CATENA vol. 19, p. 493–509 Cremlingen 1992

Loessic Silt Deposits in the Western Himalayas: Their Sedimentology, Genesis and Age

L.A. **Owen**, B.J. **White**, H. **Rendell** & E. **Derbyshire**

Summary

Loess is abundant in the foreland basins of the Himalayas. However, it is poorly developed within the intermontane basins of the western Himalayas and Karakoram. Selected sections were studied from the Swat Himalaya and the Karakoram Mountains. Fieldwork and sedimentological analysis including grain size, mineralogy and microfabric showed that the loessic sediments have been reworked and some have undergone weak pedogenesis. These silts are not true loess, rather a "loessic colluvium". Thermoluminescence (TL) dates from the loessic sediments in sections from the Swat valley provided younger ages than earlier workers had suggested. This is consistent with reworking of the loess in these areas. It is concluded that care must be taken when using loessic silts for TL in similar mountainous terranes.

1 Introduction

There are thick deposits of loess and colluvium in the foreland basins along the southern margin of the trans-Himalayan mountain belt. At the western end of the Himalayas two main regions have attracted much attention. The Potwar Plateau, where a maximum thickness of 11 m of loess is exposed in the Soan valley (Rendell 1989) and the Kashmir Basin where thicknesses of 8–10 m have been described (Rendell et al. 1979). However, little work has been done on the loess within the high mountains themselves. This study describes the nature of the loessic deposits present within the mountains at the western end of the trans-Himalayan mountain belt with particular reference to the Swat Himalaya and Karakoram Mountains (fig. 1). The potential problems of using loessic silts to date landforms using thermoluminescence (TL) dating are also discussed.

ISSN 0341–8162

0341–8162/92/5011851/US$ 2.00 + 0.25

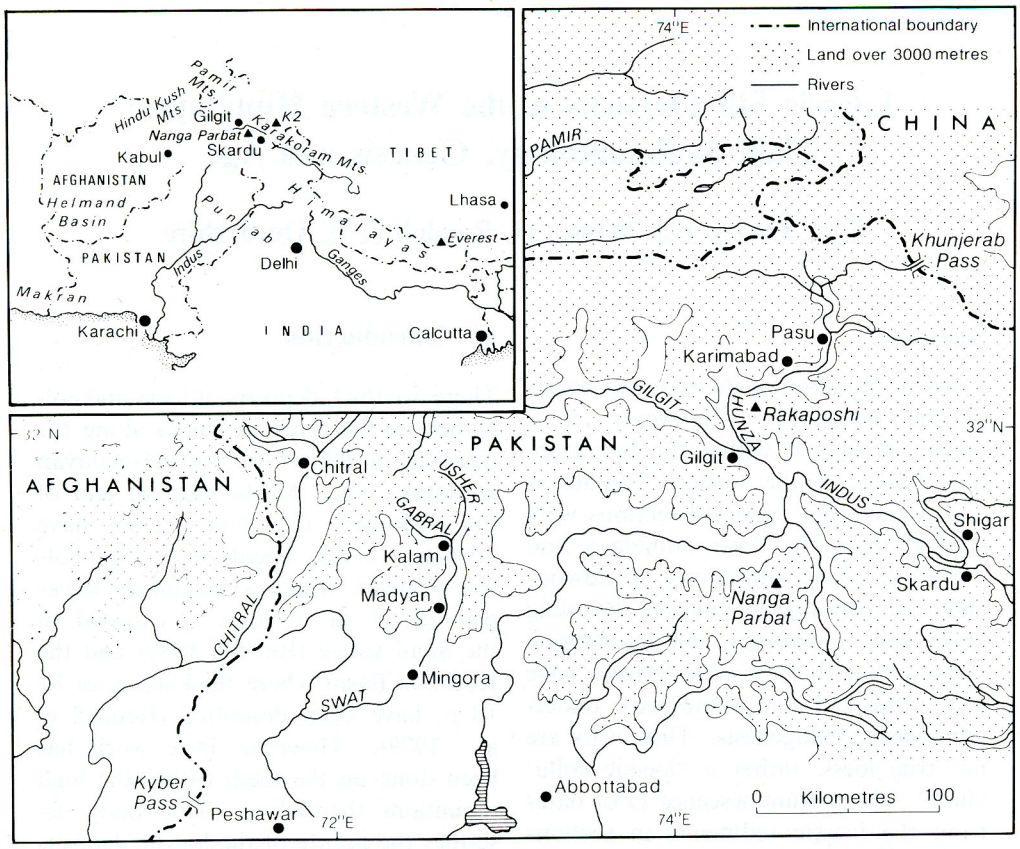


Fig. 1: *Map of the western Himalayas, showing Swat and the Karakoram Mountains.*

Kalam glaciation Late Stade Intermediate Stade Early Stade
Gabral glaciation Late Stade Early Stade
Laikot Glaciation

Tab. 1: *Glacial chronology for Swat Kohistan (after Porter 1970).*

2 Field locations

2.1 Kalam loess

Porter (1970) in his study of the Quaternary glacial record of Swat-Kohistan used the loess deposits that mantle the terraces and moraines as one of many criteria to construct a three-fold glacial chronology of the area on the basis of relative dating of glacial periglacial sediments (tab. 1). He believed that the oldest glacial deposits have the thickest loess mantles, having a longer interval of time available for loess deposition than successively younger terraces. Further,

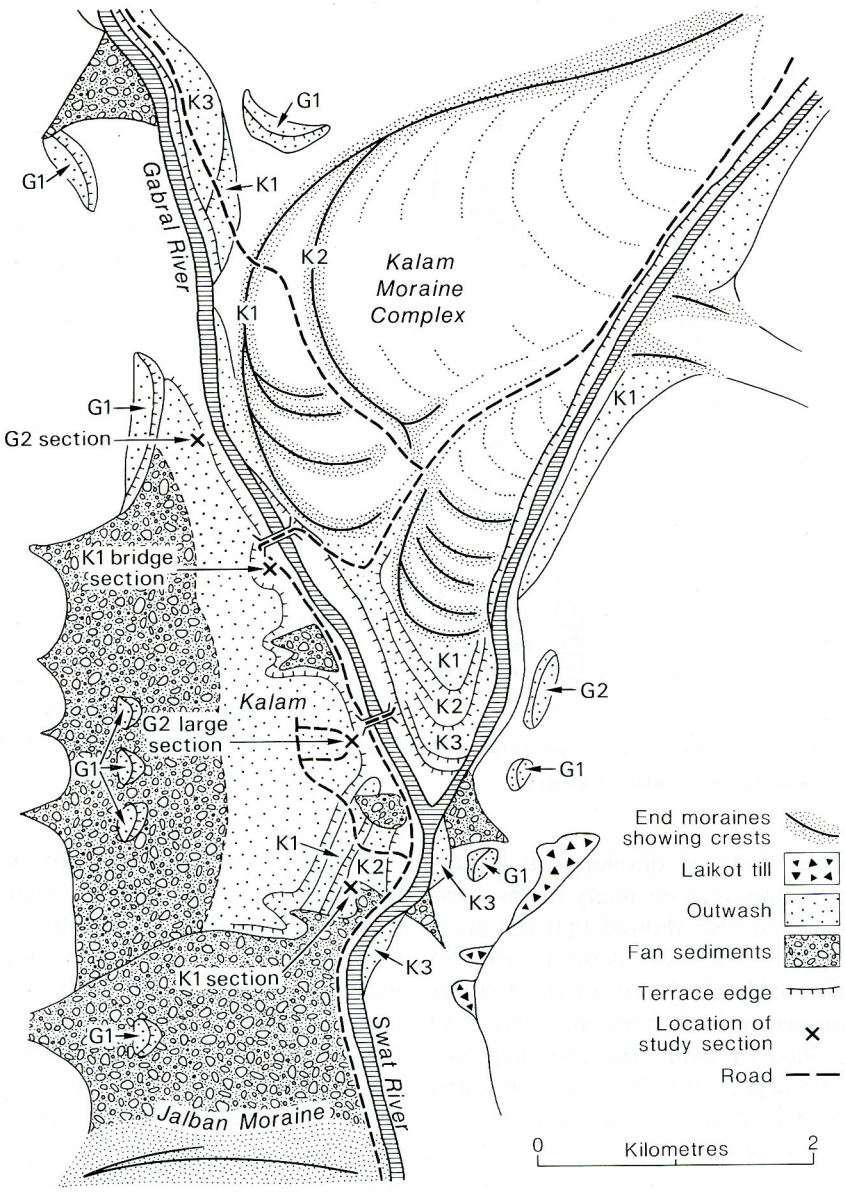
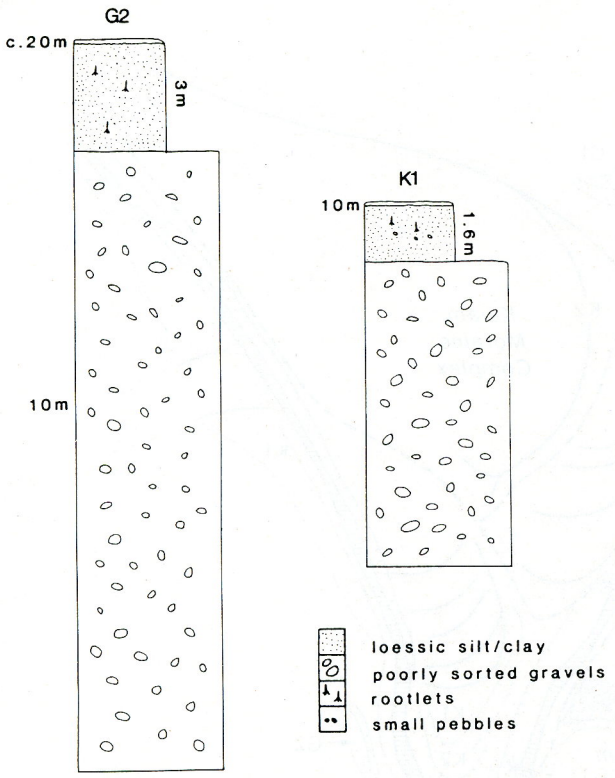


Fig. 2: *Map of the area around Kalam village showing the locations of the loess sections (adapted from Porter 1970).*



Colluvial loessic silts on outwash terraces ,Kalam,Swat valley,Pakistan.

Fig. 3: *Sedimentary logs of the loessic sections from GII and KI terraces.*

he noted that soil development is particularly apparent on many of the loess mantles and also showed that the gravels beneath the loess deposits are frequently oxidised. Many of the terraces are capped by colluvium and some have been tilled by man. He also suggested that the degree of soil development and depth of oxidation of outwash gravel is a function of time.

Samples of loess from Porter's (1970) sections were collected initially in order to date them using thermoluminescence (TL), so as to place absolute age constraints on his glacial chronology. Upon close examination of this loess, however, it became apparent that much of it had been reworked. In order to validate any TL dates on these sediments it was important to identify the type of loess present, i.e. if the loess was primary and formed *in situ* with its lower layers deposited soon after the deposition of the underlying landform. If it can be shown that loess has been reworked then an unknown period of time separating its deposition from that of the underlying deposit would seem to indicate, making the silts much younger in age and providing inaccurate dates for the underlying deposits or landforms.

Eight main sections were examined around the village of Kalam, three of them in detail (fig. 2). These were cho-

Photo 1: *Loessic sediment at the Gabral II section in Swat. Note crude horizontal fissility. The pocket compass provides scale.*

Photo 2: *Loessic sediment in the Bagrot valley. The hand of one of the authors rests on a boulder within the section.*

sen because they comprised silt-rich sediments which resembled true loess, i.e. a narrow size range in the coarse silt grade, an open framework structure, the absence of laminations and a tendency to collapse when wetted and loaded.

2.1.1 Gabral II large section

This is the thickest of the loessic sediments examined (fig. 2 and 3; photo 1) comprising 3 m of massive silt overlying poorly sorted gravels and mantling the terrace surface. The silts are of medium to fine silt grade, but contain occasional small pebbles and sand grains. Rootlets are present, oxidised at the base, and become more prolific up-section. The silts have the subvertical joints characteristic of loess, but also a weak subhorizontal fissility emphasized by wide lenticular voids.

2.1.2 Gabral II section

A second section of Gabral II age was examined to compare the lateral consis-

tency of the loess cap. This section is about 2.1 m thick and has essentially the same sedimentary characteristics as the Gabral II large section.

2.1.3 Kalam I section

This section comprises 1.6 m of thick silt overlying poorly sorted gravels. Its sedimentary characteristics are similar to the loessic sediments in the Gabral II section, but the silts are finer grained, the sub-horizontal fissility is better developed, and a greater organic content is apparent (fig. 3).

2.1.4 Kalam I bridge section

This section comprises 2.3 m of silt, medium to fine grained, with a weak sub-horizontal fissility. Clusters of pebbles and small cobbles are present within the silts. There is no apparent erosion surface between the pebbles and the silts. Rootlets are very abundant throughout the top metre of this section, the silts grading up into organic-rich clays.

2.2 Karakoram loess

Loessic deposits within the Karakoram Mountains have not previously been described in detail. Thin loessic deposits are present throughout the mountains mantling terraces, moraines and alluvial fans. Sections were examined in the Bagrot valley, Hunza valley and the Skardu basin.

2.2.1 Bagrot valley

Loessic sediments up to 2.6 m thick is present in the upper Bagrot valley 3 km east-north-east of the snout of the Hirandu glacier, on the southern slopes of Rakaposhi Mountain. This forms a thick cap on the lowest terrace comprising coarse silts with an open framework structure, no apparent sub-vertical jointing, and abundant rootlets in the top third of the section. Small pebbles are present throughout the section and, near the middle of the section, a small boulder was observed (photo 2).

2.2.2 Karimabad, Hunza valley

The majority of loessic deposits within the Karakoram comprise cm-thick caps of silt on the surface landforms. An example was collected from a gently-sloping (<10°) debris flow fan on the south side of the Hunza valley 12 km east of Karimabad. The silts mantle cobbles and pebbles on the top of the diamicton, but there is no apparent abrupt contact between the matrix of the diamicton and the overlying silt, but translocation of fine silt into the underlying diamicton could be seen.

2.2.3 Skardu Basin

In the south-eastern corner of the Skardu Basin thick loess deposits are present on terraces at a height of about 3200 m. The silts mantle morainic fans and bedrock deposits thickening westwards and obtaining thicknesses in excess of 2.5 m (photo 3). These silts are sedimentologically similar to the Bagrot loessic deposits.

3 Sampling

Oriented blocks weighting approximately 1 kg were collected from pits dug to a depth of 70 cm (McGown & Derbyshire 1974). The samples were collected in shadow, wrapped in thick aluminium foil

Photo 3: *Loessic sediment in the Skardu Basin.*

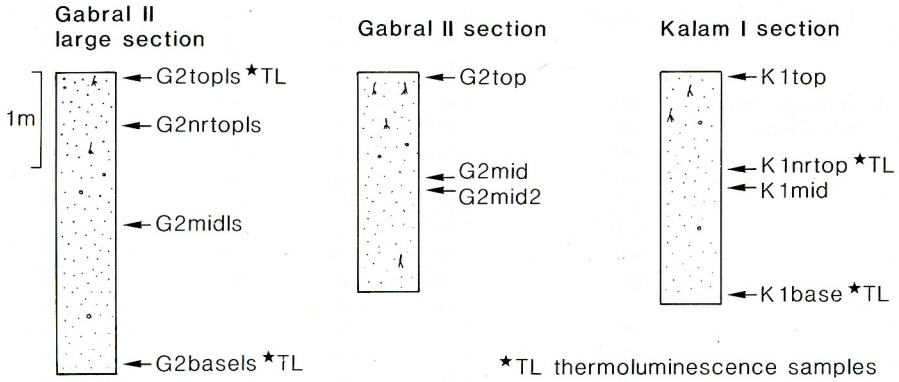


Fig. 4: *Schematic logs showing the position of the Kalam I and Gabral II samples within the sections.*

and sealed in plastic bags to limit exposure of the samples to sunlight to ensure that TL dating could be carried out as accurately as possible. Figures 2 & 4 show the positions of each sample collected in the Kalam area and tab. 2 lists the samples collected from the Karakoram Mountains.

The Kalam samples were sub-sampled in a dark room at Leicester University to avoid light exposure and one sub-sample was repacked in aluminium foil and sent to the University of Sussex for TL dating.

4 Laboratory work

4.1 Particle size analysis

The samples were crumbled between the fingers and passed through a 63 um sieve. Less than 1% of each sample was found to be coarser than 63 um. The <63 um

		Folk & Ward (1956) Statistics			
		Mean/phi	Sorting	Skewness	Kurtosis
Skardu Samples	SK	5.93	1.70	0.63	1.16
	SK2M	6.47	1.79	0.67	0.80
	Karimabad	5.56	1.68	0.69	0.73
Kalam Samples	G2 BSE	8.51	2.45	0.33	0.24
	G2 MID	8.62	2.18	0.44	0.43
	G2 TOP	9.16	2.41	0.31	0.32
	G2 Mid 2	8.18	2.75	0.47	0.20
	G2 NRTOP	8.08	2.50	0.43	0.33
	G2 LSMID	6.97	2.01	0.58	0.75
	KI MID	8.38	2.78	0.44	0.19
	KI TOP	8.17	2.68	0.48	0.38
	KII MFTP	8.67	2.68	0.33	0.23
	KI BRGE	8.26	2.60	0.41	0.21
	KI NRBSE	8.34	2.69	0.39	0.23
Lanzhou loess	China	6.30	2.59	0.60	
		7.22	2.74	0.48	(after
		6.42	2.54	0.39	Derbyshire
		6.13	2.21	0.51	& Mellors
		7.18	2.66	0.46	1988)
Lanzhou palaeosols	China	7.65	2.99	0.36	
		7.85	3.10	0.42	
		7.78	3.09	0.45	
Holocene loess NW China	S94	5.96	1.73	0.62	1.09
	S92	7.22	2.75	0.69	0.50
	S87	6.75	2.40	0.69	0.70
	S67	7.11	2.46	0.66	0.60
	S73	6.35	2.05	0.65	0.97
	S70	7.33	2.52	0.64	0.53
	S65	7.30	2.54	0.67	0.43
	S1	8.24	3.01	0.31	0.33
	S2	7.94	2.68	0.21	0.35
	S8	8.95	2.88	0.16	0.37
	S5	8.48	3.38	0.31	0.40
	S10	8.20	2.89	0.28	0.38

Tab. 2: *Particle size statistics comparing western Himalayan loessic sediments with loess from northwestern China.*

fraction was placed in a 0.1% solution of calgon and immersed in an ultrasonic bath for 20 minutes. The grain size distribution was determined using a Micromeritic 5000 ET SediGraph. Folk & Ward (1956) statistics were applied to the particle size distributions.

4.2 Calcium carbonate content

The $CaCO_3$ content for each sample was determined manometrically using a Bascomb Calcimeter (Avery & Bascomb 1974).

4.3 Clay mineralogy

The clay grade fraction (<2 um) was obtained by decanting the clay fraction held in a suspension of the silt sample in distilled water. The clay and silt mineralogy for each sample was determined using X-ray diffraction of samples air-dried, glycolated and heated to 650°C using the methods of Brindley & Brown (1980) and Carrol (1974).

4.4 Microfabrics

Orientated blocks were studied using the scanning electron microscope (SEM). An EDAX (electron diffraction x-ray analysis) was used in cojunction with the SEM to help determine elemental composition of constituent grains.

4.5 Thermoluminescence

In order to obtain TL dates it is necessary to determine both radiation dose accumulated since the sediment particles were last exposed to light (the Equivalent Dose), and the annual radiation dose. Equivalent dose determinations were made for four of the Kalam loess samples using "fine grain" techniques (Zimmerman 1971). After acid pretreatment and size separation by sedimentation, aliquots of a suspension, in acetone, of the 2–10 micron polymineral size fraction of each sample were pipetted on to clean 10 mm diameter aluminium discs. A batch of 36 discs was prepared per sample. The sample discs were used to make measurements of the natural TL, and also subjected to a range of treatments including additive radiation doses, optical bleaching and radiation doses after bleaching. Discs were preheated at 230°C for 1 minute before being glowed out to 400°C at a heating rate of 300°C/s. Laboratory radiation doses were administered using ^{90}Sr and ^{241}Am sources. TL emissions were monitored through Schott UG11 (ultra-violet) and Chance Pilkington HA3 (heat-absorbing) filters using an EMI 9635Q photomultiplier. The equivalent dose was determined by both the additive dose and the regeneration methods (Aitken 1985). The sample dosimetry was determined by a combination of thick-source Beta counting and X-ray fluorescence analysis.

5 Results

5.1 Particle size analysis

Fig. 5, 6 and tab. 2 show the particle size characteristics for the loessic sediments in the Kalam and Gabral sections. All the samples are poorly sorted and skewed towards the fines and lie in a relatively narrow particle size distribution envelope. The Kalam I loess forms a very tight envelope compared to the Gabral II loess which varies erratically up-section. Similarly, the Karakoram loessic sediments are poorly sorted and skewed towards the fines, but are rather coarser grained having 60% in the coarse silt fraction (fig. 5).

5.2 Calcium carbonate content

Samples from the Kalam and Gabral sections contains no $CaCO_3$. The Karakoram loessic silt, however, contains 2–5% $CaCO_3$. SEM work showed that this $CaCO_3$ was present as limestone clasts and no secondary carbonate either in the form of cements or as coatings or authigenic calcite was recognised.

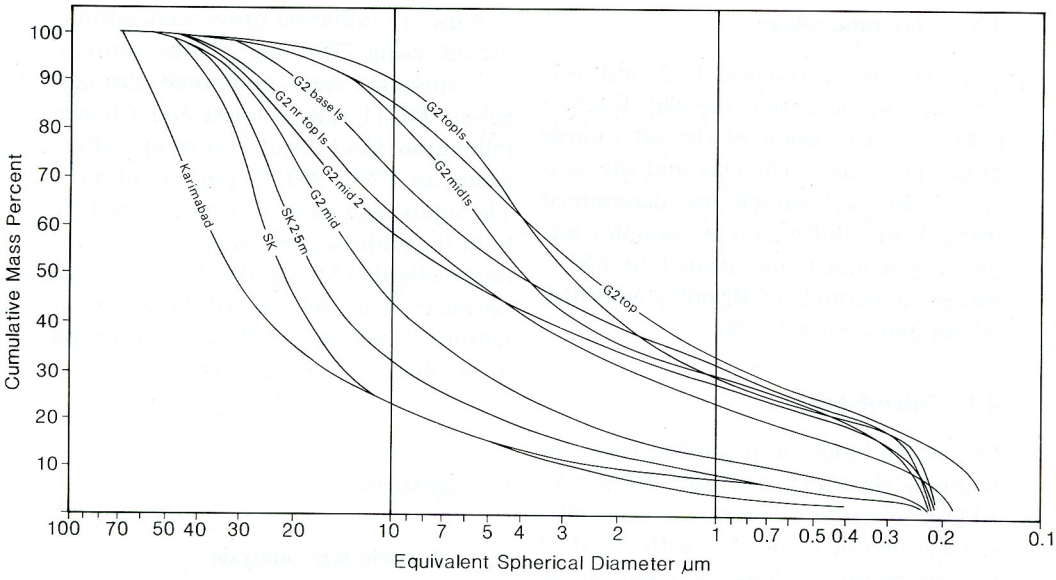


Fig. 5: *Pacticle size distribution curves for the Gabral II loessic silt samples and loessic silts from the Karakoram Mountains.*

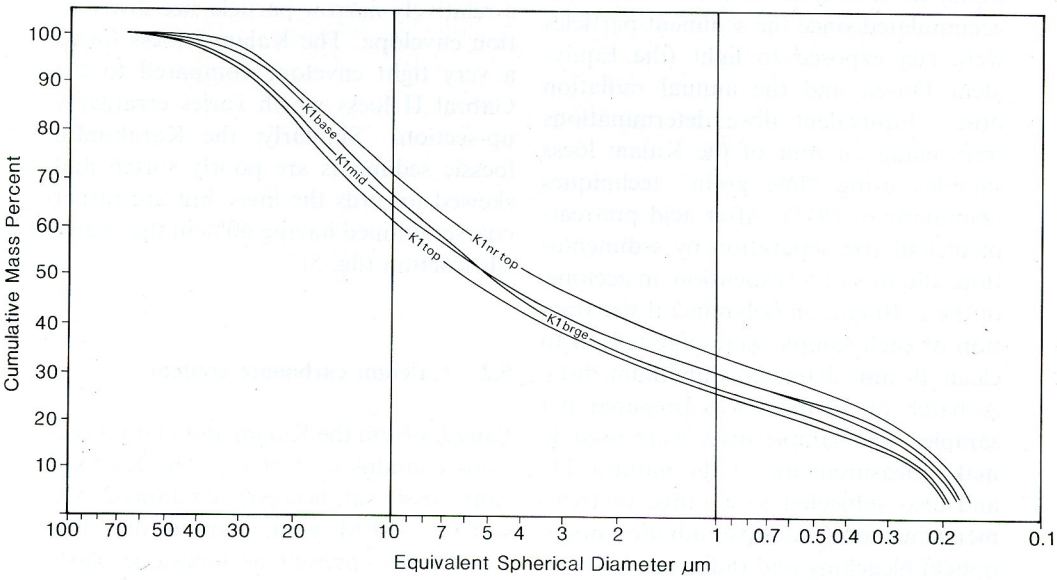


Fig. 6: *Particle size distribution curves for the Kalam I loess.*

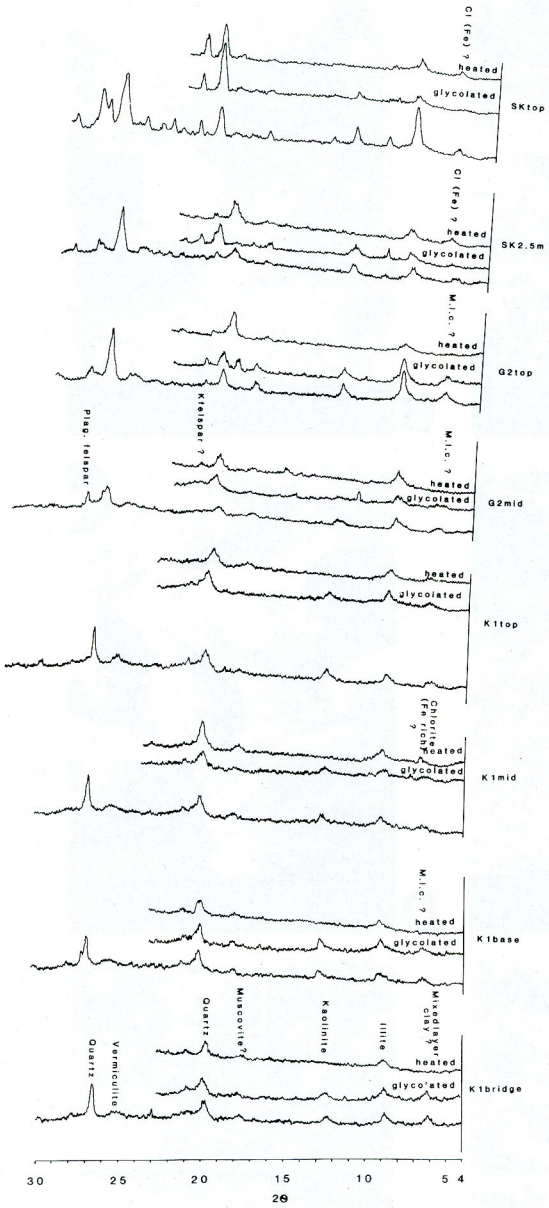


Fig. 7: *X-ray diffractograms for the mineralogy of samples of loessic silt from Swat and the Karakoram Mountains.*

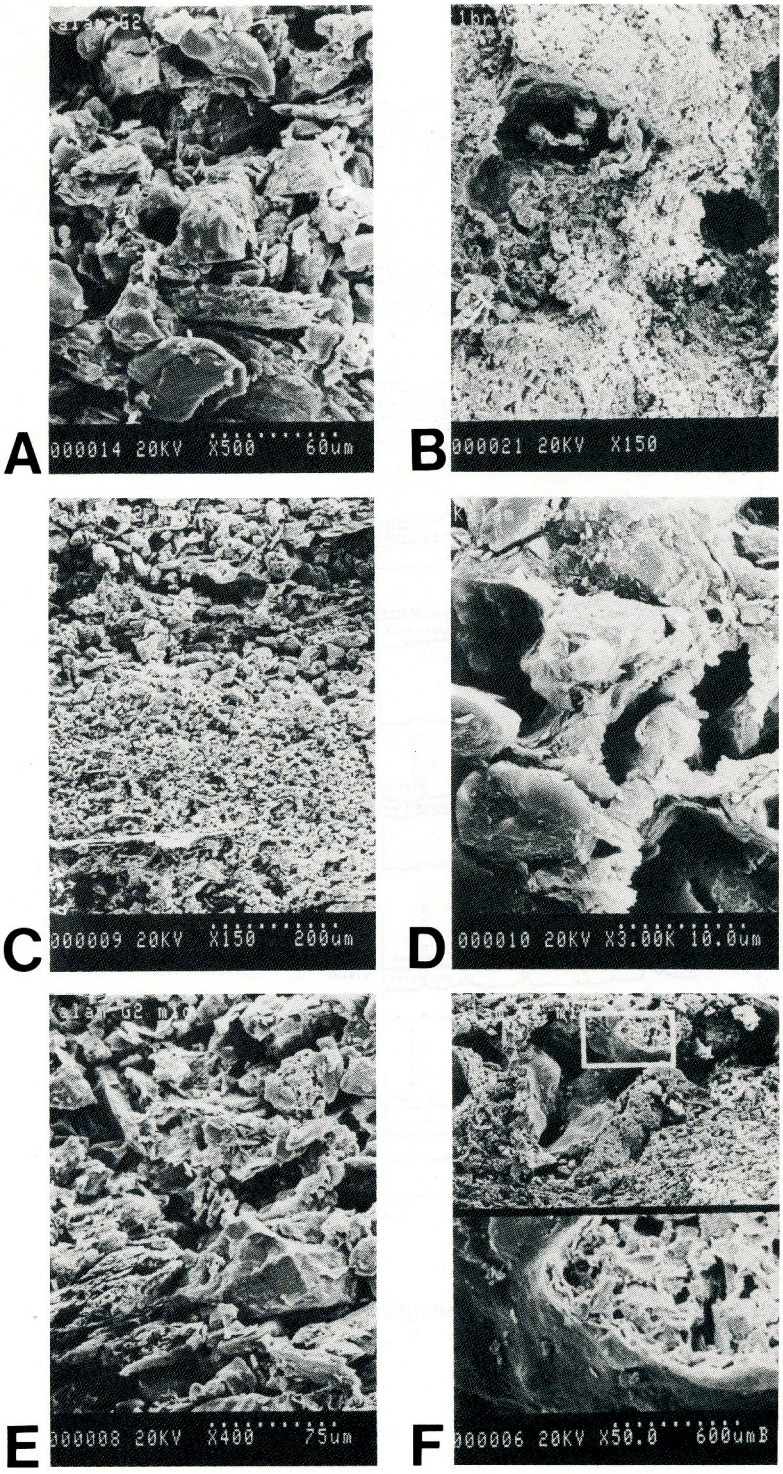


Photo 4: *Scanning electron photomicrographs of loessic silt from Kalam.*

A) Isotropic fabric with an open framework of large grains and fine silts interspersed within the framework;
B) Burrows within the sediment;
C) Laminations picked out by grain size differences: note gradational contacts between laminations;
D) Clay bridges due to frequent wetting and drying of the sediment;
E) Porous open framework with a weak horizontal alignment of many of the larger grains;
F) Iron oxide precipitate coating secondary pores within the sediment.
(All photos are vertical sections with top on the top of the photomicrograph.)

5.3 Clay mineralogy

Fig. 7 shows X-ray diffractograms for the clay minerals present in each sample studied from the Swat Himalaya and the Karakoram Mountains. All the samples are rather similar comprising, illite, kaolinite, muscovite, quartz, plagioclase and orthoclase feldspars, and minor quantities of mixed layer clay. No secondary or authigenic clay minerals were identified nor were any of these recognised in the SEM.

5.4 Microfabrics

5.4.1 Swat Kohistan loessic silts

Photo 4 shows typical textures of the Swat-Kohistan loessic silts. Large silt grains form open frameworks and are coated with fine silts and clays, though they do not form the cutans because they do not completely cover the grains but are irregular and patchy (photo 4). Aggregates of fine silt are present and may be described as poorly developed peds, an example being seen in the top right hand corner of photo 4E. Fine silt and clays frequently form bridges between large silt grains (photo 4D and 5). Tabular voids are often present (photo 4B) indicating bioturbation as a result of soil faunal activity or the growth of rootlets. The permeability produced by such tabulat voids facilitates the precipitation of iron oxides which can be seen to coat their surfaces e.g. the middle left side of photo 4F. Fig. 8 shows the corresponding EDAX trace for iron oxide coating shown in photo 4F. Secondary clay minerals are extremely rare, but photo 5 shows an example of authigenic chlorite, growing between large silt grains.

Some samples have a weak lamination, not visible to the naked eye (photo 4C), the result of grain size differentiation and the presence of horizontally-disposed large platy minerals.

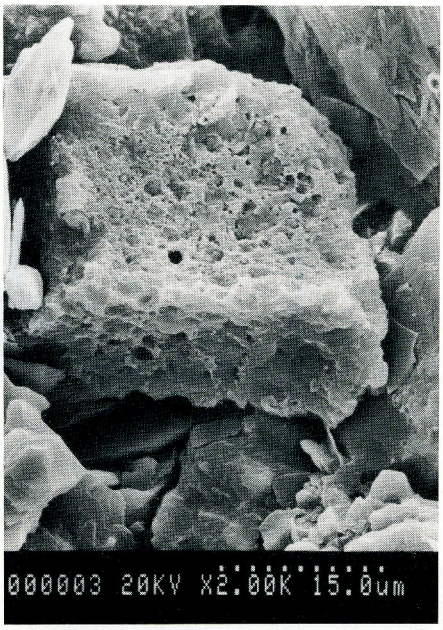


Photo 5: *Scanning electron photomicrograph of authigenic chlorite on a feldspar grain in loessic silt from Kalam.*

5.4.2 Karakoram loessic silts

These comprise large silt grains forming an open framework structure with irregular coatings of clay and silt on the larger grains (photo 6). Clay bridges are rare and neither laminations nor secondary clay minerals are present.

5.5 TL dating

The results of the TL dating programme are summarised in tab. 3. The dosimetry data have been adjusted to take account of the water content of the sediments. The water content was estimated to be

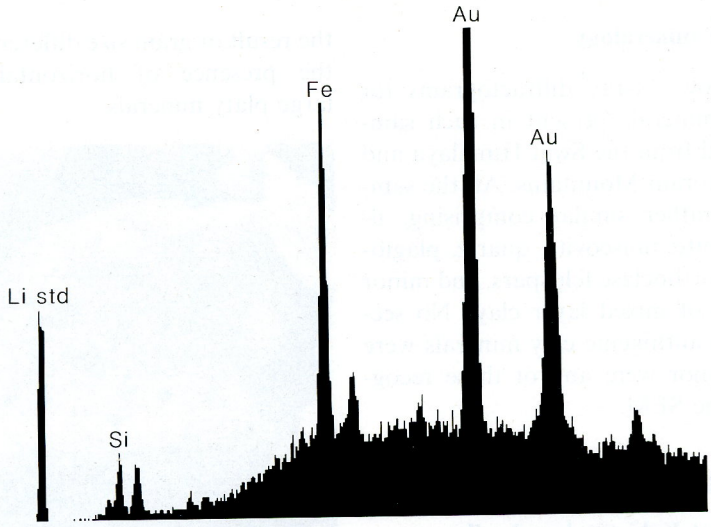


Fig. 8: *EDAX trace for the iron rich precipitate in photo 4F.*

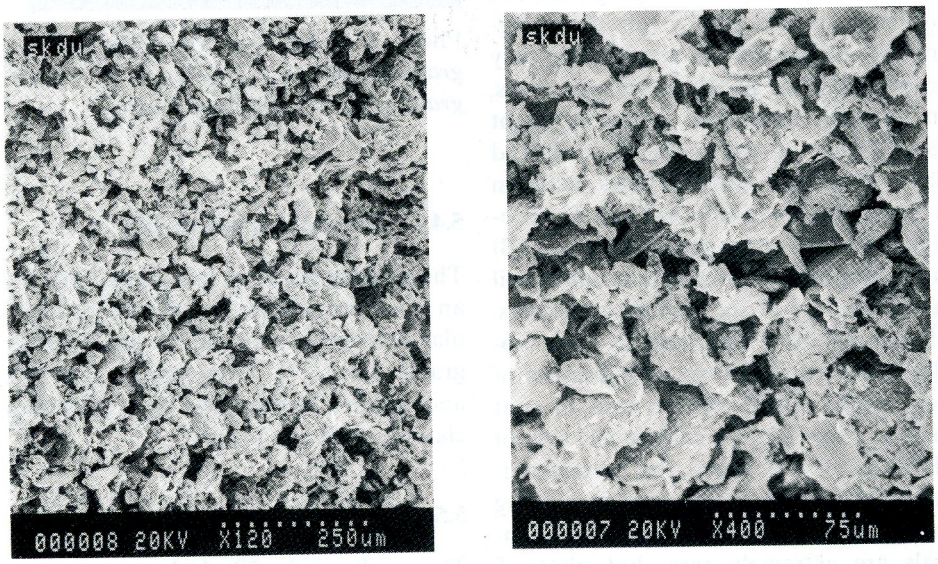


Photo 6: *Scanning electron photomicrographs of loessic sediment from the Skardu Basin, showing isotropic fabrics with an open framework at different scales.*

Kalam Loess: TL age estimates and dosimetry data					
Sample	U ppm	Th ppm	K2O%	a value	annual dose
K1mtop	2.50	12.70	1.79	0.178	0.00492
K1base	2.53	12.90	1.66	0.196	0.00509
G2top1s	3.79	19.40	2.09	0.154	0.00657
G2base1s	4.20	21.00	1.66	0.180	0.00738

Additive dose method		Regeneration method	
Equivalent Dose (GY)	TL age (Ka)	Equivalent Dose (GY)	TL age (Ka)
29.1±3.0	5.88±0.53	30.4±1.5	6.7±0.6
12.0±3.9	1.95±0.20	14.6±1.7	2.85±0.30
129.5±7.0	19.71±2.20	147.7±3.1	22.4±2.0
105.8±6.0	14.36±1.49	134.3±6.6	18.2±2.0

Tab. 3: *TL age estimates and dosimetry data for the Kalam loessic sediments.*

10% ± 5% dry weight. The data indicates that the K1 material is of Holocene age. The G2 material is considerably older and dates to the Late Pleistocene. This scatter on the measurements of natural TL is consistent with some reworking of the material. With the exception of sample G2 basal, the TL age estimates obtained by both methods of ED determination (additive dose and regeneration) are in good agreement within the measurement errors.

6 Discussion and conclusion

The loessic deposits within these high mountain areas are thin compared with loess deposits found in the foreland basins. They contain reworked pebbles and, in some locations, even boulders which may have been incorporated into the silts by overland flow or by rolling down slope following rockfall or colluvial activity. The silt material itself is predominantly primary consisting of quartz, muscovite, feldspar and kaolinite, derived from granitic rocks, and illite and chlorite, from metamorphic rocks. No secondary clay minerals have been recognised and carbonates are absent in Swat, but are present in the Karakoram silts where detrital carbonate grains have been derived from local outcrops of limestone and marbles.

The Karakoram samples are almost identical to the aeolian reworked Holocene silt from northwest China (tab. 2, S94) but distinctly coarser and better sorted than the remaining Chinese samples (all Upper Pleistocene). In contrast, the Kalam series samples are uniformly finer-grained than both the Karakoram samples and the Chinese loesses, less positively skewed and with much lower kurtosis values than either. The finer grain size of the Kalam material may simple be a function of the available bedrock sources: for example, there are more fine-grained source rocks such as schists and phyllites in the Kalam area compared to the Karakoram where coarse-grained granitic rocks predominate. However, the possibility that these particle size distributions are

a function of a different mode of deposition should be considered. The particle size and microfabric data for the Karakoram silts from Skardu are similar to those of aeolian-reworked Chinese silt of late Holocene age. The Kalam material, however, is quite different from the Skardu silts and Chinese loess. However, both its microfabric and grain size characteristics are similar to weathered and translocated Chinese loess (tab. 2). The Kalam silts contain fine laminae, a variable sand percentage and small pebbles, and the microscope fabric shows both bioturbation, grain anisotropy and size segregation (laminae).

There is much evidence for reworking after deposition. Clay bridges represent progressive wetting and drying of the silt while fine aggregates of fine silt may represent pedogenic units. The rootlets and burrows suggest biogenic processes and that a sparse cover of vegetation may have been present as the loess accumulated. Pores produced by the rootlets enhanced the movement of fluids and clays in the sediment and helped precipitate iron oxides. The weak sub-horizontal fissility and lenticular voids indicate that the sediment underwent frequent freezing and thawing. In the Karakoram loessic silts these characteristics are less obvious. These microfabrics are more typical of continental loess sediments (c.f. Derbyshire & Mellors 1988). This may be because the Karakoram Mountains are much more arid than Swat Himalaya as the Indian monsoon is inhibited in the Karakoram Mountains by the mountains of the Great Himalaya. These samples have much in common with redeposited loess as determined by laboratory experimentation (c.f. Mücher & Vreeken 1981, Vreeken & Mücher 1981) and are therefore a loessic colluvium rather than a true loess.

It is concluded that the loessic silts examined in the western Himalayas are not loess deposits *senso strito*, but rather loessic silt derived from glacial outwash, lacustrine silt beds and aeolian accumulations which were then reworked on slopes and they underwent weak pedogenesis. In such a situation, silts overlying major Quaternary landforms, such as moraines and glacial outwash terraces, may be considerably younger in age than the underlying features. The very young TL ages obtained for the Kalam loessic sediments are an example of this: they are considerably younger than any reasonable estimates of the age of the glaciations in the Kalam region. It thus appears that great care must be taken when using loessic sediments for dating Quaternary events, in geomorphologically dynamic landscapes such as those of High Asia.

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Addresses of authors:
L.A. Owen
Department of Geography
Royal Holloway and Bedford New College
University of London
Egham Hill
Egham Surrey TW20 OEX
U.K.
B.J. White
E. Derbyshire
Department of Geography
University of Leicester
Leicester LE1 7RH
U.K.
H. Rendell
Geography Laboratory
University of Sussex
Brighton
Sussex BN1 9QN
U.K.