Proc. Univ. Bristol Spelaeol. Soc., 2019, 28 (1), 103-128

1965 SEDIMENT SAMPLES FROM PICKEN'S HOLE AND A DISCUSSION OF THE NATURE AND ORIGIN OF AEOLIAN SEDIMENTS IN THE MENDIP AREA

by

P.L. SMART and D.C. FINDLAY

ABSTRACT

Acid treated sediment samples collected from Pickens Hole during excavations in 1965 are predominantly silt sized but are poorly sorted. The sample from Unit 6 is significantly coarser than those from the other units. The latter are similar in grain size distribution to non-acid treated samples from the base of the Pleistocene sediments at Brean Down. The grain size data suggest that these sediments are either directly derived from loess, or more likely derived by colluviation from pre-existing soils developed on a loessic parent material. The significant clay content may be derived by weathering of unstable minerals such as feldspar and chlorite and supports the suggestion for a period of pedogenesis prior to redeposition in the cave. This loessial origin is supported by the morphology of quartz in the silt size fraction which differs significantly from that of acid insoluble residue from the Carboniferous Limestone, but is comparable to that of quartz from Mendip soils which are thought to be aeolian in origin. More generally heavy mineral data for Mendip soils have been suggested to indicate derivation from the east, although a more local origin for the high chlorite and mica may also be considered, either locally from the Mercia Mudstone or from the braid plain of the River Severn to the west. A westerly source is also indicated by heavy mineral data from coversands in the area and also more widely in the UK. Soil parent materials mapped by Findlay (1995) in the Mendip area are coarser to the west than the east. The coarser materials are confined to lowlands and slope base situations, whereas extensive and thick fine deposits have accumulated on the Mendip plateau, especially to the east. This evidence also strongly suggests a derivation of aeolian material from the west and confirms the results from heavy mineral data. This suggestion is however contrary to the generally accepted model of Catt (1978) for an easterly North Sea source.

INTRODUCTION

This paper reports the results of sediment samples taken in 1965 by D.C. Findlay then of the Soil Survey for England and Wales. The details of sample treatment, results and interpretation were given in a brief report to A.M. Apsimon, and are in the UBSS Picken's Hole archive. They have not previously been reported and so are presented here for information. The paper has been drafted by Smart and follows the discussion presented by Findlay with additional cross references and interpretation by Smart in the light of more recent work, including the report of Findlay himself on the deposits at Bourne which are associated with the fan emerging from Burrington Coombe (Findlay and Catt, 2006). The discussion of regional coversand and loess deposition which was prompted by issues of interpretation of the Findlay data is wholly the work of Smart but draws on Findlay's (1965) work on soil parent materials in the Mendip area. Findlay is deceased and thus was not able to comment on this paper.

METHODS

A suite of 17 sediment samples were taken. Sample depth was not recorded, but square, face and the context numbers are given. Only 6 samples were actually analysed and reported (Table 1). The samples were treated with HCl to remove carbonates, washed and treated with Calgon to disperse the sediments. Clay and fine silt were removed by successive decanting. The samples were dried and mechanically sieved using 70, 200 and 1000 µm mesh to obtain coarse sand, fine sand and coarse silt fractions. The sand and silt fractions were then examined using a petrological microscope and notes made on the form, mineralogy and relative abundance of the grains present. Carbonate content and loss on ignition were also reported, presumably using standard Soil Survey methods.

In fact results are presented for 6 grain size fractions, clay (<2 µm), silt (2-20 µm), coarse silt (20-50 µm), very fine sand (50-100 µm), fine sand (100-200 µm) and coarse sand (200 µm-2 mm). Thus, some alternative standard Soil Survey method such as pipette analysis may have been employed, as indicated by the inclusion of the fine grain sizes. Note that in sample 10 (Unit 3) 'abundant dolomite' was recorded during the microscope examination. This suggests that the carbonate removal may only have been partial using the methods applied, dolomite generally being slower to dissolve than calcite.

Table 1. *Sample details for sediment samples from Picken's Hole squares B, E and F taken by Findlay in 1965.*

Sample	Unit	Context	Field Description
3	U6	F14	Clean yellow sand
5	U5	F8	Red-brown clay loam
8	U3	E10	Pale stone-less sandy silt loam
10	U3	E7	Breccia with brown sandy silty loam
12	U1	E3	Brown silty clay loam
14	U5	B14	Red silty clay loam

RESULTS

For total carbonate content and loss on ignition, there is good agreement between samples taken in the Findlay and later Smart samplings. For simplicity, the results are discussed and interpreted in Smart and Springall (in prep).

Grain size data and the Grain Size Index (GSI) (ratio of coarse silt to fine silt and clay used by Antoine *et al* (2009) to characterise loessial sediments) are included in Table 2, and the sediment description, mean grain size and sorting calculated using the Method of Moments in Gradistat (Blott and Pye, 2001) for the acid treated samples are presented in Table 3. The coarsest sample is derived from Unit 6 and is significantly different from all the other samples, whilst Units 5 and 1 have the finest mean grain size. There is a poor relationship between GSI and phi mean grain size, but as might be expected as GSI is a measure of dispersion, the relationship is rather better for sorting. The relationship is not however statistically significant at 90% confidence level even after elimination of sample 8 which appears as an outlier. GSI is low for one sample from Unit 5, but not the other indicating some degree of heterogeneity in this unit, and is highest for sample 10 from Unit 3, but again not for a second sample (8) from this unit. Only 2 modes in the grain size distributions were determined, 5.0 phi and 2.8 phi (31 and 144 µm). The latter is the first mode in the coarsest sample (3), but the former is the first mode in all other samples.

The quartz which makes up the bulk of the acid-treated samples is of the same general character in all samples irrespective of the Unit from which they are derived. The coarser elements are often prismatic or aggregated and are partly crystalline and contain inclusions. The finer particles, however, tend to be clear irregular angular fragments without faces and inclusions. Traces of white mica are present in all samples but are more common in samples 12 and especially 14 (Units 1 and 5 respectively). The 'sandstone' reported from sample 5 is in fact an aggregate of quartz grains similar to those found in the fine sand faction of the other samples. It is unclear whether these aggregates had not been completely decalcified or whether they had a non-carbonate cement. Feldspar was not reported.

Table 2. *Percentage grain size data for sediment samples from Picken's Hole squares B, E and F taken by Findlay in 1965. GSI = Grain size index (ratio of coarse silt to fine silt and clay), Antoine et al 2009.*

Sample	Unit	Grain Size (µm)						<20 µm	GSI
		<2	>2<20	>20<50	>50<100	>100<200	>200<2000	%	
3	**U6**	12	8	12	27	29	11	20	0.60
5	**U5**	35	21	15	8	10	10	56	0.27
8	**U3**	29	12	17	11	11	18	41	0.41
10	**U3**	17	21	36	11	8	7	38	0.95
12	**U1**	28	28	26	7	5	6	56	0.46
14	**U5**	21	29	29	6	7	8	50	0.58

INTERPRETATION: SEDIMENT GRAIN SIZE

The mean grain size for the acid treated samples is significantly less than that for non-acid treated samples reported by Smart and Springall (2019) (in fact only one sample from each data set overlaps, average mean grain size acid treated samples 5.67 compared to 3.08 phi, 20 and 118 µm). But the sorting is significantly higher for acid treated than untreated samples (2.75 compared to 1.89 phi). It is also notable that in the acid treated samples 50% are unimodal (the others being bimodal), whereas in the untreated samples there are no unimodal samples, and only 25% of the samples are bimodal. This suggests both that the coarser material in the Picken's Hole sediments is dominantly carbonate, and that additional modes are introduced from this material which were not represented in the acid treated fraction. Note however that the secondary (2.8 phi) mode in the acid treated samples is also present in 35% of the untreated samples, and of course the finer mode was not sampled by Smart and Springall (2019) as size determinations did not include analysis of material less than 4 phi (63 µm).

Grain size analyses for Nordrach soil and Carboniferous Limestone acid insoluble residue samples are given in Findlay (1965) but have rather a limited grain size resolution. There is no difference in the average grain size distribution between the 2 sets of samples, which both have a high clay size content, and plot close to sample 2-12B from Brean Down, the finest of the samples from this site. The high silt and clay content is similar to acid treated samples from Picken's Hole, but it is unclear from the text whether the soil samples were acid treated (Cornwall in Apsimon *et al*., 1961).

Table 3. *Sediment type and sieve size statistics for acid treated sediment samples from Picken's Hole squares B, E and F taken by Findlay in 1965. Figures in brackets and mean and standard deviation for phi sample means omitting outlier sample 3.*

Sample	**Unit**	**Type**	**Description**	**Mean** ϕ	**Sorting** ϕ
3	**U6**	Unimodal very poorly sorted	Very coarse silty fine sand	4.3	2.5
5	**U5**	Bimodal very poorly sorted	Very fine sandy mud	6.3	3
8	**U3**	Bimodal very poorly sorted	Very fine sandy mud	5.4	3.3
10	**U3**	Unimodal very poorly sorted	Very fine sandy very coarse silt	5.6	2.5
12	**U1**	Unimodal very poorly sorted	Very fine sandy coarse silt	6.4	2.6
14	**U5**	Bimodal very poorly sorted	Very fine sandy coarse silt	6	2.6
			Average	5.7 (5.9)	2.8
			Standard Deviation	0.77 (0.43)	0.31

Figure 1 compares the acid treated sediment size distributions from Picken's Hole with those for untreated samples determined by Cornwall and Vink from Brean Down (Apsimon *et al* 1961), from Holly Lane, Clevedon by Gilbertson and Hawkins (1974), from coversands at Kenn by Gilbertson and Hawkins (1978) and the average of 7 loess derived Devon soil samples from Harrod *et al* (1973). At Brean Down, there is a clear pattern of decreasing clay and especially silt sized material, and an increase in sand from the base of the deposit in Unit 12C to the Main Sand Unit 9, as clearly shown in Apsimon *et al* (1961) Figure 24. The Kenn cover-sand is somewhat finer than the Brean Main Sand, but has a grain size distribution rather similar to the acid treated sample from Unit 6 at Picken's Hole. In the Pickens Hole samples the effect of progressive admixture of the 2.8 phi (144 µm) mode in samples 12>14>5>8>3 is clear. This does not however correspond to a simple stratigraphic pattern representing Units 1, 3, 5, 3 and 6 respectively. Sample 3 which has only the coarser mode present is very similar in grain size distribution to untreated samples from Unit 10B at Brean Down, just below the Main Sand, and Unit 6 at Holly Lane, with a grain size distribution at the fine end of coversand sediments (see Figure 8.19, Ballantyne and Harris, 1994). All the other samples are more similar to the more poorly sorted and finer Brean samples from the lower part of the sequence (Units 12C, 12B and the lower part of Unit 12A), and the lower sample from Holly lane (U3). One sample from Brean (sample 2 from Unit 12B the clay band) is significantly finer than the acid treated samples from Picken's Hole, with more than 55% clay-sized material, and also shares the rather poorly sorted character of the majority of the acid treated samples. Hunt (2006) has interpreted this unit to comprise pellets from an eroded soil, and reports the presence of interglacial taxa such as *Carpinus* (common hornbeam), whereas the remainder of Unit 12 includes interstadial pollen which he suggests is recycled and deposited with predominantly aeolian material.

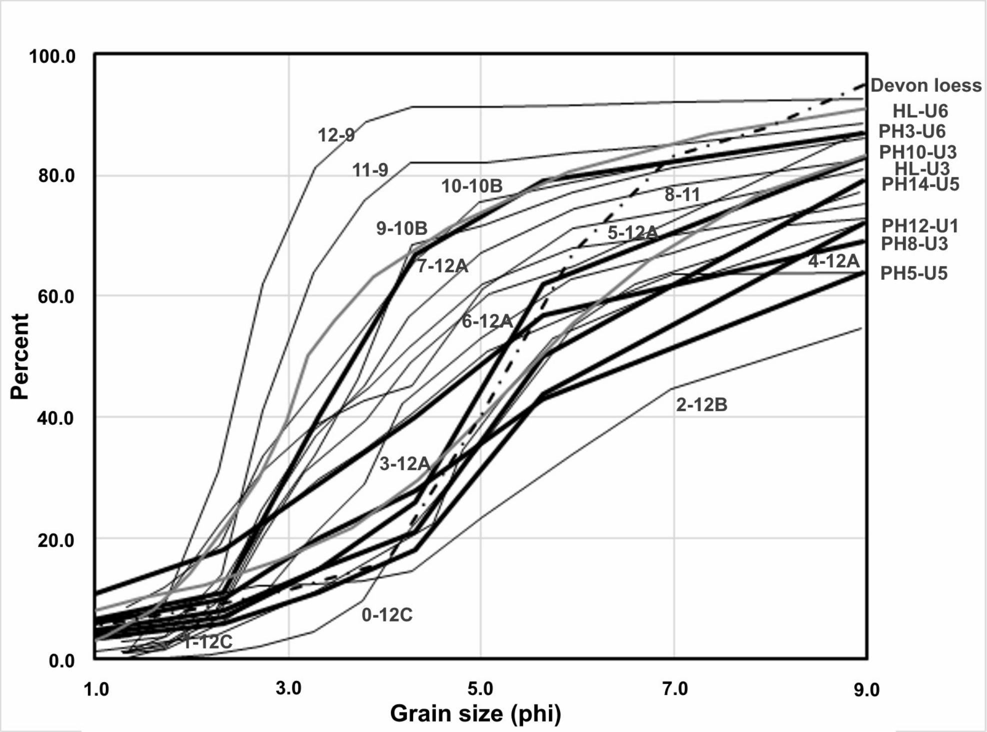

Figure 1 *Cumulative grain size curves for acid-treated samples from Picken's Hole (bold lines labelled on right axis with sample number and Unit), Brean Down from Cornwall and in Apsimon et al, 1961 (feint lines labelled with sample number and Unit adjacent to line), Holly Lane from Gilbertson and Hawkins, 1983 (grey lines labelled on the right axis) and the average of 7 loess derived soil samples from Harrod* et al, *1973 (chained line).*

The similarity of the grain size distributions for the lower samples from Brean Down and the acid treated samples from Pickens Hole suggests that these may represent the fine end member of a series of sediments with an increasing aeolian coversand component (although the exact grain size of the sand depends on climatic and local conditions as indicated by the coarse Cheltenham coversands described below). Based on the mineralogical evidence discussed above, the fine component appears not to be derived from in situ weathering, but rather from an inherited loessial component. For Picken's Hole acid treated samples (with the exception of sample 3 from Unit 6), on average 48% of the material is <20 µm in size (range 38-56%). This material is long-travelled or fine dust (Muhs, 2013) which is regionally rather than locally derived. The agreement of the acid treated and non-acid treated sample curves for this fine component suggests either that this fine-grained end member has been decalcified, or that as in loess from the North West European loess belt, there is no differences in the grain size of the carbonate (c20-24 % by weight) and non-carbonate components (Antoine *et al* 2009). The continued presence of marine shell fragments and terrestrial molluscs in the lower units at Brean (Hunt, 2006) support the latter, but these may of course be derived from the windblown coversand component, being protected from later leaching by the thick calcareous main sand which overlies them. Note however that there is significantly more clay sized (>7 phi 8.0 µm) material in all the Picken's Hole and lower Brean Down samples than the average grain size of Devon loess-derived soils. This is most probably due to weathering of unstable minerals including chlorite, feldspars, mica and epidote which are a significant component of loess (Muhs, 2018), as is well illustrated by the work of Vancampenhout *et al* (2013) for the Rocourt pedosequence in Belgium. The latter is 1.6 m thick and developed during the Eemian interglacial c130-114 ka on loess derived in MIS 6 (Saalian). The lower B units of the soil complex have significantly more clay than the parent material or higher soil horizons. This results partly from illuviation, but more significantly from the greater weathering of the lower parts of the soil complex than the upper, the soil complex being formed by continuous accumulation with the A horizon deposited much later (82-70 ka) than the lower horizons. Thus both time and differences in climate have caused enhanced weathering of the lower horizons, as indicated by the higher bulk chemical composition expressed as a chemical index of alteration (CIA) = (Al2O3/(Al2O3+CaO*+Na2O+K2O)*100) where CaO* is defined as the CaO content of the silicate fraction).

There therefore seems to be grain size evidence for regional accumulation both of coversands and loessial sediments, the latter being subjected to a significant period of pedogenic weathering increasing the clay content. Subsequently these sediments have become destabilised and have been shed from their original site of deposition downslope by hillwash and other colluvial processes.

Summary Grain Size

1. Acid treated sediment samples from Pickens Hole are predominantly silt sized but are poorly sorted. They are similar in grain size distribution to non-acid treated samples from the base of the Pleistocene sediments at Brean Down.
2. Together with the mineralogical evidence, the grain size data suggest that these sediments are either directly derived from loess, or more likely derived by colluviation from pre-existing soils developed on a loessic parent material.

3. The significant clay content which may be derived by weathering of unstable minerals such as feldspar and chlorite supports the suggestion for a period of prior pedogenesis prior to erosion and redeposition.

INTERPRETATION: SEDIMENT MINERALOGY

Findlay (1965) reports that the acid insoluble residue from the Carboniferous Limestone is predominantly silt size (98% 0.02-0.06 mm), has less than 2% of feldspar (c98% quartz) and is impoverished in heavy minerals. The limited sand-sized quartz comprises chert, or chert and euhedral quartz aggregates, while the silt-sized quartz is predominantly (70-80%) euhedral, with minor amounts of flaky detrital grains, although some samples 'had a predominance of detrital grains' (detailed data are not presented). No specific data are presented on the mica content of these residues. Thus the fine and possibly also the coarse quartz in the insoluble residue from the Carboniferous Limestone is very different in morphology to that from the Picken's Hole sediments, the fine fraction of which comprises angular detrital grains lacking well-developed quartz crystal prisms. Note however that chert is absent from the Clifton Down Limestone at Picken's Hole, but may have been present at Findlay's two reported sample sites. The coarse quartz fraction at Picken's Hole may therefore represent weathering residues from the known diffuse quartz mineralisation at the site (see Smart and McArdle 2019), possibly indicated by the presence of 'bubble inclusions'. This local derivation is confirmed by 'the absence of similar quartz at Churchill and Brean Down' which is mentioned in Findlay's report on the Picken's Hole sediments.

Findlay (1965) also reports comparable mineralogical data for Lulsgate and Nordrach series soils. Lower samples (>50 cm) from the Nordrach soil had a somewhat reduced proportion of euhedral quartz in the silt fraction compared to the Carboniferous Limestone residues, and up to 5% feldspar, but the higher Eb horizon (30-35 cm below the surface) had only 10-15% euhedral quartz, the remainder being angular of flaky fragments. Such detrital quartz fragments, which predominate in the Picken's Hole samples, are >95% for the Lulsgate soil, which also has 5-10% feldspar. Findlay (1965) argues that the detrital quartz which lacks inclusions and euhedral faces is of aeolian origin, a suggestion supported by the difference in abundance and composition of the heavy mineral suite of Mendip soils compared to the Carboniferous Limestone residues (Table 4). Similar arguments have been developed by Catt and Staines (1982) for soils in the Lizard and other areas in Cornwall where the elevated ratio of feldspar to quartz is suggested as diagnostic of an aeolian origin for soils in south Devon (Harrod *et al*, 1973) and more recently for silty sediments from Unit 2 in a core from the Gordano Valley, east of Clevedon (Hill *et al* 2008). However, in north west England, Wilson et al (1981) report that Triassic sandstones have characteristically high feldspar concentrations (9-27% of the light mineral fraction), and a local source from the Triassic lowlands around the Mendips could also be possible.

At Brean Down, Cornwall (in Apsimon *et al* 1961) reports increasing rounding of quartz grains up-section from the Basal Breccia (Unit 13) to the Middle Breccia and Bone Bed (Unit 11), some grains from which exhibited matt surfaces. At Picken's Hole in contrast the quartz grains are prismatic (larger sizes) or irregular and angular (smaller sizes). Unfortunately Cornwall does not provide a complete sequence of sediment samples, but notes that quartz from Unit 8, the 'buried soil' which overlies the main sand body is also predominantly angular, suggesting a comparable source to that for the sediments sampled at Pickens Hole. Brean Units

Source	Zircon	Tourmaline	Garnet	Rutile
	Z	T	G	
Welsh Source Rocks				
Lower Paleozoic	8	<2	0	<2
Old Red Sstn	70	<10	0-15	10
Millstone Grit	70	<10	0	10-15
Coal Measures	67	7-8	0-4	10
AIR Carboniferous Lstn	68	15	2.5	15
Mendip soils	21	15	11	15
Gordano U2	5.6	3.4	2.3	1.3
Devon loessic soils	7.3	4.7	1.5	3
Bourne silts U2 & U3	27	17	27	5
Bourne sands U5 & U5A	13	27	41	2.5
Bourne gravels U4, U6, U7	39	7.7	2.7	8.3
Cheltenham Sands	7.8	34	45	2.8
Severn Terrace	18	18	48	2.7
Liassic Clay	nd	5	60	16
Lizard soils	16	5.7	2.3	5.3
Yorks & Lincs silts	13	4.7	7	3.7
Norfolk coverloams	13	2.6	7.9	6.6
Kent loess	23	1.5	8.6	9.4
Thanet (Kent) sandloess A Inv	54.7	8	10.6	10
Thanet (Kent) sandloess B Inv	34.1	9.1	12.1	7.6
West Sussex loess	15.5	3.8	3.6	5.4
New Forest				
Upper Brickearth>=20 cm (63-250 µm)	26.1	36.4	2.6	8
Upper Brickearth>=20 cm (16-63 µm)	33.4	9.2	1.5	9.5
Upper Brickearth >20 cm (16-63 µm)	28	7.8	2.3	11.1
Lower Brickearth (16-63 µm)	32.1	10.6	1	13.7
Devensian till Lincs	14	3.7	8.4	3.2
Devensian till Yorks	17	4	10	4
Older Tertiary SE England	2.4	10.5	9.5	7.9
Younger Tertiary SE England	39.4	10.8	17.6	11.5
NW England Coversands	13	50	5	2.5
E England Coversands	18	50	39	4.2

Stuarolite	**Epidote**	**Chlorite**	**T/Z**	**G/Z**	**E/Z**	**C/Z**
	E	C				
nd	nd	90	<0.25	0	nd	11.25
nd	nd	10	<0.14	0.00-0.21	nd	0.14
nd	nd	5	<0.14	0	nd	0.07
nd	nd	10-15	0.10-0.12	0.00-0.06	nd	0.15-0.22
0	1	2.5	0.22	0.04	0.01	0.04
1	15	21	0.71	0.53	0.71	1
0.1	7	68	0.61	0.41	1.25	12.09
0.5	15	55	0.65	0.21	2.11	7.49
2.5	5	10	0.64	1.00	0.19	0.37
4	0.8	0.5	2.12	3.51	0.06	0.04
0.5	0.5	31	0.2	0.07	0.01	1.04
5.5	0.83	nd	5.12	6.29	0.1	nd
4.3	2	nd	1.08	2.78	0.15	nd
<1	nd	nd	nd	nd	nd	nd
0.7	38	8.3	0.37	0.15	2.46	0.53
0.9	37	21	0.36	0.54	2.83	1.58
0.7	51	4	0.2	0.61	3.95	0.31
1.4	43	3.3	0.07	0.38	1.9	0.15
4.2	4.3	nd	0.15	0.23	0.08	nd
2	15.1	nd	0.27	0.38	0.57	nd
0.4	37.6	15.1	0.25	0.23	2.43	0.97
4.5	9.1	3.1	1.39	0.1	0.35	0.12
0.4	28.6	6.5	0.28	0.04	0.86	0.19
0.3	30	10.1	0.28	0.08	1.07	0.36
0.3	30.6	4.1	0.33	0.03	0.95	0.13
0.7	26	25	0.27	0.6	1.86	1.78
0.7	29	19	0.24	0.59	1.71	1.1
2.3	48.8	nd	4.6	6.8	28.5	nd
6	4.1	nd	0.4	0.5	0.1	nd
0.6	0.6	nd	4	0.4	0.05	nd
8.5	9.2	nd	2.86	2.24	0.52	nd

Table 4 (previous pages). *Selected published heavy mineral data for Quaternary deposits in the South-west of England and other areas. Only heavy minerals reported for Bourne by Findlay and Catt (2006) are show, additional mineral abundances are given in the original sources. Data sources: Findlay and Catt (2006) Bourne, percent heavy minerals in fine sand fraction (63-250 µm). Harrod et al (1973), average (n=8) percent heavy minerals in silt fraction of Devon loessic soils (20-60 µm), no data is presented for the fine sand fraction. Hill et al (2008), Gordano valley Unit 2 core GVH17 3.88 m, percent heavy minerals in silt fraction (16-63 µm). Briggs (1975) average (n=6 and 3) for Cheltenham Sands (and associated Beckford Terrace Sands) and River Severn Main Terrace percent heavy minerals in fine and medium sand fraction (53-1000 µm), and for Liassic Clay (no analytical details or source provided). Catt et al (1974) average (n=8) for silty drift of Yorkshire and Lincolnshire, averages for Norfolk coverloams (n=5), Kentish loess (n=7) Lincolnshire Devensian till (n=12) and Holderness Yorkshire Devensian till (n=7) as percent heavy minerals in silt fraction (16-63 µm.) South Wales source rocks Griffiths (1939) percent heavy minerals in fine sand fraction (63-250 µm). Catt and Staines (1982) average (n=6) for loessic soils in Cornwall, silt fraction (16-63 µm). Murton et al (2003) average for samples from above and below involutions (n= 4 plus one sample from below which matches the above mineral suite and 5 respectively) and for older and younger Tertiary sediments from SE England (n= 6 and 8 respectively), fine sand fraction (50-250 µm). Reynolds et al (1996) percent heavy minerals in fine sand fraction (63-250 µm) for Upper Brickearth (n=18), and coarse silt fraction (16-63 µm) for shallow (n=18) and deep (n=10) samples from Upper Brickearth and from Lower Brickearth (n= 11) and West Sussex loess (n=4). In the following sources data is presented only in abundance classes, and are converted to percentages using the mean value for the abundance class. Findlay (1965) Lulsgate and Nordrach soils and acid insoluble residue Carboniferous Limestone from Mendip Hills, silt (20-50 µm) and very fine sand fraction (50-80 µm) were separated but are not discriminated in data reported. Northwest and Eastern coversands Bateman and Catt (1985) fine sand fraction (63-250 µm, n=2 and n=3 respectively). Abbreviations: Lstn Limestone, Sstn sandstone, U unit, A Inv above involutions, B Inv below involutions, nd not determined.*

11 and 12 below the Main Sand (Unit 9) were reported to contain a few grains of glauconite (reported from Triassic evaporative facies and from enigmatic spherulites from Wickwar by Jeans, 2006), which was not noted in the samples from Brean Unit 13. Glauconite is however generally recognised but scarce (<2%) light mineral in loess derived soils in Cornwall (Catt and Staines 1982). Distinctive red coloured quartz grains are also reported from Brean Down Unit 13, and suggested to derive from the Triassic or Tertiary sediments, although in South Wales Griffiths (1939) suggests this colouration is specific to sediments derived from the Old Red Sandstone.

There is no specific heavy mineral data from Picken's Hole, but work has been undertaken at a number of other local sites which provides information on possible sources of aeolian sediments. The heavy mineral composition of silt size material from Gordano Unit 2 (Hill *et al* 2008) and from Devon soils (Harrod *et al* 1973) is very similar (Hill *et al* Table 4, and Table 4), and is uniform over the whole of the Devon area sampled. It does however differ significantly from the loess derived Nordrach and Lulsgate soils reported by Findlay (1965), possibly because weathering has reduced the amount of chlorite present (which also increases the percentage of more resistant mineral such as zircon). All the above also differ from the data reported by Catt and Staines (1982) from Cornwall, these samples generally having more silt-sized epidote, zoisite, zircon, green hornblende, tremolite, rutile, garnet and spinel, but less glauconite, chlorite and biotite. They are more similar in composition to silty soils from Yorkshire, 'coverloams' from Norfolk and Kent loess (Table 4). Catt *et al* (1974) have argued that the similarity of the heavy mineral composition of these deposits to those of Devensian tills in Yorkshire and Lincolnshire suggests that glacial-derived outwash in the North Sea basin was the source for these aeolian deposits Subsequently Catt (1978) showed that there was a systematic increase in the percentage of the flaky minerals chlorite and mica, and a decrease in the modal grain size of silt from the east to the west of England excluding Cornwall. He suggested that this was a result of westward shape and size sorting of the deposits downwind from the North Sea basin source area. This argument is supported by the depletion of chlorite in eastern loess samples compared to the Devensian tills. However, both chlorite and mica (and glauconite) are present in the Mercia Mudstones and other Triassic sediments (Jeans 2006), so a local source is also a possibility.

Heavy mineral data are also reported for loess derived and other sediments by Findlay and Catt (2006) from a sequence of sediments exposed at the distal margin of the gravel fan that debouches from the mouth of Burrington Coombe (Table 4). They suggest that 2 major phases of deposition followed by pedogenesis are represented in the Bourne sequence. The first phase (Units 4-8) comprises fan gravels and then coversands prior to a major period of pedogenesis under interglacial conditions. After cryogenic disturbance, in the second sediment body (Units 1-3) they recognised a phase of loess deposition interrupted by ice wedge casts between Unit 2 and 3, followed by present day pedogenesis (note that their grain size data is for acid treated samples). They tentatively suggest that the 2 major depositional phases can be related to the two phases of gravel deposition in GB Cave, which are uranium series dated to 150-130 ka and 30-45 ka (unpublished work of Atkinson, Smart and Ford, referenced to Farrant 1995 in Waltham *et al* 1997). The deposits have also been reviewed by Hunt in Campbell *et al* (1998), although as they are no longer accessible their report is based largely on the prior publication of Findlay (1977). Whilst they accept the basic 2 depositional phase model of Findlay (1977) and Findlay and Catt (2006), they also suggest that an additional phase of coversand deposition and subsequent soil development may be represented in the disturbed strata at the top of the lower sediments.

The heavy mineral composition of the loess-derived sediments (Table 4) is more similar to that given for Lulsgate and Nordrach soils than to the Devon and Gordano loess which have much higher abundance of chlorite and epidote (Devon), although expressed as a ratio to zircon all 4 sediments are very similar (Table 4). Both chlorite and epidote are susceptible to weathering which could possibly explain this difference as the ratio of tourmaline to zircon is rather similar. The Bourne sands are however very different, with elevated garnet and staurolite and very low epidote and chlorite (Table 4). These sands also differ from the underlying gravels which derive from the Old Red Sandstone and probably to a lesser extent Carboniferous strata, with much lower tourmaline to zircon and garnet to zircon ratio than either the loessic sediments or the coversands, due to the elevated percentage of zircon compared to these other sediments. Zircon is a resistate mineral and is abundant in recycled sediments including the Old Red Sandstone (Table 4). The Bourne heavy mineral data therefore differentiate 3 sediment types, Old Red Sandstone derived fan gravel sediments, aeolian? coversands (units 5 and 5A) and loessic silts (U2 and 3) which appear to be derived from local Mendip soils, rather than from a regional loessic sediment input.

Somewhat surprisingly, the Mendip coversands are quite similar to the Eastern England coversands in terms of their heavy mineral composition (Table 4). These are derived from local bedrock including Triassic Sherwood and Cretaceous sandstones and associated fluvio-glacial deposits. The similarity in composition may thus arise from a common (mixed?) Mesozoic sandstone source derived from the Midlands and discharged south to the Severn estuary. Strong support for this argument comes from a heavy mineral data for Cheltenham and Beckford Terrace Sands (Briggs, 1975). These are very coarse compared to typical aeolian coversands, but whilst the latter appear to be fluvial in origin, the former are more clearly coversands. The heavy mineral and grains size composition is however identical suggesting the Beckford Terrace material is simply reworked from the coversands. A relatively old radiocarbon date gives an age of <31900 – 32500 cal BP, but topographically the sands are associated with the 2nd or Worcester Terrace of the River Severn which postdates the LGM, 3rd or Main Terrace (Gibbard et al 2017). The Bourne Sands and Cheltenham Sands both have a high garnet content, as is reported for the present River Severn by Barrie (1980). They also have elevated staurolite and low epidote compared to other sediments listed in Table 4, and tourmaline is elevated compared to zircon. A common source is clearly indicated which appears from the limited data presented by Briggs (1975) to be similar to that of the River Severn Main Terrace. Briggs concludes that the Cheltenham sands were derived by deflation of River Severn sediments by westerly winds.

Palmer (1934) and earlier authors have compared the heavy mineral suite of samples from coversands at Holly Lane, Brean Down and a now lost site at Bleadon with potential source sediments from Dartmoor, South Wales and Devon and Cornwall (Tertiary sands). No details of the specific units sampled, nor the number of samples are given, except at Brean where the sample appears to be from the Main Sand (Unit 9). The data are in terms of non-quantitative abundance classes (which is why they are not included in Table 4) and were undertaken by several different workers. The results from Brean are somewhat different to those from Holly Lane, lacking apatite, staurolite and epidote, together with a number of other minerals of low abundance. This may be possibly a result of the low general abundance of heavy minerals at Brean Down, or a different analysis scheme (acid treatment will remove apatite and siderite). Griffiths (1939) has suggested that staurolite, kyanite, epidote and andalusite are diagnostic of drift derived from Irish Sea ice as they are predominantly metamorphic minerals absent from the Upper Palaeozoic clastic and carbonate rocks of South Wales which source local Welsh ice. The coversands could thus be derived during ice retreat by deflation of drift emplaced during the Last Glacial Maximum. However, the distinctive metamorphic minerals could also be derived as part of the headwater sediment load of the Rivers Wye and Severn, with deflation from the last glacial braid plain described by Gibbard *et al* (2017). In either case, winds would be from the west as for the Cheltenham Sands.

Reynolds *et al* (1996) have presented a very careful study of the mineralogy of brickearths (=aeolian sediments?) in the New Forest which deserves rather wider recognition. They identify Upper (18.8-14,5 ka) and Lower (c100-150 ka) brickearths using a variety of field, pedological and micromorphological criteria, and demonstrate significant differences in heavy mineral composition (Table 4, selected minerals only, see original reference for full tabulation). Note that there are significant differences in the heavy mineral content of fine sand (250-63 μm) and coarse silt (16-63 μm) sizes, and between the >= 20 cm and < 20 cm depth samples of the Upper Brickearth in the coarse silt fraction. These differences are attributed primarily to weathering, which is recognised by many workers as of considerable importance. For example in relation to the Shirdley Hill Sands, Lancashire, Wilson *et al* (1981, p227) write:

‘Our interpretation of provenance takes into account considerable post-depositional changes in heavy mineral content due to weathering. Unless such changes are identified, mineralogical analyses can provide misleading evidence of sediment provenance.’ However, the preferential inclusion of chlorite and epidote in the coarse silt fraction may still be due to aeolian sorting. Compared to West Sussex loess, the New Forest brickearths indicate a significant incorporation of local material from the Tertiary sands. Such mixing of local and regional material may be similar in significance to regional 'downwind' changes.

In reviewing the results from heavy mineral analyses of loess in Belgium, focusing specifically on green hornblende which has proved to be diagnostic of deposits of different age, Pirson et al (2017) have emphasised that there are often specific methodological issues which make comparison of results from different workers difficult. These include the grain size selected, separation methods, sample size and treatment of mineral weathering and uncertainty in grain identification. As in the study of Palmer (1934) quoted here, there may also be issues in the exact stratigraphic position from which the samples are derived. Careful resampling and consistent analysis of coversands and loessic sediments from both surface and cave sites in south west England is perhaps overdue.

Summary - Sediment Mineralogy

1. The morphology of quartz in the silt size fraction of Picken's Hole sediments differs significantly from that of acid insoluble residue from the Carboniferous Limestone, but is comparable to that of quartz from Mendip soils. The latter are thought to be aeolian in origin.
2. Heavy mineral data (not available at Picken's Hole) confirm this interpretation, with Catt (1978) suggesting a loess source derived by easterly winds from the North Sea outwash plain during Quaternary low sea levels. A more local origin for the high chlorite and mica may also be considered, either from the braid plain of the River Severn, or locally from the Mercia Mudstone.
3. Heavy mineral data from coversands in the Mendip area indicate a different source to that of the loess, most likely from the glacial braid plain of the River Severn, or drift exposed after retreat of the last glacial Irish Sea ice.
4. There are significant procedural limitations in comparing heavy mineral suites reported by different workers. Furthermore, local weathering of labile components may have a major impact on the reported composition and bias interpretation of sediment source.

DISCUSSION: NATURE, SOURCES AND TRANSPORT DIRECTION OF AEOLIAN SEDIMENTS IN THE MENDIP AREA

The Local Context

Aeolian-derived loessic sediments have also been suggested as significant components in the Devensian sequence at Sun Hole, Cheddar (Unit II, Collcutt *et al*, 1961) and Unit A3 at Hyena Den, Wookey Hole (Campbell in Tratman, 1971), although this is based mainly on the reported predominance of silt sized sediments. In the cave sites and also some of the surface sites such as the Gordano valley and the Burrington fan at Bourne discussed above, the loessial material is colluvial, having been deposited on adjacent surface slopes and subsequently remobilised. This is indicated at Gordano (Hill *et al.* 2008) by the incorporation of significant amounts of calcite (8.5%) and chert (6.5%) derived from the limestones in the sand sized material in addition to quartz, feldspar and muscovite which are usual in loess (respectively 72.7, 10.7 and 1.7%), and by increase in the clay fraction due to pedogenic weathering of the more labile minerals including feldspars, chlorite and mica.

Coversands which have a larger grain size and more clearly aeolian character as they are often banked against cliffs are recognised at Brean Down (Apsimon *et al,* 1961), Holly Lane, Clevedon (Gilberston and Hawkins, 1974), Uphill, Weston Super Mare (Harrison 1977) and a number of other temporary exposures in the area (Gilberston and Hawkins 1983). They are also reported from the Quaternary deposits of the adjacent lowlands, though no detailed studies on their mineralogy or specific dating have been conducted. The most significant sites are at Kenn, just north of Picken's Hole. Here Gilbertson and Hawkins (1978) report a 'continuous layer of red/brown silty sand c0.5 m thick' (1 m elsewhere), both pre- and post-dated by cryoturbation and ice-wedge casts. These are overlain unconformably by Flandrian (Holocene) silts, and underlain by older Burtle Beds deposits which are provisionally associated with MIS 7 based on mollusc amino acid ratios. The coversands were loosely attributed to the Last Glacial maximum. Grain sizes are comparable to the finer parts of Unit 9 at Brean Down with which they are correlated, but which are ascribed an earlier age based on recent optically stimulated thermoluminescence dating (60.7±5.5 - 47.8±4.5 kyr, Currant *et al*, 2006). Similar post MIS 7 coversands are recognised at Portfield, where they may be colluvial and both Greylake and Low Ham (Coombe Member 'reworked from marine sands by aeolian, wash and ephemeral fluvial processes') where they are post MIS 5 based on amino acid ratios (Hunt, in Campbell *et al* (1998). At Kenn, only one site (New Cut Drain, Gilbertson and Hawkins, 1978, figure 22) shows directional sedimentary structures, with fore-sets to the west suggesting winds were from the east, the converse of that at Cheltenham (Briggs, 1975). Gilbertson and Hawkins (1978) suggest that the lack of distinct sedimentary structures in the coversands was due to niveo-aeolian sedimentation, with deposition of accumulated windblown material by melting of snow. More recent work in South-west France and a review of present-day deposits, suggests that the horizontally bedded sand may be wet sand sheets deposited where the ground-water table was at times at or near the surface, with grain size also affected by seasonal variations in wind speed and sediment source giving grain size lamination (see Sitzia *et al*, (2015), and also Kasse (1997) for late glacial sand sheets in northern Europe). It seems clear that both the marine marginal Burtle Beds which were likely deposited regionally on the lowlands adjacent to Pickens hole, and the fluvio-glacial deposits derived from the River Severn and exposed with falling sea level would provide sources for aeolian sediments in the area, providing winds were predominantly westerly.

Rather similar wet sand sheet deposition is also recorded in the post-Ipswichian (post-MIS 5e) Langley Silt complex at Heathrow Airport by Rose *et al* (2000), where predominantly aeolian (or aeolian and sheet wash) deposition continued until the end of the Younger Dryas (11.5 cal BP) interrupted by phases of periglacial cryoturbation and ice wedge growth, and the formation of an argillic brown soil ascribed to the Windemere Interstadial (c 14.5 -12 cal BP). Rose *et al* (2000) suggest that the silts originated from dust transported in suspension whilst sand grains were transported by saltation and traction and were only locally derived. Similar prolonged periods of continuous loess deposition are recognised in the Northwest Europe loess belt e.g. at Nussloch in Germany (Antoine *et al*, 2009) in France (Antoine *et al*, 2016) and at Remicourt in Belgium (Haesaerts *et al*, 1999), although the rate of deposition varies significantly through time and space (Frechen *et al* 2003, Rousseau *et al* 2014).

Soil Parent Materials on Mendip

In the Mendip study area, there is a rapid transition with steep slopes between the lowlands of the Somerset Levels (c <7 m AOD) to the south and west, and the much higher and relatively flat Mendip plateau (c 250 m AOD). Findlay (1965, his Figure 7) mapped the parent material for soil development in the Mendip District, reproduced here in modified form as Figure 2. He identified 'gravelly head' both as fans debouching from the gorges and also fringing the higher slopes around the main Old Red Sandstone summits (not segregated in Figure 2). The former host the Langford soil series, typically overlying Mercia Mudstone at depth, but comprising up to 60% sand in the C horizon at >1 m depth. Elsewhere on the western margins of the hills he mapped 'loamy head' which again includes significant amounts of sand sized material which is absent from the underlying Mercia Mudstones. The deposits may reach 1.5 m in thickness, thinning upslope onto Mercia Mudstone, and often having a thin layer of angular Carboniferous Limestone or Dolomitic Conglomerate clasts separating the sandy loam from the underlying marls. He suggests that these deposits represent 'breccia and sand once banked against the limestone slopes and now occurring on lower slopes due to redistribution in the last phases of solifluction and by the later processes of rain-wash' (p16), and suggests a colluvial derivation from aeolian sediments. Further to the east along the southern slopes, and when active rivers are present such as the Lox Yeo draining the Vale of Winscombe, he maps the slope foot deposits as 'riverine clay and hill-wash'. On the higher slopes for instance between Westbury sub Mendip and Wookey Hole, the soils are mapped as Worcester series, which generally has a Mercia Mudstone parent material. However, here the characteristic silty clay loam is not derived from the bedrock (which is the predominantly carbonate Triassic Dolomitic Conglomerate) but from the colluvial aeolian material. The shallow Lulsgate series is the predominant soil on the plateau slopes, and Findlay (1965, p64) notes that 'the soils are sandier to the west owing to the incorporation of blown sand'. There may therefore be some lateral variation in the grain size of the aeolian material along the southern margin of the Hills from coarser loams in the west to finer material with more clay to the east

In the uplands, Findlay distinguishes between relatively thin soils developed directly over Carboniferous Limestone and the Dolomitic Conglomerate and much deeper soils developed over an extensive area of 'silty plateau drift' which mantles the plateau around and east of Priddy. This material has a maximum in the 20-60 μm range with >60% silt sized material and <25% clay, and as discussed above shows significant differences in the morphology of quartz and heavy minerals present compared to those in the acid insoluble residue of the limestones. It is considered to be loessial. The most extensive soil series developed on the silty drift is the Nordrach series, which is typically >1 m in depth, has a well-developed Bt horizon and unlike the shallower soils retains some carbonate at depth. Much shallower soils (the Lulsgate series as mapped at Picken's Hole) are mapped to the west and on steeper slopes, but this gives way to the east and on the plateau surface to the Mendip Complex, essentially a local scale mix of shallow Lulsgate and deeper Nordrach soils. An example of this is found to the south-east of Cheddar and west of Priddy where Ford and Stanton (1968) map a number of large closed basins which have deep 'silty plateau drift' infill, but relatively shallow soils on the surrounding slopes, presumably as a result of colluvial erosion processes. The Lulsgate soils are also relatively thin on the dip slopes of the limestone, which are paralleled by topography, as on the west side of Wavering Down east of Pickens Hole. The clear implication is that either these were 'by-pass' slopes with aeolian material transported up to the plateau, or that aeolian derived soil material has been lost by colluvial process from these steeper slopes. This suggestion conforms with detailed work on sand ramps, which Bateman *et al* (2012 p 161) suggest 'might be viewed as lying on a continuum between endpoints created, respectively, solely by aeolian processes or solely by hillslope processes. At the aeolian end of this continuum would be mountain-front climbing or falling dunes. At the alluvial end of the spectrum would be a variety of features including talus cones and alluvial fans. Between these end points, sand ramps display a variety of aeolian and hillslope sediments, and the relative importance of these inputs may vary over time.'

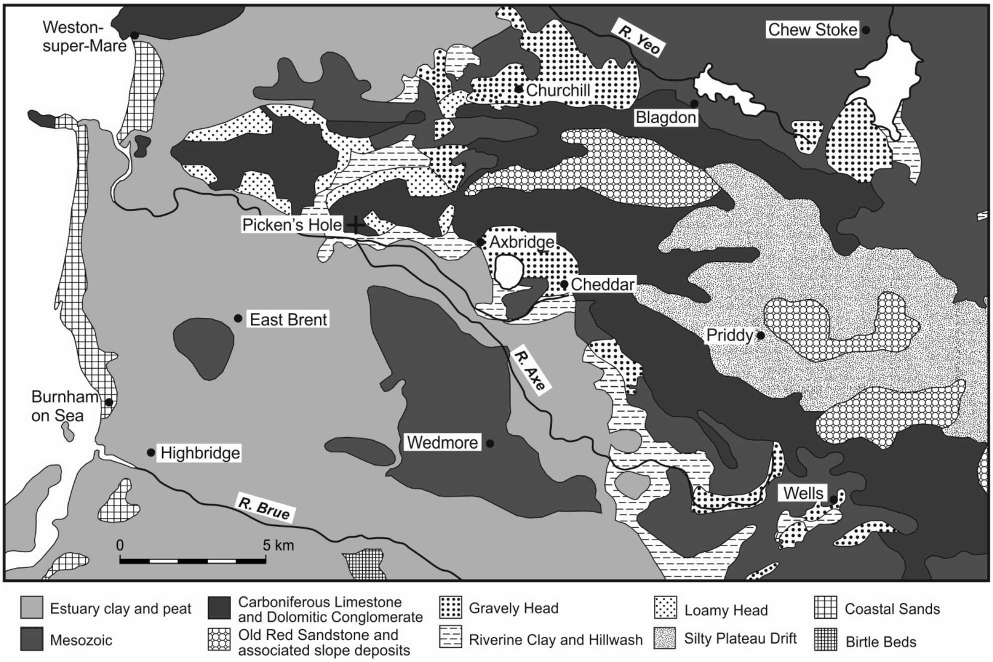

Figure 2. *Soil parent materials redrawn after Findlay (1965) for the Mendip area.*

Aeolian Sedimentation and the Role of Topography

Although some authors (Vandenberghe, 2013) suggest there are characteristic grain size modes for loess, there is rather a global continuum with local grain size modes dependent on the material available, conditions for entrainment, windspeed and distance from source. This continuum also extends into more sandy material with terms such as coverloams (Catt*, et al* 1974) and sandloess (Smedley, *et al* 2017) bridging to coarser coversands. At some sites such as Villiers-Adam in the north Paris Basin (Antoine, *et al* 2003) there is a considerable range of grains sizes in different units, with the sand-sized material derived locally from the Tertiary sands. Sands (>50 µm) are transported by traction and saltation (Pye and Tsor, 2009) which give transport distances of a few hundred to 10s of km, whilst for coarse silt (20-50 µm) saltation and especially suspension under high wind speeds may involve maximum distances of a few hundred km. Only the fine silt and clay sized material which may be taken higher into the atmosphere is transported globally (Muhs 2013). This model accords with the distance dependent grain size and mineralogical sorting convincingly displayed in south west France (Bertran, *et al* 2011, Sitzia, *et al* 2015 and 2017) which is perhaps a useful analogue for the Mendip area.

There is also substantial geochemical evidence to support this 'coarse is local, silts are regional, fines are global' model (Muhs, 2018 and Rouseau, *et al* 2014 for example). There are also important feedbacks between grain size and entrainment. Where the water table is not near the surface, sand sheets are dry and the moisture content is low limiting vegetation and allowing remobilisation of existing sediments. This effectively increases transport distances by continued saltation if there are no intervening topographic barriers, as described for the late glacial sand sheets of the Netherlands by Kasse (1997).

Topography constitutes a major modifying factor for transport distances by limiting creep and saltation on positive slopes, and by increasing deposition from suspension downwind of topographic highs due to deceleration and the development of a zone of detachment with slowed or reversed airflow (Pye and Tsor, 2009). In sandy desert areas the resulting forms comprise climbing dunes on the positive slope, cliff top dunes immediately at or behind the crest and shadow dunes on the lee slopes (Pye and Tsor, 2009). For cold climate deposits, local cliff top accumulations can be seen at some sites, such as the Roy Street and Eau-Claire dunes above the cliffs of the Chippewa River, Wisconsin, USA (Schaetzl, *et al* 2018, Fig 5 and 10), but these are relatively rare. In some areas, such as the eastern Ebro basin, Spain (Boixadera, *et al* 2015) aeolian sediments are recognised primarily on windward foot slopes, and comprise sand sheets and ramps developed of quite coarse locally sourced material. Downwind the more limited deposition and steep topography which enhances erosion makes recognition of true aeolian units difficult. More generally, cold climate loessic sediments are either absent or thin and patchy on windward slopes and much thicker on leeward slopes, as recorded for sands on the slopes of the Plateau Girondin, in south west France by Sitzia, *et al* 2017, Fig 5), and for loess in northern France by Antoine, *et al* (2016). The latter note that 'in plateau contexts, the sediment budget is generally poor and is characterized by dominant erosional processes with low sedimentation rates' (p6). For late Wisconsinan loess in parts of the Upper Mississippi River basin, Mason, *et al* (1999) observed that 'where valley side slopes are steep and or high, sand transport out of the valley was limited, this allowed thick, long-term loess accumulation on ridgetops immediately adjacent to the valley. Where valley side slopes were lower and more gently sloping, sand was transported out of the valley at high enough rates to effectively re-entrain most of the loess that was temporarily deposited.' (p231). The Northstar Sand Ramp described by Schaetzl, *et al* (2018, their Figure 5) which rises above the sand sheets covering the plain is a good example of the latter situation. More generally, there is a pattern of thick loess accumulation downwind of ridges, for instance downwind of the Girondin Plateau in south- west France (Sitzia, *et al* 2017) and for the Peoria Loess of south west Minnesota and north east Iowa (Mason, *et al* 1999). In the case of the former, deposition was enhanced by reduced windspeed over the Garonne valley, and in the latter by increased topographic roughness in the upland due to deep fluvial valley incision. Topographic roughness is also the cause of the transition from a low relief sandy foreland source zone with dunes, though a sand loess transition zone to relatively thick silty loess and eventually a deprived fine dust zone at elevation in the Qilian Shan mountains, central north China (Nottebaum, *et al* 2013).

There is also substantial size differentiation in such topographically anchored aeolian deposits, with coarse sediments accumulating at and before the slope base, and only finer material transported in suspension making it up the positive slope and accumulating on the lee slope. Sands on the western flank of the Northstar Sand Ramp (Wisconsin) pass to silt-rich loess on the lee slope, this pattern being general for both ramp and non-ramp situations in the area with 2-4 times the silt and less than 1 times the sand content immediately downwind of topographic highs (Schaetzl, *et al* 2018, Fig 7). This process is not a simple size sorting from a specific source material of given grain size distribution, rather grain to grain impacts occurring on the coarse material generates further fines (Smalley and Vita-Finzi, 1968; Muhs, 2013), which are then suspended and can be transported upslope. Mason, *et al* (1999) also emphasise the importance of saltation in enhancing transport by ballistic impact on surface grains, with saltation and thus transport being limited on positive slopes above the sandplain. This general topographic size differentiation model is supported by many field examples. In Belgium the boundaries between coversands (which dominate the lowland coastal plains), sand loess (which is confined to a narrow band on the rising slopes), and loess which forms thick deposits on the uplands are very clearly topographically defined (Paeppe and Somme, 1970), and at the classic Nussloch site in the Rhine valley, Germany (Antoine, 2009) there are local sand dunes and fine sand layers in aeolian deposits on the alluvial plain of the River Rhine at an elevation of 105 m, but steep slopes rise up to the Kraichgau Plateaux 145-175 m higher, where very thick and predominantly silt sized loess deposits occur behind the ridge at an elevation of 190 m.

Process models and actual examples of topographic control of aeolian sediment and grain size distribution inform interpretation of the Mendip soil parent materials described above, and suggest sediment supply from the west. The deposits are sandier to the west than the east, but conversely the finer deposits to the east are much thicker. Although there may have been aeolian deposition on the western slopes, this may have been limited by the coarser grains size of this material limiting both cohesion and vegetation growth which would increase deposition, and by the by-pass nature of the slope transport system, or it may have been lost by colluviation, which was responsible for deposition of this and other material derived from erosion of the bedrock in the slope base drift deposits.

Aeolian Transport in the UK during the Last Glacial

Above we have reviewed sediment distribution evidence that suggests the aeolian deposits in the Mendip area were deposited predominantly by winds blowing from the west. Although specific directional sedimentary structures are lacking, the presence of marine mollusc fragments in the Brean Down and Holly Lane deposits and foraminifera in the latter suggest a westerly origin, as also reported for the Cheltenham Sands (Briggs 1975). At only one coversand site (New Cut Drain, Gilbertson and Hawkins, 1978, Figure 22) were directional sedimentary structures present suggesting winds from the east.

Unfortunately both loess and sand sheets generally lack distinctive sedimentary structures which provide unambiguous information as to wind direction at the time of deposition. Rather, as discussed above, wind direction is inferred from mineralogy which may indicate a sediment source, from grain size and from the thickness and distribution of the sediments. It is on this basis that Catt (1978) suggests most loessial material in UK soils is derived from the east where the deposits are thickest, of coarser grain size and have a lower proportion of the light flaky minerals chlorite and mica. There are several different versions of loess depth maps for the UK, that of Catt (1978, Figure 1) simply maps loess >0.3 m deep, and is notable as it clearly identifies areas in Essex for example where loess appears to be mapped as a valley infill. In later maps, such as Antoine *et al* (2003, Figure 1) the Essex area is shown as having a continuous loess cover <2.0 m thick. Overall the impression generated by this map is of far more extensive and possibly thicker loess deposits. Only 2 areas within the UK are identified as having loess >2.0 and <4.0 m thick, the north coast of east Sussex and the coast of West Sussex and Hampshire north east of the Isle of Wight (New Forest). More recently Mildowski *et al* (2015) published a map based on papers in 1977 and 1988 by Catt (not accessed here) which reverts to a more refined distribution of loess for >0.3 <1.0 m thick. This also highlights the West and East Sussex areas as >1.0 m thick, but also includes some small areas to the north and south of the Thames in this class. Based on these published thicknesses, there does not seem to be a systematic east to west pattern in thickness, and in particular the occurrence of relatively thick deposits in the New Forest which is well west of the most easterly loess in East Sussex argues against such a pattern. It is also worth pointing out that the Nordrach soils on Mendip (which are thought to be derived from loess) are typically >1 m deep (Findlay 1965). Some care is also needed because employment of total thickness may include the accumulated thickness of deposits of different ages, as is known to be the case in both the east and west Sussex and Hampshire areas (see Parks and Rendell 1992, and Clarke *et al* 2007).

Interpretation of both grain size and mineralogy is also problematic as it is clear that in many areas there was inclusion of local material within the deposited aeolian sediment (Renssen *et al* 2007). Examples include the contribution of Chalk to the Langley Silts described by Rose *et al* (2000), Thanet Sands in the lower calcareous brickearth of East Sussex (Mildowski *et al* 2015) and fine sand derived from local Tertiary strata in the New Forest brickearths (Reynolds *et al* 1996). Without more extensive dating, it is not possible to be certain whether loess accumulations in one area are synchronous with those in others. But it is important to point out that there are significant differences in suggested wind direction for deposits of similar general characteristics within the same geographical area. For instance, in south west England, Harrod *et al* (1973) indicate an easterly derivation, whilst immediately to the west in Cornwall the thicker accumulations south and east of higher ground on Land's End are interpreted by Catt and Staines (1982) as a lee effect indicating emplacement by a wind from the north-west. In Devon the loess has a different heavy mineral composition compared to eastern sources, a derivation from a local source in Irish Sea drift being suggested.

In the case of UK coversands which are more locally derived, the situation is rather clearer, with a balance of evidence in favour of transport from west to east. For example in an excellent paper, Bateman (1998) has mapped the distribution of coversands in Lincolnshire south of the Humber estuary. To the west of the Trent they report a thick (5.5-8.5 m) sequence of sands which in the south continue to the east where the Lias Scarp is poorly defined. Where the scarp is more clearly defined topographically, the sands are present on the west (scarp) face but not the east, deposition recommencing on the Lincolnshire Edge scarp which again has thick deposits (3.5-4.5 m) with much thinner sediments on the dip slope (<2 m). Coversands are not mapped in the adjacent vale, but reach 6 m thick on the scarp of the Lincolnshire Wolds. No coversands are found further to the east. The firm conclusion is that winds were from the west. In the Brecklands a careful systematic sampling and early statistical analysis by Chorley *et al* (1966) indicates coarsening of the sands to the north-east. However, the degree of explanation of the linear trend surface fitted is very poor (11%), and a quadratic surface is a rather better, but still a poor fit (22%). The former has been widely accepted as indicating emplacement (or modification) by winds from the North Sea basin, but the latter would suggest local sources were important in controlling the size distribution, most probably variations in the local till composition as originally suggested by the authors. At Girton in Nottingham, Baker *et al* (2013) report winds predominantly from the west, but with occasional strong easterly winds forming high angle dune slip faces to the west. In the Vale of York north-westerly winds have also been suggested for coversand deposition by Matthews (1970), and a western source is suggested for coversands in the Outer Hebrides by Gilbertson *et al* (1999). Evidence of south-westerly/westerly palaeowinds during the Loch Lomond Stadial (Younger Dryas) has also been suggested based on blown snow nourishing cirque glaciers in northern England and Scotland (Sissons 1979, Mitchell 1996). For the Shirdley Hill Sands in Lancashire Pye *et al* (1995) suggested a westerly wind direction, but subsequently Wilson *et al* (1981) found that the

Shirdley Hill Sands lack clear directional evidence being derived from reworked fluvioglacial deposits by 'gentle multi-directional winds'.

Summary - Nature, Sources and Transport Direction of Aeolian Sediments in the Mendip Area

1. Aeolian derived sediments are recognised at a number of cave and surface sites in the Mendip study area, but in some cases lack distinctive sedimentary structures which may indicate the direction of sediment transport. Many are also secondary resulting from colluvial transport.
2. Topography is a major modifier of sediment deposition patterns in terms of both sediment thickness and grain size, with coarse sediments on lowland and lower windward slopes, and much thicker and finer deposits downwind of topographic obstacles.
3. In the Mendip Hills aeolian soil parent materials mapped by Findlay (1995) are coarser to the west than the east. The coarser materials are confined to lowlands and slope base situations, whereas extensive and thick fine deposits have accumulated on the Mendip plateau, especially to the east. The evidence strongly suggests a derivation from the west.
4. Based on grain size and mineralogy of loessial sediments in the UK Catt (1978) has suggested transport from the North Sea by easterly or north easterly winds. However, some caution is needed as at some sites specific local sources are indicated suggesting that model of a regional patterns derived from a single North Sea source may be incorrect.
5. Directional evidence is rather clearer for UK coversand deposits with transport predominantly by westerly winds, although some sites show evidence of multiple wind directions.

CONCLUSIONS

For all units sampled at Pickens Hole (Units 1, 3, 5 and 6?), the bulk of the matrix sediment appears to be derived from an aeolian loess source, rather than weathering of the local Carboniferous Limestone. The same conclusion has previously been drawn from Nordrach and Lulsgate soils in the area by Findlay (1965). Colluvial transport of this loess blanket is evident at several other sites (Walton in Gordano and Bourne) and has also been used to explain the large volumes of fine grained sediments infilling closed basins in the Central Mendip Hills (Ford and Stanton 1969). The loess appears to have been subjected to pedogenic weathering increasing the clay content, and has probably a variable admixture of coarser material derived from Irish Sea drift and/or the glacial River Severn braid plain. By analogy with other sites it is likely that aeolian deposition continued at variable but significant rates for much of MIS 2, 3 and 4. Furthermore, at Bourne some 9 km east-north-east from Picken's Hole it is possible to demonstrate two separate phases of aeolian deposition, coversands which are capped by an interglacial soil, and a later phase of loess deposition which is affected by ice wedges.

There appears to be a fundamental divergence between the widely accepted model of Catt (1978) which suggests that loess in the UK is derived predominantly from the North Sea sediment source area during glacial lowstand conditions and is transported over much of the southern part of Britain by easterly winds, and alternative models which emphasis a more local component predominantly transported by westerly winds. The distribution of aeolian derived soil parent material types and thickness mapped in the Mendip area by Findlay (1995) is more readily interpreted in terms of the latter model, as are the coastal coversands deposits for instance at Brean Down. Such a model is also in accord with available mineralogical data. A western derivation is also compatible with much more extensive field data from the UK. Unfortunately specific global circulation model data for the southwest of England is not available and in any case may be unreliable due to imprecise model boundary conditions.

Much of the work reviewed for the Mendip and regional areas is relatively old. Thus for example the results of heavy mineral sampling are often affected by specific methodological issues which include the grain size selected, separation methods, sample size and treatment of mineral weathering and uncertainty in grain identification. This therefore makes comparison of results from different workers difficult. Many of the deposits have also not been well dated, and the degree to which they are contemporaneous is not know. Careful analysis of newly available data sources such as soil trace element data may be useful in addressing the distribution of loessial sediments (Scheib and Lee, 2009). For example it appears to be anomalous that the Mendips have received a substantial covering of loessial material which forms the basis of the present thick soils, and that the Sherbourne soil of the Cotswolds is thought to be wholly derived from bedrock materials despite its predominant silty clay loam texture (Courtney and Webster, 1973 and Findlay, 1976). If the western source model is adopted the escarpment topography of the Cotswolds might have been expected to result in significant lee accumulation as on Mendip, especially as coversands are identified with a River Severn braid plain source at Cheltenham.

ACKNOWLEDGEMENTS

I thank Abby George for drafting Figure 2 (funded by the Oliver Lloyd Memorial Fund), Mark Bateman (University of Sheffield) and Denis-Didier Rousseau (Sorbonne Université) for discussion on the nature and timing of coversand and loess deposition and the encouragement of the editor.

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P.L. Smart
School of Geographical Sciences
University of Bristol
Bristol BS8 1SS
England
nzoia1@aol.com

D.C. Findlay
deceased.