabric mainly composed of a dusty clay groundmass with some striations evident, and has moderate impregnation with amorphous sesquioxides and humified organic matter, as well as common fine to very fine charcoal fragments throughout. Samples LG 1/3 and 1/4 are essentially similar to the Samples LG 1/3 and 1/4, although they are moderately better sorted and less porous (Fig. 9h).

Sample number	Description	Interpretation
Embobut River Profiles:		
1/5, 270-280cm	vughy and fine channelled, reddish brown, fine sandy/silty clay loam with abundant pure to dusty clay coatings and infills of fine channels, and fine gravel throughout	aggradation of eroded soil and fine gravel pebbles, probably with a mixture of colluvial and alluvial inputs, with common humified organic matter, suggestions of a former much greater organic content, and silty clay illuviation
1/3, 300-310cm	lower unit of fine blocky sandy/silty clay with its upper part being a much darker brown with greater amorphous humic staining	alluvial aggradation with possible organic Ah horizon development as a floodplain/terrace surface
1/4, 360-370cm	finely laminar, reddish brown silty clay alternating with fine sandy/silty clay loam, with frequent fine iron pans or crusts	minor alluvial flood events of varying water velocity indicative of alternating slow flow and standing water, subject to intermittent drying out, surface crust formation and evaporation
1/1, 380-390cm	reddish brown, small blocky silty clay loam with abundant sesquioxides and humified organic matter	well structured alluvium; not an old land surface
1/2, 410-420cm	reddish brown blocky silty clay loam interrupted by lens of calcareous fine sandy silt clay loam	well structured alluvium interrupted by flood event and evaporation; not an old land surface; implication of greater depth of alluvial soil profile beneath
6/1, 200-208cm	three units of amorphous sesquioxide impregnated, reddish brown, porous fine sandy/silty clay loam interrupted twice by horizontal lenses of dark brown silt with slight amorphous sesquioxide ‘crusting’	three alluviual units indicative of slightly different components and flow/volume of flood events
6/2, 230-240cm	four units of similar amorphous sesquioxide impregnated, reddish brown, fine sandy/silty clay loam marked by very thin planar voids, with the transition to the different units characterised by a slightly denser groundmass, greater/lesser porosity, greater/lesser impregnation with	four alluvial units indicative of slightly different components and flow/volume of flood events

	amorphous sesquioxides, and/or denser fine quartz components	
6/3, 240-252cm	heterogeneous mixture of silt and very fine quartz with a vughy fine sandy/silty clay loam, strongly impregnated with amorphous sesquioxides	disturbed alluvial soil, possibly with rooted vegetation once present
6/4, 280-290cm	weakly developed blocky sandy/silty clay loam with a few zones and concentrations/lenses of brown silt and occasional fine laminar infills of vughs with dusty clay	alluvial soil with some stability developing and occasional influx of minor flood-derived silt and silty clay; implication of greater depth of alluvial soil profile beneath
Lagam Gully Profile:		
1/4, 205-215cm	golden to reddish brown, sandy loam with silty clay adhering to and bridging the grains and present as irregular, fragmentary aggregates, moderate sesquioxides and humified organic matter and common fine to very fine charcoal fragments throughout; *c*. 10% fine gravel content, sub-rounded	disturbed, fine gravel and colluvial soil derived from B horizon soils and weathered substrates upslope with anthropogenic charcoal input
1/3, 315-325cm	as above	disturbed, colluvial soil derived from B horizon soils upslope with anthropogenic charcoal input
1/1, 350-359cm	golden to reddish brown, porous, poorly sorted, bridged grain to granular, sandy (clay) loam with common dusty clay, and moderate amorphous sesquioxides and humified organic matter, and fine to very fine charcoal fragments; *c*. 10% fine gravel content in upper 2cm of slide	disturbed, colluvial soil derived from B horizon soils upslope with anthropogenic charcoal input
1/2, 359-369cm	as above; but gravel-free	disturbed, colluvial soil derived from B horizon soils upslope with anthropogenic charcoal input

Table 4: Summary micromorphological descriptions and interpretations

<u>Interpretations</u>

Lagam Gully Profile

The lower half of the Lagam Gully profile (*c*. 2.05-3.59m) appears to be indicative of poorly sorted, sandy loam material aggrading over time. There are no distinguishing features that suggest there is a buried soil at the base of this profile as suggested in the field. Porosity is quite high, and coupled with the poor to moderate sorting of the grains indicative of disturbance, probably much mixed by the soil fauna (i.e. by termites especially), although it is not typically bioturbated in small aggregates. This material is probably mainly accumulating through receiving pulses of eroded soil material from upslope in the form of overland flow (cf. Kirkby 1969a & b). There are no visible indications of stop/start episodes, although these could have been rendered invisible through subsequent mixing processes. Unusually there is very little down-profile, within-soil illuviation of silt and clay fines typical of colluvial soils. This could conceivably be that this fine material is actually flushed through and out of the profile downslope and into the floodplain below, thus forming the predominant sediment size in the floodplain deposits (see below). In addition, there is a very low organic carbon content and high magnetic susceptibility. This could be a consequence of the irrigation regime practised on these valley slopes for the past few centuries (Davies 2008), resulting in regular water flushing through the matrix and therefore little deposition of fine material against the walls of the capillary voids as would otherwise be expected (cf. Kuhn *et al*. 2010), as well as much surface drying and incorporation of weathered natural leading to strong concentrations of secondary iron throughout the profile (Lindbo *et al*. 2010). Also, this profile's material may be largely composed of eroded B horizon soil material rather than organic topsoils which appear to predominate in the alluvial profiles in the Embobur River valley. Nonetheless, there is at last two metres of slow, gradual and homogeneous, soil hillwash accumulation represented by the lower half of this profile.

The nature of the sedimentation changes dramatically in the upper half of the Lagam Gully profile. In general there is a coarsening of material being deposited from *c*. 2.05m up-profile, including coarse sand and fine gravel contents both increasing up-profile and occurring in lens and zones of greater/lesser intensity. For example at 1.93-2.05m there is an horizon of fine sand and fine gravel, from 1.2-0.9m the fine gravel content increases, and from 0.9-0.7m there are zones and 'stringers' of horizontally oriented fine to medium stones. This coarsening and variable energy inputs is suggestive of more and more severe phases of instability upslope and pulses of erosion down-slope, which must result from intensifying landscape modifications. There are similar features of low organic content and high magnetic susceptibility which also indicate the continuing incorporation of eroded lower parts of soils and weathered bedrock, probably as saturated overland flows. These features could well be associated with changes to the scrub woodland cover on the slopes, as well as the creation, use and uptake of the fields and irrigation system immediately upslope. Only in the uppermost 70cm does the matrix return to being a dark brown sandy loam as the present day topsoil/ploughsoil, similar in texture to the colluvial lower half of the profile.

Fine to very fine charcoal is ubiquitous throughout the profile, but very little in the way of organic matter otherwise. This suggests the inclusion of anthropogenic-derived burnt organic material into the fields, perhaps by stubble burning as much as anything else, carried down-profile in the pore space through irrigation water and soil faunal mixing. Other organic remains have been destroyed by a combination of oxidation and bioturbation.

The Embobut River Profiles

The Embobut River profile 1 at the foot of the slopes and upper margin of the floodplain exhibited a series of colluvial and alluvial aggradation horizons making up the upper terrace of the Embobut valley. These were more or less composed of the same material – a fine sandy silty clay loam to silty clay loam, dominated by impure or silty clay throughout its groundmass, with variable inputs of fine gravel pebbles and a high organic matter content. There are indications of stop/start deposition, as well as minor influxes of stronger velocity river outwash flooding indicated by the fine sand 'stringers' and low velocity flood episodes suggested by the discontinuous silt lenses. In particular, the deposit at a depth of *c*. 2.9-3.5m is an alluvial horizon which may have been a terrace surface for a period in the past as indicated by its good structure, darker brown colour and greater organic content. Above this horizon, the upper *c*. 2.9m of the profile has a considerable but variably oriented fine gravel content which is suggestive of a strong colluvial (or hillwash) component. There were also intermittent periods of deposition in shallow standing water, often prone to drying out and evaporation leading to the formation of secondary calcium carbonates and sesquioxides of iron at temporary and/or terrace surfaces.

A ubiquitous feature throughout the whole deposit sequence is the presence of clays and impure (or dusty) clays comprising most of the groundmass and also occurring as coatings of the void space. These range from almost pure (or limpid) to slightly dusty to dusty with variable inclusions of micro-contrasted silt and organic matter to almost dirty coatings with common included micro-charcoal and humified organic matter, and sometimes these coatings exhibit micro-lamination (Bullock *et al*. 1985, 111-5; Kuhn *et al*. 2010). These finest soil size grades of silt and clay will be the most easily carried down-slope by rainsplash erosion, in hillwash, and downstream in floodwaters to become overbank alluvium (Kirkby 1969a &b; Kuhn *et al.* 2010), and then their subsequent movement down through the soil profile (i.e. illuviation) in percolating soil water (Kuhn *et al*. 2010, 220-1). These processes will be exacerbated by bare soil exposures associated with arable agriculture, periods of high rainfall and associated seasonal flooding. In the Embobut floodplain profiles, it is suggested that the illuviation of pure clay is associated with the presence of clear depths of shallow standing water from rainfall/flood events and slow downward percolation, and dusty clays are associated with variable saturation under shallow muddy water containing eroded soil material from upslope/upstream in the immediate valley catchment, also from rainfall/flood events, as well as the physical disturbance of the bare upper parts of the hill-slope or terrace soil profile. Also, the ubiquitous amounts of amorphous iron in the groundmass of all the soils/sediments observed in the whole Embobut valley soil system will help to limit clay dispersal and translocation, thus aiding the concentration of illuvial clay and silty clay in the profile (De Coninck *et al*. 1976), a process described as secondary illuviation that is associated with saturated soils and redoximorphic conditions (Fedoroff 1972).

The Embobut River profile 6 in the floodplain was representative of the lower terrace sequence. It exhibits a series of alluvial silty clay aggradational events in the lower *c*. 1m of the profile exposures, leading to terrace formation, succeeded by higher velocity deposition with riverbed material over a further *c*. 2m above. Note that the base of the alluvium was not visible in the exposed river sections and further fieldwork is required to ascertain the depth and thickness of these alluvial floodplain deposits. As in Profile 1, the alluvial horizons are predominantly composed of silty clays which probably derive from eroded topsoils in the immediate catchment upstream and upslope through rainfall and overland flow entrained in river flood events and then redeposited in shallow, standing overbank floodwater conditions.

The upper *c*. 2m of the Embobut River profile 6 is composed of alternating and superimposed horizons (or units) of finely bedded sand/silts, medium sand and fine gravel, coarse sand and fine gravel, and one horizon of small blocky, orangey brown, silty clay alluvial material at 0.9-1.0m. As this profile is located more in the central part of the Embobut floodplain, it has been affected by river and riverbank avulsion in the past giving it its much coarser and more variable deposit sequence. Nonetheless, there is a demonstrable change from slow alluvial aggradational system to one of higher energy and river channel bed avulsion and redeposition which requires further investigation and dating. This is especially important to see whether the major change in erosive energy is consistent between the lower hill-slope and floodplain areas in the Embobut system, and whether it can be related to changes in land-use and/or environment, or both.

A possible model of landscape development to test

From the initial geoarchaeological evaluation and subsequent laboratory analyses, it is possible to suggest a sequence of soil/sedimentary history for the Tot-Embobut-Kerio landscape over the recent past and possibly as far back as the last 10,000 years or so (Table 5). Obviously this will need further detailed mapping, description, sampling and analyses, and importantly dating using radiocarbon and OSL methodologies, and comparison with the known ethnographic and historical narratives, but is sufficient to present a model of landscape development to test further.

With the advent of the Holocene and post-glacial warming, afforestation took place over the whole landscape with concomitant ferallitic soil development under a rain-fed regime. This is possible given today's rainfall levels of between 600-900mm per year on the valley floor to up to 1400mm per year in the adjacent highlands (Davies and Moore, in press). Locating definitive *in situ* earlier Holocene archaeological sites and buried soils remains problematic, and will require further investigations. Some impact on the woodland followed at some point yet to be ascertained, but perhaps occurred for some length of time (measured in hundreds/thousands of years), through dispersed and light-touch human activities. This human intervention was sufficient to start some colluvial processes and eroded soil accumulation in the below-escarpment toeslope areas and alluvial aggradation in the Embobut and Kerio River valleys and floodplains, up to a thickness of about 2 metres. These eroded soils were consistently organic and silt and clay-rich. This suggests that there was some tree clearance and soil disturbance on the lower slopes northwest of Tot, combined with periods of good rainfall, which led to some erosion and downslope movement of organic ferallitic soils via overland flow, with some of that eroded fine material redeposited at the base of slope and floodplain margin, and some of it entrained in the river system such that it was subsequently re-deposited as overbank silty clay alluvium in the wider Embobut floodplain. The depth and extent of this earliest evident alluvial phase requires considerable exploration. And when these minimal, slow and gradual erosion/aggradation processes began is open to debate at this stage given the largely unknown record of human agricultural activity prior to *c*. 300 years ago in this region.

Then there was a major change from a minimally erosive and aggradational system to one of much greater severity. This change is exhibited in the Embobut River Profile 6. It involved greater depths (*c*. 1.5-2m) and coarser soil erosion on both the footslope and alluvial floodplain areas, as well as river channel and riverbed avulsion and redeposition in the floodplain itself. This sedimentary and depositional change and the formation of the first/lower terrace in the Embobut River system crucially requires secure dating and relating to the known archaeological and ethnographic records. It is possible that this major change may be associated with the intensive development of hillside farms and the furrow irrigation system over the last two-three hundred years, but this remains to be proven. Certainly all of this eroded material took on a coarser character suggesting greater intervention on the slopes above and exposure of some weathered bedrock material. In addition, the Embobut River began to change course more rapidly and regularly, exhibiting very different flow velocities and volumes of water as seen in the alternating fine to very coarse matrices accumulating, and creation of sand/gravel levees. This material forms the lower terrace of the Embobut River today.

More recently there has been a relatively lengthy phase of stabilisation, probably representing at least the last 50-100 years, as suggested by the upper terrace floodplain soil in the Embobut River valley. The relatively high organic carbon and phosphorus values also suggest a degree of manuring of present-day topsoils indicative of good agricultural practice today. Nonetheless, it is known from existing local farmers utilising the modern floodplain area today for arable crops (and at least from the 1980s) that it is still risky to plant cash crops as they can be destroyed overnight by individual flash flood events.

Up until now the system has been one of intermittent, slow but continuing erosion and soil accumulation, but it has changed relatively recently to one of incision and removal of soil/sediment in the lower slopes area and the Embobut River floodplain. Local farmers (Mr Atomic, Nelson and William, pers. comms.) indicate that this process began very recently, from the mid-1970s. In places there has been over 4m of incision and new gullying in both the toeslope and in the floodplain zones of the landscape. New channels regularly form and re-form in the Embobut floodplain, and both first and second terrace deposits are often scoured away by large volumes of floodwater, ruining both new fields and cash crops on the floodplain margins, with coarse sand/fine pebbles deposition and levee creation in the channel floor.

The most recent event is the construction of the Canadian Red Cross irrigation system in 2012-13 to take water from the Embobut River upslope to a large area (*c*. 225ha) of the Kerio River floodplain southeast of Tot to enable crop agriculture on a new extensive and large scale not seen before in this landscape. Although this system is now only partly operational, it is understood that it will be maintained and fertilisers provided to local farmers for a period of only three years. What will happen afterwards in terms of maintenance, sustainability and success of the project will bear careful observation and analysis.

Time period	Settlement and landscape events
Earlier Holocene	development of ferallitic soils under scrub woodland; illuviation of fines and developing soil structure; natural fertility associated with vegetative cover and good rainfall
? Later Holocene	human intervention with vegetation clearance, settlements and shifting agriculture leading to hillwash accumulation at the base of the Elgeyo escarpment and alluvial aggradation processes in the Embobut-Kerio floodplain
18th AD to 1970s	establishment of agricultural communities with an extensive irrigation and arable agricultural system on the escarpment slopes, and shifting agriculture practised on the valley floodplain floor; increased but slow colluvial deposition at the base of the slopes and alluvial deposition and aggradation in the Embobut-Kerio floodplain
? unknown	change from slow, seasonal accumulation of overbank alluvial sedimentation to more variable mixture of overbank and redeposition of reworked riverbed coarse material; suggests greater human intervention in the wider landscape leading to greater instability and increased water erosion processes
1970s	substantial depth and extent of river floodwater incision in the Embobut-Kerio River system; incision and exposure of 1st and 2nd river terraces; perceived increased risk of flooding affecting crop harvests in the alluvial floodplain area, which continues to today
1970s-2012	return to generally greater stability in the system and renewed slow, seasonal deposition of overbank alluvium, with occasional flood events and river channel avulsion, and the incision and creation of Lagam Gully in 2007
2012-2013	Red Cross irrigation system built; with large *c*. 225ha area of clearance and uptake of land for arable crops on the alluvial floodplain of the Embobut-Kerio River system

Table 5: Model landscape development scenarios

The soil systems, resilience and sustainability

From this initial field and laboratory work, it is clear that there are two quite different soil systems present today in the environs of Tot. The slope settlement and irrigated farming system that has been in use for the past 300 years or so is dominated by considerable depths and extents of soils subject to hillwash processes. These fine sandy silt loam soils are not very organic, not well structured, and are dominated by fine particles such that they are quite free-draining and not especially moisture retentive. Thus, rainfall and regular irrigation as well as the addition of organic matter through manuring and regular fallowing are essential to maintaining the health of these soils and their suitability for cash food cropping today.

The second soil system equates with the present day floodplain area of the Embobut-Kerio River system, and even this area exhibits three different zones of soil development. First, the footslope-floodplain margin area is characterised by extensive zones of hillwash over alluvium of considerable depth, but which are all comprised of re-deposited ferallitic soils. Although these soils exhibit a better structure than the hillwash soils just upslope, they are also low in organic content and have a low nutrient status, and the ubiquitous secondary iron oxides formation is detrimental to drainage and root penetration, thus making these soils less than well suited for arable agriculture. Indeed much of this zone of thick ferallitic soils is occupied by the main road and ribbon urban settlement, or is not much used for arable fields. Second, the Embobut floodplain zone is occupied by multiple, laminar channel bed fills of sands and gravels, and two sets of sandy clay loam terrace deposits, both of which are sometimes farmed today. Although cash cropping can be a risky undertaking because of occasional flood destruction events (Mr 'Atomic,' pers. comm.), the first/second terrace soils are probably more resilient and much better suited to arable crops because of a better structure and greater integral clay component, and therefore better nutrient and water retention capacities. Thirdly there is the extensive Keria floodplain area currently under the Red Cross clearance and irrigation scheme. Here the soils are coarse, gravelly sandy loams, which are very poorly structured with minimal organic and clay contents, and free-draining. So with the change from the pre-existing shifting agricultural regime alternating with savannah scrub re-growth to one of irrigated, cleared land for cash crops like maize, there is huge potential for soil degradation and failed crops in the near future.

Thus there are very different classes of risk and resilience, and therefore sustainability, evident in the Tot soils. In soil terms, the footslopes and terrace zones should be the best soils with the best resilience, but it is the irrigated slope areas that are probably the most resilient and sustainability because of a lengthy period of varied land-use with a well-established settlement and field pattern supported by a well functioning and shared irrigation system, as well as and sympathetic land management. The coarse soils and sediments of the infilled channel zones and the Kerio floodplain are probably the worst in terms of arable potential and resilience. This is admirably demonstrated by several centuries (or more) of traditional shifting agriculture system practiced over most of the floodplain still today, and is a direct human response to knowing what will work in this landscape for best productivity and viable use.

Future research and the next steps

There are a number of unknowns that require further fieldwork and analysis to understand both the long-term landscape history of this area, as well as how this landscape system has functioned so well over the past few hundred years.

It is crucial to discern a firm chronology for the major soil/sediment/river history events already described in this report. These will probably be best provided by Optically Stimulated Luminescence dating (or OLS), and would need to include:

- dating the Lagam Gully sediment profile and the depositionary (fine to mixed coarse/fine) change at a depth of about 1.93m
- dating the range of alluvial deposition at Profile 1 on the margin of the Embobut River floodplain
- dating the change from fine alluvial to coarser riverbed deposition at Profile 6 in the Embobut River floodplain
- dating the basal and upper surfaces of the 1st and 2nd terraces in the Embobut River valley.

The spatial extent and depths of colluvium, alluvium and terrace areas should be recorded and mapped with respect to current land use and past/modern settlements. The mechanisms and derivation of these deposits need to be fully understood with respect to past and present land-use strategies, and relative chronologies of deposition determined, and related to the known ethnographic narratives.

The nutrient base and elemental components of the modern soil system and colluvial/alluvial sediments and both buried and modern soils present need to be established as an index of fertility and their ability to grow/sustain particular food crops. On the face of it, this landscape system is successful because of well managed, community-based irrigation system and both small scale and shifting agricultural practices, not because the ferallitic soils present are especially fertile in their own right.

A hydrological model of the current river and irrigation furrow system should be established. The water quality and nutrient status of the Embobut River system and the irrigation furrow system, both on the Elgeyo escarpment slopes around Tot and in the valley below, need to be established. This may already be available from the current Canadian Red Cross irrigation project.

It is crucial to assess the impact and potential sustainability of the Canadian Red Cross water harvesting scheme on the furrow system and its associated fields, well as the large area of new agricultural plots on newly cleared land in the Kerio River floodplain, now and over the next three to five year period. There is a strong likelihood that this floodplain irrigation project will fail to be a success without proper soil conservation and fertilisation practices being instilled in the life of the farming community.

Finally, as the existing farming settlement system around Tot and Pokot has been so well studied over the past 35 years from an ethnographic narrative perspective (Moore 1986; Davies 2008; 2012), there is an unrivalled opportunity to ground-truth soil micromorphological and geo-chemical evidence in both the irrigated field systems on the hill-slopes and the shifting field system in the floodplains, as well as the detailed use of space and activities represented in the farmsteads themselves.

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Figures

1. An irrigation furrow on the slope above Tot

2. The Canadian Red Cross spillway on the slope above Tot

3. The Lagam gully profile near Tot

4. Profile RP01 in the River Embobut valley

5. Characteristic upper and lower terraces in the River Embobut valley

6. Profile RP06 in the River Embobut valley

7. The Red Cross irrigation pipe trenches in the River Keria floodplain

8. Photomicrographs of Embobut River Profile 1:

a) photomicrograph of small to irregular blocky, reddish brown sandy/silty clay dominated by dusty or impure clay in the groundmass, sample R Pr 1/1 (frame width = 4.5mm; cross polarized light)

b) photomicrograph of very strong impregnation with amorphous sesquioxides and a considerable presence of humified organic matter, with abundant dusty clay in the groundmass as well as lining the void space, sample R Pr 1/1 (frame width = 2.25mm; cross polarized light)

c) photomicrograph of lens of fine sandy silty clay loam with common infills of amorphous calcium carbonate, sample R Pr 1/2 (frame width = 4.5mm; cross polarized light)

d) photomicrograph of fine humic lenses, sample R Pr 1/2 (frame width = 4.5mm; cross polarized light)

e) photomicrograph of very fine charcoal fragments and punctuations in the fine groundmass, sample R Pr 1/2 (frame width = 4.5mm; reflected light)

f) photomicrograph of laminar silty clay alternating with fine sandy/silty clay loam, all strongly impregnated with amorphous sesquioxides, sample R Pr 1/4 (frame width = 4.5mm; cross polarized light)

g) photomicrograph of fine blocky, dark brown, fine sandy/silty clay loam, upper part of sample 1/3 (frame width = 4.5mm; plane polarized light)

h) photomicrograph of reddish brown, fine sandy/silty clay loam with abundant pure to dusty clay coatings and infills of fine channels (frame width = 2.25mm; cross polarized light)

9. Photomicrographs of Embobut River Profile 6:

a) photomicrograph of fine laminar infills of vughs with dusty clay, sample 6/4 (frame width = 2.25mm; cross polarized light)

b) photomomicrograph of vughy fine sandy/silty clay loam, all strongly impregnated with amorphous sesquioxides, especially around void boundaries, sample 6/3 (frame width = 4.5mm; cross polarized light)

c) photomomicrograph of finely laminar silt and fine sandy silt with plant material strongly impregnated with amorphous sesquioxides, sample 6/3 (frame width = 4.5mm; cross polarized light)

d) photomomicrograph of two superimposed units of similar reddish brown fine sandy/silty clay loam marked by a planar void strongly impregnated with amorphous sesquioxides (frame width = 4.5mm; cross polarized light)

e) photomicrograph of disturbed, slightly heterogeneous, strongly amorphous sesquioxide impregnated, reddish brown, porous fine sandy/silty clay loam (frame width = 4.5mm; cross polarized light)

f) photomicrograph of lens of dark brown silt with slight amorphous sesquioxide ‘crusting’ , sample 6/1 (frame width = 4.5mm; cross polarized light):

g) photomicrograph of poorly sorted, bridged grain to granular, sandy loam with moderate amorphous sesquioxides and humified organic matter, as well as common fine to very fine charcoal fragments, sample Lagum Gully 1/1 (frame width = 2.25mm; plane polarized light)

h) photomicrograph of porous sandy loam with moderate amorphous sesquioxides and humified organic matter, as well as common fine to very fine charcoal fragments, sample Lagum Gully 1/4 (frame width = 4.5mm; cross polarized light)

Appendix 1: The field section profile descriptions and samples taken

<u>Embobut River profiles</u>

RP01 (1 13 40.3N/35 39 29.6E)

0-60	brown sandy silt loam; modern agricultural topsoil
60-290	reddish brown, irregular small blocky to massive, fine sandy silt, with occasional horizontal zones of fine sub-rounded pebbles; colluvium
290-350	mottled brown/reddish brown fine sandy silt as above; colluvium
350-375	mixed horizon of coarse sand, organic sandy silt and gravel lenses; alluvium and eroded riverbed material
375-425+cm	dark greyish brown sandy clay loam with fine irregular blocky structure; ? buried alluvial soil

<u>Samples taken:</u> Blocks for micromorphological analysis at 410-420, 380-390, 360-370, 300-310 and 270-280cm; Small bulk samples for geo-chemistry at 410-420, 380-390, 360-370, 300-310, 270-280 and 10-20cm

RP02 (Grid Refs needed)

0-50	brown sandy silt loam; modern agricultural topsoil
50-200	pale brown, irregular small blocky to massive, fine sandy silt, with occasional horizontal zones of fine sub-rounded pebbles; colluvium
200+cm	riverbed cobbles

RP03 (Grid refs needed)

0-50	brown sandy silt loam; modern agricultural topsoil; with small channel irrigation system using pumped water from river; all sited on top of 1st terrace

RP04 (Grid refs needed)

0-20	brown sandy silt loam; modern agricultural topsoil and upper surface of 2nd terrace
20-100	alternating horizons of pale yellow fine sand and pale brown fine sandy silt
100-140	dark greyish brown, irregular small blocky to massive, fine sandy loam; stabilised alluvial floodplain soil; acts as upper surface of 1st terrace
140-250	pale yellowish brown fine sandy silt; alluvium
250-350	grey fine sandy silt and fine gravel; alluvium
350+cm	riverbed cobbles

RP05 (Grid refs needed)

0-20	brown sandy silt loam; modern agricultural topsoil and upper surface of 2nd terrace

20-100	alternating horizons of pale yellow fine sand and pale brown fine sandy silt
100-150	dark greyish brown, irregular small blocky to massive, fine sandy loam; stabilised alluvial floodplain soil; acts as upper surface of 1st terrace
150-250	pale yellowish brown fine sandy silt; alluvium
250-350	grey fine sandy silt and fine gravel; alluvium
350+cm	riverbed cobbles

RP06 (1 13 59.0N/35 40 24.1E)

0-20	brown sandy silt loam; modern agricultural alluvial topsoil and upper surface of 2nd terrace
20-40	pale brown fine sandy silt; alluvium
40-50	fine horizontally bedded fine sand; re-deposited riverbed material
50-90	horizontally bedded coarse sand and fine gravel pebbles; re-deposited riverbed material
90-110	mottled orangey brown silt with crumb structure; alluvium
110-148	horizontally bedded fine sands; re-deposited riverbed material
148-168	pale greyish brown silt; alluvium
168-178	grey fine-medium sand and fine gravel pebbles; coarse sand and fine gravel pebbles
178-198	pale greyish brown fine sandy silt; alluvium
198-240	mottled brown/orangey brown silt with fine irregular blocky structure; slowly aggrading alluvium
240-290	reddish brown, mottled orange, fine sandy clay loam with columnar blocky structure; *in situ* alluvial soil with much rooting
290+cm	riverbed sand and cobbles

Samples taken: Blocks for micromorphological analysis at 280-290, 240-252, 230-240 and 200-208cm; Small bulk samples for geo-chemistry at 280-290, 240-252, 230-240 and 200-208cm; Pollen spot sample at 280-290cm

Lagam gully profile (1 12 28.4N/35 39 01.1E)

0-70	dark brown fine sandy silt loam; modern agricultural topsoil
70-90	horizon of large cobbles and tabular stone

(level of water pipe, as exposed in 2007)

90-193	reddish brown medium-coarse sand with fine gravel content increasing up-profile; colluvium
193-205	horizontally bedded fine sand and common fine gravel; stream/furrow? deposit

205-307	reddish brown medium-coarse sand with abundant fine gravel; colluvium
307-359	stone-free reddish brown fine sandy silt; colluvium
359-374	brown fine sandy silt loam; *in situ* land surface and buried soil
374+cm	weathered, mica-rich hard rock substrate

Samples taken: Blocks for micromorphological analysis at 359-369, 350-359, 315-325 and 205-215cm; Small bulk samples for geo-chemistry at 359-369, 350-359, 315-325 and 205-215cm; Also spot small bulk samples taken of a termite mound and weathered hard rock substrate

Appendix 2: The detailed soil micromorphological descriptions

Embobut River Profile 1

Sample 1/1: 380-390cm

Structure: columnar to irregular blocky, <4mm; porphyric; *Porosity*: 5% channels, <4cm and <1mm long, <1.5 and <250um wide, accommodated; 5% vughs, sub-rounded to irregular, <500um; *Mineral components*: limit 100um; coarse/fine ratio: 30/70; coarse fraction: 2% coarse, 10% medium 18% fine quartz, sub-rounded to sub-angular, 100um to 1-2mm; fine fraction: 10% very fine quartz, 50-100um, sub-rounded; 60% silty clay (dusty clay); reddish to dark brown (CPL/PPL); *Organic component*: whole groundmass obscured by humic staining; *Pedofeatures*: *Textural*: predominantly dusty clay of groundmass and coating grains and voids/channels, weak to moderate birefringence, much obscured by amorphous humic matter and sesquioxides, reddish/black to yellow to golden red (CPL), orangey brown to gold (PPL); *Amorphous*: all groundmass with moderate to strong amorphous sesquioxide staining; rare (1%) rolled silty clay aggregates, <500um.

Sample 1/2: 410-420cm

Three units: Lower unit 1(0-0.5cm): as for unit 2 above, except for very strong amorphous sesquioxide reddened; distinct horizontal boundary; Middle unit 2 (0.5-1.5cm): *Structure*: small to irregular aggregated/blocky, <2mm, <1cm; *Porosity*: 5% irregular to sub-rounded vughs, <500um; *Mineral components*: mixture of 40% calcium carbonate in irregular zones, <2mm, pale brown (CPL), grey (PPL), and 60% sandy silty clay loam of similar composition to fabric of sample 1/1, reddish/golden brown (CPL), reddish brown (PPL); slightly wavy distinct boundary; Upper unit 3 (1.5-7cm): as for fabric in sample 1/1, all strongly impregnated with amorphous sesquioxides.

Sample 1/3: 300-310cm

As for Sample 1/1 fabric.

Sample 1/4: 360-370cm

Four units: Lowermost unit 1 (0-1cm): *Structure*: fine laminae, <1mm; *Mineral components*: as for Sample 1/1; often exhibits thin surface crusting or panning with amorphous sesquioxides and humus; distinct horizontal boundary; Lower unit 2 (1-4cm): *Structure*: small sub-angular blocky, <5cm; *Porosity*: 10% channels, <1cm long, <250um wide, partly accommodated; 5% vughs, sub-rounded, <250um; *Mineral components*: c/f ratio = 40/60; coarse fraction: 5% coarse, 15% medium and 20% fine quartz, sub-rounded to sub-angular, 100um to 1mm; fine fraction: 15% very fine quartz, 50-100um, sub-rounded; 10% amorphous calcium carbonate in voids and as irregular aggregates; 45% silty clay; reddish brown (PPL), strong reddish brown (CPL); *Organic components*: few to occasional (2%) fine charcoal, <2mm, sub-rounded; irregular but distinct boundary; Middle unit 3 (4-7cm): as for unit 2 below, except up to 25% amorphous calcium carbonate in irregular zones and aggregates; irregular boundary; Uppermost unit 4 (7-7.5cm): as for unit 2, except *Mineral components*: c/f ratio = 60/40; coarse fraction: 5% coarse, 25% medium and 30% fine quartz; fine fraction: 10% very fine quartz; 30% silty (dusty) clay in groundmass.

Sample 1/5: 270-280cm

Structure: aggregated, <500um, to small irregular blocky, <1cm; clear unit break at mid-way point of sample, marked by very narrow planar void, <250um; *Porosity*: 15-20% vughs, irregular to interconnected, <4mm; *Mineral components*: as for Sample 1/1; golden to reddish brown (CPL/PPL); *Pedofeatures*: *Textural*: 5% pure clay coatings of vughs/channels, yellow to gold (PPL), moderate birefringence; 5-10% dusty clay coatings of vughs, occasionally showing weak micro-lamination, weak to moderate birefringence, yellow to golden brown (CPL); remainder as dusty clay of groundmass, weak birefringence, golden-reddish brown (CPL).

Embobut River Profile 6

Sample 6/1: 200-208cm

Three units: Lower unit 1 (0-2.2cm): apedal to very weakly small irregular blocky; *Porosity*: up to *c*. 35%, 250um to 2mm, irregular; *Mineral components*: c/f ratio = 20/80; coarse fraction: 10% medium and 10% fine quartz, 250-750um, sub-rounded to sub-angular; fine fraction: 10% very fine quartz, 50-100um, sub-rounded; 70% silty clay; golden to reddish brown (CPL), brown to reddish brown (PPL); *Pedofeatures*: *Textural*: 5% pure clay coating voids, gold (CPL), moderate birefringence; 65% dusty clay in groundmass and coating voids, weak to moderate birefringence, gold to golden brown (CPL), yellowish brown (PPL); *Amorphous*: most vughs and clay coatings strongly impregnated with amorphous sesquioxides, reddish black (CPL/PPL); distinct but intermittent boundary with *c*. 5-6mm thick lens of very fine quartz (10-20%) coarse silt (50-60%) and silt-sized organic matter (10%) and gold (CPL) clay (10%); golden-reddish brown (CPL/PPL); with thin crusting with amorphous sesquioxides at top and base of the lens; distinct but intermittent boundary; Middle Unit 2 (2.2/2.8-4cm): even, heterogeneous mixture of unit 1 fabric and lens fabric; distinct lower and upper boundary with *c*. 2mm thick lens similar to previous lens described above; Upper unit 3 (4.2-6.5cm): as for unit 1 fabric.

Sample 6/2: 230-240cm

Four units: Lowermost unit 1 (0-2.7/3.5cm): *Structure*: porphyric, poorly sorted; *Porosity*: 15% vughs, irregular to sub-rounded, <1mm; *Mineral components*: c/f ratio = 30/70; coarse fraction: 10% medium and 30% fine quartz, 100-750um, sub-rounded to sub-angular; fine fraction: 10% very fine quartz, 50-100um, sub-rounded; 60% silty clay; dark reddish brown (CPL/PPL); *Organic components*: 10% very fine charcoal fragments and organic punctuations, <50um; *Pedofeatures*: *Textural*: 60% dusty clay of groundmass and lining voids, all strongly impregnated with amorphous sesquioxides, weak to moderate birefringence; *Amorphous*: strong impregnation of whole groundmass; very strong around voids, reddish black (CPL/PPL); distinct boundary defined by intermittent planar void, *c*. 75um wide and strongly coated with amorphous sesquioxides; Middle fabric unit 2 (2.7/3.5-5.8/7.8cm): same fabric as unit 1, except for: *Porosity*: 25-30% irregular to interconnected vughs, up to 3mm; *Amorphous*: less strongly impregnated with amorphous sesquioxides; boundary marked by slightly greater concentration of fine quartz sand; Upper fabric unit 3 (5/8/7/8-7.8/10cm): same fabric as unit 1; boundary marked by thin zone of denser groundmass, greater amorphous sesquioxide impregnation and slight break in fabric; Uppermost fabric unit 4 (7.8-10cm): same fabric as unit 1.

Sample 6/3: 240-252cm

Three units: Lower unit 1 (0-4/8cm): heterogeneous, poorly sorted mixture of two fabrics; *Porosity*: 10% channels, <1cm long, <250um wide, partly accommodated; 20-30% vughs, irregular to interconnected, <2mm; *Mineral components*: Main fabric (70-90% of groundmass): c/f ratio = 40/60; coarse fraction: 10% medium and 30% fine quartz, sub-rounded to sub-angular, 100um to 1mm; fine fraction: 20% very fine quartz, 50-100um, sub-rounded; 40% silty clay; reddish brown (PPL), strong reddish brown (CPL); *Amorphous*: whole groundmass with strong impregnation of amorphous sesquioxides; many voids also lined with amorphous sesquioxides and dusty clay; Minor fabric (10% of groundmass): *Mineral components*: 30% very fine quartz; 60% coarse silt; 10% dusty clay; brown to dark golden brown to reddish brown (CPL/PPL); clear boundary; Middle unit 2 (4/8-6.3/9cm): same as for the minor fabric above; clear boundary; Upper unit 3 (6.3/9-11cm): same as for lower unit 1.

Sample 6/4: 280-290cm

Structure: weakly developed small blocky, <6cm; *Porosity*: 10% channels, <5cm long, <500um wide, partly accommodated; 10% vughs, irregular to interconnected, <1mm; *Mineral components*: c/f ratio = 40/60; coarse fraction: 10% medium and 30% fine quartz, sub-rounded to sub-angular, 100um to 1mm; fine fraction: 20% very fine quartz, 50-100um, sub-rounded; 40% silty clay; reddish brown (PPL), strong reddish brown (CPL); interrupted at mid-slide by a *c*. 2-4mm thick zone of greater silt and very fine sand material; *Pedofeatures*: *Textural*: 35% dusty clay in groundmass and coating grains and voids, weak birefringence, reddish gold (CPL);

c. 5% micro-laminated dusty clay coatings of vughs, reddish gold (CPL), moderate birefringence; *Amorphous*: whole groundmass and most voids with moderate to strong impregnation of amorphous sesquioxides.

Lagam Gully Profile 1

Sample LG 1/1: 350-359cm

Structure: apedal to weakly aggregated; bridged grain to granular; open porphyric to gefuric/chitonic; moderately well sorted; *Porosity*: 20-30% open and interconnected, <2mm; *Mineral components*: *c*. 10% fine gravel in upper 2cm of slide, <1cm, sub-rounded; c/f ratio: 60/40; coarse fraction: 10% coarse sand and biotite, 30% medium and 20% fine quartz, 100um-2mm, sub-rounded to sub-angular; fine fraction: 15% fine quartz, 50-100um, sub-rounded; 25% silty clay, adhering and between grains; reddish brown (CPL), brown to golden brown (PPL*);* *Organic components*: moderate humic staining of groundmass; *Pedofeatures*: *Textural*: dusty clay coating grains and in groundmass, weak birefringence, golden brown (CPL); *Amorphous*: moderate amorphous sesquioxide impregnation throughout.

LG 1/2: 359-369cm

Same as sample LG1/1, except for: no gravel component and <5% very fine charcoal, <500um.

LG1/3: 315-325cm

Same as sample LG1/1, except for: much lower porosity of *c*. 5-10% vughs and greater groundmass of dusty clay (*c*. 40%).

LG1/4:

Same as LG 1/1, except for: all bridged grain structure and fragmentary aspect to aggregates; 10% very fine charcoal; 10% fine gravel throughout slide; much lower porosity of *c*. 5% vughs; and greater groundmass of dusty clay (*c*. 50%).