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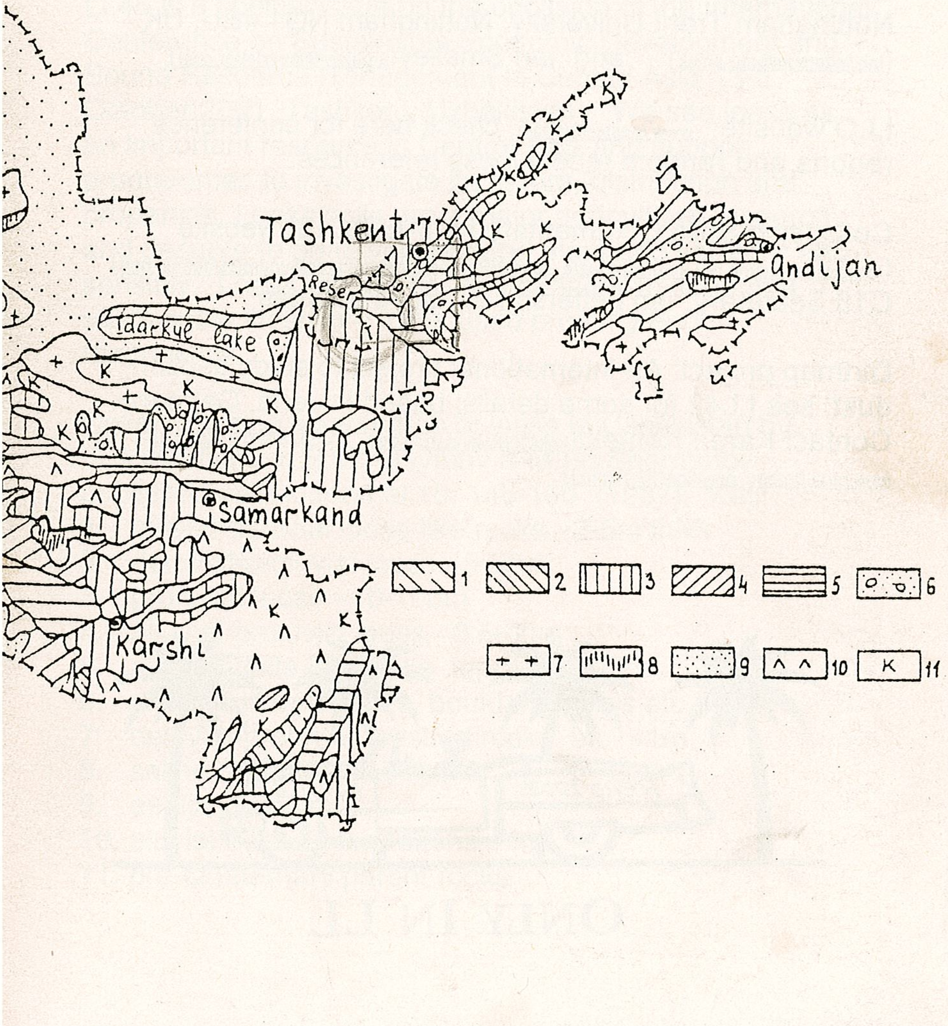
LOESS LETTER 46

NQUA Loess Commission
AEG Collapsing Soils Commission C18

NTU Geohazards Group
DIRTMAP 2001



Addresses, Meetings, etc..

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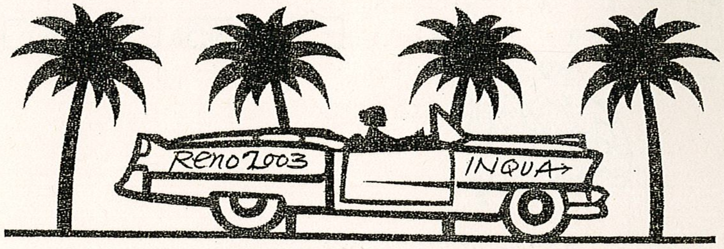
LLO website: www.loessletter.com check here for conference reports and random recent loess references.

Collapsing Soils Commentary(for IAEG/C18) website (http://construction.ntu.ac.uk/graduate_school/Research/geohazards/Synergies/default.htm)
C18 Secretary: Ian Jefferson at above address

Dirtmap project: An international project to study aeolian dust; see LL42 for some details; based in Jena, Germany. Contact Karen Kohfeld(kek@bgc-jena.mpg.de) Website (www.bgc-jena.mpg.de/bgc_prentice/start1.html)



ONLY IN LL.

LL46. Loess Letter is the newsletter of the Loess Commission of the International Union for Quaternary Research INQUA, and the Collapsing Soils Commission C18 of the International Association for Engineering Geology & the Environment IAEG. It is published by the GeoHazards Group in the School of Property & Construction at Nottingham Trent University. It appears twice a year, usually in April and October; edited by Ian Jefferson & Ian Smalley. It supports the Dirtmap project (organised from the Max Planck Institute in Jena).

LL46 is a special issue on the occasion of the International Conference on Sustainable Economic Development and Sound Resource Management in Central Asia (3-5 October 2001, Tashkent, Uzbekistan). We see loess as an important resource in Central Asia and support programmes to investigate its nature, distribution and properties. Loess soils are a major agricultural resource and deserve to be developed and managed carefully and sensibly. Loess ground has the capacity to support a sustainable lifestyle – if it is used properly and responsibly.

Cover. From a sketch map of loess in Uzbekistan by. G.A.Mavlyanov, S.M.Kasymov & M.Sh.Shermatov published in GeoJournal 15, 145-150 (1987). Key:

1. eluvial-deluvial loess-like rocks ~2-5m thick
2. deluvial-proluvial loess ~5-30m
3. proluvial loess ~10-100m
4. alluvial-proluvial loess ~0.5-30m
5. alluvial-delta loess-like deposits~~20m
6. alluvial gravel, sands, boulder gravels etc ~5m
7. deluvial-proluvial crushed rocks etc ~1m
8. saline regions and bogs
9. aeolian sands
10. eluvial-deluvial formations ~1m
11. pre-Quaternary parent rocks

LLO. Loess Letter Online. www.loessletter.com. How are we doing on keeping LLO up to date? Not particularly well-but not too badly. It serves more as a reference site than an up-to-the-minute notice board (and is likely to stay this way). Check here for general outlines of project areas of current interest; e.g. the Danube region, North Africa, Central Asia etc.

Meetings. Loess people come together at a whole variety of conferences and meetings. Major conferences provide a good opportunity for members and associates of the Loess Commission and C18 to meet. We try to identify at least one major meeting per year at which significant loess activity takes place. LL readers will be preparing for the 16th INQUA Congress to be held in Reno, Nevada on 23-31 July 2003. You need to register an interest in this important conference by 31 January 2003- an email link is required- no paper will be involved. Website http://www.dri.edu/DEES/INQUA2003/inqua_home.htm. The big event for 2002 is the 9th IAEG Congress 16-20 September in Durban, South Africa. The theme here is 'Engineering Geology for Developing Countries'(see announcement in this issue of LL).

LL46. This issue of LL is dedicated to the memory of G.A.Mavlyanov- the doyen of Central Asian loess investigators- his work is carried on at the Uzbekistan Academy of Sciences Institute of Seismology- which is named after him. LL46 contains material from the special issue of Quaternary International (edited by E.Derbyshire) which was produced for LoessFest'99; it also contains a second (& final) installment of reports from the Jena 2000 workshop of the Dirtmap project; plus our usual contribution from China (courtesy of Arid Land Geography). A serious issue- not so many cartoons.

LOESS IN UZBEKISTAN

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Abstract

Loess is widespread in Uzbekistan; in fact Uzbekistan and neighbouring regions in Central Asia rank as one of the world's major loess regions. This loess, the basis for productive soils in most of the country, is a key part of the Uzbek economy, and the degradation and loss of capacity in the loess soils is a major economic drain. The economic health of Uzbekistan requires that the loess soils be understood and nurtured, be appreciated and used carefully. There is a recent history of catastrophic misuse, and much restoration action is required.

Keywords: Loess, hydrocollapse, ground improvement, development, sustainability

1. Introduction

In Soviet times the loess in Uzbekistan was studied, largely by workers from the Uzbek Academy of Sciences, and essentially led by G.A.Mavlyanov. His major monograph (Mavlyanov [1]) is still the basis for loess investigations in this region, and contains key loess maps, Under the Soviet academic/scientific system each region tended to develop one single accepted authority: for example V.P.Anan'ev in Rostov-on-Don, or M.P.Lysenko in Leningrad, E.M.Sergeev in Moscow, V.T.Krutov in Kiev. Latterly these loess authorities had large influence, in a very authoritarian system, and influenced the direction of Soviet loess research. Geographical research was particularly influenced by I.P.Gerasimov the Director of the Geographical Institute of the whole Soviet Academy of Sciences, having a special interest in loess, had large scale influence. Unfortunately he subscribed to the Dokuchaev-Dimo-Berg view of loess formation and this led to a situation where the true nature of loess deposits and loess soils was not appreciated (see Smalley & Rogers [2]). There are problems in untangling the Soviet legacy, and the INQUA Loess Commission is actively involved in this process.

The major city in the Central Asian region is Tashkent, and this is founded on loess, near to the slopes of the Tien Shan range. Tashkent is a leading 'loess city' – like Kyiv its location and construction factors relate very strongly to the loess. A basic reference paper for loess in the Tashkent region is Smalley [3] but the basic model for the formation of the Tashkent loess is usually called the 1978 model, after the first outline proposals in Smalley & Krinsley [4]. The 1978 model suggests that the Uzbek loess is a true mountain loess with the particles being produced in the mountains of High Asia and largely transported by the Amu-Darya and Syr-Darya and related rivers. Particle production is a powerful test of loess forming theories and certainly demonstrates that the Berg 'eluvial' theory cannot be true. To make a loess deposit, loess material must be available. For loess material to be formed large geo-energy is required. Major loess deposits are associated with regions where large amounts of geo-energy were available in the Quaternary and late Tertiary times; e.g. the glaciated regions of north Europe and North America, or very high tectonically active mountain regions. Where there was no glaciation and no high active mountains there tends to be no significant loess, e.g. Australia, Africa.

2. Process

Yeliseyev [5] identified five theories that had been advanced to explain the origin of loess soils in Central Asia; these were the proluvial theory of G.A.Mavlyanov, the alluvial theory of Yu.A. Skvortsov, the deluvial theory of N.P.Vasil'kovsky, the soil theory of I.P.Gerasimov and the aeolian theory of V.A.Obruchev. A careful examination of all the processes involved in the formation of the Uzbekistan loess suggests that all of these investigators may have certain factors and validities to contribute to the whole complex picture. The basic aeolian ideas of Obruchev are certainly true, loess material is blown into position to form loess deposits, and the position of Tashkent in the Tien Shan foothills suggests that there has to be a proluvial contribution to the local soils.

The 1978 'Tashkent' model of loess formation in Central Asia used the PTD System to describe a series of events which led to the formation of loess deposits. The PTD System [6] breaks down the whole process into a succession of Provenance events, Transport events and Deposition events- it was supposed to divide the whole process into scientifically accessible parts, which when assembled, would indicate the true history of loess deposits.

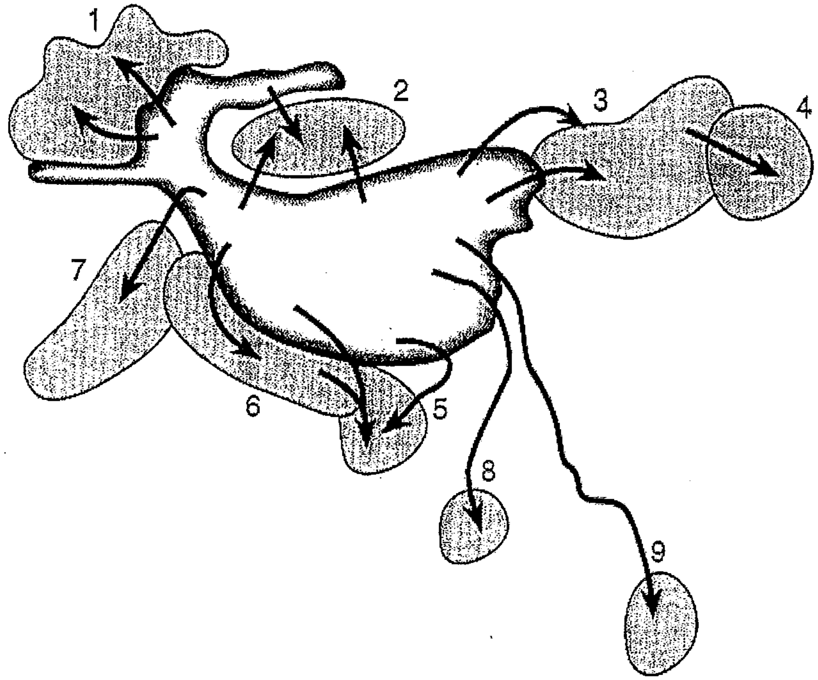

Figure 1: Distribution of silt deposits around High Asia (after Assallay *et al.,* [7]). 1 Central Asian loess, 2 Tarim basin loess, 3 North China loess, 4 North China alluvial plain, 5 Bangladesh, 6 North India alluvium, 7 Indus alluvium, 8 Irrawaddy delta, 9 Mekong delta.

Figure 1 shows the setting of the Central Asian loess, with respect to the disposition of silt deposits around High Asia. High Asia is the extremely uplifted region caused by the crustal overlap resulting from the collision of tectonic plates. This is a region of great height, of great tectonic activity, of much release of geo-energy, of extreme climatic variability, and it is a great source of silt material, which goes to supply some of the world's major loess deposits. The region shown in Figure 1 is vast; zone 1 is the Central Asian region containing the loess of Uzbekistan; zone 3 is the Chinese loess where the various P, T and D factors have combined effectively and produced deposits with vast area cover and great thickness (see Smalley & Krinsley [4]). In the zones around High Asia it is observed that the southern deposits in more humid climates often stay as alluvium and do not reach the T stages for conversion to loess; but in the more arid north loess deposits tend to form.

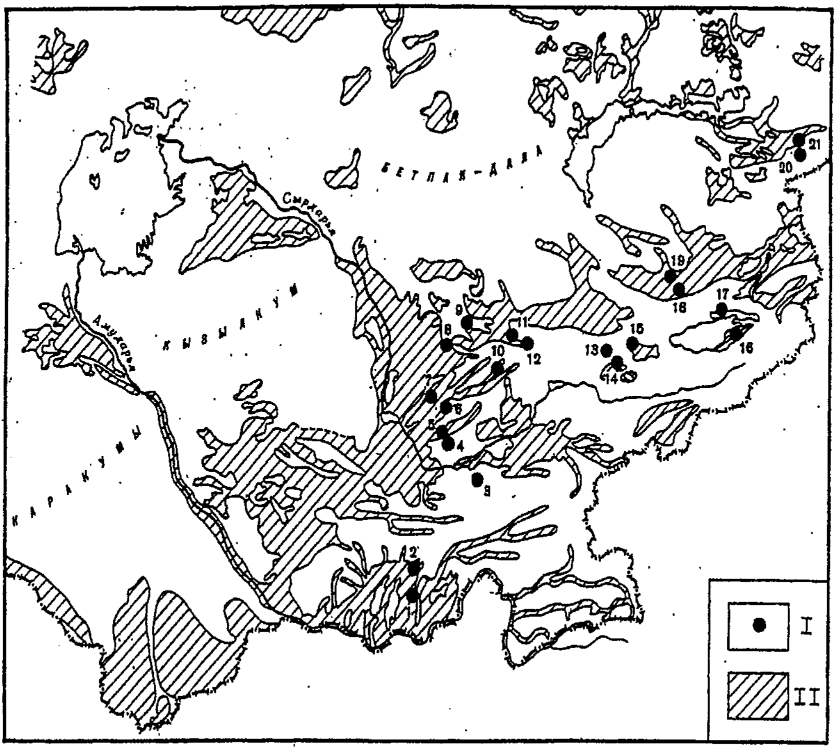

Figure 2: Loess in Central Asia (after Kriger et al., [8]). Shaded areas are loess regions; numbers are sampling sites and study areas. Note 2 Dushanbe, 7 Tashkent, 13 Frunze, 18 Alma-Ata.

The actual loess deposits in and around Uzbekistan are shown in Figure.2. This is by Kriger *et al.,* [8] and shows loess cover and sampling sites in the region which Kriger calls Central Asia and southern Kazakhstan. The loess might be divided into two regions; the truly desert part obviously connected to the two rivers, and a part closer to the mountains, a peri-montane region, containing the Tashkent loess. When Smalley [3] was describing his model of the Tashkent loess he concentrated more on the origins of the desert related material; his model can be revised to take more account of the mountain regions, and perhaps reconcile it with Mavlyanov's 'proluvial' loess. Mavlyanov [1] certainly mapped proluvial loess in the Tashkent region.

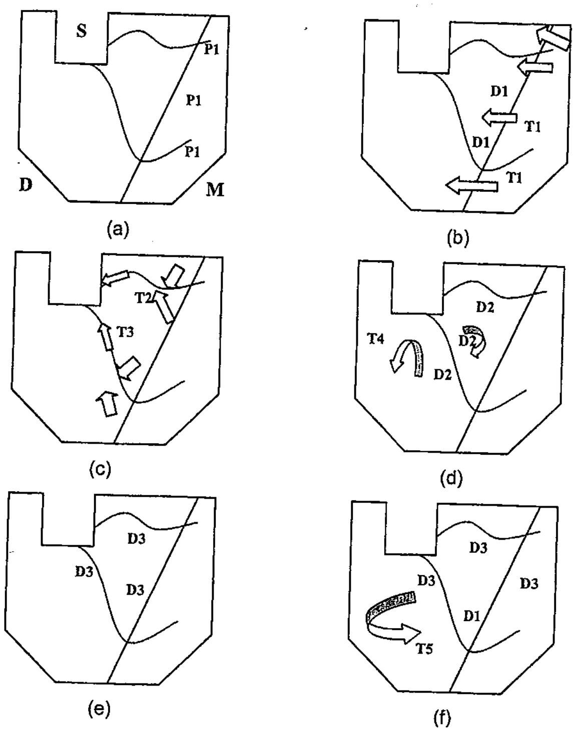

Figure 3: The 1978 Tashkent loess formation model. A revised version of the Smalley [3] diagram showing stages in the formation of loess deposits in an idealized landscape. External symbols indicate M mountains, D deserts, S inland sea. Two rivers flow from M through D to S.

Figure 3 shows an improved version of the 'Tashkent 1978' model for loess deposit formation with the PTD stages indicated. The stages can be discussed separately. If the overall stage structure can be described adequately then the basis for a formation model exists; the exact nature of the stage events can then be discussed; a two stage consideration gives flexibility. The original Smalley sketch map covers, in an extremely generalised way, the territory of Uzbekistan, with the Aral Sea (S) in the NW corner, and the Tien Shan mountains (M) in the SE. The rivers (R) represent the Amu-Darya and Syr-Darya. The sequence begins with particle production, a key event which was often neglected in earlier attempts to describe loess deposit formation.

- P1. The formation of silt particles, in the high mountains. There are two major ways to form loess particles, a simple obvious way by glacial grinding, and another way by weathering in high cold tectonically active mountains. The description of the formation of mountain loess particles is unsatisfactorily vague but there is no doubt that 'High Asia' (Fugure 1) delivers vast amounts of silt-sized particles to form loess deposits in China, Central Asia and related regions- this is 'mountain' loess (Smalley & Derbyshire [9]).

- T1. The first transportation event to be listed. Deciding the level of event definition is itself a critical process. The initial aim is to produce a series of critical and defineable events. The first transportation event moves material from the mountain down towards the piedmont region, and further into the river catchments. Does the Mavlyanov proluvial process operate at this early stage? The difficulty would be to form a sorted deposit. There does not appear to be enough time or geo-activity to form a sorted deposit (i.e. a true loess deposit).

- D1. A mixed deposit is formed in the foothills region; some sorting may have occurred but mixed deposits should predominate. This stage was described by Smalley [3]; it represents a poorly defined event but it is difficult to introduce more precision. D1 is the result of T1; necessary early stages in the loess deposit forming process.

- T2. Some complex transportation activity here; some particles may be raised by the wind from the mixed deposit and carried away in suspension but the major activity is probably (in terms of eventual loess deposit formation) still fluvial and involves the introduction of the finer particles (sand size and smaller) into the major rivers- an event which leads directly to

- T3. Transport out into the desert regions by (in particular) the Amu-Darya and Syr-Darya. These rivers are/were powerful transporters of suspended material, in fact Suslov (p.472) [10] claimed that "There is no other river in the world that carries as much suspension material as does the Amu-Darya". This major river is a key factor in loess deposit formation, as are many large rivers. The Danube, the Mississippi, the Missouri, the Yellow- are all great loess providing rivers. There is a classic simple picture of loess material distribution. Loess material is formed and introduced into large rivers, it is carried considerable distances and deposited as floodplain deposits; aeolian transport then moves the silt material a relatively short distance to form a classic airfall deposit, with all the defining loessic qualities. The Amu-Darya and Syr-Darya fit this simple model. T3 is the major movement event.

- D2. Relatively well sorted floodplain deposits are formed, in particular of particles in the size range 10-50 um; Suslov recorded 64.3% of these particles in the Amu-Darya alluvium. These are the raw material for desert loess, and it is the rivers which place them in the desert setting, as D2 alluvium.

- T4. Although the sorted deposits have a relatively high stability their desert situation exposes them to erosion by sand grain impact and this injects silt-sized particles into the airstream [11], [12] and they are transported in suspension. Many only travel short distances but some are carried out into the Kyzyl Kum desert.

- D3. Deposition close to rivers, but also at desert fringes. The formation of well-sorted loess deposits with silt sized particles and open structures; nutrient rich but prone to hydroconsolidation; most material delivered by the T4 stage but some direct from D1/T2.

- D4. Post-depositional changes. The D3 deposit may be more stable than the D2 deposit because it is less exposed to desert processes. Some lime and clay minerals may accumulate, these will stabilise the loess structure and produce the classic loess composition.

- T5. The 1978 model ended at D4 but T5 has been added to emphasize the fact that loess soils are unstable in the landscape; they are prone to soil erosion, so event T5 is further aeolian movement as a result of soil erosion. In looking at the formation process of a loess deposit in historical terms it now becomes important to pay close attention to stage T5.

So the event sequence now has ten stages. The important event that this approach added to the studies of Central Asian loess was the P1 stage; the relative importance of the subsequent T and D stages can be discussed and modified, but a clearly identified P1 gives the operation a firm basis.

3. Commentary

An important study of loess in Uzbekistan, and in the rest of Central Asia is that by Rozycki [13], he had access to the work of Mavlyanov and his Tashkent Institute; he wrote " The loess deposits of Middle Asia are better known ... than those from other Asiatic terrains, first of all owing to the numerous geological and engineering studies and also from the results of the studies systematically carried out at the Institute of Hydrology and Engineering Geology of the Uzbek Academy of Sciences under the leadership of G.A.Mavlyanov......

Moreover, the particular importance of this area is connected to the fact that it was here that the ideas of Pavlov and Glinka were formulated, and Dokuchaev's attitude was crystallised. Pavlov and Glinka and Dokuchaev were advocates of the so-called deluvial-proluvial theory of the origin of loess.."

([13] p.76). The interesting thing about the many theories of loess formation in Central Asia is that aspects of all of them can be incorporated into the event sequence and it can be shown the many apparently irreconcilable differences can be successfully reconciled (given a good place to start from). Dodonov [14] has proposed a stage process, which was discussed by Assallay *et al.,* [7]. A very perceptive commentary was supplied by Yeliseyev [5] and this has influenced the present work considerably. Yeliseyev [5], in particular, pointed out the problems of achieving a sorted deposit. One of the main defining features of a loess deposit is the narrow size range in the coarse silt size- the processes in the deposit formation operation must ensure very effective sorting, and Yeliseyev deployed this observation as a major criticism of the Mavlyanov proluvial approach.

Rozycki ([13] p.82) made some relevant comments about the P1 and T1 stages:

"There is no doubt that the dust material forming the loesses of the mountain foreland derives predominantly, if not entirely, from the higher parts of the mountain zone. From there it was swept downhill by rainfall water and in the dry places ... by the wind. By way of mudflows and further runoff of the waters it reached the rivers and in the zone of their vanishing was accumulated in the form of proluvia and alluvia chiefly composed of segregated dust material. Up to this point Pavlov was undoubtedly right in constructing his theory of the deluvial-proluvial origin of loess. The reservation shouild be made, however, that the theory does not apply to loess proper but to loess-like dusts accumulated in the valleys at the base of the mountains."

4. Conclusions

Some system and organisation is becoming apparent in the investigations of the nature and formation of the Uzbekistan loess, but further studies are required. The deposits out in the desert, associated with the great rivers seem to be explicable, but the deposits in the "mountain foreland" require more investigation.

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Ecologists plot to turn the tide for shrinking lake

Quirin Schiermeier, Munich

The Aral Sea is dying. Researchers have given up hope that the central Asian lake — which was the fourth-largest in the world before intensive Soviet agriculture diverted the rivers that feed it — can ever be restored.

But a group of ecologists and economists is nonetheless discussing plans for a conservation strategy that could eventually reverse the ecological ruin of the region surrounding the shrinking lake. Germany and the United Nations Educational, Scientific and Cultural Organization (UNESCO) are backing the plan, for which scientific preparations could begin in Uzbekistan next year.

Over the past half-century, the Aral Sea has lost four-fifths of its volume and more than half of its surface area as water from the main rivers that flow into it, the Amu Darya and the Syr Darya, was diverted to irrigate cotton fields in the surrounding region.

The vanishing of the lake has triggered an ecological disaster, with desertification of what used to be the lake's floor and heavy salination of the surrounding water table and soil.

Intensive farming has also caused widespread pesticide contamination, according to scientists who have visited the region. Illnesses such as hepatitis, respiratory diseases and anaemia are widespread, and shortages of food and drinking water are worsening, a crisis that has been compounded by the exceptionally dry summers of this year and last.

Now researchers at the Center for Development Research (ZEF) in Bonn are hoping to stop the rot by introducing sustainable patterns of land and water use to the region. They want to undertake a pilot scheme, after a preliminary investigation, to test the idea in the province of Khorezm, Uzbekistan, 400 kilometres south of the Aral Sea.

Under the scheme, around one-fifth of the irrigated cotton fields in the area would be converted into forest or hedgerow. More efficient farming would enable the remaining area to yield the same amount of cotton, the plan's architects say.

Christopher Martius, scientific coordinator of the project and an ecologist at the ZEF, thinks that local cotton growers can be persuaded to support the plan. "It is a legacy of Soviet times that most farmers in Uzbekistan have received solid scientific and agronomical training," he says. "Many of them have already signalled interest in participating."

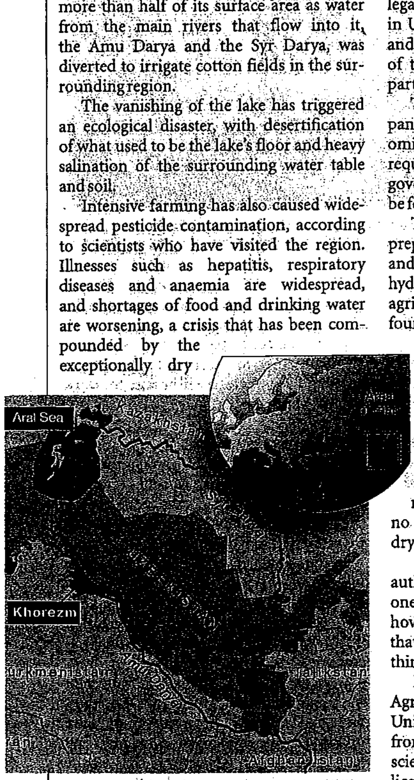
The changes in land use would be accompanied by legal, administrative and economic reform, and its success will therefore require strong backing from the Uzbekistani government, which Martius also thinks will be forthcoming.

The initial phase of the project will prepare for the pilot by studying the ecology and economy of the region, including its hydrology, environment, demography and agriculture. This study will take up to four years, says Martius, after which a pilot will be implemented on a single farm and then, perhaps, throughout the 6,300 square kilometres of the province.

The new strategy aims to mitigate the consequences of the changing environment, rather than trying to rescue the Aral Sea. A UNESCO report released last year said that there was no prospect of preventing the sea from drying up.

"Changing the behaviour of people and authorities will not be easy," says Paul Vlek, one of the directors of the ZEF. "We hope, however, that we will be able to demonstrate that, even in a crisis situation, it is sensible to think ecologically."

Local scientists from Tashkent State Agricultural University and Urganch State University will be involved in the project from the outset. If, as expected, the German science ministry approves a grant of 3 million euros (US$2.7 million) for the study phase, work on the project could begin next spring. ■



Washed up: ecologists can't save the Aral Sea but they hope to reduce the effects of its demise.

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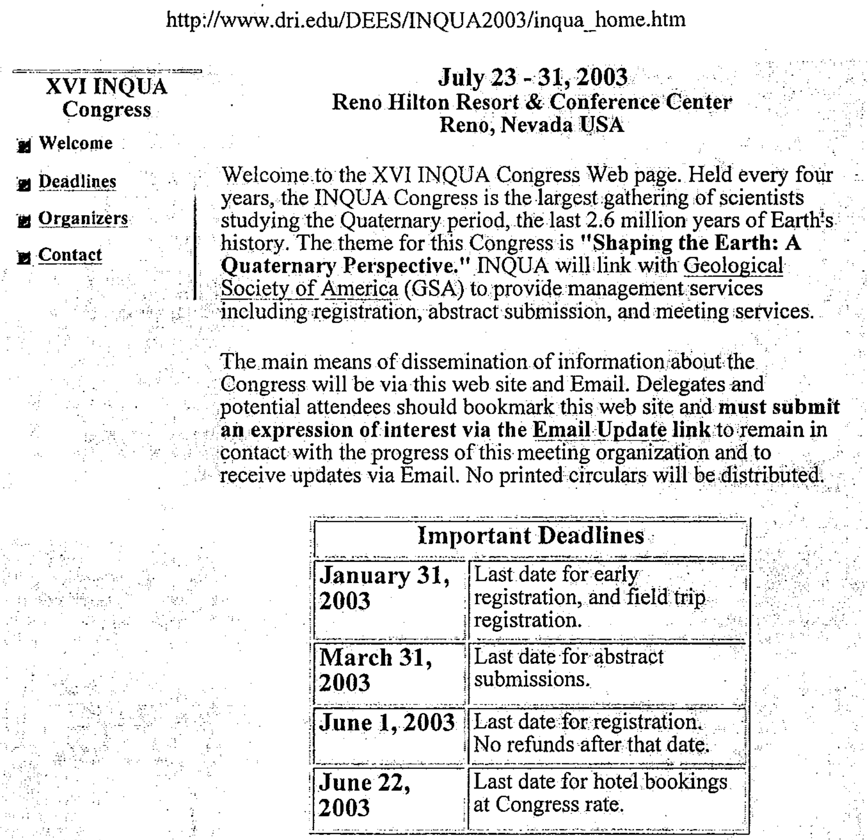

http://www.dri.edu/DEES/INQUA2003/inqua_home.htm

XVI INQUA Congress

- Welcome
- Deadlines
- Organizers
- Contact

July 23 - 31, 2003
Reno Hilton Resort & Conference Center
Reno, Nevada USA

Welcome to the XVI INQUA Congress Web page. Held every four years, the INQUA Congress is the largest gathering of scientists studying the Quaternary period, the last 2.6 million years of Earth's history. The theme for this Congress is **"Shaping the Earth: A Quaternary Perspective."** INQUA will link with Geological Society of America (GSA) to provide management services including registration, abstract submission, and meeting services.

The main means of dissemination of information about the Congress will be via this web site and Email. Delegates and potential attendees should bookmark this web site and **must submit an expression of interest via the Email Update link** to remain in contact with the progress of this meeting organization and to receive updates via Email. No printed circulars will be distributed.

Important Deadlines	
January 31, 2003	Last date for early registration, and field trip registration.
March 31, 2003	Last date for abstract submissions.
June 1, 2003	Last date for registration. No refunds after that date.
June 22, 2003	Last date for hotel bookings at Congress rate.

PERGAMON

Quaternary International 76/77 (2001) 1–5

Characteristics, stratigraphy and chronology of loess and palaeosols, and their application to climatic reconstruction: a preface

This special volume, concerned with *Loess and Palaeosols: characteristics, stratigraphy, chronology and climate* includes a selection of the 56 papers and 33 posters presented at "LOESSFEST '99", an international conference held in the University of Bonn, 25 March–1 April 1999. The meeting was held under the aegis of the International Union of Quaternary Research (the Commission on Loess) and the International Geological Correlation Programme (Project 413 — 'Understanding Future Dryland Changes from Past Dynamics').

It was Professor Ludwig Zöller of the Department of Geography in the University of Bonn who first suggested that a meeting might be held in the Rhine valley to celebrate the 175th anniversary of the first description of the Rhineland loess at the *locus classicus et typicus* at Haarlass (near Heidelberg) by Karl Caesar von Leonhard. The occasion of this suggestion was the 'stock-taking' meeting on *Wind-blown Sediments in the Quaternary Record* held in the University of London in January 1994 (Derbyshire, 1995a, b), and also sponsored by IGCP and INQUA. It was followed, in April 1994, by a NATO workshop on *Genesis and Properties of Collapsible Soil*, held in the University of Loughborough, UK, to consider specifically the applied and geotechnical aspects of loess (Derbyshire et al., 1995). Actively encouraged by Professor Ian Smalley (then Secretary and now President of the INQUA Loess Commission), the writer had little trouble in persuading Professor Zöller to make up the three-man Organising Committee.

The agreed aims of the meeting were to provide an opportunity to review the current state and future directions of loess research. The plan was to meet about five years after the meetings in London and Loughborough, and to provide the opportunity to see in the field both classic and important recent exposures of the Rhineland loess–palaeosol succession. There was a further reason why such a meeting was considered timely. This was the opportunity it would provide for the terrestrial aeolian community to confer with climatic modellers in the evaluation of existing information on terrestrial aeolian accumulations. The aim here was to establish a foundation for a data-base for aeolian fluxes in the Last Glacial Maximum. By the time of the Loessfest '99 meeting, this initiative had been named Dust Indicators and Records of Terrestrial and Marine Palaeoenvironments or 'DIRTMAP' (Kohfeld and Harrison, in press).

The collection of papers presented here illustrates very clearly the breadth of studies currently being undertaken on loess and the soils that develop upon it. The collection begins with two papers, the first on the nature of the silt particles making up the primary material of loess deposits and the second on the distinctive bulk behavioural properties of loess that make it such a hazardous surficial material. Wright reports on quartz silt generation using a series of laboratory simulations. She shows that both fluvial and aeolian systems are very proficient producers of quartz silt, the energetic, periodic fluvial regimes characteristic of many arid and semi-arid environments effecting considerable comminution. Potential sediment pathways in the formation of 'desert' loess are considered, and this forms the basis of a proposed sequence of events to explain the loess deposits around the Sahara. It is concluded that silt sources and generation mechanisms are probably much more diverse in the case of 'desert' loess than for glacial loess. The collapse of the engineering soil structure, and the associated mass failure of slopes in the thick loess of North China in terms of failure of the cementation bonds characteristic of much loess is next considered by Dijkstra. Although most of the physical properties of the loess in this large region show little variation, there are important variations in the modes of failure and collapse potential arising from varying thresholds of cementation bond failure and packing transformations. Dijkstra uses novel in situ tests, together with laboratory geotechnical methods, to show how these factors may enhance understanding of the slope instability mechanisms that trigger the often annual, catastrophic mass movements in the loess of a very highly populated region.

There follows half a dozen papers in which the dynamics and chronometry of the loess of Asia are central concerns. The first paper, by Graham, Ditchburn and Whitehead, describes important new Be isotope profiles of a 17 m loess–palaeosol sequence near Wanganui, in New Zealand, that provide the first Southern Hemisphere comparison with data from the classic region of

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the Chinese Loess Plateau. This set of profiles, dating back to ca. 500 ka BP, offers new insights into the provenance and diagenetic history of the loess. The fact that the average ^{10}Be concentration in the New Zealand case is about double that found in the Chinese loess is explained by the higher mean rainfall, and the consequently higher ^{10}Be depositional flux, in the New Zealand source area. A case is made for local provenance mainly from recycled fluvial deposits with some littoral marine input and little, if any, from the Australian mainland. The data show a negative correlation between ^{10}Be/^{9}Be and δ^{18}O, suggesting that the glacials in New Zealand were relatively arid compared to the present, even though rather wetter than the source areas of the Chinese loess. Comparison of a new magnetic record for North Africa with global proxy climate records by Dearing, Livingstone, Bateman and White also shows close correlation with the loess–palaeosol sequences in China, as well as the marine oxygen isotope (OI) record, for the OIS 8.0–5.4. They use coupled mineral magnetic measurements and a new chronology based on luminescence dating to confirm the presence of at least four phases of pedogenesis during the period 100–250 ka in the loess–palaeosol sequences on the Matmata Plateau, southern Tunisia. Preliminary attempts to infer palaeoprecipitation levels from modern analogues of soil magnetism-climate associations suggest that, during the periods 100–120 ka and ~200 ka, precipitation was $> 400\,\mathrm{mm\,a^{-1}}$, compared with modern values of $< 150\,\mathrm{mm\,a^{-1}}$. Moving southwards, a study of the geomorphology of dated aeolian and fluvial sediments in northwestern Namibia by Eitel, Blümel, Hüser and Mauz shows that, between about 30 and 8 ka, several metres of loessic alluvium accumulated in valleys and depressions. Both locally produced weathering detritus and allothonous dust blown in from the Western Kalahari to the eastern margin of the Namibian Desert were involved. Results confirm that northwestern Namibia was more arid than today during the Last Glacial Maximum (OIS 2). It is shown that the severely arid conditions persisted until about 9–8 ka BP, when a rather more humid climate began to prevail, with more intensive rainfall. It appears that this Early to Middle Holocene climatic change was not restricted to the N.W. Namibian region but represents a remarkable environmental change across the whole of southwestern Africa.

Turning to the interpretation of late Quaternary temporal patterns of dust flux from the Asian mainland into the North Pacific, Nilson and Lehmkuhl show, on the basis of a comparative literature review, that the dust signals indicate three such patterns. They cast a critical eye upon the common assumption that an increase in dust accumulation is an indication of increased aridity in the Asian interior. They point to a number of additional factors that may explain temporal and regional differences in dust accumulation. These include eustatic exposure of the continental shelf and the effect upon the atmosphere of changing sea-ice extents, variable frequency of meteorological situations conducive to long-range dust transport, variation in the strength of dust-bearing winds, changes in the wet deposition rate, and variations in dust-trapping vegetation cover. They conclude that simplified assumptions on the reasons for dust variability may lead to incomplete or even erroneous palaeoecological conclusions. The theme of dust dynamics is continued in the paper by Feng, on conditions on the Mongolian Plateau over the past 20,000 years. Using sedimentary data, supported by ^{14}C dates and some extrapolated ages for the sand-loess-soil section at Khyaraany (on the northern Mongolian Plateau), Feng is able to show that, in contrast to the marine OIS 3 palaeosols (dated at 24,500, 28,900, 30,700, 34,400 yr BP) that formed under oxidizing conditions, two palaeosols in OIS 2 (15,090 and 13,030 yr BP) and two Holocene palaeosols (8300, 4070 yr BP) formed under reducing conditions. Conditions of either weaker winds or more abundant vegetation generally dominated the latter part of the last glacial (15,090–8300 yr BP), during which three palaeosols (incipient histosols) were formed around 15,090, 13,030 and 8300 yr BP. Two conclusions are reached. First, the northern boundary of the Gobi (stony desert) has retreated as many as nine times in the past 40,000 years (ca. 34,400, 30,700, 28,900, 24,500, 15,090, 13,030, 8300, 4070 yr BP and then in the past 2000 + years). Second, in the light of the negative correlation between the susceptibility values and the silt percentages and organic matter contents, it is proposed that the reducing conditions of incipient histosol formation contributed to the alteration of magnetic minerals from strong forms of oxidized iron to weak forms. Thus, the magnetic susceptibility signal is essentially an indicator of redox cycles. The less well-documented topic of Late Holocene accumulation of loessic dust is taken up by Rost in his description of deposits in the alpine meadow belt of the Wutai Shan (2000–2400 m) in the Shanxi Province of North China. He shows that these silty drapes were transported, in the first instance, by the wind but that they have been modified to some degree by local reworking and syn-depositional weathering. A Late Holocene age (no older than about 3400 yr) is established by ^{14}C dating of included wood fragments and charcoal. The view is taken that a lowering of the treeline, caused by a climatic deterioration since the Holocene Optimum, as well as the formation and maintenance of a dense alpine meadow vegetation cover, favoured the accumulation of dust. Additional factors may have included alternation between dust source areas in the N.W. Chinese deserts and changes in the downwind accumulation area provided by the mountain barrier of the Wutai Shan.

Continuing the Asian theme, the paper by Bäumler presents the results of pedogeochemical analysis of soil development in aeolian deposits overlying moraines and landslide debris in the Khumbu Himal of eastern Nepal. The structure of the solum, pre-weathering of the loess, degree of soil weathering, and the age of depositional phase and subsequent soil development are determined using a number of measures supported by radiocarbon dating. Several depositional episodes of loess-like material are recognised up to at least 5000 m asl, indicating differences in age and source of the aeolian material, or different degrees of weathering independent of recent soil forming processes. Several palaeosols date from the Holocene. Additional data from radiocarbon dating of buried A horizons and charcoal indicate a period of loess accumulation 3000–4000 years ago, this material resting on older aeolian deposits of early Holocene age.

Soil evolution and plant succession in the latter half of the Holocene is the subject of the next paper by Khokhlova, Voronin, Malashev, Golyeva and Khokhlov. This reports on morphological and biomorphic analyses of a soil chronosequence in the Chechen depression of the Northern Caucasus. Palaeosols are described as being buried under archaeological monuments at about > 5000, 3800–4000 and 1600–1700 BP and the modern soils. The first two series of palaeosols developed in rather warmer and drier climatic conditions than those buried at 1600–1700 BP and beneath the modern soils. In the late Atlantic period in this region annual temperatures were 0.5°C higher and annual precipitation $100\,\mathrm{mm\,yr^{-1}}$ lower than at present. The transition to the Sub-boreal period was climatically unstable, with the transition to moister and cooler conditions. The climate has since fluctuated. It is shown that loess-like material accumulated at the same time as pedogenesis in the latter half of the Holocene. It appears that alternating periods of active sedimentation and pedogenesis occurred on this stable, Late Pleistocene land surface. Palaeoclimatic interpretations, based on the clay mineral composition of the loess and palaeosols of the plains region of Ukraine, are considered next by Perederij. Some 16 Pleistocene climatic stages (8 warm and 8 cold) are reflected in the clay mineral composition. Mineralogical analysis of the clay fraction (defined as < 0.001 mm) of loess and palaeosols show that the main clay minerals are of the smectite group (montmorillonite, nontronite, beidellite), together with hydromicas, mixed layer hydromica–montmorillonite minerals, kaolinite and halloysite. Chlorite, goethite, calcite, gypsum and quartz are also present. Content of the principal minerals differs between the palaeosols and loess horizons of different ages. Regional differences in clay mineral composition are also recognised for two Middle Pleistocene stages: composition at 12 sites indicates temporal (rhythmic) and spatial (regional) changes that clearly reflect palaeoclimatic conditions.

In the first of 11 papers concerned with the loess of Western and Central Europe, an account of the loess deposits of the Bohemian Massif (Czech Republic) by Cilek, brings the discussion back to several aspects concerning silt provenance, dust transport paths, the role of relief in loess distribution and the evidence for post-depositional modification of aeolian silt, or ‘loessification’. It is shown that the loess in the Central European hilly regions, with high accumulation rates, frequently provides relatively high-resolution ‘floating’ stratigraphies that contain both local and Europe-wide climatic signals. The minor peaks arise from local factors such as slope processes, discontinuous inputs, and palaeometeorological location in the former ice age landscape. It is pointed out that although the loess–palaeosol series are often seen as a palaeoclimatic proxy reconstruction, macroscopic features such as laminations corresponding to individual dust storms are better explained by meteorological factors. Heavy mineral studies in the Czech Republic suggest that the North Atlantic Oscillation (NAO) wind pattern functioned even during the last glacial cycle. A strong case is made for the view that rapid consolidation of accumulating silts by cementation bonds was the key factor in loessification. The experiments reported in this paper demonstrate that significant quantities of white chalky and powdery loess calcite and Si–Al hydroxides are released during repeated freeze and thaw cycles, and so play an important role in this process. Consideration of European loess as a periglacial facies is continued in Issmer's paper on the Vistulian loess of Poland. Vistulian loess is found only in western Poland, as a series of small patches draped over a range of glacial and glaciofluvial landforms, including end moraines, till plains and outwash plains. Two loess lithofacies are described: massive and laminated, the latter containing three sub-facies (cryptolaminated, laminated loess in sensu stricto, and banded loess). There appears to have been a close match between the active aeolian zone and the periglacial zone during the Vistulian in this region.

There follows an impressive review by Ložek of the nature and importance of molluscan fauna as indicators of Quaternary palaeoenvironmental conditions in Europe. Malacofaunas from the loess series in Bohemia and Moravia have provided rich evidence of environmental change, particularly for the last interglacial–glacial cycle. A number of important conclusions are reached. For example, loess malacocoenoses differ in their composition from all known molluscan assemblages in present-day Europe and show a relatively uniform character in space and time. Moreover, they reflect specific environments (‘loess steppe’) with a cold-continental climate, grassland with discontinuous turf and ‘raw’ soils rich in salts. These malacocoenoses differ considerably from those of the modern sub-polar zone. The loess was the product of pleniglacial phases. Its occurrence was very limited in the early glacial phases, and the malacofauna in these loess horizons shows an absence of most sub-polar or alpine species. It is noted that, in pedocomplex I (PK I = δ^{18}O stage 3, Stillfried B) none of the malacological records indicate a warmer climate, its assemblages being very similar to those found in the loess. Fully developed woodland malacocoenoses reflecting warm and humid climate characterise the Interglacials, even in areas where such assemblages did not develop during the Postglacial. It is shown that, at higher elevations and in moister areas, different sediments, soils and molluscan assemblages existed at the same time. Their correlation with the loess sequences remains poorly documented because of a dearth of reliable fossil and stratigraphic evidence.

Three papers on the Carpathian Basin follow. The first, by Horváth, discusses the mineralogy and provenance of two marker horizons, the (older) Bag Tephra and the Paks Tephra in loess of Middle and Upper Pleistocene age in Hungary. Geochemical analysis suggests that the most likely origin of the Bag Tephra is the Roman or the Campanian volcanic fields in Italy. Similar geochemical investigation of the Paks Tephra is still in hand, but preliminary results suggest the same sources. The highly contentious topic of the chronology of the older Hungarian loess in general and the MB pedocomplex in particular is discussed. It is pointed out that, in contrast to the matching of tephra horizons, the correlation of palaeosol horizons is more complex, requiring time-consuming micromorphological analysis because of local effects on soil development and the weathering effects that are an integral part of pedogenesis. Palaeoecological aspects of late Quaternary sedimentation in the Carpathian Basin are discussed by Sümegi and Rudner in two related papers. The first reports the results of analyses of charcoal layers in loess near Tokaj. On the basis of radiocarbon dating, it is shown that *Picea*-containing taiga forest-steppe habitats existed in this region between 29 and 21 ka BP. The forests were subject to extensive fires that appear to have affected the entire basin. The firing temperature (600–700°C) is consistent with natural forest fires. Detailed evidence shows that the burnt fragments are in situ and undisturbed by subsequent surface processes. Macroscopic charcoal remains and the molluscan fauna provide dating control and environmental information in a second paper concerned with changes in the ecology of this region. Two well developed and one weakly developed charcoal layers are described as resting on top of a palaeosol within loess profiles that accumulated in the last glacial period, between ca. 70,000 and 15,000 years BP. Palaeoecological analysis of the charcoal layers and Molluscs lead to the conclusion that recurring boreal forest steppe habitats characterised the Carpathian Basin, the woodlands mostly consisting of *Picea* trees in the north and *Pinus sylvestris* in the south, as well as six other arboreal species. Study of younger charcoal layers suggests that re-establishment of forest with a similar composition occurred every 2000–5000 years in response to fires, although densities may have varied. The time needed for the forest-steppe to redevelop remains to be determined.

A group of four papers provide new data and perspectives on the loess-palaeosol succession in Germany. Hilgers, Gehrt, Janotta and Radtke apply luminescence (TL and OSL) dating and pedological techniques to establish the age of the northern boundary of the Weichselian loess belt in northern Germany. It is known that the uppermost 2 m of the aeolian sediments accumulated in a short period, towards the end of the Late Glacial and the early Holocene. The age span runs from ca. 8 until 15 ka with the averages concentrated at ~ 11 ka, regardless of the method or mineral fraction used. These data agree well with the results of oxygen isotope analysis of ice cores from Greenland (12.85–11.65 ka). During this period, the transition from the Younger Dryas to the Preboreal, the climatic and environmental conditions favoured vigorous aeolian activity. Earlier suggestions that the northernmost loess deposits in Northern Germany represent the return of strong aeolian processes under the cold and dry conditions of the Late Glacial are thus confirmed. In their review of the Middle Rhine region, Boenigk and Frechen confirm that the loess-palaeosol sequences here provide a relatively detailed and continuous terrestrial record of climate and environment change for the past 200,000 years. However, recent stratigraphic and chronological investigations of loess-palaeosol sequences in sections at Tönchesberg and Koblenz-Metternich (Middle Rhine) indicate that the last interglacial and glacial cycle is preserved in much more detail than has previously been recognised. In both sections, the last interglacial soil is covered by at least 10 palaeosols, post-dating the brown forest soil of the Eemian (OIS 5e). A high-resolution record of the last interglacial–glacial cycle in the Upper Rhine region of Germany provided by loess–palaeosol sequences at Nussloch is analysed by Antoine, Rousseau, Zöller, Lang, Munaut, Hatté and Fontugne. Using samples at 10 cm intervals, this study highlights the response of the loessic environment to global climatic variations during the last cycle. The basal soil complex shows a pedosedimentary evolution that indicates a clear transition towards increased continentality between the end of the Eemian (5d) and the beginning of the Pleniglacial. The Lower Pleniglacial was initially very arid with loess accumulation followed by stratified niveo-aeolian sands. The Middle Pleniglacial complex (ca. 55–30) shows a decline in loessic sedimentation, with two stable phases marked by Cambisols and tundra gleys. Organic silts in this intermediate phase (interstadial) yielded ^{14}C dates of 32–33 ka BP. The thick (> 10 m) Upper Pleniglacial loess started to accumulate before the OIS 3/2 transition. Finally, a correlation of loess–palaeosol stratigraphy in Germany, Belgium and France, and spanning the whole of the last interglacial–glacial cycle, is proposed. This is followed by discussion of the results of a study by Terhorst, Appel, and Werner of a loess–palaeosol sequence from the last and the penultimate glacial–interglacial cycles in south-west Germany, using pedological, geochemical and rock magnetic methods. Problems of separating the influence of palaeo-relief, hydrology and climate complicate the interpretation, but their results show that even minimal degrees of soil formation may cause a distinct enhancement of the magnetic properties. Higher magnetic susceptibility (MS) values are found in the more oxidized parts of the palaeosols, while hydromorphic processes operating on the ferrimagnetic minerals tend to lower the signal: both record past changes in the palaeoenvironment. Extremely low MS values characterise the reduced greyish zones of the interglacial Bt horizons. Other complications are introduced because MS may vary laterally along a horizon within a profile. Ferrimagnetic mineral concentrations are lower in eluvial horizons than in the loess, with higher values in illuvial horizons. It is concluded that palaeoclimatic interpretations based solely on MS should be treated with great caution. The last of the papers on the European region is an account of loess in southern Spain by Günster, Skowronek and Zöller. Samples from several sites that include Late Pleistocene loess were analysed using palaeopedological methods. The resultant regional pedostratigraphy is a high-resolution indicator of changing climate during the last interglacial/glacial cycle in the Western Mediterranean. Ten fossil soils of different ages show some similarities to the Middle European loess stratigraphy. It is inferred that the Late Pleistocene sequence, even in this sub-humid to semi-arid region of southern Spain conforms with the general model for western Europe, with loess accumulation in dry phases (stadials) and soil formation in wetter (interstadial) conditions.

The last paper in this volume, by Sayago, Collantes, Karlson and Sanabria, presents an overview of the genesis and distribution of the Late Pleistocene and Holocene loess of Argentina, with special reference to the loess in the northern, sub-tropical region. Regional factors are shown to be important in explaining loess distribution, taking into account the general SW-NE loess transport path throughout Argentina. The available dating confirms the age of the superficial loess as Pleistocene and Holocene. It is suggested that the Late Pleistocene loess depositional episodes match the highest dust concentrations found in the ice core records at both poles. The prominent influence of volcanic materials, affecting not only the loess mineral composition but also the genesis and evolution of the loess–palaeosol sequences, is emphasised. Finally, the importance of the palaeosols as indicators of palaeoenvironmental conditions is clearly demonstrated by descriptions of outcrops in the pre-Andean valleys of north-western Argentina.

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4. A Brief Summary of Midcontinental North American Loess

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Loess of late Quaternary age is abundant in the central part of North America, found mainly in a broad, 1500 km-long east-west belt in the states of Ohio, Indiana, Illinois, Iowa, Nebraska and Colorado and a narrow, 1500-km north-south belt extending from Wisconsin to Louisiana. Loess is the most important parent material for agricultural soils in the United States.

Loesses deposited prior to the last glacial period are known to exist in the entire region. The oldest of these that is dated is the Loveland Loess, which, based on direct TL dating of the loess itself, is about 120,000 to 160,000 years old, and apparently correlates with the penultimate glaciation, or oxygen isotope stage 6. A well morphologically well expressed palaeosol called the Sangamon soil is developed in this loess and apparently dates to the last interglacial period, equivalent to oxygen isotope stage 5 (or the Eemian interglacial in European terminology) and probably also part of stage 4. The youngest pre-last-glacial loess, found east of the Mississippi River, is called the Roxana Silt, and dates to sometime in the interval between ~50,000 and ~30,000 yr BP, based on radiocarbon and TL methods, equivalent to some or all of isotope stage 3. An equivalent unit called the Gilman Canyon Formation is found west of the Mississippi River.

Most studies over the past 50 years have focused on loess of the last glacial period, referred to as the Peoria Loess. It is a massive silt loam that is as thick as 50 m in parts of western Nebraska, as thick as 40 m in western Iowa (east of the Missouri River), and as thick as 20 m to the east of the Mississippi River in Illinois. Despite the appearance of a continuous blanket over the mid-continent region, Peoria Loess composition is not spatially uniform. East of the Mississippi River, carbonate content of loess is higher, reflected in higher abundances of CaO and MgO. West of the Mississippi River, particularly in Nebraska and Colorado, loess is lower in carbonates, but higher in K-bearing minerals and plagioclase, reflected in higher K_2O and Na_2O contents. Clay mineral content is also higher in loess of the western part of the region, reflected in higher Al_2O_3 and Fe_2O_3 contents.

Peoria Loess composition at a given site also varies as a function of age/depth. For example, a thick loess section in western Iowa has low carbonate content in its lower 10 m, probably reflecting syndepositional leaching during slow loess accumulation. The 10-m above this zone have carbonates, but relatively low fine silt and clay contents, reflected in relatively low Al_2O_3 and Fe_2O_3 contents. The uppermost 20 m of the section are also calcareous, but much higher in clay and fine silt, reflected also in relatively high Al_2O_3 and Fe_2O_3 contents. The changes in particle size in this section are interpreted to reflect a shift from an exclusively local source (the Missouri River) to a local source augmented by far-travelled, fine-grained loess derived from western sources. Although there have been few studies of this detail, they indicate that a simple picture of a spatially and temporally uniform sediment blanket is probably not realistic for the region.

Radiocarbon ages of Peoria Loess show that loess deposition, while occurring broadly within the last glacial period, did not take place at the same time everywhere. Maximum-limiting radiocarbon ages (of organic matter in a soil formed in the uppermost Roxana Silt and the Gilman Canyon Formation) are as old as 30,000 to 34,000 years in some places and as young as 20,000 to 22,000 years in other places. Minimum-limiting ages are much more difficult to obtain and are based mainly on snails found in the upper parts of the loess in areas east of the Mississippi River and on organic matter in a soil that separates Peoria Loess from an overlying Holocene loess farther west. These minimum-limiting ages range from about 10,000 to 12,000 years. Rare occurrences of charcoal or spruce needles in the lower and middle parts of Peoria Loess yield radiocarbon ages of 12,000 to 20,000 years. Limited TL analyses of Peoria Loess have mostly yielded ages of about 17,000 to 24,0000 calendar years BP.

Numerous studies, dating back to the 1940s, have shown that Peoria Loess shows considerable variability in particle size away from river valleys that were major outwash-bearing valley trains from the Laurentide ice sheet during the last glacial period. With increasing distance east of the Missouri, Mississippi, Wabash and Ohio Rivers, Peoria Loess is thinner, lower in sand and coarse silt, higher in fine silt and clay, and lower in carbonates. Decreasing thickness reflects a decreasing supply of sediment away from a source whereas the increase in fine particles reflects the winnowing of coarse particles away from that source. The decrease in carbonate content reflects syndepositional weathering away from the source where sedimentation rates are lower.

Despite the obvious link to glacial outwash sources in Indiana, Illinois, Wisconsin, and Iowa, loess found to the west of these states, in Nebraska, Kansas, and Colorado, seems to be unrelated to sediment derived from the Laurentide ice sheet. Drainages adjacent to loess in this part of the region (the Great Plains) have headwaters that were not fed by meltwaters of the ice sheet during the last glaciation. Although meltwaters from much small glaciers in the Rocky Mountains fed Great Plains rivers during the last glaciation, it is unlikely that this was the major supply of silt to the region; Rocky Mountain glaciers were relatively small, but loess in Nebraska is as thick as 50 m. Isotopic studies (Pb isotopes in feldspars and U-Pb ages of zircons) have shown that loess in eastern Colorado is partly derived from a non-glacial source and loess in Nebraska is mostly derived from the same non-glacial source. This previously unsuspected parent sediment is volcaniclastic siltstone of the Tertiary White River Formation, which is exposed over large areas of the central Great Plains, to the north and northwest of the loess belt.

There are at least five major issues regarding Peoria Loess, all-important to climate modelling efforts, that need to be addressed in future studies. (1) It is not known why Peoria Loess is so much thicker than all pre-Peoria loesses, including those that date to major glaciations, such as the Loveland Loess of the penultimate glaciation. (2) It is not known how much of Peoria Loess in glacial terrain is not glaciogenic, but derived from far-travelled nonglacial sources now confirmed to exist in the central Great Plains. Continued isotopic studies of different size fractions could possibly answer this question. (3) Because mainly bracketing radiocarbon ages are the age control on Peoria Loess, it is not known what the variability in sedimentation rate within the last glacial period might have been, i.e., did sedimentation occur mainly in the early part of the last glacial period, at the last glacial maximum or during deglacial time. Detailed, high-precision OSL dating could answer this question. (4) The spatial trends in loess thickness, particle size, and carbonate content, as well as isotopic identification of non-glacial loess sources in central Great Plains, all indicate that last-glacial palaeowinds were likely from the west or northwest. This observation is in conflict with most AGCM results, which show dominantly northerly or northeasterly winds due to the presence of a strong glacial anticyclone over the Laurentide ice sheet. Studies of modern loess deposition in periglacial regions could possibly address this question if seasonally variable winds are responsible for the difference between the observed and modelled palaeowinds. (5) The identification of non-glacial loess sources in the Great Plains region is in conflict with simulation of last-glacial dust sources, using a linked AGCM-biome-biogeochemical model. The amount of dust/loess generated from this source far exceeds that recorded by other source areas of North America (Alaska, southwestern USA, Mexico) that were simulated by this model.

5. Loess-Palaeosol Records in Siberia

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General Background

Loess and loess-like deposits in Siberia are distributed mainly in the southern part of the territory (between 50° and 59° N latitude and 66° and 97° E longitude), covering a broad geographical area ca 1500 km wide (from north to south) of about 800,000 km2 between the Ob and Angara River basins north of the Altay and Sayan Mountains. They represent a continuation of the Eurasian loess belt spanning from Western Europe across the Russian Plains to the north-central China Loess Plateau. The Siberian loess ranges in thickness from a few metres in the Angara River valley and the Lake Baykal area in the east to up to 40 m in the Yenisei River valley in the southern Central Siberia, and reaching up to 150 m on the Priobie loess plateau in the west. The loess sections are locally intercalated with other aeolian, alluvial, and colluvial deposits (sands, silts, and clays), and interstratified with variably developed palaeosols, documenting a complex nature of the Pleistocene environments.

The Siberian loess record spans throughout the Quaternary Period, yet it is locally rather fragmentary or completely absent for the earlier stages (mainly preserved on the Ob Plateau and in the Kuzbass Basin in the western and central part of the territory, respectively). The most complete and nearly continuous sections date to the Late Pleistocene (the Yenisei area). The present climate is strongly continental with cold and dry winters with little snow cover, and warm to hot summers with mean annual temperature of –0.5 to –2 °C.

Current studies

The Siberian loess has been studied in detail during the last several years following the previous field investigations and chronostratigraphic interpretations made by Russian colleagues (e.g., Zykina et al., 1981). The principle Late Quaternary chronological system follows the scheme subdividing the Late Pleistocene into four climatic stages (the Kazantsevo Interglacial, the Zyryanka Glacial, the Karga Interstadial and the Sartan Glaciation), corresponding to Oxygen Isotope Stage (OIS) 5-2.

The major focus of the present studies is 1) the stratigraphy of long-term subaerial records in south-western Siberia (Zykina, 1999), 2) the high-resolution Late Pleistocene climatic records and related palaeoenvironmental evolution of landscape and biota (Chlachula et al., 1997, 1998), and 3) a chronological refinement of the loess archives for the last 130 ka by TL and OSL dating in central southern Siberia (Frechen and Yamskikh, 1999).

A particular attention is paid to the loess deposits in the upper Yenisey River valley, comprising the most complete record to date in this part of northern Eurasia for the last two glacial-interglacial cycles (Chlachula, 1999). A total of 32 pedogenic horizons from the OIS 7-1 time interval have been previously recognised in the area (Chlachula et al., 1997). The local loess mineralogy is characterised by quartz (54-72%) and feldspar (10-23%), calcite (4-7%) chlorite (3-6%), biotite (2-3%) and other minerals. The mineralogical composition and the fresh surface morphology of the fine silt fraction indicate a local provenance of the sediment, although most of loess in southern Siberia is assumed to have been derived from the ice-sheet from the north.

Study methods and approaches

The present complex investigations are aimed at specifying the nature and rate of loess sedimentation and the subsequent pedogenic modification and to reconstruct environmental conditions prior to, during, and after formation of the fossil soils. The principal study aspects used as indicators of the past climatic change in the fossil palaeosol horizons are the TOC and CaCO3 content; grain size and mineralogy of the sedimentary matrix; fossil periglacial features (solifluction, cryoturbation, frost wedge casts); and magnetic susceptibility.

Particular attention has been paid to magnetic susceptibility, low-frequency (LF) and frequency-dependent (FD%), as this has proven to be a reliable indicator of the past climatic change in the larger study area (Chlachula et al., 1997, 1998; Chlachula, 1999). The relationship between the climatic change and magnetic susceptibility fluctuation is clearly evident, with the LF susceptibility maxima corresponding to the intervals of the most intensive loess deposition and the minima correlating with the most developed chernozemic palaeosols. An intense wind activity leading to accumulation of greater quantities of larger ferrimagnetic (mainly magnetite) grains is believed to account for the magnetic susceptibility increase during cold (stadial) intervals (Chlachula et al., 1998). A similar pattern has been observed in loess in southwestern Siberia (the Ob Plateau). The total magnetic susceptibility capacity of palaeosol horizons is clearly not a function of weathering intensity and time, as in Europe or China, but depends a priori upon the quantity and quality of primary magnetic minerals within the unaltered parent material inherited from original geological sources. Magnetic susceptibility, coupled with other palaeoclimatic proxy data, has proven to be a very sensitive indicator of the past climate change in the broader area.

Late Pleistocene loess-palaeosol records

A series of high resolution loess-palaeosol sections has been investigated in the Ob, Yenisei and Angara River basins as a part of the 1500 km W-E continental transect project in 1997-1999, with a principal focus on the last interglacial (OIS 5, sensu lato). The results show patterned climatic variations and uniformity of natural environments across the south Siberian territory during the Late Pleistocene (Chlachula and Kemp, in prep). The key Late Quaternary records from the Northern Minusinsk Basin in the southern Krasnoyarsk region (Kurtak sections 29 and 33) and the southern Priobie loess plateau north of the Altay Mountains (Biysk and Iskitim sections) provide evidence for a strongly fluctuating climatic change in this part of Eurasia during the Late Quaternary. Magnetic susceptibility (low frequency and FD%) records, with maximum deviation amplitudes between 130 and 10 ka BP, together with other palaeoenvironmental proxy data (grain size, %CaCO3 and %organic carbon variations) show a globally diagnostic trend for the last glacial-interglacial cycle.

The last interglacial (sensu lato) includes several warm as well a very cold stages (correlated with OIS 5e-5a). A strongly continental warm climate culminating around the peak of the last interglacial (OIS 5e) is followed by a gradual shift to more humid and cooler conditions during the subsequent interstadial stages (OIS 5c and 5a). The cold substage 5d is documented by up to 1.5 m deep frost wedge casts dissecting the OIS 5e chernozem (TL dated to 125 ka), indicating a dramatic decrease of temperature and humidity, and establishment of a cold tundra environment. This evidence corroborates with the data from the Lake Baykal (Karabanov et al., 1998) suggesting an intense glaciation in Siberia during the last interglacial. Following this time interval, the climate in southern Siberia became more pronounced with very cold and dry stadials during the last glacial stages (OIS 4 and 2) interspersed with moderate mid-last glacial (OIS 3) interstadials.

Past climate change and natural environments

The past climatic variations are well monitored in the stratigraphic loess record indicating a similarity of natural environments in the steppe-parkland zone across southern Siberia. The initial pedogenic alteration of parent material is expressed by incipient gleying in a cold, humid environment within a seasonally waterlogged setting and a cold periglacial tundra. A progressive leaching of calcium carbonate from the loessic substratum accompanied by organic matter accumulation reflects a gradual increase of summer temperatures and surface stability that contributed both to prolonged weathering processes and formation of brown (forest-tundra) soils, and, under warmer conditions, of chernozemic (parkland-steppe) soils. An analogous pattern is documented in the Late Pleistocene loess sections in western Siberia (Zykina, 1999), with reactivated soil formation processes during surface stabilisation under warmer conditions and subsequent solifluction and cryoturbation due to climatic cooling and increased humidity.

Summary and conclusion

With respect to the mid-continental geographical location with largely reduced atmospheric effects of the world's oceans, the Siberian loess – palaeosol records are of major importance for mapping the Quaternary climatic and environmental change in central Eurasia and the principle mechanisms behind the process. Due to the pronounced climatic continentality and geographical isolation between the Central Asian mountain systems in the south and the Arctic Ocean in the north, the Siberian loesses provide an excellent source of high-resolution palaeoclimate proxy data of regional, as well as global, significance. Particularly the Late Pleistocene (OIS 5-2) loess archives have a key relevance for establishment of the close correlation framework between the European, Central Asian and Chinese loess-palaeosol records within the major W-E continental transect, and represent a significant source of proxy data for reconstruction of past climates and climate change in the Northern Hemisphere.

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6. Loess from South America

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Distribution and age

The distribution of loess in southern South America covers most of the Chaco-Pampean plain of Argentina (Bolivia and Paraguay) and small areas of the western mountain environments. Loess was also reported in neighbouring areas of Uruguay and southern Brazil. Teruggi (1957) mapped the distribution of loessoid sediments (reworked loess and loess-like sediments), indicating that secondary loess was even more abundant than primary loess. Still the distinction between primary and secondary loess constitutes a major topic of discussion.

The beginning of the loessoid sedimentation cycle has been related to a phase of Andean orogeny that resulted in the elevation of the Andes Cordillera in the late Miocene (*circa* 10 Ma) which acted as a barrier to moisture laden Pacific winds. This initiated "the desertification of Patagonia caused by the rain shadow while precocious Pampas environments probably came into prominence at about this time" (Patterson and Pascual, 1972 in Marshall et al., 1983). The late Tertiary deposits as well as the Quaternary loess material, are mainly composed of volcaniclastic fine sandy silts, mostly modified by pedogenesis and reworked by aqueous transport agents. The scarcity of primary aeolian facies is attributed to their low preservation potential in the sedimentary record.

Stratigraphically, although the late Cainozoic loessoid complex was grouped under several different names, Pampean Formation (and informally Pampean sediments) is the most commonly used as a collective term including both Tertiary and Quaternary deposits. The two most important type sections are the Mar del Plata sea-cliffs and the Paraná river bankfulls. The classical concepts on the origin of Argentine loess are mostly based on the grain size and mineralogical analysis of samples from the Mar del Plata type section (Teruggi, 1957). Later, this study was extrapolated to the rest of the Chaco-pampean plains, resulting in an oversimplified model of the Argentine loess record.

The regional loess record

During the last twenty years a renewed interest on the Quaternary, brought about several studies on palaeomagnetism, sedimentology, vertebrate palaeontology, palaeopedology, palynology and stratigraphy in different areas of the Pampas (Mar del Plata, northern Buenos Aires, south central Santa Fé, west central Córdoba) and NW Argentina (Tucumán). Although significant results were obtained the timing and climatic significance of the loess record is still difficult to interpret and correlate within the region because of the different methodological approaches followed and the lack of integration between the studies.

The Mar del Plata-Miramar type section (38° 10′S, 57° 40′ W) consists of loess-like sediments reworked by fluvial streams and slopewash while primary loess facies are minor sedimentary components. The late Pliocene to Late Pleistocene-Holocene record is continuously exposed with a thickness of 20-30 mts along 35 km of sea-cliffs. The sedimentation was discontinuous including important hiatuses. Lithostratigraphic, pedostratigraphic, biostratigraphic (vertebrate palaeontology) and magnetostratigraphic studies were performed. Pedogenesis deeply modified the deposits with faunal activity (both invertebrates and vertebrates) playing a significant role in the reorganisation of the original material. The age control is mostly based on vertebrate assemblages (land-mammal ages, stage-ages) (Tonni et al., 1992) and magnetostratigraphy (Orgeira y Valencio, 1984, Ruocco 1989, Orgeira, 1988). Numerical ages were recently obtained (Schultz et al., 1998). This section is particularly important to study the Pliocene-early Pleistocene interval consisting of a 20-m thick sequence of loess- (loessoid)-palaeosols.

In the Mar del Plata-Bahia Blanca area (38°'S- 38° 30'S; 58° 60° W) several studies on grain size, mineralogy, ^{14}C (among others, Zárate & Blasi, 1993, Bidart, 1996) and palynology (Prieto, 1996) were conducted on the late Pleistocene-Holocene record (sandy loess, loessial sands).

The northern Pampas of Buenos Aires (33° 45'S- 36°S; 56°W - 59° 30'W) is a type area of the Pampean Formation where classical studies on the stratigraphy and palaeontology of the Pampean loess were performed (Ameghino, 1889, González Bonorino, 1965). Since 1985, several sections have been the focus of analysis on palaeopedology (Teruggi & Imbellone, 1987, Imbellone & Teruggi, 1993; Zárate et al. ms), palaeomagnetic studies (Bobbio et al. 1986, Nabel et al. 1999, Bidegain, 1998), environmental magnetism (Orgeira et al., 1998, Nabel et al., 1999), geochemical analysis (Galet et al., 1998; Morrás, 1999) and vertebrate palaeontology (Tonni et al., 1999). General information on the grain size, mineralogical composition and chemical composition (carbonate, organic matter) is available. Following general models, loess was attributed to arid conditions and palaeosols to more humid and warmer conditions (Tonni et al., 1999). The age control is based on magnetostratigraphy and vertebrate palaeontology. Still, the correlation with deep-sea cores is not possible.

South central Santa Fé (32° 30'S- 33°S; 59° 45'W - 61° 45'W) and also the eastern part of Córdoba

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黄土形成过程的实质与环境

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提 要 黄土地层的形成实质上是土壤化过程，不同特性的黄土层代表了不同的成壤作用。不同地区的黄土主要是草原、荒漠草原和森林草原地区发育的灰钙土、栗钙土、棕钙土、棕漠土和黑垆土。与红褐色古土壤相比，黄土是冷干气候条件下发育的灰黄色古土壤，黄土层能够作为冷干气候的指示。根据灰黄色古土壤与红色古土壤的交替，可将250万年来黄土区气候变化分为51个旋回与亚旋回。

关键词 黄土本质 黄土化过程 灰黄色古土壤 环境

中图分类号 P931.6 **文献标识码** A

1 黄土的土壤特征

1.1 黄土层中的土壤结构和粘化特征

野外调查可见，黄土具有清楚的宏观土壤结构，主要有似棱柱状结构、棱块状、团块状及团粒状、根孔和虫孔等结构。黄土中的土壤结构在不同地区存在很大差异，反映了成壤条件不同。在黄土高原东南部，黄土的结构以似棱柱状和团块状为主；在黄土高原的中部以团粒状为主，团块状少量；在黄土高原的西北部则以团粒状和状粒为主。在西安附近，黄土中的似棱柱状结构体长50cm左右，棱柱体直径约为0.5～1.5cm；团块结构中的团块大小为0.5～1.0cm，形状为多角形，不规则形；团粒结构中粒径大小为0.1cm左右。似棱柱状结构的棱柱体和团块结构中团块之间分界较明显，易于识别。由于团粒的粒径小，边界不明显，肉眼识别有一定困难，具这种结构的土体表面有团粒大小的起伏变化。粒状结构在黄土中就是粉砂质粒状结构，具这种结构的土体表面较平坦。

黄土高原中部和西北部的黄土以粒状和团粒状结构为主，这样的结构是成壤作用弱的显示，是干旱偏冷地区土壤的特征之一。我国西北现代土壤就以粒状结构为特征，不见团块状和棱柱状结构存在。黄土中的红褐色古土壤是公认的典型土壤，但在兰州、甘肃靖远等干旱区，这些古土壤也是以粒状结构为主。尽管较干旱地区黄土中不见似棱柱状和团块状结构，但生物作用形成的虫孔和根孔之类的土壤结构却是常见的。因此，不能认为没有似棱柱状和团块状结构的黄土就不是古土壤。

为了从微观上确定黄土的土壤特点，我们在西安刘家坡、宝鸡陵塬、陕西洛川和兰州等剖面中、晚更新世各层黄土中共采集56块样品进行磨片观察。结果表明，西安和宝鸡剖面中更新统黄土中一般都有光性定向粘土发育，洛川剖面只有个别黄土层中有光性定向粘土发育，兰州剖面无光性定向粘土存在。黄土中光性定向粘土的特点是以流胶状和斑点状为主，呈块状等大个体者较少，颜色偏黄。这表明黄土中的光性定向粘土的发育较弱，其中Fe_2O_3的含量较少，显示出当时降水较少，温度较低。微结构中的光性定向粘土显示出有些黄土层经历了较强的成壤过程，具有粘化的表现。

1.2 黄土发育时的生物和土壤淀积产物

按照土壤学的定义，土壤是成壤作用形成的、能够生长植物、含有机质的疏松土层。黄土发育在水上条件下，其形成过程中必然有植物的生长。黄土中发现的植物根、枝残体是当时植物生长的直接证据。对西安刘家坡剖面第一层至第七层黄土和红色古土壤作了11块样品的胡敏酸和富里酸测定，结果表明这七层黄土胡敏酸和富里酸总含量为0.0382

国际地质对比计划项目(IGCP379)及国土资源部"九·五"重点项目(9501104)研究成果
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~0.0524(C%)，而且黄土层中这两种有机酸与红褐色古土壤中差别不大。据洛川剖面黄土氨基酸测定[1]，黄土层中含有多种氨基酸，而且马兰黄土及其它少数黄土中的氨基酸比红褐色古土壤中还高，证明黄土发育时的生物产生了相当数量的有机酸。黄土中的有机酸不但指示黄土是含有机质的土层，而且可以指示黄土是含成壤过程中形成的有机质的古土壤。

黄土中的动物化石同样显示黄土形成时的地表面有植被发育。最能说明黄土发育时地表有植被发育的是迁移能力很小的啮齿类和蜗牛，这两类化石也是黄土中数量最多的。据研究，黄土中的蜗牛化石以华蜗牛—虹蛹螺组合占优势。蜗牛迁移能力较弱，活动范围很小，它们的大量存在充分表明黄土经历了成壤作用。据观测，蜗牛每秒钟前进 1.5mm，在黄昏和夜间外出觅食，然后返回栖息场所。蜗牛的这一特性决定了它们的埋藏地点往往是生活的地点或死亡的地点。蜗牛化石在黄土中零星分布，并不集中于某一层位，并常见壳顶朝天埋藏的现象，证明它们是在风尘堆积时随地面缓慢增高被埋藏的。黄土中的蜗牛几乎都是陆生成分，它们主要以禾本科及双子叶绿色植物为食，这表明在黄土发育过程中作为成壤作用主要因素的动植物是一直存在的。黄土中啮齿类化石的数量仅次于蜗牛化石的数量，啮齿类是以植物枝叶或其种子为食，指示黄土发育过程中具备土壤化的生物因素。

黄土中的 $CaCO_3$ 含量、存在形式对认识黄土的土壤化很有意义。黄土高原东南部 $CaCO_3$ 含量在10%以上，西北部含量高达20%左右，现代风尘中 $CaCO_3$ 含量为3%左右，我国荒漠区土壤中 $CaCO_3$ 含量一般为10%左右。黄土中 $CaCO_3$ 含量高是黄土经历了较长时间成壤作用的结果[3]。在风化成壤过程中，来自大气降水中的 $Ca(HCO_3)_2$ 经蒸发淀积在黄土之中。每一黄土层的发育过程长达几万年，漫长的过程必然会从大气降水中获得相当数量的 $CaCO_3$。根据现代风尘和现代荒漠区土壤 $CaCO_3$ 含量以及黄土中 $CaCO_3$ 含量进行推断，黄土中约有5%~10%的 $CaCO_3$ 来自大气降水。因此，黄土中 $CaCO_3$ 含量高表明它经历了成壤作用。

黄土中的 $CaCO_3$ 含量虽然高，但原生 $CaCO_3$ 的含量比较少，主要以次生形式存在[3,4]。黄土中的 $CaCO_3$ 主要以斑点、假菌丝、薄膜形式存在，呈结核形式存在者较少，这是较干旱条件下发育的土壤的特征[3]。黄土中 $CaCO_3$ 存在的特殊形式是土壤化的标志，实质上是土壤的淀积产物，是风尘不断堆积条件下发育的、分层不明显的淀积层。

由上可见，黄土具有土壤的特征和形成土壤的条件，它是风尘连续堆积条件下发育的土壤。但黄土是否为成熟的土壤呢？据年代学研究，每万年发育的黄土一般为 0.6m[5]，这表明黄土有充分的时间发育为成熟土壤，它发育弱和不具红色的原因是冷干气候决定的。

2 黄土形成与演变

弄清黄土形成过程或黄土化过程能加深对黄土形成实质的认识。一般所说的黄土化过程是风尘堆积物在弱碱性的氧化环境中，受到雨水和生物等的作用，其中的碎屑方解石大部分被溶解，并转入粒间溶液，再因强烈蒸发，重新沉淀出来成为次生碳酸盐；次生碳酸盐与少量铁、锰氧化物包裹着粉尘颗粒，使之成为浅灰黄色、疏松多孔和具大孔隙的黄土[6]。上述认为的黄土化过程或成黄土过程实际上是碎屑方解石转变为次生 $CaCO_3$ 的过程。根据成壤过程中 $CaCO_3$ 发生淋溶和淀积的特征可知，黄土化过程中原生 $CaCO_3$ 向次生 $CaCO_3$ 的转变是成壤作用的一个方面，是气候较干旱条件下的微弱淋溶和淀积过程。过去对黄土化过程或成黄土过程的认识主要强调了原生 $CaCO_3$ 的转化作用，而对生物的作用考虑不够。据作者研究，黄土化过程还包括极为重要的生物作用、大气降水中 $CaCO_3$ 的聚集作用以及一定的粘化作用。黄土化作用的结果具体表现在黄土的特征上。黄土的有些特征是在黄土化过程中形成的，有些特征是从风尘中继承下来的。通过分析不难确定，黄土的灰黄色、疏散、粒度细、分选很好和无层理等方面的特征是从风尘中继承下来的，黄土富含次生 $CaCO_3$、具土壤结构、含大孔隙以及垂直节理等特征才是黄土化过程中形成的。据风尘发展的趋势分析，从风尘中继承下来的特征在黄土化过程中会有一定变化，如黄土发育过程中会使风尘变密，粒度变细，颜色略变深等。那么在黄土化过程中形成的特征又是怎样产生的呢？下面分析黄

土化过程中的主要作用和黄土特征的形成。(1) $CaCO_3$ 的微弱淋溶、淀积和聚集作用：黄土中原生 $CaCO_3$ 向次生 $CaCO_3$ 的转变实质上是碎屑 $CaCO_3$ 在大气降水作用下受淋溶和淀积的过程，只是干旱区淋溶弱而已。黄土中的次生 $CaCO_3$ 并不都是由原生 $CaCO_3$ 转变来的，有约3%~10%[7]的 $CaCO_3$ 来自大气降水。来自大气降水中的 $CaCO_3$ 是通过蒸发淀积在黄土层中的，代表 $CaCO_3$ 的聚集过程。原生 $CaCO_3$ 向次生 $CaCO_3$ 的转化和大气降水中 $CaCO_3$ 的聚集使黄土获得了富含次生 $CaCO_3$ 的突出特征。(2)生物的作用：动植物的活动在黄土中产生虫孔和根孔，这是黄土突出特征之一大孔隙形成的主要原因。生物的作用还是黄土含有机质和团粒结构的重要原因。(3)粘化作用：在成壤较强的条件下，黄土中部分矿物分解，产生粘粒、光性粘土胶膜和似棱柱状结构。

由于不同地区生物、气候条件存在差异，黄土化过程就存在着不同。根据黄土化作用的特点和产生的结果不同，初步可分为三种黄土化类型。(1)淋溶和生物作用都较弱的黄土化过程：在年平均降水量小于200mm的荒漠草原条件下，无粘化作用发生，在黄土化过程中起主导作用的是微弱的淋溶和生物作用。原生 $CaCO_3$ 在降水少和蒸发强的情况下，向下移动很小的距离便发生淀积。在原生 $CaCO_3$ 向次生 $CaCO_3$ 转变的同时，大气降水中的 $CaCO_3$ 也不断在黄土中发生淀积。由于淋溶作用很弱，黄土中也有 $CaSO_4$ 的淀积。弱的生物活动使黄土中根孔和有机质含量少。这种黄土化的结果使黄土含有较丰富的非结核形式的次生 $CaCO_3$，但大孔隙少，土壤结构不明显。(2)淋溶作用和生物作用都较明显的黄土化过程：在平均年降水量200~450mm的草原气候条件下，生物作用和淋溶作用都较明显，而粘化作用未发生。原生 $CaCO_3$ 受淋溶作用而向下显著迁移，并发生淀积，由原生 $CaCO_3$ 转变成的次生 $CaCO_3$ 和来自大气降水中的 $CaCO_3$ 是通过蒸发和下渗饱和两种方式淀积的。由于淋溶作用较明显，黄土中没有 $CaSO_4$ 存在。明显的生物作用使土层含有丰富的根孔、虫孔、团粒和较多的有机质。这种黄土化的结果使黄土富含非结核形式的次生 $CaCO_3$ 较丰富大孔隙和土壤的团粒结构。(3)淋溶、粘化和生物作用都较明显的黄土化过程：在年平均降水量500mm左右的森林草原条件下，淋溶、粘化和生物三种作用都较强烈。由于降水量较多，$CaCO_3$ 迁移深度较大，原生 $CaCO_3$ 较快地转变成为次生 $CaCO_3$。原生 $CaCO_3$ 的转变和来自大气降水中的 $CaCO_3$ 的淀积也是通过蒸发和下渗饱和淀积两种方式进行的，但下渗饱和淀积 $CaCO_3$ 数量较第二种黄土化过程为多。生物的明显作用产生了大量根孔、虫孔和一定量的有机质，粘化作用使黄土粘土含量增加，光性粘土有所发育，团块结构形成。这种黄土化的结果使黄土含有 $CaCO_3$ 薄膜、斑点、钙丝和结核，而且具有较丰富的大孔隙和清楚的团粒、团块结构、

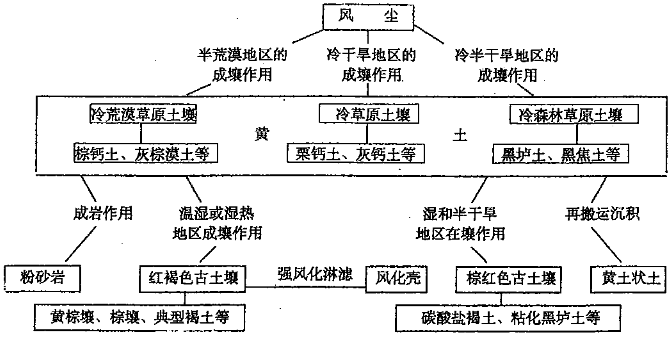

图1 黄土形成与演变

Fig.1 Formation and evolution of loess

似棱柱状结构和少量的光性粘土胶膜。

鉴于以上所述，可以得出黄土化作用就是成壤作用，不同的黄土化作用代表不同生物气候条件下的成壤作用。根据黄土的结构，$CaCO_3$ 存在的形式，无粘化或弱粘化的特点和作者以往的研究[4,8,9,10]，可确定不同地区黄土的土壤类型主要为栗钙土、灰钙土、棕钙土和黑垆土等。黄土形成后还会发生变化，这种变化随所处的条件差异而不同。黄土化过程及黄土形成后的演变可用图1表示。

3　黄土地层气候划分

过去认为黄土地层中发育了37层红色古土壤[11]。作者对关中地区调查得知，发育完整的黄土地层包括了42层黄土和41层红褐色古土壤。如果考虑到第1、2、3、5层红色古土壤的复合以及第1、6、7、9层黄土中发育弱的棕红色古土壤的存在，那么黄土地层包括了50层红褐色古土壤和51层黄土。如上述，黄土是冷干气候条件下发育的灰黄色古土壤(表1)，黄土与红褐色古土壤的交替代表了温湿与冷干气候的变化。根据这种变化情况，可将2.5Ma以来的生物、气候、土壤的演变分为101个阶段，构成51个旋回和亚旋回。

表1　关中地区黄土与古土壤划分

Tab.1　Division of loess and paleosols in Guanzhong area

年代(Ma)	2.50～0.73	0.73～0.128	0.28～0.01	0.01～0.00
黄土与古土壤总层数	59	26	10	6

在2.5Ma以来的深海氧同位素曲线上[12]，可分出105个阶段，构成53个旋回。黄土地层生物、土壤、气候的变化与深海氧同位素划分基本相同，两者可相当好地对比。

4　结　　论

综上所述，可得出如下认识：(1)黄土具有明显的土壤结构、淀积产物和有机等土壤的特点，黄土是在冷干气候条件下发育的灰黄色古土壤。黄土的土壤类型主要为灰钙土、栗钙土、棕钙土、黑垆土等。(2)黄土主要是风尘堆积过程中经草原、森林草原和荒漠草原地区较弱的成壤作用形成的。在这样的成壤作用条件下，只能形成灰黄色为主的古土壤，这样的古土壤也是发育成熟的土壤。(3)黄土土壤剖面分层不清的主要原因是风尘的连续堆积和 $CaCO_3$ 连续淀积所致，其次是成壤作用较弱造成的。(4)黄土与红褐色古土壤的交替是土壤、生物、气候环境变化的显示，黄土完全可以作为冷干气候的指示。根据黄土与红色古土壤的交替，可将2.5Ma以来土壤、生物、气候演变划分为51个旋回和亚旋回。

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ESSENCE AND ENVIRONMENT OF LOESS FORMATION

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Abstract

There are soil macrostructure in loess, such as similar prismy sturcture, lumpy structure, grangular structure, root holes, and microstructure, such as optically oriented clay film developed in stronger soil formation processes. Loess is rich in $CaCO_3$, but it is mainly secondary and is the illuvial products formed by dissolving and depositing of $CaCO_3$ and is a sign of illuvial layer of $CaCO_3$. These characteristics show that loess experienced soil formation processes. The fossil animals, such as snail, and a lot of root holes also indicate that the loess formed in soil formation processes. The developmental process of loess was longer than of mellow soils, the reasons why it didn't change into red-brown paleosols were cold and arid climate and the features of the soil formation processes. The soil profile of loess is not clear, which results from continual dust deposition and $CaCO_3$ illuviation. Loess developed mainly in steppe, desert-steppe and forest-steppe areas, the loess in different areas and of different characteristics is mainly Sierozems, Chestnut Soils, Brown Soils, Brown Desert Soils and Loessial Soils.

Soil formation mainly indudes weak dissolving, migrating and illuvating of $CaCO_3$ as well as weak biological action in desert-steppe. $CaCO_3$ exists in the form of powder and spots and $CaSO_4$ sometimes occurs in the areas where soil structure develps poorly and root holes and insect holes are a few. The obvious migrating and illuviating of $CaCO_3$ and forming of biological structure are the dominant processes in which loess develops in steppe areas. $CaCO_3$ exists in the form of film and soil structure, such as granular structure and root holes, is obvious in the areas. Besides notable migrating and illuvating of $CaCO_3$ as well as forming of biological of structure, clay grouting sometimes occurs in forest-steppe areas in the formation process of loess. $CaCO_3$ nodules often occur, granular, lumpy, similar prismy sturcture and root holes developed well, and organic substance is high in content and optically oriented clay film sometimes can be seen in the areas.

Grey-yellow loess that is the paleosol can be used as a mark in reconstructing paleoclimate. According to the alternation of loess and paleosol, the biological, soil and climatic changes since 2.5Ma can be classified into 101 stages consistuting 51 cycles and sub-cycles.

Key words: essence of loess; processes forming loess; grey-yellow paleosols; environment.

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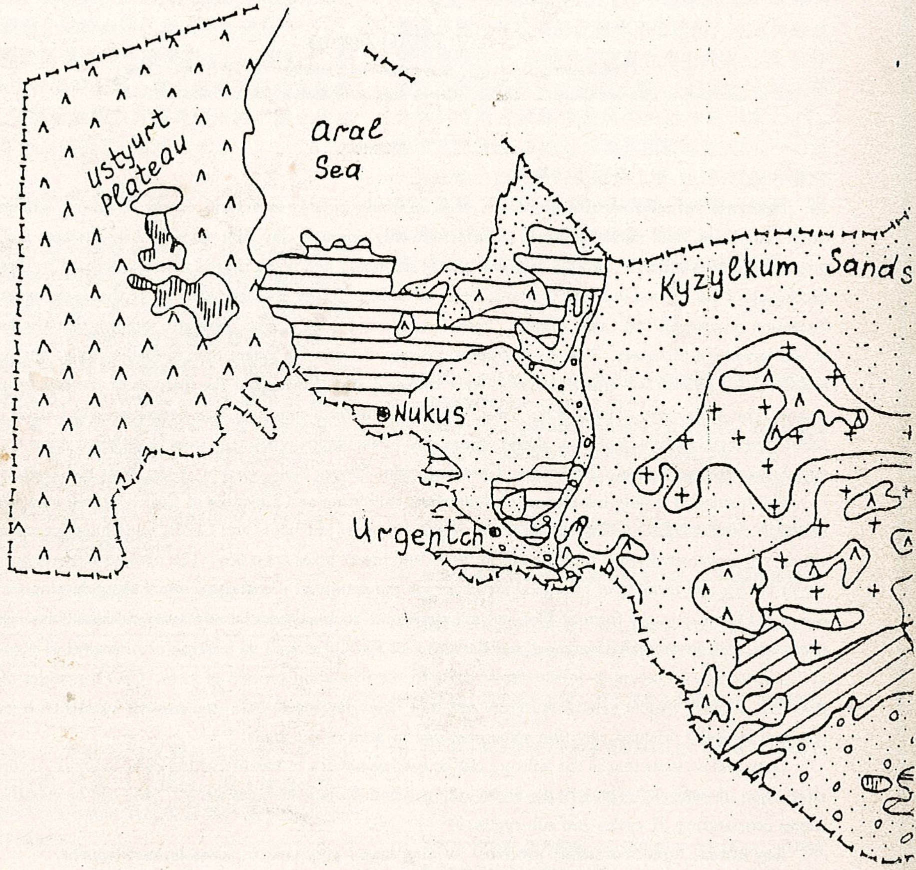

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