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Lost loesses

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Abstract

Loesses form wide belts in front of previously glaciated areas. Their thicknesses may be considerable, changing in Eurasia from maximally a few metres in the west to a hundred metres or more in the east. The Eastern (particularly Chinese) loesses are mostly unrelated to glaciations. The periglacial loesses from China and elsewhere predominantly date from the last Pleistocene glaciation: relatively few comparable occurrences are known from earlier Quaternary glaciations. As it is difficult to imagine that the conditions in front of the land-ice masses during the earlier glaciations differed fundamentally from those of the last one, considerable quantities of loess must have disappeared. This disappearance, which is commonly ascribed to fluvial and eolian erosion, is not easily explained as equivalent deposits that may have the older loesses as a source, are practically absent. A possible explanation might be that loess is recycled during successive glaciations. Some loess disappears during interglacials by erosion, but this quantity is more than compensated by the formation of new silt particles. The implication would be that the loess deposits increase in volume for each new glaciation.

Keywords: silt; periglacial processes; sediment recycling; sorting; eolian abrasion; glacial grinding

1. Introduction

Few problems in Quaternary geology have raised so much controversy as loess. Even the definition has led to ever ongoing discussions, but we will adhere here to the simple description by Smalley and Jary (2004) that loess is essentially eolian silt. Most loess discussions relate to its origin (Rozycki, 1991). The origin of the particles, which consist for the largest part of 20–50 μm particles (Tucker, 2001) and thus consist of silt but do not coincide with the entire silt range (2–64 μm), has been – and still is – subject of heated debates, indeed, and a generally accepted explanation is still lacking, although several hypotheses have been put forward that might provide at least a partially satisfactory explanation.

It is not only the origin of the loess particles that still poses a problem. The genesis of loess deposits has also led to many discussions. It has become clear, however, that there are at least two types of loess deposits: one type is formed under periglacial conditions, commonly in front of an ice cap, whereas the second type is built up by small particles formed in mountainous areas (Smalley and Jary, 2005). In addition, there are loess-like deposits that consist essentially of loesses that have been transported by water after they had been deposited by wind. We will restrict ourselves here mainly to the periglacial loesses (Fig. 1).

One of the problems related to periglacial loesses is why it seems that much less of this loess type seems to be deposited nowadays in periglacial areas than during the last ice age (possibly apart from Alaska). One would expect that a loess belt be deposited in front of the present-day ice caps, but hardly any

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Fig. 1. Typical Weichselian (=Wisconsinan) apparently homogeneous glacial loess with slight pedogenetic features at Bialy Kosciol (Niemcza-Strzelin Hills, SW Poland). Photograph by Zdzislaw Jary, University of Wroclaw, Poland.

significant recent loess is to be found. This seems to imply that the climatic and/or geological conditions near the present-day ice front differ from those conditions during the last glaciation. Considering the extent of the loess belt formed in Eurasia during the last glaciation (the loess in Northern America is much less distinctly distributed as a belt: Busacca et al., 2004), it is not realistic to assume that the geological conditions near the ice front were then different everywhere from now. This would leave different climatic characteristics as the main cause for the present-day lack of loess deposition, but such a difference is also difficult to imagine. Moreover, such a difference would raise new problems, because our ideas about the climate during the ice ages are largely based on climatic observations at places that are considered to offer now comparable circumstances.

A loess problem that is rarely touched upon is the almost complete lack of loesses from ice ages before the last one (although some Pre-Pleistocene loessites – though not necessarily deposited under periglacial conditions – are known: see, for instance, Johnson, 1989; Chan, 1999; Wang et al., 2005). Particularly in America and Western Europe, Pre-Wisconsinan and pre-Weichselian periglacial loesses are also much rarer (and commonly much thinner) than Wisconsinan and Weichselian loesses. It is true that many of the deposits formed during previous Pleistocene ice ages may have been removed by erosion during interglacials (by, for instance, fluvial processes), but this does certainly not explain their almost complete absence. Glacial diamicts (tills) from earlier ice ages have been relatively well preserved, and are even used to reconstruct the lines of maximum ice extent of those glaciations. The total volume of loess deposits from the last glaciation is much larger than the total volume of tills from this glaciation, and one might therefore assume that this was also the case during earlier glaciations. If, however, the diamicts from those earlier glaciations are the main deposits that have been left and if volumes of contemporaneous loess larger than those of the diamicts must have existed, huge volumes of the loesses deposited during those cold times must have been eroded.

2. Loess formation, deposition and erosion

If large volumes were deposited during the successive Pleistocene glaciations and if the loesses from each glacial would have been eroded during the immediately following interglacial, there must have been not only a repeated and long-lasting supply of silt-sized material, but there must also have been eroded a huge volume of this specific type of sediment. This leaves one well known question (where do the loesses come from?) and one rarely (if ever) asked question: where did the eroded loesses go to?

2.1. Loess formation

It may well be that the above questions are interrelated. It seems therefore worthwhile to summarize some of the ideas about loess formation. The origin of loess can, obviously, only be explained satisfactorily if the source of the huge amount of silt particles can convincingly be identified (cf. Jary and Kida, 2000). Both warm areas (e.g. hot deserts) and cold regions (e.g. cold deserts, slopes of the Himalaya Mountains) have been proposed as such source areas (Tsoar and Pye, 1987; Pye, 1996; Aleinikoff et al., 1998), and it has been shown that they provide vast amounts of grains that fit in the loess granulometry. Furthermore, source areas for the loesses of the last glaciation have been proposed that do not exist any more (e.g. the North Sea, which had fallen dry during the Pleistocene glaciations as a result of sea-level lowering). Finally, glaciation-related processes contribute to silt production by grinding of larger fragments during ice transport. All four sources, however likely to contribute to the volumes of periglacial loesses, raise questions.

2.2. Hot deserts

Due to wind abrasion and weathering (some authors stress also the role of salt weathering and frost action: Pye, 1987; Wright et al., 1998; Wright, 2001; Smith et al., 2002), vast amounts of silt-sized particles are currently formed in hot (sandy) deserts. This will have been the same during the Pleistocene, although climatic differences (pluvials and interpluvials) may have affected the rate of silt production. The silt (dust) produced nowadays may circulate by wind activity within the desert area for some time, but finally will be blown far away. Red Sahara dust frequently reaches NW Europe, where it may be deposited during rain fall, leaving a distinct, characteristic film of red dust.

The distribution of this dust is fairly haphazard, though large-scale wind patterns obviously strongly determine the distribution pattern. There is, however, not any indication of a loess belt formed this way. Although the wind patterns were different during the ice ages (Wisconsinan wind patterns were partly reconstructed on the basis of loess distributions: Muhs and Bettis, 2000; Mason, 2001), it is highly unlikely that dust from the subtropics contributed significantly to the periglacial loesses; this view is supported by, among other arguments, the occurrence over large distances of a coversand belt, in between the Weichselian/Wisconsinan ice front and the loess belt.

2.3. Cold areas

Cold deserts such as the Gobi store silt-sized particles in a similar way (and Gobi dust sometimes reaches the United States: Holden, 2001). Such deserts are relatively scarce, however, and their distribution cannot explain the occurrence of loess belts that extend over thousands of kilometres. Even if they contribute significant amounts of loess-sized material, as in China to the loess plateau, their role may be of only secondary importance because the Gobi desert is a place of storage rather than a place of production of small particles (Sun, 2002). In addition, the distribution of cover sands and loesses is a strong argument against these deserts as a primary source for the periglacial eolian sedimentation during the successive ice ages.

A fairly new finding is that much silt-sized material is produced in the high and steep parts of the Himalaya Mountains (and possibly in other young, high mountains as well). This 'new' source could explain many characteristics of the loess belt formed during the last ice age: it would be well understandable that the loesses in the Eurasian loess belt are thickest in China (short transport), and that they thin towards the west (ever longer transport distances). The loess on the Chinese loess plateau, which covers some 440,000 km^2 (Liu, 1985), reaches extreme thicknesses of over 100 m (Lu et al., 2004). It is not the result of sedimentation during only the last ice age, however, but was built up during at least some 7 million years (Ding et al., 1999). It includes the so-called red clays (Fig. 2) that are eolian deposits with partly a Pliocene age (Miao et al., 2004). The significance of the thick Chinese loesses for understanding the genesis of the periglacial loesses from the Pleistocene ice ages may therefore be limited.

The thinning of the Eurasian loess belt from China to the west (Jary, 2004) seems consistent with measurements of wind directions in cover sands. The hypothesis of the Himalayas as a principal source may explain the huge loess hills in this area (Fig. 3) but it has the disadvantage that the present-day formation of silt does not seem to result in a real loess belt around this mountain chain. Climatic conditions in the Himalayas may have been slightly different during the ice ages, but it seems unlikely that this could result in such a great divergence of the silt distribution as witnessed between now and the last ice age.

2.4. Drowned source areas

During the ice ages, numerous shallow-marine areas fell dry. In many cases these areas became

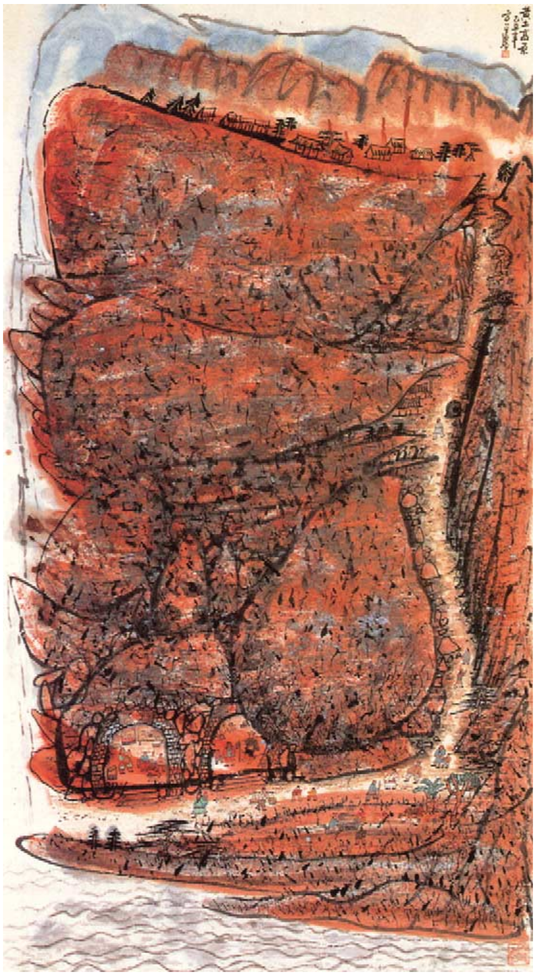

Fig. 2. The colour of the vast Chinese loess plateau due to both loess and eolian ‘red clays’ has inspired many artists. This ink drawing of the plateau by Fang Zhaolin (1985) is in the Hong Kong Museum of Art.

occupied by meltwater streams that built up glaciofluvial deposits. These deposits represent, as a rule, braided (or anastomosing) streams rather than meandering ones. Whatever type of stream they were, the deposits will have been a mixture of all grain sizes. Considering the lack of vegetation, wind activity may eventually have blown out most of the finer material. The cover sands in The Netherlands, for instance, have been suggested to have their source area in the present-day North Sea. This hypothesis is unlikely, however, on the basis of measured wind-formed structures, as well as on the basis of the heavy-mineral content.

In addition, the Eurasian loess belt is situated, for its larger part, so far away from areas that fell dry during the ice ages that the large volumes of loess cannot be explained this way.

2.5. Glacial grinding

Grinding of glacially transported rocks has already been found early to be a possible source of silt-sized particles. It is highly doubtful, however, whether the loesses can be explained this way. The reason is that loesses consist, on the average, of 50–70% quartz, 5–30% feldspar, 5–10% mica, 0–30% carbonate and 10–15% clay minerals (Pye, 1987), whereas the rock material carried by the ice has, as a rule, a different (and regionally strongly varying) composition. The ice that reached NW Europe during the last glacial, for instance, came from Scandinavia (Overweel, 1977) where it eroded deep valleys in predominantly metamorphic and magmatic rocks with mainly a – roughly – granitic composition that has a quartz/feldspar ratio that is lower than in loesses. This implies that during glacial grinding fine feldspar particles must have formed that are lacking in the loess, so they must have gone elsewhere. Weathering of the feldspars into clay minerals is unlikely – if not impossible – because the Holocene with its relatively short duration and its cold to temperate climate in the previously glaciated areas and their forelands offered insufficient opportunity for such an alteration. One must therefore conclude that, if grinding of stones carried by the ice is an important source of loess particle indeed, deposits must be found elsewhere that are relatively enriched in feldspars (and other minerals). To my knowledge, such Quaternary deposits are not known.

Another, strong, argument against glacial ice as a main producer of silt is that the present-day land-ice masses do not seem to produce sufficient material that is suitable for wind transportation and deposition in the form of loess. It is commonly thought that the ‘ice-produced’ silt became first deposited by meltwater streams on sandurs, and then – during dry periods – were eroded by the wind. If this were true, the discrepancy in loess formation might be due to the fact that the present-day sandurs (best illustrated by the Icelandic examples) represent an exceptional morphological stage and differ fundamentally from those that existed during the last glaciation (Zielinski and Van Loon, 2002, 2003).

2.6. Deposition of loess

The loess belt formed during the last glaciation covers a vast area that is partly rather flat, partly undulating. In contrast to the cover sands which in many places increase the relief of the depositional site, loess covers tend to form more or less horizontal

Fig. 3. Large loess hills near Lhasa (Tibet) in the Himalayas.

deposits in flat areas, whereas they tend to level off height differences in undulating areas (Pye, 1996; Mason et al., 1999). This has long be explained as a consequence of more air turbulence at elevations and less turbulence at the lee side of such elevations. The resulting shape of the loess cover, viz. thinnest on elevations and thickest in depressions, can be better explained, however, by mass wasting. Indeed, many loess-like deposits seem to have undergone some transport by water and many such deposits accumulated in previous depressions even seem to have formed by settling from suspension in shallow pools or lakes.

Grain-size analysis of these redeposited loesses most commonly does not yield any significant differences with eolian loesses, neither is there any significant difference in petrographic composition, unless the material was washed down from slopes with such a thin loess cover that underlying sediments were also carried along. More remarkably, loess deposits that are found thousands of kilometres apart from each other tend to have fairly identical characteristics. This is exceptional for terrestrial deposits, and it underlines that the silt-sized particles cannot be the result of processes that are area-dependent.

2.7. Erosion of loess

One of the most remarkable characteristics of loess is its resistance against erosion. Vertical erosion does not start easily; rather is a superficial film of loess removed if water runs down a loess-covered slope. Once, however, a small channel has been eroded, it seems that erosion proceeds relatively easily, though only in a vertical direction. The loess walls along such channels remain vertical as well shown at numerous sites in China (Fig. 4), and widening of the incised gullies proceeds extremely slowly, where the loess covers reach extreme thicknesses, of over a hundred metres. So much loess is eroded nowadays that the particles give the Yellow River its yellow colour, and that the sea in which the river embouches is called the Yellow Sea. Yet, only a small fraction of the Chinese loess seems to have been eroded away.

Wind erosion of loess plays, as a rule, a minor role. When the loess is wet, it will not be eroded by the wind. When it is covered by vegetation, it will hardly be affected by the wind. Specific climatic conditions (dry, cold) are therefore required for eolian erosion of loesses. Such conditions are apparently insufficiently present now in the areas covered by loess.

The Holocene has now lasted longer than the last interglacial (Eemian) and possibly also longer than some earlier interglacials. One might thus expect that more loess has been eroded during the Holocene than during the Eemian. In addition, loess erosion during the Holocene has been accelerated by man-induced deforestation and by agriculture. Yet, exceptional Holocene loess erosion seems far from reality, as hardly any loess from the last-but-one glacial has been left, whereas the loesses from the last glacial are still abundantly present. Once more, it must therefore be concluded that either only limited

Fig. 4. Chinese village on the loess plateau, surrounded by steep loess cliffs.

amounts of loesses were deposited during previous glaciations, or that the loesses have been removed by a process that has previously hardly received any attention.

3. Recycled loesses

The principle of uniformitarianism ("the present is the key to the past") is, unfortunately, not applicable in all its aspects to problems related with glacials, when much larger parts of the world than nowadays were covered with glacial ice. One might try to overcome this disadvantage, however, by imagining what would happen if a new glacial would start. The ice would, on the northern hemisphere, advance to the south, and the zone without vegetation would do the same. Eventually the present-day loess belt would become barren and exposed to deflation. The silt-sized particles of the 'old' loess could thus become recycled to form a new loess belt, climatologically and sedimentologically consistent with the new situation.

Amelioration of the climate would then result in a retreat of the ice and a northward shift of the vegetation boundary. The fertile loesses (Fig. 5) would soon become grown over and deflation would stop. A new situation would thus be achieved that closely resembles the present-day one, though possibly (depending of the maximum extent of the ice during the 'new' glaciation) at another latitude.

Fig. 5. Succession of loess with two well developed soil horizons at Bojanice (NW Volhynia Upland, Ukraine). Thanks to the fertile loess cover, the Ukraine has long been the granary for both Russian and European countries. Photograph Zdzislaw Jary.

Local recycling of loesses has been suggested earlier (by, among others, Kohfield and Harrison, 2003), but this cannot explain the almost total disappearance of older loesses. A large-scale (not necessarily entire) recycling of loesses would, however, explain why so little loess from older glaciations is present in the geological record. It could also contribute to the solution of the still not yet well understood problem of the origin of the loesses. Relatively little 'fresh' silt particles would be required for the formation of a loess belt during each new glaciation: a new supply would be necessary only to compensate for the loss of loess due to erosion during the interglacials, and for the loesses that would not be exposed to deflation because they had been covered by younger deposits. The relatively small supply of fresh silt particles can easily be taken care of by the various source areas and 'production mechanisms' that are currently hypothesized to be responsible for loess formation.

If all the hypothetical source areas and production mechanisms would be able only to compensate for the losses of loess during interglacials (and for the loess-sized particles that are blown into the sea during the glacials themselves), the question arises how a loess belt could have been formed during the first Pleistocene glaciation that would have been vast enough to survive the first interglacial and to act as the source for a new belt. The most logical answer to this question is that the various source areas and production mechanisms produce more loess-sized particles than get lost during the interglacials. As a result, each new glaciation would, while producing new loess, have a source area (in the form of the loess belt from the previous glaciation) that comprises a larger volume of loess than any previous glaciation had before. Consequently, it must be assumed that each glaciation produces a loess belt with a higher loess volume than any earlier glaciation did.

Such a recycling, in combination with new supply, would not only explain the questions of loess formation and of the apparent disappearance of older loesses. It explains also why few (peri)glacial loesses from the last-but-one glaciation are found, and practically none of still earlier glaciations: not only did some erosion and large-scale recycling remove most of these older loess deposits, but their original volume must have been considerably smaller than the volume of the present-day loess deposits. Few loess is lost, and more new loess is formed. The next glacial will therefore probably result in a loess belt with a higher volume than the present-day one.

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