Elsevier Editorial System(tm) for Quaternary International
Manuscript Draft

Manuscript Number: QUATINT-D-13-00593R2

Title: Loess and Bee-eaters II: the 'Loess' of North Africa and the nesting behaviour of the Northern Carmine Bee-eater (Merops nubicus Gmelin 1788).

Article Type: ED@80

Keywords: Loess; ground materials; soil geography; Niger river; Scheidig World loess map; Northern Carmine Bee-eaters.

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Manuscript Region of Origin: CHAD

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I submit the paper ‘BE2’ for possible publication in the ED@80 edition of Quaternary International
Best Wishes Ian Smalley

Loess and Bee-Eaters II: The 'loess' of North Africa and the nesting behaviour of the Northern Carmine Bee-Eater (Merops nubicus Gmelin 1788)

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A large, long-streamered, highly gregarious blue and shocking pink bee-eater,... C.H.Fry

Abstract

The Northern Carmine Bee-Eater (*Merops nubicus*) lives and breeds in a well demarcated region stretching across Africa close to the 15°N line of latitude. The Bee-Eater zone appears to be associated with a band of loess, defined by Scheidig on his 1934 map as second-order loess. Bee-eaters are known to favour loess for nesting tunnels and it appears that the 15°N material is sufficiently loess-like. Obvious sources for particulate materials for the 15°N band are the Fonta-Djalon highlands which supply sedimentary material to the River Niger; the Bodele Depression, the deepest part of Lake Megachad, source of dust for the World; the Ethiopian highlands at the eastern end of 15°N which supply silt to the Nile system and particulates to the 15°N region. In soil moisture terms the region is ustic, which is possibly a necessary condition for bee-eater nests. The clastic material requires an ustic environment. The River Niger can be seen as a loess river; in some senses a mirror-image of a major loess river like the Danube; but where a restricted range of particle imputs leads to a restricted range of loess deposit outputs. Nevertheless loess river considerations can be applied. The Niger delivers second-order loess and an

important loessic admixture to the landscape. Enough loess for selective nesters like the Carmine Bee-Eaters to build their nest tunnels in it. It seems likely that climate change will cause a change in bee-eater distribution; it seems unlikely that they will abandon their nesting regions, the living and wintering zones may shift.

Key words: Loess, Northern Carmine Bee Eater, ground materials, soil geography, climate change, desert loess, Niger river, Scheidig world loess map.

1. Introduction

In the first paper of the 'Loess and Bee-Eaters' series we focussed on the European Bee-Eater (*Merops apiaster*) in its nesting environment in the European loess (Smalley et al 2013, commentary by Heneberg 2013). That was a study of loess material from the point of view of its use by the birds- a further exploration of the 'Heneberg compromise' between the strength of the material giving tunnel stability and the excavatability of the material allowing long, elaborate nesting tunnels to be built. The coincidence of nesting sites and loess deposits in Europe was demonstrated with reference to the world map of loess distribution by Scheidig (1934). This is a very old map but it is still the most useful world map of loess distribution. It is not a map of high precision but it clearly indicates the position of the known definite loess deposits (nachgewiesen) and suggests the position of deposits and materials which are not quite so definitely identified as loess (wahrscheinlich oder moglich); perhaps this could be called 'second-order loess'.

Here we focus on the possible band to the south of the arid regions of North Africa (see fig.1). This is a band of 'loess' associated with the Sahara desert; it could be 'desert loess'. It occurs in a region closely associated with the lives and activities of the Northern Carmine bee-eater (*Merops nubicus*) see fig.2. The critical region is shown in fig.3 which is adapted from the great bee-eater treatise by Fry (1984), a book that underpins on-going bee-eater studies. The critical region in Africa might be referred to as the '15 degree zone' since there is a high level of coincidence of bee-eater activity and the 15°N line of latitude; these are 'low latitude' bee-eaters.

In contrast to the long travelling European Bee–Eater the Northern Carmine Bee-Eater stays within a relatively narrow band of latitude, moving to the north for breeding, and back to the south for wintering. The northern zone, the breeding band, shows a remarkable coincidence with the ‘loess’ distribution demonstrated in fig.1. This suggests that this African ground material might be true loess- because the bee eaters like it; or it might be a material close enough in texture and properties to provide a good substitute for ideal loess. In this paper we focus on this African zone of possible loess and consider sedimentological and environmental reasons why it might be good ground for bee-eater nesting.

2. The Scheidig 1934 loess map

This map remains the only reasonably detailed map of the world-wide distribution of loess. Why no more recent versions? Two answers appear immediately (1) it would be a large labour to produce a careful map covering the entire world, so mapping has been restricted to regions of thick and obvious loess and (2) it may be that the map is accurate enough, is satisfactory in indicating where loess might be found.

There is a problem with the 15°N band; it sits on the southern fringe of a great desert and might possibly be called ‘desert’ loess- but that introduces a touch of controversy about the possible existence of desert loess. One good reason for studying the northern carmine bee-eater in its 15°N setting is to consider the nature of the ground in which it nests. Can we provide some sedimentological processes that will deliver ground which is enough like the true loess for the bee eater to find it satisfactory and to nest in it? How do the Sahara desert, and perhaps the Niger and other rivers, provide ground for nesting?

Perhaps there needs to be recognition of two types of loess deposit, essentially as shown on the Scheidig map. The major default loess deposits would be significant deposits in their own right, typified by the deposits in north China. These are large deposits, formed by specific loess deposit forming mechanisms, representing significant geomorphological items in the widespread landscape; loess qua loess, epitome loess, including the Ur-loess of Smalley and Krinsley (1981). The other type of loess-containing system is represented by the landform or deposit which contains a significant amount of loess material but where the loess material is not dominant. Britain is a good example of this situation. Most of the soils in southern Britain are influenced by loess, there is a significant input of loess material but there are few obvious loess ‘deposits’.

This situation could exist in the 15°N band. There are regions nearby where suitable material could be produced, but these are not areas of great productivity. There are transportation agencies in place and there is time for deposits to accumulate, and there is a relatively arid climate which allows the deposits to retain their identity. The 'ustic' contribution may be considerable. This is the region of 'second order' loess. The regions of first order loess are the great deposits of China and North America and those delivered by the Danube and Rhine and other rivers. The Danube delivers material for first order deposits; the Niger delivers material for second order deposits- but the deposits are large enough and loesslike enough for perceptive creatures to utilise them.

3. Desert loess

There are many significant studies of desert loess; the idea has been discussed for many years (see in particular Butler(1956), Wright(2006) Smalley and Krinsley (1978), Tsoar and Pye (1987), Crouvi et al (2008, 2012). There is, underpinning the discussion on the nature and distribution of desert loess, the question of the origin of the material. It is argued that if there is no way to produce the sedimentary material for the deposit then the deposit cannot form. For there to be a 15°N deposit, it is necessary to find some sources of material. The Niger river is building a delta (two deltas) from silty material, so it must be acquiring this material somewhere along its considerable length. It starts in the mountains in West Africa where it could receive material from mountain weathering (as the Danube receives material from the Alps) but then it heads into the desert and has the chance to acquire material produced by specific deserts processes. There are various desert processes; see a discussion in Livingstone and Warren (1996, p.57); including all sorts of exotic mechanisms including salt weathering after Cooke and Smalley 1968) but these particle-producing desert processes tend to make very fine material 'small' dust rather than loessic large dust (to use the Stuut et al 2009 terminology)..

The problem with desert loess is to associate it with a desert- in particular the Sahara. Penck was forthright in his claim that the Sahara lacked a loess region associated (der Sahara fehlt ein loessgurtel) and yet Wright(2001) has produced an elaborate scheme which allows desert associated material to form a desert loess deposit. Scheidig placed his moglich band across the continent at around 15N. There are tenuous observations and connections to be made. For example, the town of Kano in northern Nigeria is known as the City of Mud because it is largely made of adobe. Adobe is basically loess; it is certainly not simple mud (which is essentially just a mixture of clay minerals and water). Adobe is a more complex material which when wetted can generate a low order cementing action, the adobe reaction (Rogers and Smalley 1995), which renders it such a useful building material. This is a very low order cementing reaction, not to be compared in strength development to the hydration of Portland cement- but of the same chemical type. Hydration of calcium silicates is involved but the powerful silicates like C_2S and C_3S are not made in Nature. The low order adobe reaction is akin to the pozzolanic action which gives secondary strength to conventional concrete construction. Kano in the 15°N region is partially built from a loess type material, material from Scheidig's 15°N band.

There are various confusions about desert loess, and one of the most fundamental must be about the nature of the aeolian material produced in deserts, or associated with loess deposits. Two major types of material (focussing on suspension loads) might be recognized and their natures should be fully appreciated. There are two major particle populations under discussion. Stuut et al (2009) have called these 'small' dust, and 'large' dust: this appears to be something of a simplification but it probably catches the sedimentological essence. Small dust would typically be fine mineral dust with a particle diameter perhaps in the 3-5μm region. This is the material blown high across the Atlantic to improve the soils of the Amazon basin and to provide aluminium deposits in Jamaica. It can be clay mineral aggregates, diatoms from the Bodele Depression, fine quartz impact debris, other primary minerals. It can be lifted from desert regions and transported vast distances at great heights. Various particle production mechanisms are involved (Smalley et al 2005, O'Hara-Dhand et al 2010, Crouvi et al 2008, 2012).

Large dust is loess dust, mostly quartz, with a mode particle size of around 20-40μm. It travels in suspension but at a lower height and for a smaller distance than small dust. One of the major threads of the desert loess discussion involved attempts to find desert-specific mechanisms which could produce this material. In the Danubian situation the material is produced in mountains, by intense weathering processes and local glaciations during cold phases of the Quaternary. In Ukraine and Western Russia, and in North America this material can be produced by the actions of large continental glaciers.

Producing large dust is a complex process to which internal and external factors contribute. There are few obvious sources for significant amounts of large dust to be produced, for supply to the 15°N band.

However, insignificant amounts might be produced for a long time and these could accumulate into almost significant deposits: not first-order deposits, but maybe second-order deposits. Some tentative source areas are indicated on fig.1: EH the Ethiopian highlands; known to be a good source of material because they supply the Nile silt which has so usefully accumulated for such a long time. Some may be carried to the west and contribute to the 15°N band, but this has not been remarked upon. This could be a source of some large dust particles. BD, the Bodele depression, is now recognized as the major source of small dust in Africa (on the planet). However, this is essentially small dust and it is mostly destined for far distant travel. Extra strong winds may move some large dust into the 15°N region; it seems logical than some should fall into the Niger River catchment, for subsequent re-transportation. FJ, the Fonta-Djalon highland, is the moderately mountainous region which is the source of the river Niger. This can deliver weathered material which is transported by the river and supplies the western part of the 15°N band. There is the question of whether the desert to the north contributes particles to the 15°N band. There is a mechanism whereby impacting sand grains can contribute small dust (O'Hara-Dhand et al 2010) and there are large sand seas within Sahara proper but it seems unlikely that this is a significant source of large dust particulate material. The key word is significant; among the vast amount of material produced there could be some 'large' particles.

Paradoxes creep in; we accept that a sand sea can be a significant source of very fine material- small dust. The stress state inside a sand grain suggests that fine material could be spalled off the surface by impacts; the combination of internal energy and external impact energy should be enough to cause a small crack which can lead to the formation of a small dust particle. Very occasionally, with very strong winds blowing, and a very small proportion of highly stressed quartz sand particles available perhaps a modest amount of large dust might be formed- large dust at the smaller end of the large dust range(see e.g. the observations of Glaccum and Prospero(1980) who found Saharan large dust particles on the Cape Verde Islands). There are an awful lot of 'mights' and ‘possibilities’ in this discussion. The deserts are vast and the amount of sand material available is enormous; the mode product is the small dust particle (the production mechanism of which still requires investigation) but at the tail ends of the size distribution there will be outsiders to contribute to deposits of large dust. The discussion of proportions is difficult; particularly since our knowledge of the actual nature of the 15°N loess deposit is so limited.

4. The Northern Carmine Bee-Eater

The Northern Carmine Bee-Eater (*Merops nubicus* Gmelin 1758) nests in the Scheidig African loess region- see fig.3. Fry (1984) and Fry et al (1992) give some nesting details. The birds use high fresh cut ‘sand’ cliffs, preferably free of vegetation, usually found near large meandering rivers. The nests are nearly always in perpendicular or steep sloping river banks; they may spread over the cliff top into flat ground above. Fry reports the nesting density at about 60/m², which is shown in a *very* idealized representation in fig.4.

Instantly a point of discussion arises; the term ‘sand cliffs’ almost certainly really means silt cliffs; and it also seems fairly certain that these are bluff type cliffs, like say the loess bluffs on the River Danube. These are not river banks in the proper sense of the word- i.e. the sort of river bank that a kingfisher will nest in. These are loess cliffs, typically built from material delivered by large river, like the Niger, carried by aeolian transportation for a short distance and deposited to eventually form quite a thick loess deposit.

The Northern Carmine Bee-eater prefers to nest in vertical loess cliffs, like its close relative, the European Bee-eater. Is it reasonable to ask the question, why does the European bee-eater fly all the way to the Danube basin, and yet the Northern Carmine Bee-eater is satisfied with the more modest deposits of the 15°N region, including the Niger basin? The Blue cheeked bee-eater appears to favour the second order loess deposits in India and Pakistan; how does this geographical loess specificity arise? The reasons for choosing loess appear obvious: ease of tunnelling, strength of structure, a permeable system, local strengthening though compaction, possible adsorptive qualities for dealing with waste- and there may be many as yet unappreciated reasons. This conglomerate of reasons is sufficient to encourage the European bee eater to fly a long distance to exploit it

5. Tunnels

The nesting tunnel is critical: this is where the bird/ground interaction occurs. This is where the ground properties are critical. We hypothesize that ground texture is one of the key controls on nesting behaviour of bee-eaters. There are tunnel aspects other than ground texture which need to be considered. There are problems of ventilation, problems of build-up of waste material, growth of bacteria. Tunnel environments have been discussed by Fry (1984, p.234) and it is apparent that a complex bioenvironment exists in the nesting part of the tunnel system. Cyanobacteria may have a role to play in this situation; they appear to have a role to play in loess deposit formation (Smalley et al 2011, Svircev et al 2013).

The placing and the spacing of the tunnels is of interest. Fry suggested that 60 tunnels/m^2 was reasonable. There is another compromise here. The birds are social creatures and wish to nest close together, but the ground strength has to be taken into account. Fig.4 shows a Monte Carlo simulation of a 60 tunnels/m^2 situation; this is a random placement of tunnels. This is the situation produced if the tunnels are placed at random and a density of 60/m^2 is aimed at. This is not an entirely random distribution-each tunnel is ascribed a zone of influence; the method of generating the random distribution is exactly the same as that deployed to produce random crack networks in cooling basalt flows (Smalley 1966). Examination of fig.4 indicates that 60 tunnels/m^2 is not a particularly crowded situation. Tunnel diameters are 6cm and inter-tunnel spaces are very variable. Whether comparing putative nests in fig.4 with the basalt cooling situation is debateable. The basalt system is close to ideal for the formation of a random geo-network and the Monte Carlo result fitted the ground conditions exactly. But a lot more variables might exist in the nest-site selection procedure. Fig.4 shows a not particularly crowded environment, quite large inter-nest gaps appear. The sample space is actually infinite because opposite edges are identified- note, for example, that nest 34 overlaps the left and right boundaries. There is no edge effect. In natural counting there might be an edge effect so an extra nest has been introduced- nest 60 appears twice.

We propose that fig.4 gives an unrealistic view of nest distribution because, although there is no reason to suppose that the birds behave in other than a random manner, there is a time span for the formation of the nesting pattern that probably affects placement. The bird knows not to excavate too close to an existing tunnel and thus the distribution is skewed towards a wider distribution. Fig.4 is too 'uneven' there are zones of concentration and zones lacking nests, in reality a more uniform, pseudo-random distribution would be expected. It would be interesting to determine how the nesting packing deviates from an ideal two dimensional packing, a classic hexagonal network. See Rajala and Penttinen (2012) for a detailed study on this topic, via an analysis of the dispersion and placing of sand-martin nests.

It might be worthwhile to consider another index: a 'nest space index' which relates the desire of the birds to congregate and the limitations imposed by the properties of the ground.

6. Soil science at 15°N

15°N is just about the northern limit of a large region of Africa where ustic moisture conditions prevail. These are shown in outline in fig.5 (after Wambeke 1992). Ustic is a key word; it is drawn from the complex and convoluted terminology of the USDA System of Soil Taxonomy; one of the two complex, complete systems of worldwide soil classification (the other is the FAO System). It can be hard to generalise about soil taxonomy terms because they come with so many conditions and requirements attached but ustic means 'dryish'. Dryish is a term not widely used in soil science but it falls between udic (damp, maybe humid) and xeric (dry), and ustic regions, by and large, fall between udic and xeric regions. Fig.5 map shows remarkable relationship to the fig.3 map. The northern ustic region is the zone of the northern carmine bee-eaters, and the southern ustic zone is the region of the southern carmine bee-eaters. And the northern boundary between ustic and xeric has an interesting relationship to 15°N.

The ustic moisture regime probably has an interesting set of implications in a geotechnical sense. Here the moisture, concentrated at the bond point in the soil aggregate is in a position to contribute quite considerably to the tensile strength of the system- which in aquic or xeric or even maybe udic regimes it is possibly not. The xeric region would seem to be the ideal region for a loess type structure to exist; a brittle ground that forms free standing cliffs with a low plasticity index. A good test for the existence of this type of ground might be the bee-eater test. Can bee-eaters dig into it? Do they use it for nesting purposes? They offer indications that this is indeed ustic loess type ground with the agreeable compromise between tensile strength and excavateability.

6. Rivers and loess: the River Niger situation

The Danube is a loess river (Smalley et al 2010). It collects loess material from the Carpathian mountains, from the Alps, from the Dinaric Alps, from highlands ringing the basin. It delivers material for many significant deposits along its length and determines the nature of the loess landscapes for much of Eastern and Central Europe. These are much studied deposits, the Danube flows close to or through some of the most important centres of European thought and scientific research.

The Niger could be a loess river, not on the grand scale of the Danube perhaps, but delivering significant amounts of loess material and developing local loess deposits and loess landscapes. These deposits are not intensively studied; there is doubt about the status of the material, as the Scheidig classification showed, and they are placed in regions lacking in scholars and scholarly activity. Both rivers deliver deposits which could be remarkably similar, and which bee-eater birds judge to be acceptable and usable nesting ground. Loess = bee-eater ground; the question is does bee-eater ground = loess? The second equation needs qualifying, there is a place for ‘almost always’ or ‘usually’ or ‘often’. An interesting question is, how strong to make this qualifying term.

The Niger rises in the Fonta-Djalon (FJ in fig.1) highlands in S.E. Guinea and initially flows in a generally north-east direction. It crosses 15°N and heads into desert terrain and then turns south and east and heads for the Niger delta. The Niger is 4180 km long (c.f. the Danube at 2860 km) and drains a basin of 2,117,700 km2 (Danube 817,000 km2). The basin extends out into the arid regions (see fig.1).

If it is to be a loess river there has to be a supply of loess material. It is described as a ‘clear’ river because it carries relatively little suspended material; compared say to the Nile which is a ‘muddy’ river carrying a considerable sediment load. This means that the Niger will supply relatively little material for deposits- but it will supply some. It has built a substantial delta at the coast, and even an inland delta upstream of Timbuktu. Material is available in the region but in terms of loess deposit formation it is relatively modest amount of material; perhaps enough to form some relatively unimpressive deposits.

7. The Lake Chad basin as a source of particulate materials

Lake Chad is very close to the intersection of 15°N and 15°E. The Lake Chad basin is the source of a vast amount of airborne particulate material; in fact the Bodele Depression(the deepest part of old Lake Megachad) is widely regarded as the single greatest source of airborne dust on the planet. The basin is in the 15°N region and contributes sedimentary material to the 15°N deposits.

The most visible and most studied part of the basin output is the small dust which is carried in high suspension and can travel enormous distances. It is widely believed that this dust, carried across the Atlantic, provides the soil for the great rainforests of Brazil and South America in general.

Stuut et al (2009) made the simple distinction into 'small' dust and 'large' dust in order to emphasize the essential difference between the very small long travel dust, and the short travel dust which provides the material for loess deposits. These are distinctive materials and different modes of formation are involved in their production.

The Lake Chad basin is a good source of clay-mineral based small dust[CMA particles] (Evans et al 2004, Smalley et al 2005, Stuut et al 2009) and Monte Carlo controls on dust size have been discussed (Smalley et al 2005). Mega-lake Chad, the old enormous Lake Chad was a great sink for sedimentary material and now provides an effective source for aeolian sedimentary material. Much of the material delivered from the Lake Chad region (in particular from the Bodele depression) consists of diatoms. Vast amounts of diatoms were deposited in Lake Megachad and now become available for aeolian transport. These of course have a biological size control and they exist essentially in the silt size range; ideal for wind pick-up and aeolian transportation. The soil material which is delivered to the South American forests carries some plant nutrients. The nutrient content is not high in absolute terms but the long time accumulation has delivered a large amount of useful soil material. It seems likely that the actual nutrient ions are associated with transported clay minerals. The clay minerals exist as clay mineral aggregate particles. The lake bed sediment structure offers a controlling geometry to the sediment which aeolian lift forces exploit to produce a wind carried sediment load which largely consists of small dust (mode size say 3-5 µm).

The Lake Chad geomorphology is remarkable. In wetter times the lake was supplied with weathered material from several adjacent sets of mountains and this weathering detritus settled into this large lake. The meteorological conditions are such that now strong winds blow in the old lake region and these pick up and carry large amounts of sediment. A large amount of clay mineral material must be carried across the Atlantic; some evidence for this can be derived from the aluminium rich deposits in Jamaica. A simple clay mineral consists of oxygen, silicon and aluminium and it is that aluminium, usually contained in a gibbsite layer that has built the mineable deposits of Jamaica.

The clay mineral aggregate particle is a typical product of dry lakes. In Australia, this forms the parna deposits, which behave in many ways like loess deposits, and although attention has been focussed on the very fine material crossing the Atlantic the downwind parts of Africa also receive material. If the very fine material is carried westwards across the Atlantic the coarser material falls out into the Niger catchments, and can contribute to second order loess in the 15°N region. Another compromise here: the mode product is small dust but under some conditions large dust might be produced. Again at the ends of the size distribution curve will be larger particles which can contribute to large dust deposits. The vast production of particles means that occasionally rogue particles will be produced, but the overall production is so Vast that the number of rogue particles will be significant.

8. Climate change at 15°N

A University of Durham study has used Northern Carmine Bee-eaters as indicators of climate change. They have predicted the spread of bee-eaters based on assumptions about climate change. The climate change discussion needs to take into account the availability of suitable ground. Maps have been published (Birdlife 2012) showing projected distributions of northern carmine bee-eaters in 2025, 2055 and 2085. These are simulated distributions based on projected future climate change. The maps were generated by relating the species current range to current climate and then projecting this relationship on to future climate simulations.

Fry (1984, p.197) has indicated that the two kinds of Carmine Bee-eaters have savannah breeding ranges north and south of the equator and about 2000 km apart(see fig 3). Although they winter in low latitudes the fact that neither of them nests in the savannahs between Lake Turkana and Lake Malawi suggests that the summer climate there is unsuitable, presumably being too warm and humid. Climatic conditions similar to the present day have prevailed for 10-11,000 years, but before that for a period of some 20,000 years Africa was up to 6 C° cooler and far more arid, particularly at the time of the worldwide glacial maximum around 17,000 years ago.

Then, and until about 11,000 years ago, Carmine bee-eaters would have ranged uninterruptedly across dry East Africa, and it would only have been when forest began to spread from relict Congo patches eastward through the Lake Victoria basin and probably all the way to the coast in the warm pluvial period from 7,000 to 10,000 years ago that bee-eaters would have been divided into discrete northern and southern populations.

9. Commentary

The Scheidig 1934 map of world distribution of loess is one of the key documents in the history of the investigation and study of loess. It is still the most significant and useful world loess distribution map, as is witnessed by its continued appearance in major Quaternary reference works, most notably 'Das Eiszeitalter' by Paul Woldstedt. The latest edition of this work (Woldstedt 1960) carries the Scheidig map through towards modern times.

However, certain aspects of the map are neglected. Scheidig had a simple definition of the loess deposits he wished to record: they were either 'nachgeweisen' i.e. *definite*, or they were 'wahrscheinlich oder moglich' which translates directly as and could be summarised as *possible*. The definite deposits have been studied at length and with the growth of loess stratigraphy and palaeoclimatology in great detail and with great precision. The possible deposits have been somewhat neglected, in particular that large band across Africa (see fig.1) and the regions in the north-west of the Indian sub-continent. Neglected for various reasons: difficult to access, not of any particular economic interest, not presenting interesting engineering problems, not being near centres of academic activity, hard to define in a loessic sense, not falling securely within the field of interest of any particular discipline etc. Of course that last reason is no longer valid and interest in the great African possible loess band is subsumed within the large grasp of Quaternary Studies.

Also, it appears that the African possible band has a remarkable coincidence with the breeding range of the Northern Carmine bee-eater birds (*Merops nubicus*)(see fig.3) and this introduced several interesting reasons for study and investigation. Here is another definition of the 15°N loess band and the implication of bee-eater use is that the 15°N band merits study as loess. The European bee-eater (*Merops apiaster*) travels thousands of kilometres to nest in the European loess, the loess is so special, so desirable that enormous migration flights are useful and worthwhile. If it is the essentially loessic nature of the European deposits which is so attractive then the similar attractions in the 15°N band suggest that this material has many proper loessic qualities. It qualifies for investigation as loess. It deserves investigation into sources of particulate material to construct the deposits, the various modes of transportation required to bring the material into position, and modes of deposition and controls on deposit location and structure.

The idea of a 'loess river 'might be applied to the River Niger. The idea that large rivers might have an important role in the formation of loess deposits is gaining ground (Smalley et al 2009). Easy enough to apply the loess river ideas to the Danube, but perhaps more difficult to the Niger. But the sedimentological and geomorphological visions are in place for the Niger and we can see interesting sources of particles which can eventually end up in loess deposits. The 15°N region is very closely related to the Ethiopian Highlands which supply silt to the Nile and could supply large dust to the eastern end of the 15°N band. The Bodele Depression, the great source of small dust sits just to the north of the 15°N band and is in fact incorporated into Scheidig's possible loess region. Very strong winds blow through the Bodele Depression region and most of the material lifted travels high and far but such strong winds could raise some large dust which could be deposited in the Niger basin; an easterly wind could deliver large dust directly from the Bodele Depression to the Niger basin. And at the other end of the 15°N band is the highland region where the Niger rises. It supplies particulates; it will supply particulates for the inland delta. The desert to the north may contribute particles to the 15°N loess system. A mechanism has been proposed whereby impacting sand grains generate small dust (O'Hara-Dhand 2010) and with extensive sand seas to the north it seems likely that impact debris will find its way into the 15°N band.

10. Conclusions

Bee-eaters nest in loess ground. In Europe the loess distribution correlates with the distribution of European bee-eaters (Heneberg 2013). This correlation can offer information about bee-eaters and about loess. Our approach is that we seek information about loess from bee-eaters, rather than vice-versa. The birds should offer insights into the nature and distribution of the ground.

Bee-eaters can(and do) nest in other grounds than loess. The study of the European bee-eaters(Smalley et al 2013) attempted to show, from a soil mechanics viewpoint, why loess ground was so suitable for bee-eater nests. Loess does offer a remarkable combination of strength and excavateability which makes it excellent nesting ground. The proposed loess ground at 15°N in Africa appears to be very acceptable to the Northern Carmine Bee-eater, for nesting purposes. Their presence reinforces the view that this ground, although only marked as 'possible' loess ground on the Scheidig map, has many of the properties of true loess.

From the loess point of view this is a region which has not received much study. If there is to be a loess deposit there has to be a source of loess material, and perhaps fluvial systems to move the material into position. The Niger is not a loess river like the Danube, but it is required to deliver much more modest deposits. The Fonta-Djalon highlands are not the Carpathians but they are required to produce a smaller amount of material, and possibly have a much longer time span over which to do it. Loess should form in the 15°N region; it appears to have done so. The Northern Carmine bee-eater nests in this probably loessic ground.

Acknowledgements

This paper has been prepared as part of the tribute to Professor Edward Derbyshire. He has worked effectively to promote the study of loess and we recognise him as one of the

great ‘facilitators’. His wide vision of the science and the study of loess easily encompasses birds in the loess (as well as mammoths, snails, tunnels, houses and deep foundations).

References

Birdlife International/ Durham University. 2012. Species climate change impact factsheet.: Merops nubicus. http://www.birdlife.org

Butler, B.E. 1956. Parna- an aeolian clay. Australian Journal of Science 18, 145-151.

Cooke, R.U., Smalley, I.J. 1968. Salt weathering in deserts. Nature 220, 1226-1227.

Crouvi,O., Amit,R., Enzel,Y., Porat, N., Sandler, A. 2008. Sand dunes as a major proximal dust source for late Pleistocene loess in the Negev desert, Israel. Quaternary Research 70, 275-282.

Crouvi,O., Schepanski, K.,Amit, R., Gillespie, A.R., Enzel, Y. 2012. Multiple dust sources in the Saharan Desert: the importance of sand dunes. Geophysical Research Letters 39, L13401, doi:10.1029/2012GL052145.

Evans, R.D., Jefferson, I.F., Kumar, R., O’Hara-Dhand, K., Smalley, I.J. 2004. The nature and early history of airborne dust from North Africa: in particular the Lake Chad basin. Journal of African Earth Sciences 39, 81-87.

Fry, C.H. 1984. The Bee-eaters. T.and A.D. Poyser, Calton 304p.

Fry, C.H., Fry, K., Harris, A. 1992. Kingfishers, Bee-eaters and Rollers: A Handbook. Christopher Helm/ A.C.Black, London 324p.

Glaccum, R.A., Prospero, J.M. 1980. Saharan aerosols over the tropical North Atlantic-mineralogy. Marine Geology 37, 295-321.

Heneberg, P. 2013. Decision making in burrowing birds: sediment properties in conflict with biological variables. Quaternary International 296, 227-230.

Livingstone, I., Warren, A. 1996. Aeolian Geomorphology: An Introduction. Longman Harlow 211p.

O’Hara-Dhand, K., Taylor, R.L.S., Smalley, I.J., Krinsley, D.H., Vita-Finzi, C. 2010. Loess and dust on Earth and Mars: particle generation by impact mechanisms. Central European Journal of Geosciences 2, 45-51.

Rajala, T., Penttinen, A. 2012. Bayesian analysis of a Gibbs hardcore point pattern model with varying repulsion range. Computational Statistics and Data Analysis http://dx.doi.org/10.1016/j.csda.2012.08.014

Rogers, C.D.F., Smalley, I.J. 1995. The adobe reaction and the use of loess mud in construction. Engineering Geology 40, 137-138.

Scheidig, A. 1934. Der Loess und seine geotechnischen Eigenschaften. Theodor Steinkopf Dresden Leipzig 234p.

Smalley, I.J. 1966 Contraction crack networks in basalt flows. Geological Magazine

Smalley, I.J., Krinsley, D.H. 1978. Loess deposits associated with deserts. Catena 5, 53-66.

Smalley, I.J., Krinsley, D.H. 1981. The Urloess concept and changing ideas of loess formation. New Zealand Soil News 29, 57-59

Smalley, I.J., Kumar, R., O'Hara-Dhand, K., Jefferson, I.F., Evans, R.D. 2005. The formation of silt material for terrestrial sediments: particularly loess and dust. Sedimentary Geology 179, 321-328.

Smalley, I.J., O'Hara-Dhand, K., Wint, J., Machalett, B., Jary, Z., Jefferson, I.F. 2009. Rivers and loess: the significance of long river transportation in the complex event-sequence approach to loess deposit formation. Quaternary International 198, 7-18.

Smalley, I.J., Markovic, S.B., Svircev, Z. 2011. Loess is [almost totally formed by] the accumulation of dust. Quaternary International 240, 4-11.

Smalley, I.J., O'Hara-Dhand, K., McLaren, S., Svircev, Z., Nugent, H. 2013. Loess and Bee-eaters I: Ground properties affecting the nesting behaviour of European bee-eaters (Merops apiaster L.1758) in loess deposits. Quaternary International 296, 220-226.

Stuut, J-B., Smalley, I.J., O'Hara-Dhand, K. 2009. Aeolian dust in Europe: African sources and European deposits. Quaternary International 198, 234-245.

Svircev, Z., Markovic, S.B., Stevens, T., Codd, G.A., Smalley, I.J., Simeunovic, J., Obreht, I., Dulic, T., Pantelic, D., Hambach, U. 2013. Importance of biological loess crusts for loess formation in semi-arid environments. Quaternary International 296, 206-215.

Tsoar, H., Pye, K. 1987. Dust transport and the question of desert loess. Sedimentology 34, 139-153.

Wambeke, A.van, 1992, Soils of the Tropics. McGraw Hill New York 226p.

Woldstedt, P. 1960. Das Eiszeitalter; Grundlinien einer Geologie des Quartars, Ferdinand Enke Stuttgart 3v.

Wright, J.S. 2001. 'Desert' loess versus 'glacial' loess: quartz silt formation, source areas and sediment pathways in the formation of loess deposits. Geomorphology 36, 231-256.

Figure captions

1. The Scheidig loess map of Africa; with a tentative identification of particle source zones: FJ the Fonta-Djalon highlands, BD the Bodele depression, EH the Ethiopian highlands. The catchment of the River Niger is indicated.

2. The Northern Carmine Bee-eater(*Merops nubicus* Gmelin 1788). It is important to distinguish this bird from *Merops nubicoides*.

3. The Northern Carmine bee-eater living and breeding zones near the 15N latitude line in Africa, this map from Fry(1984). Zone 1 *Merops nubicus*; zone 2 *Merops nubicoides*. Zone 1 corresponds remarkably well with the Scheidig loess zone in fig.1.

4. Northern Carmine bee-eater nest holes in a loess face. An ideal model generated by simple Monte Carlo placement of nest apertures at a density of 60 tunnels m/2. Nest diameters around 6cm.

5. Soil moisture regimes in African soils. The ustic (dryish) regime is found where bee-eaters congregate. This map after Wambeke(1992).

Figure 1 BE2

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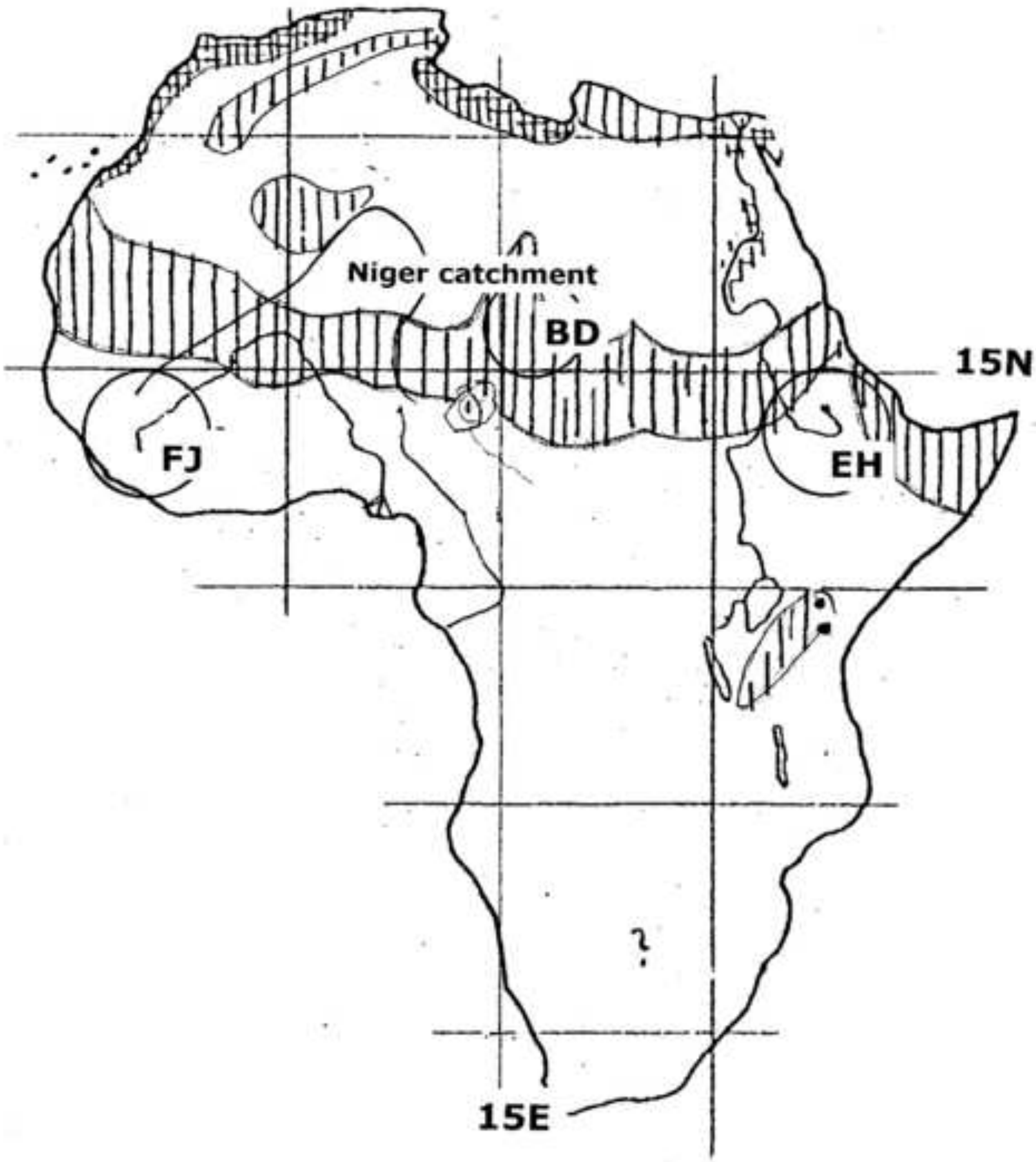

Figure BE2 fig.2
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Figure 3 BE2

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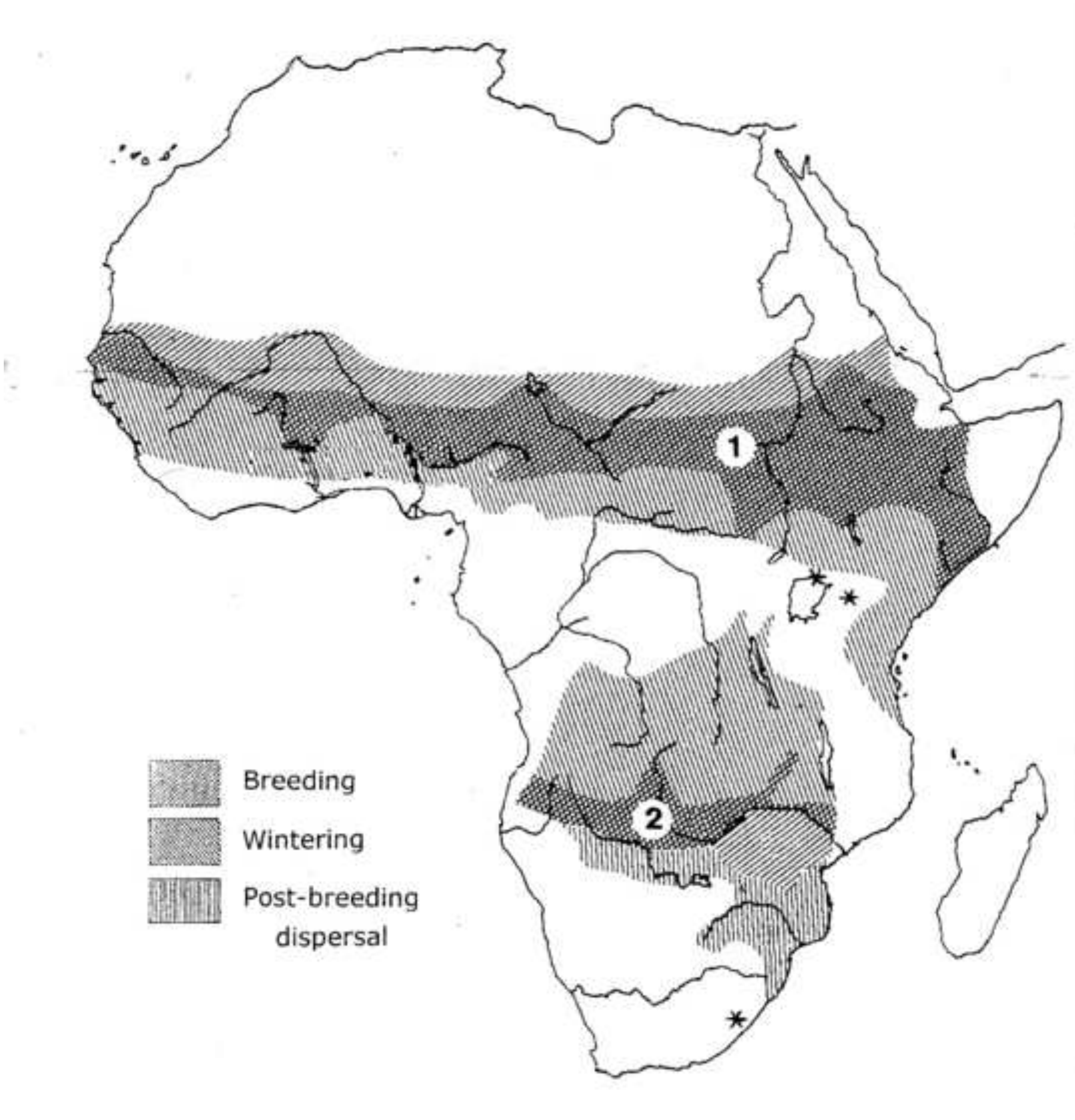

Figure 4 BE2

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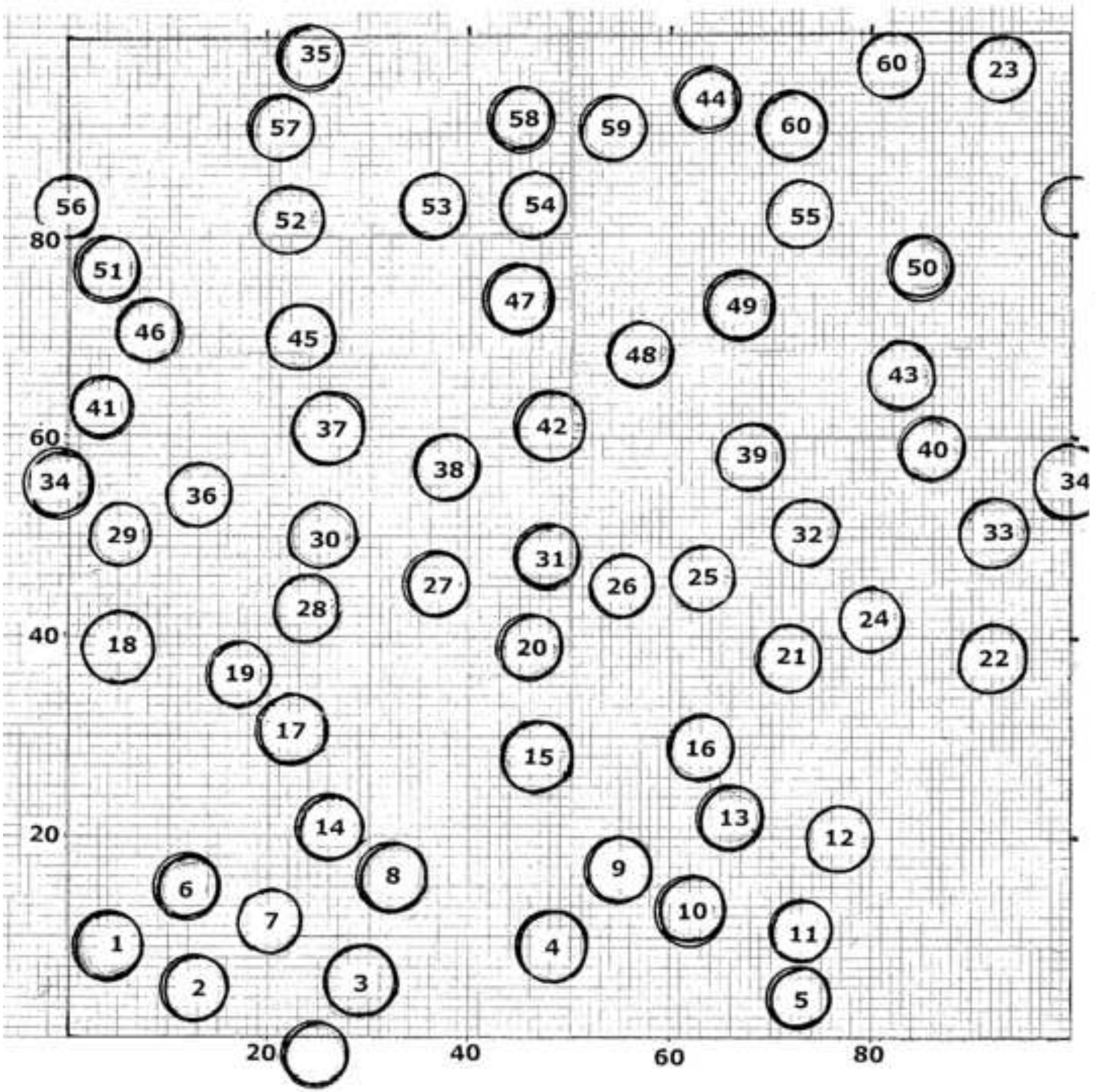

Figure 5 BE2

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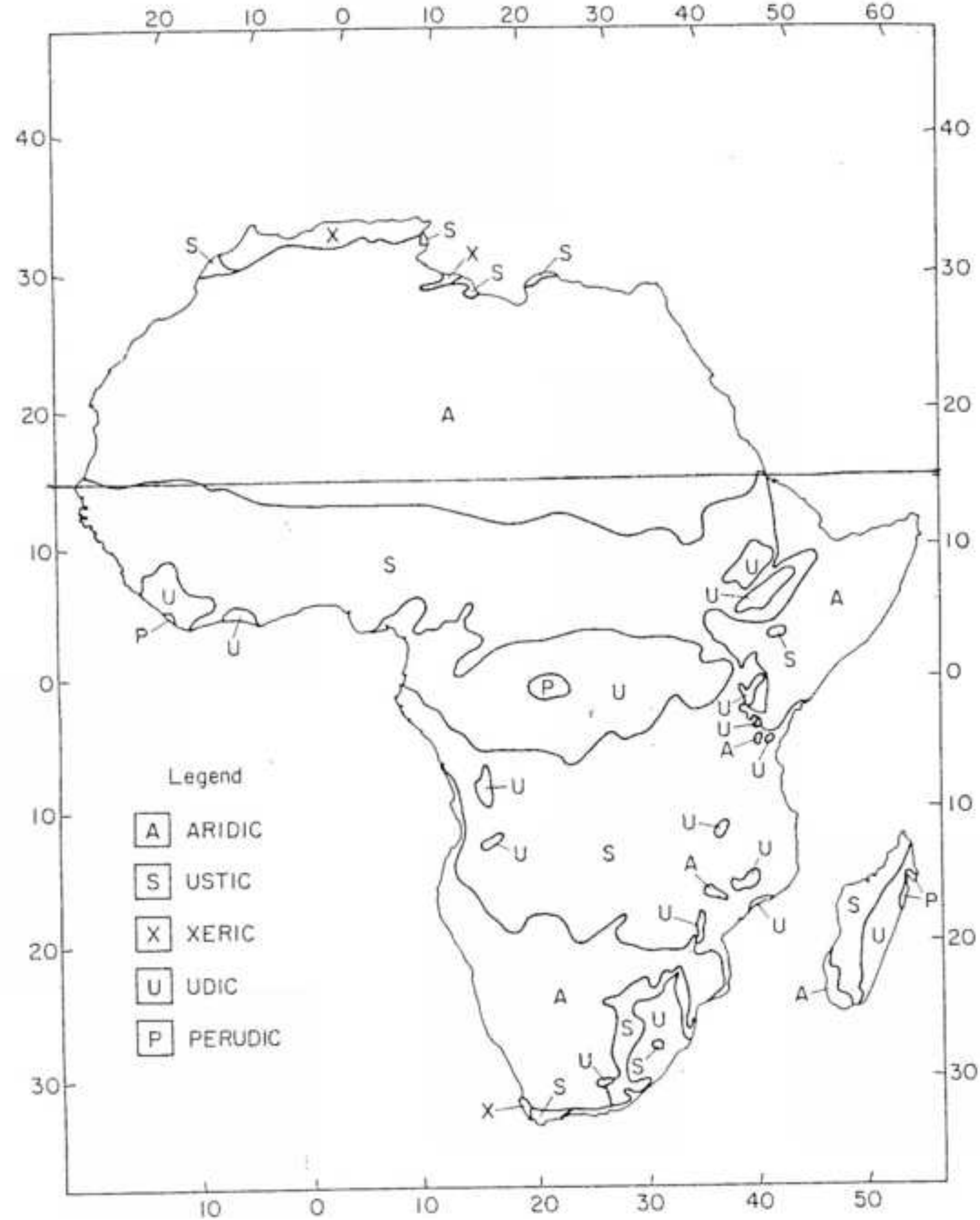

More responses to comments on QUATINT-D-13-00593R2

A few more improvements here. I have taken the opportunity of expanding the soil science section to make the significance of the ustic moisture regime clearer; I think that has improved that section- and made the soil moisture diagram more relevant.

The main additions come in the desert loess section and concern the observations made by referee 2. The problem here was to clarify the ideas of particle production in a muddled and unsatisfactory sedimentological situation. Some added data (with reference) from ref.2 helps here and a bit of rewriting removes what might be seen as an anomaly. The production of fine particles from sand seas remains as contentious as ever but I think that we have clarified the discussion position- and made a bit clearer as to how the bird observations may help in the understanding of the nature of the ground material.