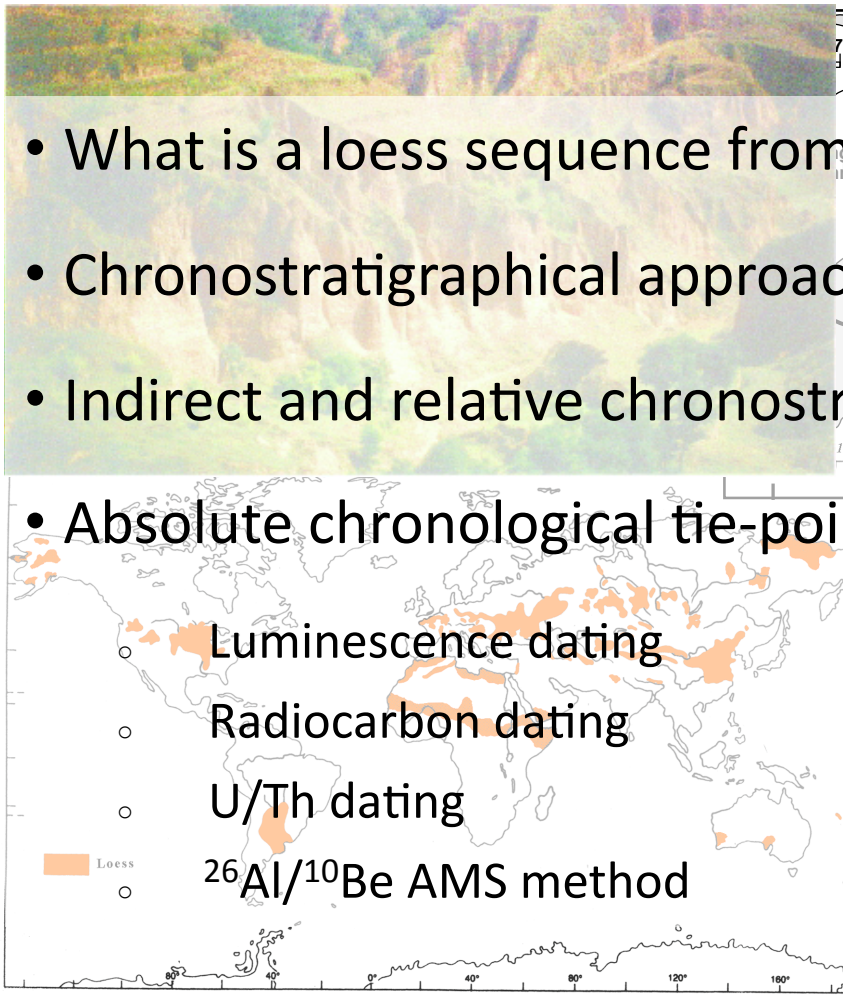
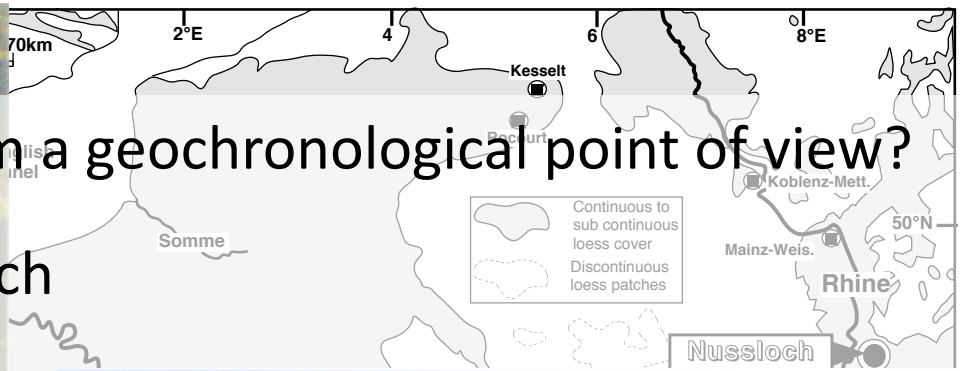
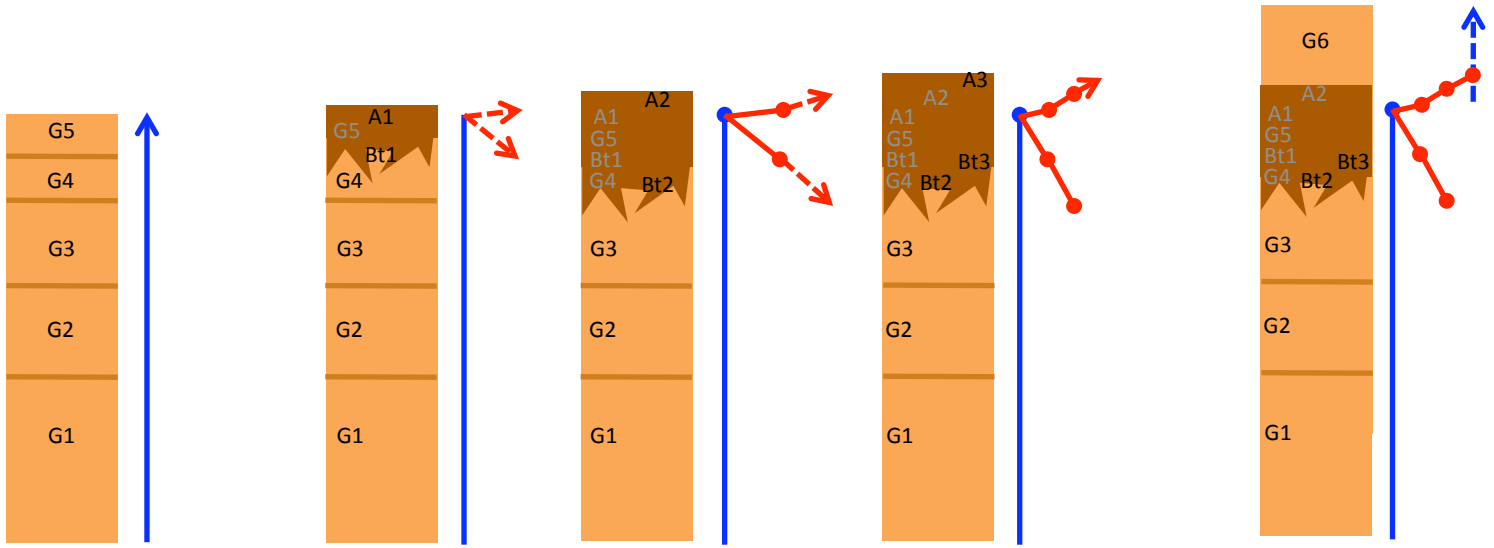
Dust record dating

- What is a loess sequence from a geochronological point of view?
- Chronostratigraphical approach
- Indirect and relative chronostratigraphy
- Absolute chronological tie-points
  - Luminescence dating
  - Radiocarbon dating
  - U/Th dating
  - $^{26}Al/^{10}Be$ AMS method





What is a loess sequence from a geochronological point of view?



loess accum.
⇒ +G1 +G2…+G5
⇒ - hiatus - erosion

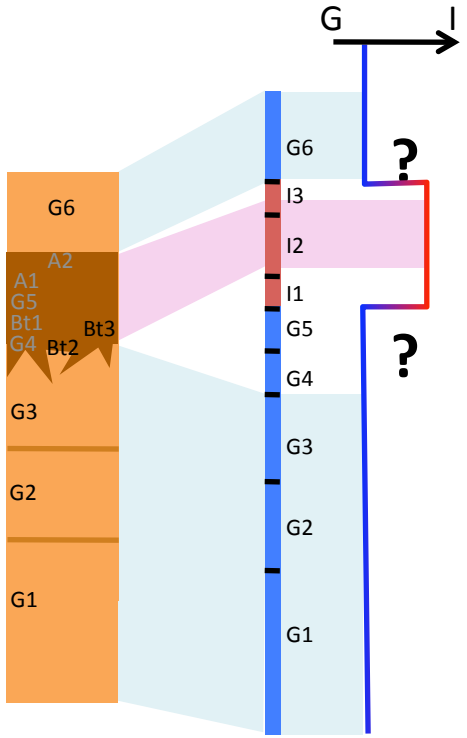
I1: soil dev.
⇒ +A1 +Bt1
⇒ -G5

I2: soil dev.
⇒ +A2 +Bt2
⇒ - A1 - Bt1
⇒ - G4

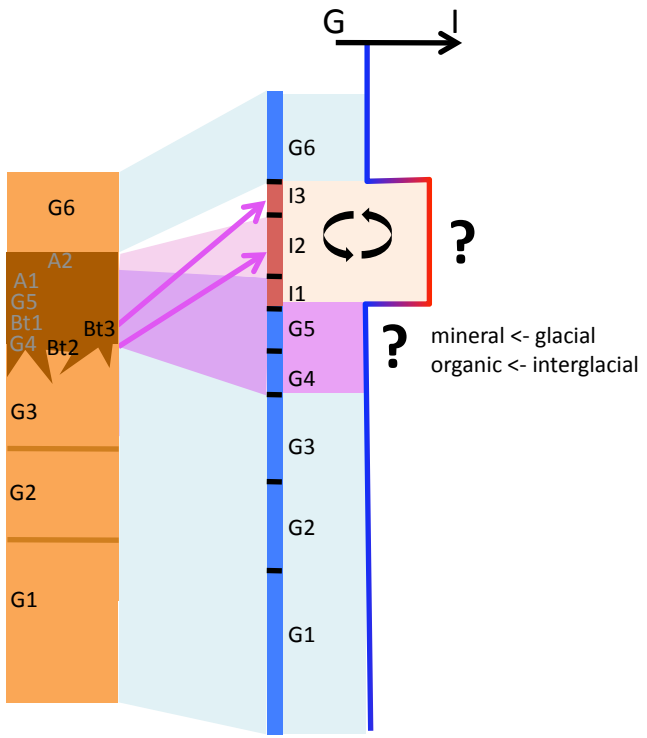
I3: soil dev.
⇒ +A3 +Bt3
⇒ - A2

erosion => - A3
loess accum. => + G6

What is a loess sequence from a geochronological point of view?



pedological features



origin of sediment components

What is a loess sequence from a geochronological point of view?

con's

hiatus
erosion
overlap
discontinuity / continuity

pro's

the most complete *proxy (itself and support of proxies)* of past climate for glacial times
the record of paleodust in continental areas

Chronostratigraphical approach

aims

to define a chronological framework that allows comparison/correlation between loess sequences.

basis

based on the model that a same sedimentological feature occurs in similar environmental conditions, similar in time and space.

Chronostratigraphical approach

* *Chronoclimatic phases*

Pedological unit is the first step to establish a chronological framework.

A similar pattern on sedimentological facies establishement is assumed for all compared sequences : typical loess deposits during cold and arid periods, soil develops during warmer and wetter periods.

-> large chronoclimatic phases are thus defined: Eemian, Weichselian, Würmian, Saalian, ...

Chronostratigraphical approach

* *Chronoclimatic phases*

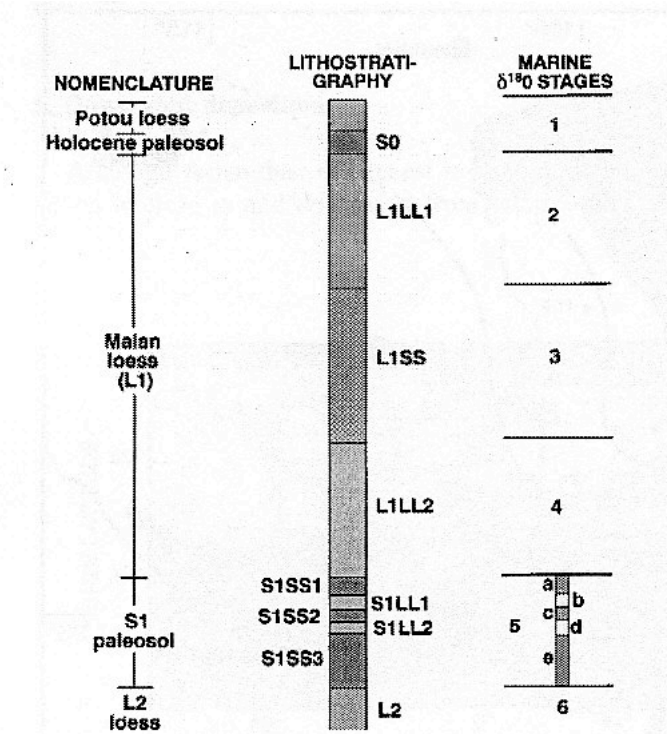


Fig. 2. Stratigraphic subdivision and nomenclature of loess and paleosols formed since the end of the penultimate glaciation and correlation with marine oxygen-isotope stages and substages. Major loess and soil units (L1, Sl) are subdivided into smaller units (e.g., L1LL1, S1SS1) on the basis of physical, chemical, and biological properties. Nomenclature follows Kukla and An (1989).

Porter et al. 2001 ESR

At this step, that's not a real chronological framework.
It's more the characterization of environmental conditions than a chronology.

Nothing more

Keep in mind that only part of interglacial is recorded in loess sequence and that part of glacial is overlapped by interglacial feature.

Chronostratigraphical approach

* *Stratigraphical phases*

Any stratigraphical complex or marker, well-dated (^{14}C, TL, K/Ar, magnetic reversal, …) or not, that would allow comparison amongst sequences

ex. for North-Western Europe:

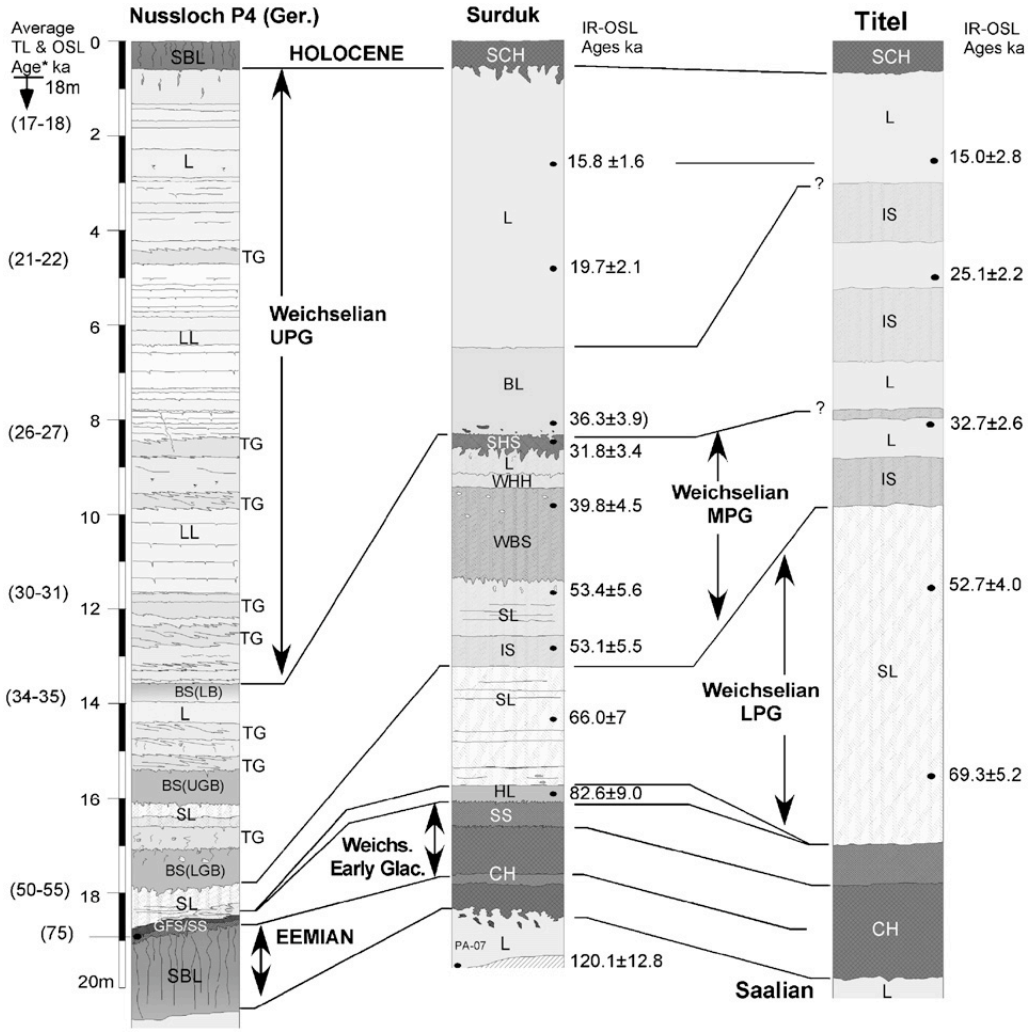
- Eltviller Tuff
- Saint-Sauflieu Complex
- Nagelbeek horizon
- ...

ex. for China:

- B/M reversal
- Potou loess
- ...

Chronostratigraphical approach

* *Stratigraphical phases*



Antoine et al., QI, 2009

Same idea but further in details for environmental description.

Smaller stratigraphical units are thus defined:

-> Lower, Middle and Upper Pleniglacial

-> Weichselian Early Glacial

Chronostratigraphical approach

aims

- to define a chronological framework that allows comparison amongst sequences.
  ⇒ at this step, there is no real need for numbers

basis

- based on the model that a same sedimentological feature occurs in similar environmental conditions, similar in time and space.

limits

- only part of interglacial is recorded in loess sequence and part of glacial is overlapped by interglacial feature. Extent of "part" depends on time and space.
  ⇒ correlation can not be perfect
- do not allow direct comparison with other type of paleorecord

Indirect and relative chronostratigraphy

aims

- Provide a quantitative chronological framework to allow comparison with others paleorecords

basis

- Based on comparison between a proxy record from loess sequence and a global paleoclimatic record regarded as a reference series:
  - ✓ some points (pointers: mostly transitions, sometimes peaks) are tied together
  - ✓ loess record is then wiggle-matched to the reference series

Indirect and relative chronostratigraphy

* *Astronomical scale*

Berger and Loutre, 1991

obliquity:	41 ka in [36.9 – 44.8] ka
precession:	21 ka in [17.5 – 26.2] ka
eccentricity:	100 ka in [97.1 – 125] ka

Indirect and relative chronostratigraphy

* *Astronomical scale*

Pergamon

Quaternary Science Reviews, Vol. 13, pp. 39–70, 1994.
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0277–3791(94)E0015–3

TOWARDS AN ORBITAL TIME SCALE FOR CHINESE LOESS DEPOSITS

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grain-size record of Baoji loess sequence which variation is interpreted as result of glacial-interglacial cyclic variations in winter monsoon intensity

⇒ should reflect orbital variations

⇒ grain size record is tuned to the orbital records of Berger and Loutre (1991)

⇒ the resulting time-scale is attested by major magnetic reversals (K/Ar ±)

what is the resulting uncertainty on the time-scale?

Indirect and relative chronostratigraphy

* *Astronomical scale*

QUATER

TABLE 2. AGE ESTIMATES, BASED ON THE FINAL CHRONOLOGY DETERMINED FOR THE STACKED ISOTOPE RECORD OF PISIAS *ET AL.* (1984)

Event[a]	Depth (cm)	Age (yr)	Error (yr)	$\delta^{18}O$ (normalized)	Event[a]	Depth (cm)	Age (yr)	Error (yr)	$\delta^{18}O$ (normalized)
	2.6	210	1070	0.92		313.6	33,210	6970	-0.38
1.1	13.0	2320	2110	0.86		324.0	35,560	[illegible]	-0.45
	13.8	2480	2200	0.86		334.5	37,370	7740	-0.38
	22.3	4200	3050	0.86		344.8	39,690	6690	-0.43
	34.4	6270	3730	0.78		354.2	41,000	6210	-0.31
	44.5	7810	4020	0.82		364.5	42,930	4970	-0.31
	54.7	9140	3990	0.53	3.13	375.0	43,880	4710	-0.34
				.31		375.7	43,940	4690	-0.34
				.00		385.3	44,820	4500	-0.37
				.06		392.2	45,570	4280	-0.37
				.12		404.4	47,300	3610	-0.26
				.42		414.6	48,900	3520	-0.21
				.62	3.3	423.0	50,210	3850	-0.17
	114.6	16,160	1480	-0.7		424.2	50,390	3900	-0.16
	123.5	17,310	1400	-0.85		434.6	51,570	4210	-0.36
2.2	129.0	17,850	1370	-0.84		444.6	52,670	4450	-0.29

20.7%

8.1%

Age Dating and the Orbital Theory of the Ice Ages: Development of a High-Resolution 0 to 300,000-Year Chronostratigraphy[1]

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Indirect and relative chronostratigraphy

* *Other reference series*

- loess grain-size record and ice-core dust
- loess organic matter $\delta^{13}C$ and ice-core $\delta^{18}O$
- loess carbonate $\delta^{18}O$ and speleothem $\delta^{18}O$
- loess lipid distribution and speleothem lipid distribution
- loess carbonate $\delta^{18}O$ and marine $\delta^{18}O$
- magnetic susceptibility to marine $\delta^{18}O$
- ….

keep in mind that reference series have large uncertainties, too!

Indirect and relative chronostratigraphy

* *comparison with deep-sea oxygen isotopic stratigraphy*

- Precise dating of OIS is problematic in many instances
- Limits and durations from the older stages can be remarkably different
- In North-Atlantic Ocean, no *Globigerina menardi* (cold environment) in layers older than OIS 16 => cold peaks older than Jaramillo envent (0.9Ma) are poorer developed than in stage 14 and younger
- Downwards from stage 17, fluctuation and amplitude of OIS curve are becoming ever moderate => information content is reduced.
- The identification of the age and duration of individual stages in marine cores is only possible relying on some "fixed " data => cumulative error for the older stages may exceed the duration of a whole stage or even of a termination period.
- Comparison of loess and paleosol sequences with deep-sea records should account for erosion hiatuses in both records (even more frequent and extensive in the continental sequences)

Pecsi, 1991, GeoJournal

it is even more difficult for the oldest part of the series

Indirect and relative chronostratigraphy

* *Magnetostratigraphy*

definition: Magnetostratigraphy is a chronostratigraphic technique used to date sedimentary sequences. The samples are analyzed to determine their *detrital remanent magnetization* (DRM)

Brunhes-Matuyama	ca 780 kans
Matuyama-Jaramillo	ca 980 kans
Jaramillo-Matuyama	ca 1050 kans
Matuyama-Olduvai	ca 1760 kans
Olduvai-Matuyama	ca 1980 kans
Matuyama-Gauss	ca 2600 kans

Because the age of each reversal is relatively well known, the correlation establishes numerous time lines through the stratigraphic section.

Indirect and relative chronostratigraphy

* *Magnetostratigraphy*

Magnetostratigraphical dating of loess deposits in China

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Switzerland

Liu Tung-sheng

Institute of Geology, Academia Sinica, PO Box 634, Be

**The age of Chinese loess deposits has long bee
Biostratigraphical and earlier magnetostratigraphic
tions placed the entire loess formation within the
The new palaeomagnetic measurements reported
bore hole section near Lochuan (Shaanxi provinc
clearly defined magnetic polarity zonation which ex
the Olduvai subchron. A late Pliocene age of
assigned to the oldest loess sediments measured. T
variations of natural remanent magnetization (NR
field magnetic susceptibility are indicative of clim
during loess deposition.**

In northern China nearly half a million squar
are covered by loess sediments. Along the midd
valley these wind-transported, yellow to red-brow
occupy a coherent area of more than 300,000 km
the loess plateau[1]. Here the loess deposits genera
a thickness of 80–120 m. Typically they consist of a

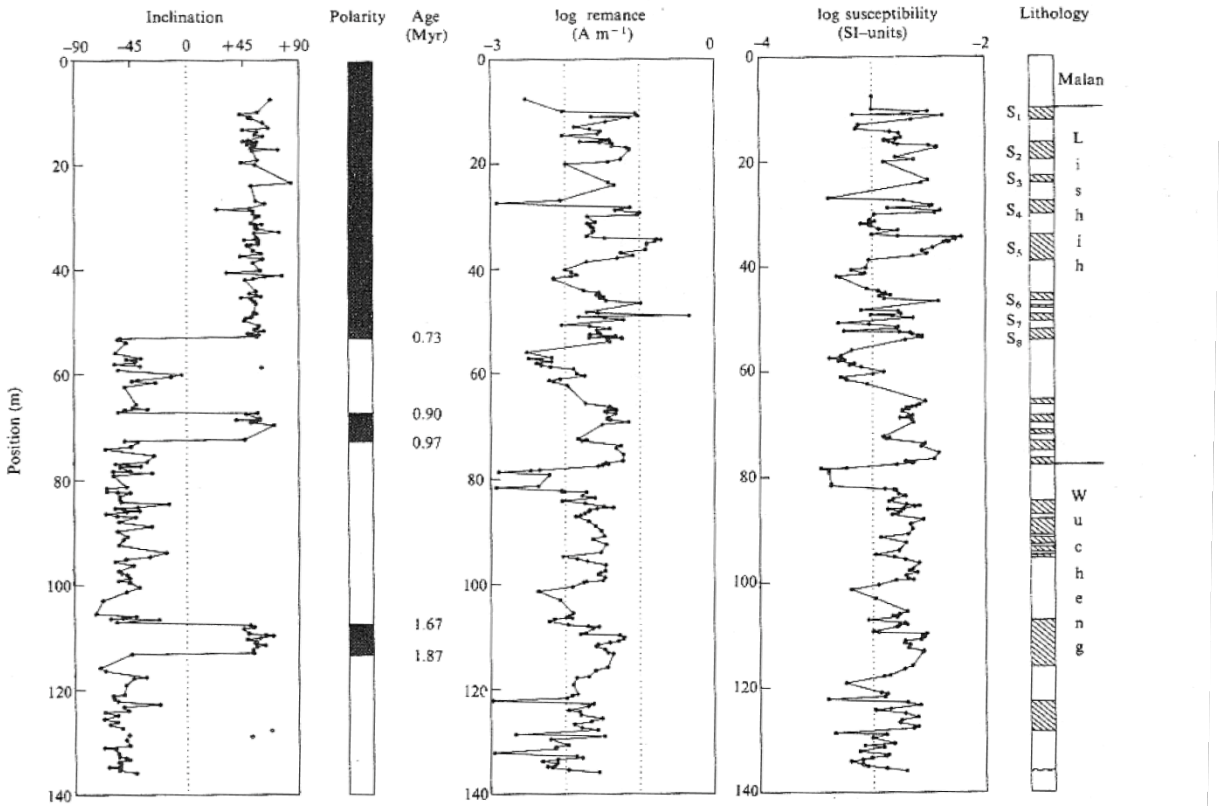


Fig. 1 Magnetic properties of the Lochuan bore hole versus core depth. Inclination data were mostly cleaned at 350 °C. The ages of polarity chron boundaries are according to Mankinen and Dalrymple[13]. Remanence intensities and susceptibilities are plotted before thermal cleaning. Lithological sequence of loess (white) and numbered soil layers (hatched) is according to Liu *et al.*[2].

Indirect and relative chronostratigraphy

* *Magnetic model*

Kukla et al. (1988) assume:

- quasi-constant depositional rate of magnetic minerals from remote sources
- decrease of susceptibility from the dilution of magnetic minerals by

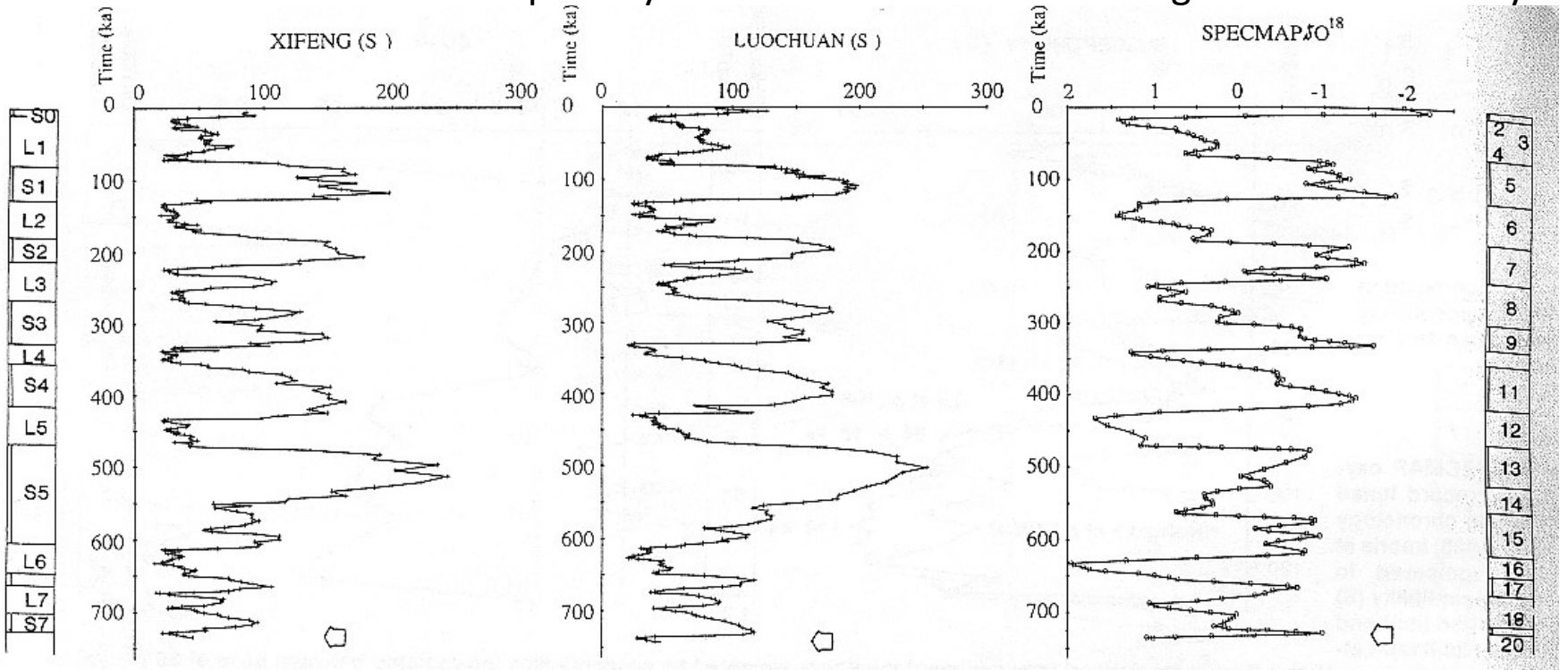


Figure 7. SPECMAP oxygen-isotope record tuned to astronomic chronology (Imbrie et al., 1984) compared to magnetic susceptibility in Xifeng and Luochuan plotted on susceptibility time scale. Interpolated between base of S0 (11 ka), base of S1 (128 ka), and Brunhes/Matuyama boundary (730 ka), marked with arrow. 1–20 are oxygen-isotope stages; S0–S7 are soil units; L1–L6 are loess units.

Indirect and relative chronostratigraphy

* *Magnetic model*

Kukla et al. (1988) assume:

- quasi-constant depositional rate of magnetic minerals from remote sources
- decrease of susceptibility from the dilution of magnetic minerals by accumulation of non-magnetic flux

⇒ relative time-scales are established by weighting depositional thickness of loess-soil units with MS and interpolating between magnetic reversal.

BUT

increase of bulk susceptibility in soils is attributable partly or largely to pedogenic processes which lead to in situ formation of magnetic minerals.

⇒ over estimation of sedimentation rate associated to paleosol development

FURTHERMORE

patterns are different according to the location on the Chinese Loess Plateau

Kukla's model suits for broad overview

Indirect and relative chronostratigraphy

aims

- Provide a quantitative chronological framework to allow comparison with others paleorecords

basis

- Based on comparison between a proxy record from loess sequence and a global paleoclimatic record regarded as a reference series:
  - ✓ some points (pointers: mostly transitions, sometimes peaks) are tied together
  - ✓ loess record is then wiggle-matched to the reference series

limits

- Chronologies of reference series have large uncertainties, too
- Uncertainties are higher for older times
- The more tie-points you have, the best it is

Absolute chronological tie-points

aims

- Provide a quantitative chronological framework to allow comparison with others paleorecords

basis

- Combine several geochronological technological approaches to get QUANTITATIVE ages (tie-points)

Absolute chronological tie-points

* *Luminescence dating*

definition: evaluation of the time elapsed since the burial of sediment.

basic premises:

- during their production and transport, mineral grains (quartz and feldspars for loess) lose most of their geological luminescence because of exposure to daylight.
- on burial, reacquisition of luminescence is initiated as a result of irradiation from ambient radioactivity

$$\text{age} = \frac{\text{acquired luminescence}}{\text{rate of luminescence acquisition}} = \frac{\text{paleodose}}{\text{annual dose}}$$

Absolute chronological tie-points

* *Luminescence dating*

excitation of luminescence can be affected by both
- a thermal stimulus (-> TL)
- an optical stimulus (-> OSL: infrared (IRSL) or green light (GLSL))

mineral transport

single/multi aliquot

$$\text{age} = \frac{\text{paleodose}}{\text{annual dose}}$$

alpha, beta and gamma rays from the decay of ^{238}U, ^{232}Th and ^{40}K
+ contribution of the cosmic ray

accumulation

Absolute chronological tie-points

* *Luminescence dating*

=> discrepancies might occur according to the technique

Table 4
Luminescence ages from Niigata and Tochigi sites

Standard					*	Component-1		Tephra	Tephra
Depth (m)	Sample	Qz blue-OSL (ka)	Polymineral blue-OSL (ka)	Polymineral IR-OSL (ka)	(%)	Polymineral blue-OSL (ka)	Qz blue-OSL (ka)	name	age (ka)
0.40								AT	26–29
0.60	Tm-1	47.6 ± 3.2	40.0 ± 2.8	36.7 ± 2.6	86 ± 12	42.1 ± 5.0	49.6 ± 3.4		
1.10	Tm-2	51.7 ± 3.5	45.6 ± 4.2	43.2 ± 3.0	87 ± 18	62.3 ± 11	55.7 ± 4.0		
1.40								DKP	~55 or older
1.60	Tm-3	86.1 ± 6.1	77.8 ± 6.2	57.8 ± 4.6	74 ± 2	72.1 ± 7.5	81.0 ± 5.9		
2.10	Tm-4	88.2 ± 6.4	87.5 ± 9.4	68.9 ± 5.3	63 ± 2	94.4 ± 8.0	98.8 ± 6.5		
2.60	Tm-5	107 ± 6.7	88.9 ± 7.2	103 ± 6.6		120 ± 13	145 ± 14		
2.80								Iz-KT	125–150
3.10	Tm-6		129 ± 11	134 ± 12	88 ± 16	155 ± 19			
3.60	Tm-7	126 ± 8.8	113 ± 9.4	107 ± 7.3	85 ± 10	112 ± 9.8	125 ± 11		
4.10	Tm-8	112 ± 7.6	109 ± 7.5	130 ± 9.1	78 ± 2	131 ± 11	156 ± 12		
4.60	Tm-9		148 ± 14	180 ± 16	84 ± 10	203 ± 21			
5.10	Tm-10	88.9 ± 8.3	117 ± 11	177 ± 17		202 ± 20	199 ± 18		
5.60	Tm-11	183 ± 14	202 ± 15	243 ± 22	84 ± 6	253 ± 23	298 ± 23		
6.10	Tm-12	121 ± 9.5	129 ± 10	163 ± 13	86 ± 1	217 ± 23	228 ± 20		
9.00								APm	330–400

Reading a luminescence table is not trivial !!

one has to know how data are obtained and has to be able to interpret in terms of luminescence signal what was the environment of the sample to date.

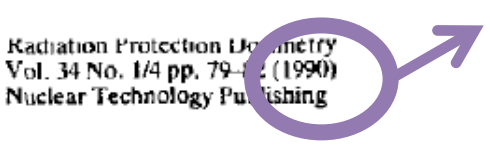
4.1	Tg-10		85.3 ± 7.3	79.2 ± 5.1		94.2 ± 10			
5.1	Tg-11	71.1 ± 4.1	85.9 ± 7.7	83.2 ± 5.1		110 ± 11	91.2 ± 6.3		
8.7								Iz-KT	125–150
8.7	Tg-12		67.9 ± 10	93.1 ± 12		Unable to separate			
9.6								APm-U	130 ± 30

Watanuki et al., 2005, EPSL

Absolute chronological tie-points

* *Luminescence dating*

- Lyoluminescence?



1990

Radiation Protection Dosimetry
Vol. 34 No. 1/4 pp. 79–82 (1990)
Nuclear Technology Publishing

LYOLUMINESCENCE OF CALCIUM CARBONATE AND POSSIBLE APPLICATIONS IN THE DATING OF LOESS AND SOILS

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Abstract — Lyoluminescence (LL) during the
γ rays was investigated. In the dose range of
sub-linear but shows no saturation. The influ
yield was studied. The traps responsible for
existence of several different traps and the po

can be measured using the feldspar and/or quartz component in TL sediment dating[9–11] this seems to be an interesting feature of a possible $CaCO_3$ LL palaeodosemeter. The annealing experiments reveal LL active centres in $CaCO_3$ which seem to survive heat treatment at 200°C and might be stable. The complicated behaviour of the $CaCO_3$ LL after bleaching is believed to be related to photo transfer between traps as has been observed in TL experiments[6].

Much more information, however, is needed for a judgement of the prospects of $CaCO_3$ as a LL palaeodosemeter for the dating of loess. Further investigations of the LL of $CaCO_3$ guided by ESR studies[12] are in progress.

Absolute chronological tie-points

* *Radiocarbon dating*

definition: evaluation of the time elapsed from the death of animal/plant

remember the definition of luminescence dating: evaluation of the time elapsed since the burial of sediment.

⇒ **we do not date the same event!!!**

⇒ animal/plant should be dead before burial

⇒ ^{14}C chronology somehow leads the luminescence one

⇒ difference will increase with grain size: a deeper layer of coarse grain than for fine grain is required to fully cover the sample

⇒ difference between both chronologies will (relatively) decrease with age and will rapidly be lower that age uncertainties

Absolute chronological tie-points

* *Radiocarbon dating*

^{14}C on plant/animal macrorests

- ❖ calibration for [0; 22 kyr] interval
  => no clear translation to "calendar" age for ages older than 22kyr BP

- ❖ what's about plant/animal physiology?
  => time life of tree? what are tree-rings for?
  => burrowing beetle/snail?
  => does snail use limestone as source of Ca?
  => what was the alimental regime of animal?

- ❖ what is the expected age?
  => adapted chemistry and methodology
  => which ^{14}C lab?

Absolute chronological tie-points

* *Radiocarbon dating*

^{14}C on sediment organic matter

❖ loess organic matter results of degradation of plant that traps dust to form loess sequence.
⇒ ^{14}C dating of loess organic matter = ^{14}C dating of plant that traps dust
⇒ should be the time elapsed since deposition and trapping of dust

❖ loess organic matter is "in place" only during typical loess phases.
⇒ isn't a reliable ^{14}C support for phases with pedogenesis because of soil turnover.

❖ based on the assumption that all organic matter previously linked to mineral sediment (dust) is oxidized during dust transport.
⇒ only works in long distance transport dust accumulation (mostly Europe, China but no US Great Plains)

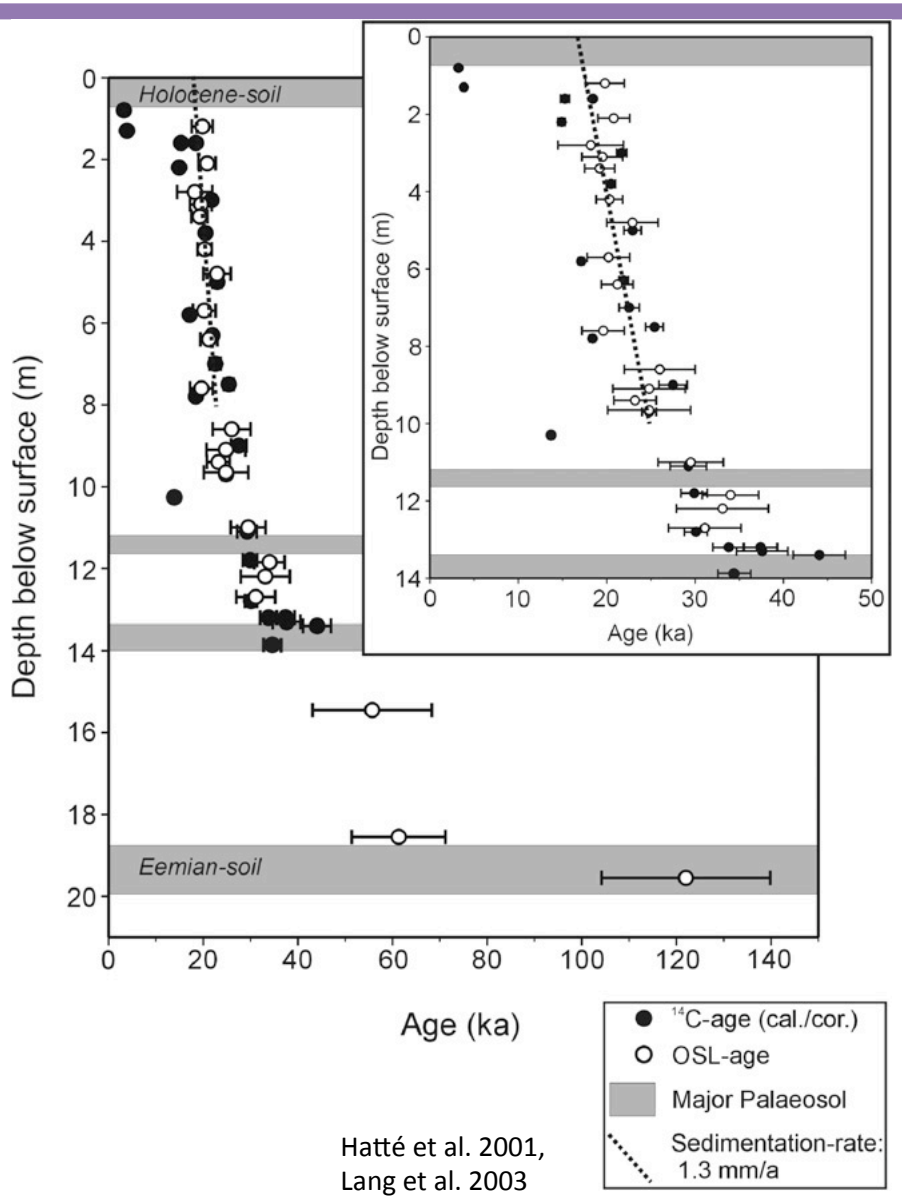
❖ organic carbon content is less than 0.1% wt of sediment
⇒ requires adequate chemical treatment
⇒ which ^{14}C lab?

Absolute chronological tie-points

* *Radiocarbon dating*

^{14}C on sediment organic matter

☺ sometimes it works...



Hatté et al. 2001,
Lang et al. 2003

Absolute chronological tie-points

* *Radiocarbon dating*

prospect: ^{14}C on n-alkanes

- n-alkanes now currently used for ^{13}C record
- allows to decipher between microbial and plant origin
- does not solve issue of soil turnover
- AMS dating is now possible on some µg of carbon

=> might solve some of ^{14}C chronology issues

Absolute chronological tie-points

* *U/Th dating*

Bull. Soc. géol. Fr., 2005, t. 176, n° 3, pp. 249-255

U-Th *vs.* AMS ^{14}C dating of shells from the Achenheim loess (Rhine Graben)

CHRISTOPHE INNOCENT[1], CHRISTINE FLEHOC[1] and FRANCIS LEMEILLE[2]

Key words. – U-Th dating, ^{14}C dating, Loess deposits, Rhine Graben, Quaternary.

Abstract. – Shells extracted from loess deposits at Achenheim (Rhine Graben) have been investigated for AMS ^{14}C and for U-Th dating by the isochron method on single shells. The two chronometers provide results that are not in agreement : the obtained ^{14}C date is 38 ka B.P. In contrast, U-Th results provide much older ages. The $^{238}U/^{232}Th$ – $^{230}Th/^{232}Th$ isochron diagram gives an age of 69 kyr, whereas a slightly younger age of 64 kyr is derived from the other, $^{234}U/^{232}Th$ – $^{230}Th/^{232}Th$, diagram. $^{234}U/^{238}U$ ratios have not been found to vary from a shell to another : the average value is 1.199, slightly higher than radioactive equilibrium. For both isochrons, the Y-axis intercept is slightly negative, which indicates that there is no evidence for a significant detrital component. Thorium 232 that is present in the shells is probably incorporated in the material. The negative intercepts suggest that the two ages have been probably "aged" resulting from a slight mobilisation of uranium. By constraining the Y-axis intercepts at 0, ages that are in good agreement from one to another, can be calculated at 60.9 kyr and 60.4 kyr, respectively. In both cases, the statistical quality of the alignment is only slightly deteriorated.

Since U-Th ages are in agreement with stratigraphic data, in contrast to the ^{14}C date, one may believe that they date the end of early diagenesis, with uranium trapping. In contrast, the AMS ^{14}C date is either thought to reflect analytical limitations of AMS ^{14}C dating for such type of material, or to date a younger geologic event. In this latter case, a possible hypothesis is that this event has triggered the slight opening of the ^{238}U – ^{234}U system.

In any case, this study demonstrates once again that surface formations often tell such complex stories that only one single dating method cannot usually be sufficient to describe precisely these histories. Instead, informations derived from different independent chronometers have to be compared.

^{14}C dating

⇒ 38 ka BP

U/Th dating

* isochron method

⇒ 69 kyr ($^{8}U/^{2}Th$ – $^{0}Th/^{2}Th$)

or 64 kyr ($^{4}U/^{2}Th$ – $^{0}Th/^{2}Th$)

* negative intercepts for both isochrons

⇒ "aged" from U mobilisation

⇒ 60.9 or 60.4 kyr

Absolute chronological tie-points

* *$^{26}Al/^{10}Be$ dating*

^{10}Be and ^{26}Al

- long lived radio-nuclides with half-lives of 1.36±0.07 and 0.717±0.017 million years, respectively
- produced primarily by cosmic rays with a known $^{26}Al/^{10}Be$ atomic ratio of 6.8:1
- common chemical characteristics

$\Rightarrow$ means for dating burial up to 3-5 Myrs

Beer et al. 1993, Shen et al. 1997, Lin et al. 2005

Absolute chronological tie-points

aims

- Provide a quantitative chronological framework to allow comparison with others paleorecords

basis

- Combine several geochronological technological approaches to get QUANTITATIVE ages (tie-points)

limits

- Each method has limits
- Concepts and methods are quite complex and require solid knowledge on the sample and its environment before applying any treatment and/or measurement
- Not only one chronology but chronologies
- How to mix/combine these chronologies?

Dust record dating

loess sequences are quite complex series
dating is quite complex, too

- Not only one chronology but several chronologies
- Only part of interglacial is recorded in loess sequence and part of glacial is overlapped by interglacial feature. Extent of "part" depends on time and space.
- Chronologies of reference series have large uncertainties, too
- The more tie-points you have, the best it is
- Concepts and methods of absolute dating are quite complex and require solid knowledge on the sample and its environment before applying any treatment and/or measurement