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1 How dusty was the last glacial maximum over Europe?

2

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18 **Keywords**

19 Loess, Last Glacial Maximum, Eurasia, Sedimentation and Mass Accumulation rates,
20 Millennial scale variability

21 **Highlights**

- 22 • Loess sequences are key paleoclimate records at mid latitudes in the Northern
23 Hemisphere
- 24 • Paleosols and tundra gleys correspond to an end in dust deposition in European
25 loess.

- 1 • Pedogenic units developed during Greenland interstadials, with the maturation
2 related to the interstadial duration.
- 3 • Mass accumulation rates estimated from the updated loess age model match well
4 with Earth System Model results.
- 5 • The atmosphere in Western Europe was dustier than over the Chinese Loess Plateau
6 during the Last Glacial Maximum.

7 ABSTRACT

8 Our study focuses on European loess sequences, particularly the eolian intervals in between
9 the observed pedogenic units. The classical concept of soil formation from parent material is
10 reformulated to estimate of the duration and the associated sedimentation rate (SR) and
11 mass accumulation rate (MAR) of these paleodust intervals. We show that the Greenland
12 Stadial (GS) duration in European loess deposits includes the thickness of the overlying
13 pedogenic unit, which in fact developed downward into the upper part of the eolian unit. The
14 lower stratigraphical limit of the eolian unit overlying the pedogenic unit corresponds to the
15 restart of the dust sedimentation of the younger GS. We illustrate this interpretation first by
16 computing both SRs and MARs first for the Nussloch key sequence, the most complete
17 European series. The correlation between Nussloch and other European loess sequences,
18 located along a 1,800 km longitudinal transect, allows computation of SR and MAR for
19 several identified GS events. Comparing GS from marine and ice core records, our study
20 shows that the two last Bond cycles are preserved in every European eolian record.

21 Bulk SR and MAR are estimated and compared for these two Bond cycles, showing the
22 highest SRs and MARs in western Europe. These indices also indicate that the last stadials,
23 embedding an Henrich event, were not the dustiest in every Bond cycle. Our estimated MAR
24 also differ from previously published computations, which did not take into account the
25 various pedogenic units present in the studied loess sequences. The bulk SR and MAR
26 estimates computed for the two last Bond Cycles from Chinese sequences from the Loess
27 Plateau indicate lower atmospheric dust than in Europe during the Last Glacial Maximum. SR
28 and MAR estimates computed from the fine-grained material for European records fit with
29 Earth System model reconstructions.

1. Introduction

Abrupt climate changes during the last glaciation are expressed as rapid transitions between Greenland stadials (cold stages - GSs) and Greenland interstadials (warm stages - GIs), characterized by large amplitude warming during GIs (Kindler et al., 2014). These abrupt changes were originally marked by iceberg discharges in the North Atlantic named Heinrich events (HE), which impacted the climate and the ocean circulations of the Northern Hemisphere. Some of these massive discharges reached southward to the Iberian margin with significant cooling the sea surface temperature and reducing salinity (Bard et al., 2000). By correlating the climate records from the Greenland ice-cores with North Atlantic sediments, Bond et al. (1993) identified a particular succession of the Dansgaard-Oeschger cycles (DO), associated with observed GIs and GS. The long-term cooling cycles were later named Bond Cycles by Broecker (1994), which are characterized by an asymmetrical and sawtooth-like pattern, similar in shape to an individual DO cycle with a duration of about 10 to 15 ka. These long-term cooling cycles start with a long and strong GI and end with the coldest GS embedding an HE. The general cooling trend of these long-term cycles is associated with the regrowth of the Laurentide ice-sheet after every HE (Alley, 1998; Alley et al., 1999; Clark et al., 2007).

The climate in Europe has been strongly influenced by millennial climate changes related to variations in the Atlantic Meridional Overturning Circulation (AMOC), the extent of northern ice shelves and sea-ice, which also affected the moisture sources of precipitation on the Greenland ice sheet, and therefore its growth (Boers et al., 2018). These variations in the extent of the sea ice during the last climatic cycle (LCC, about 130-15 kyr) affected the westerlies and the position of the polar jet stream, and consequently storm track trajectories (Lohmann et al., 2020). The resulting continental records have been mainly interpreted in terms of temperature, precipitation or vegetation changes related to the variation between GIs and GSs (Sanchez-Goni et al., 2008). The $\delta^{18}\text{O}$ increases in the Greenland NGRIP ice core record, named Dansgaard-Oeschger events (DOE), correspond to an average temperature difference of about +11.8°C on the top of the Greenland ice sheet (Kindler et al., 2014), associated with substantial reorganizations of the ecosystems in mid-latitude Europe

1 (Harrison and Sanchez Goñi, 2010; Sanchez Goñi and Harrison, 2010; Sanchez Goñi et al.,
2 2017) . Furthermore, the presence of ice sheets and ice caps over Great Britain, Scandinavia
3 and the Alps enhanced the zonal circulation during GS, as supported by numerical
4 experiments (Sima et al., 2013; Sima et al., 2009).

5 Loess sequences, eolian deposits, are well developed all over Europe, especially
6 between 48° and 52°N, where one or more climate cycles have been recorded (Kukla, 1970)
7 (Fig. 1). During the LCC intensive deposition of dust over Europe was accompanied by a
8 reduction or practically absence of arboreal cover in NW Europe during GSs (Woillard, 1978),
9 and by sea-level lowering exposing large areas of the continental shelf to eolian erosion.
10 Strong increases in fluvial transport and sedimentation by periglacial braided rivers released
11 large amounts of material available for deflation (Lautridou, 1985; Rousseau et al., 2018;
12 Vandenberghe and Maddy, 2001). Geochemical study of LGM samples from European loess
13 sequences located along a longitudinal transect from Brittany to Ukraine shows that these
14 deposits correspond only to a regional (hundreds of kilometers) transport of the available
15 eolian material (Rousseau et al., 2014). Extensive multidisciplinary investigations of European
16 loess deposits along a longitudinal transect at 50°N (Fig. 1) reveal that the millennial-scale
17 climate variations observed in the North-Atlantic marine and Greenland ice-core records of
18 the LCC are well preserved in the succession of paleosol-loess alternations or doublets
19 (Rousseau et al., 2002; Rousseau et al., 2007). Loess units represent GSs, while GIs
20 correspond to either paleosols of various types or slightly pedogenic horizons, depending on
21 the GI duration (Rousseau et al., 2017a; Rousseau et al., 2017b). Loess deposits are
22 interpreted to correspond to coarse paleodust transported at rather low elevations in the
23 atmospheric boundary layer (from about 300 to a maximum 3000 m) at local to regional
24 scales (Rousseau et al., 2014). Finer paleodust may have been transported at much higher
25 elevation by the general circulation, allowing deposition at higher latitudes (Antoine et al.,
26 2009b; Pye, 1995; Pye and Zhou, 1989; Rousseau et al., 2014; Rousseau et al., 2017b;
27 Ujvari et al., 2015; Vandenberghe, 2013). Along the 50°N transect, the Nussloch profile yields
28 the most-detailed record of the paleosol-loess alternation of the LCC making this record a key
29 European sequence (Antoine et al., 2009b; Antoine et al., 2001; Moine et al., 2017; Rousseau

1 et al., 2002; Rousseau et al., 2017a; Rousseau et al., 2007; Rousseau et al., 2017b). The
2 succession of paleosol-loess doublets in Nussloch is characterized by a variable thickness
3 and the different types of paleosols in the sequences, ranging from western Europe eastward
4 to Ukraine (Rousseau et al., 2011). These spatial characteristics help to evaluate the duration
5 of the paleosol formation, and develop a more precise chronology of the eolian deposition
6 over the vast European territory. Although a fundamental element in the definition of loess
7 stratigraphy, is to identify pedogenic units, they are very limited in the construction of reliable
8 timescales for further model-data comparisons (Rousseau et al., 2017a; Rousseau et al.,
9 2017b).

10 In this study, we propose new estimates of the sedimentation rate (SR) and mass
11 accumulation rate (MAR) of European loess sequences. First, we reconstruct these
12 parameters for the reference sequence of Nussloch, especially for the various identified GS
13 equivalents during which dust deposition occurred. Next, we expand this study to other
14 European records based on their stratigraphical correlations with Nussloch through observed
15 marker layers and available dates. Finally, our estimates are compared with previous
16 published estimates for other European loess series, and with Chinese loess sequences. A
17 comparison is also made with dust deposition reconstructions in Europe from the Last Glacial
18 Maximum (LGM) modeling studies (Kageyama et al., 2018).

19 **2. The Nussloch loess sequence**

20 The Nussloch loess sequence is the key reference for the European LCC (Zöller and
21 Löscher, 1997). It is located on the right bank of the Rhine River, south of Heidelberg in
22 Germany, on a plateau overhanging a wide floodplain (Fig. 1). The loess deposits are
23 distributed along ridges oriented NW-SE (Antoine et al., 2001) in which a succession of
24 alternating paleosol-loess doublets have been identified (Antoine et al., 2009b; Antoine et al.,
25 2001; Bibus et al., 2007; Rousseau et al., 2002; Rousseau et al., 2017a; Rousseau et al.,
26 2007; Rousseau et al., 2017b). These doublets are correlated very precisely with the
27 succession of GI-GS doublets from the Greenland NGRIP ice core through ¹⁴C dates on
28 earthworm granules (Moine et al., 2017) supporting previous stratigraphical assignment of the

1 pedogenic units, mostly for the highly dilated sedimentary section covering the 40 ka to 18 ka
2 interval. Erosion is not evident between the pedogenic and the loess units from the sampling
3 profile (see Supplementary figure 2 in (Rousseau et al., 2017a)) except for the occurrence of
4 a large thermokarst erosion gully at the base of the Middle Pleniglacial record (TK2 in
5 (Antoine et al., 2009a)). Timing of paleosol formation is in agreement with the detailed and
6 well-dated records of GI in Turkish cave deposits located at about the same longitude as our
7 easternmost studied loess sequence (Stayky in Ukraine (Rousseau et al., 2011)). In these
8 speleothems, GIs are expressed by the responses of local ecosystems by the expansion of
9 C3 plants and higher soil activity (Fleitmann et al., 2009). Interestingly, the identified
10 pedogenic units range between brown boreal paleosols to tundra gleys to embryonic oxidized
11 horizons. They are characterized by the lowest $\delta^{13}\text{C}$ from the preserved organic matter in the
12 sediment (Hatté et al., 1998), corresponding to GI 17 to GI 2, in addition to the identified
13 interglacial Bt horizon at the base of the sequence (Antoine et al., 2009b) (Fig. 2).

14 The identification of different types of paleosols and pedogenic horizons in Nussloch, is
15 fundamental. We have used the established correlation to the Greenland records (Moine et
16 al., 2017; Rousseau et al., 2017a; Rousseau et al., 2017b) to estimate the maximum amount
17 of time needed to reach their different degrees of maturation and development. To identify
18 these time lapses more precisely, we employed two independent NGRIP $\delta^{18}\text{O}$ and dust
19 concentration data to indicate variations of atmospheric temperature and dustiness in the
20 Greenland area, respectively. Our correlating strategy slightly differs from the definition of a
21 GI event duration applied in other studies, where the sharp end of the $\delta^{18}\text{O}$ decrease alone
22 defines the end of a GI. Our correlation was conducted both visually and algorithmically to
23 both proxy records (i.e., the GIs are defined to last from the beginning of the abrupt $\delta^{18}\text{O}$
24 increase or the dust concentration decrease until the time when $\delta^{18}\text{O}$ or dust return to their
25 initial value before the GI onset).

26 Rousseau et al. (2017a) have analyzed the GIs in both $\delta^{18}\text{O}$ and dust NGRIP records,
27 showing that the abrupt change in these proxies averages from 50 to 150 years. The proxies
28 have two different origins with $\delta^{18}\text{O}$ mostly from the North Atlantic surface water and the dust
29 predominantly from the Chinese northern deserts. From a statistical point of view the lead or

1 lag between the start of the change of these two proxies is negligible (2017a). Therefore, we
2 assume that although a short lag of several decades could exist between the changes in the
3 $\delta^{18}\text{O}$ in Greenland ice core and the start of the paleosol or tundra gley formation, such a lag
4 cannot be distinguished in the centennial-resolved loess deposits. Similarly, the GIs/GS
5 transitions in the $\delta^{18}\text{O}$ and the dust records, are rather contemporaneous (2017a). Therefore
6 the paleosol and tundra gley formation ended at the same time, i.e., as indicated in the
7 Rasmussen et al. (2014) chronology. To reduce the uncertainty about this time interval
8 assignment, extremely high-resolution sampling of every paleosol and tundra gley could be
9 performed but age errors between these two records still cannot be well resolved due to their
10 different sensitivity to climate changes. Consequently, we reliably estimate the duration of the
11 GIs as the maximum time for the development of the paleosols observed in Nussloch,
12 (Rousseau et al., 2017a).

13 Subsequently, Rousseau et al. (2017b), proposed an alternative way of investigating
14 the Nussloch eolian deposits in order to convert it into terms of a deposition budget. As
15 expected, when taking into account paleosol or pedogenic unit formation, SR and MAR
16 cannot be estimated by assuming a continuous accumulation of eolian deposits between two
17 available dates as is classically performed for marine, ice or lake records, Following the
18 detailed correlations defined between Nussloch and NGRIP stratigraphies (Fig. 2), with one
19 pedogenic unit corresponding to a particular GI, (Moine et al., 2017; Rousseau et al., 2002;
20 Rousseau et al., 2017a; Rousseau et al., 2007; Rousseau et al., 2017b), we applied to the
21 loess sequence the dates obtained for every start and end of a GI, as determined by
22 Rasmussen et al. (2014). This represents a reliable compromise with our estimates described
23 previously, following the acknowledged synchronicity of DO events in numerous worldwide
24 paleoclimate records (Adolphi et al., 2018). We considered that LCC paleosols in European
25 loess sequences at 50°N, were developed from the underlying loess deposits after the eolian
26 sedimentation ceased, and therefore should be considered as the upper part of the eolian
27 deposits (Taylor and Lagroix, 2015; Taylor et al., 2014; Vandenberghe et al., 2014).
28 Moreover, the eolian sequences on top of the developed paleosols can be considered to have
29 restarted after the formation of each pedogenic units. This makes the time evolution of these

1 loess sequences nonlinear and a bit more complex than the classical continuous
2 sedimentation. Therefore, considering that the stratigraphical succession of the identified
3 units was developed on the underlying parent material, the time's arrow, from the bottom to
4 the top of the sequence, always changed direction during the pedogenic development by
5 moving downward in the sequence, and finally moved upward from the top of the paleosols.
6 Such conceptual evolution of the time's arrow completely differs from that happens in Asian
7 loess sequences, and other paleoclimatological records, i.e., lake, marine or ice cores where
8 time only goes upward (Kukla and Koci, 1972; Rousseau et al., 2017a). For that reason, a
9 determined eolian interval, equivalent to a GS, corresponds to both the thickness of the
10 visible loess layer and the thickness of the layer, which underwent soil forming
11 processes (blue arrow in Fig. 2). The pedogenesis itself fits with the GI duration (red arrow in
12 Fig. 2). As a result, the Nussloch stratigraphy can be read as expressed in Table 1, allowing
13 an improved estimate the SRs and the MARs that are required for comparison with other
14 loess records and also with model outputs.

15 In the 60-23 ka b2k interval, corresponding to four long-term cooling cycles recognized
16 by, Bond et al. (1993) we have labeled "Bond Cycle a" (BCA) the cycle lasting from GI4 to
17 GS3/HE2, "Bond Cycle b" (BCB) the cycle lasting from GI8 to GS5/HE3, "Bond cycle c" (BCC)
18 the cycle lasting from GI12 to GS9/HE4, and "Bond Cycle d" (BCD) the cycle lasting from
19 GI14 to GS13/HE5 in the Nussloch loess sequence (Fig. 2). By reference to Rasmussen et al.
20 (2014) chronology, SR varies in the whole Nussloch sequence between 186 and 22 cm/kyr
21 (Fig. 2, Tab. 1). More precisely, according to the correlation of the Nussloch loess sequence
22 with NGRIP ice-core record, SR varies between 186 - 111 cm/kyr during BCA, lasting
23 between 28,900 yr and 23,340 yr b2k, 127-46 cm/kyr during BCB, lasting between 38,220 yr
24 and 28,900 yr b2k, 165-22 cm/kyr during BCC, lasting between 46,860 yr and 38,220 yr b2k,
25 and 224-59 cm/kyr during BCD, lasting between 54,220 yr and 46,860 yr b2k. Interestingly,
26 the maximum SR value in every Bond Cycle is not reached at its end, when HE was released
27 in the North Atlantic, but at its penultimate stadial (Tab. 1). This appears in agreement with
28 reconstructions of wind speed and environmental conditions which show coldest and windiest
29 GSs compared to HEs (Sima et al., 2013; 2009). Such results also agree with the

1 interpretation of the Black Sea temperature response to glacial millennial climate variability
2 during the LCC, indicating that HE-stadials in this area were cooler than the regular stadials
3 (Wegwerth et al., 2015), as also indicated by Ganopolski and Rahmstorf (2001) and Zhang et
4 al. (2014) modeling experiments.

5 To convert our SRs into MARs, we applied the equation defined by Kohfeld and
6 Harrison (2003), $MAR = f \cdot SR \cdot BD$ with SR= sedimentation rate, f= fraction of sediment which is
7 eolian, and BD = the bulk density considered as constant with a value of 1.65 g/cm^3 for loess
8 (Pye, 1987). Frechen et al (2003) previously applied this equation to European loess series,
9 among which are some of the sequences we analyzed in the present study for further
10 comparison. Therefore, the bulk MAR in Nussloch, with $f=1$, because considering bulk
11 samples, varies between 2,578 and 414 $\text{g m}^{-2} \text{ yr}^{-1}$ (Fig. 2; Tab. 1) over the 60-23 ka b2k
12 interval. Similarly to our SR computation, the bulk MAR can be decomposed into 3,067-1,825
13 $\text{g m}^{-2} \text{ yr}^{-1}$ during BCA, 2,102-762 $\text{g m}^{-2} \text{ yr}^{-1}$ during BCB, 2,723-369 $\text{g m}^{-2} \text{ yr}^{-1}$ during BCC, and
14 3,702 - 980 $\text{g m}^{-2} \text{ yr}^{-1}$ during BCD. These estimates are by far different than those from
15 Frechen et al. (Frechen et al., 2003), i.e. 6,129-1,213 $\text{g m}^{-2} \text{ yr}^{-1}$ also for Nussloch. These latter
16 values were, however calculated using a simple accumulation age model without including
17 the soil developments on top of the lower eolian units as applied in our study. Notably, both
18 our new maximum and minimum estimates indicate much lower value by a factor of 2 to 3
19 respectively, differences that are not negligible.

20 From our study, BCA is the time interval showing the highest values in both bulk SR
21 and MAR in Nussloch. This seems to be intuitively evident because this time interval
22 corresponds to the maximum dust concentration in Greenland (Rasmussen et al., 2014). This
23 period was indeed apparently the most favorable for dust emission, transport and deposition
24 in the Northern Hemisphere because of the coldest and driest conditions recorded (Clark et
25 al., 2009) and the largest deflation areas available in relation to the lowest sea level (Grant et
26 al., 2012). BCB also shows high values, but has a much smaller magnitude than that obtained
27 for BCA. However, as this result is only evident in Nussloch, testing with other high-resolution
28 European loess sequences is needed.

29 3. European loess sequences

1

2 Some other high-resolution loess sequences located at 50°N were investigated at high
3 resolution to detect the occurrence of paleosols, markers of millennial scale variations during
4 the LCC (Rousseau et al., 2018). Distributed in the same latitude from the North of France to
5 Ukraine, several representative loess records are selected for comparison with the Nussloch
6 key sequence, such as St. Pierre-lès-Elbeuf and other related sequences (France) (Antoine et
7 al., 2016; Antoine et al., 2014; Antoine et al., 1999) , Harmignies and Remicourt (Belgium)
8 (Antoine et al., 2001), Dolni Vestonice (Czech Republic) (Antoine et al., 2013), Zlota (Poland)
9 (Moska et al., 2018; 2015) and Stayky (Ukraine) (Rousseau et al., 2011). We included the
10 Serbian sequence Surduk located in the Carpathian Basin for comparison because this region
11 should have experienced a particular circulation dynamics during the LCC linked to its
12 particular geographical configuration (Antoine et al., 2009a). The basin is almost closed due
13 the presence of the Carpathian arch to the north and the east, the Alpine Ice Cap covers all
14 the Alps to the west and the Dinarides Alps to the south. Sima et al. (Sima et al., 2013; Sima
15 et al., 2009) have demonstrated a similar pattern in dust emission and transport all over
16 Europe during GS and GI conditions showing that with the vegetation development in late
17 Spring, the emission of dust was prevented, and therefore deposited at further distance. A
18 comparison of the modeling results and the geochemical study of sequences along a
19 longitudinal transect from Brittany towards Ukraine, Rousseau et al. (2014) demonstrated that
20 the eolian deposits were mainly originated from various regional sources along this
21 longitudinal transect including the English Channel. While dust pulses may have occurred
22 very locally, the general pattern remains comparable as supported by the numerous dates
23 obtained in the studied sequences.

24 The correlation of the LCC record among different sequences relies upon the
25 identification of key paleosols horizons, based on the published ¹⁴C and luminescence dates
26 and the grain size variations of these loess records. Preliminary correlations have been
27 discussed in the previous papers presenting the studied sites (Antoine et al., 2016; Antoine et
28 al., 2013; Antoine et al., 1999; Antoine et al., 2009b; Antoine et al., 2001; Moska et al., 2018;
29 Moska et al., 2015; Rousseau et al., 2011). The resulting correlations between Nussloch and

1 the other sequences has been presented in Rousseau et al. ((Rousseau et al., 2017a), see
2 description in the manuscript with references herein and the supplementary figure S1
3 illustrating the correlations between the identified groups of horizons). The thickness of the
4 identified units and their time assignment according to NGRIP chronology are presented in
5 Tables 1 and 2. By assigning the NGRIP dates to the various units of the Nussloch sequence
6 after considering identified site-specificity, we infer that BCA and BCB, the dustiest intervals
7 of the LCC in Nussloch, are preferably preserved as well in all the sequences, with the
8 exception of Dolni Vestonice where only BCA is best recorded and usable for comparisons.
9 We investigate the variations of both SR and MAR along this longitudinal transect for the time
10 intervals that these two Bond cycles represent (Figs. 3, 4, S1; Tab. 2).

11 **3.1. Sedimentation rates (SRs) (Fig. 3)**

12 Along the 50°N and if the values obtained at the site of St Pierre-lès-Elbeuf, which is a
13 composite record, and very different from the other sites, SR ranges between 231 and 104
14 cm/kyr for the maximum, and between 57 and 14 cm/kyr for the lowest values. When
15 considering the two most recent Bond Cycles, BCA always shows the highest values either
16 for the maximum and the minimum ranges (231-104 and 137-51 cm/kyr) than BCB (204-84
17 and 57-20 cm/kyr) (Tab. 2, Fig. 3). Although the general circulation was rather controlled by
18 the westerlies, a gradient emerges from the data when considering the bulk sediment with
19 higher SRs westward compared to central and eastern Europe (Fig. 3). No specific pattern
20 seems to be associated to Surduk, either during BCA and BCB.

21 **3.2. Mass accumulation rates (MARs) (Fig. 4)**

22 Along the studied transect, applying the same formula as for Nussloch and keeping St
23 Pierre-lès-Elbeuf aside, MAR ranges between 3,803 and 1,710 g/m²/yr for the maximum and
24 between 945 and 325 g/m²/yr for the minimums. Considering the Bond cycles, BCA indicates
25 the highest MAR in maximum and minimum ranges (3,803-1,710 g/m²/yr and 2,263-836
26 g/m²/yr), than BCB (3,358-1,391 g/m²/yr and 945-328 g/m²/yr) (Fig. 4; Tab. 2). The MAR
27 estimated from sequences located at 50°N, especially in central and eastern Europe do have
28 a similar pattern compared to those calculated from the Carpathian Basin, at least in Surduk,

1 Serbia. Reconstructions of bulk MARs are in agreement with former estimates from
2 Dunaszekcső in southern Hungary (Ujvári et al., 2017) indicating average values of 1,494
3 $\text{g/m}^2/\text{yr}$ and 717 $\text{g/m}^2/\text{yr}$ for BCA and BCB respectively. As already reported from our SR
4 estimates, a west-east gradient appears along the longitudinal transect with the highest
5 values from west-European sequences (Fig. 4).

6 Our finding appears to contradict with previous estimates for LGM MAR in Europe, and
7 in some cases for the same sites. Frechen et al. (2003) indicate 3,135-1,467 $\text{g/m}^2/\text{yr}$ for
8 Harmignies, 453 $\text{g/m}^2/\text{yr}$ for Remicourt, 6,129-1,213 $\text{g/m}^2/\text{yr}$ for Nussloch and 1,100-754
9 $\text{g/m}^2/\text{yr}$ for Dolni Vestonice for the 28-18ka interval corresponding to BCA. Although the
10 estimates for Harmignies by Frechen et al (2003) are close to our reconstructions, this is not
11 at all the case for the other sites. Such differences could be attributed to different age models
12 of these loess records in our case by applying the complex relationship of the
13 paleosol/pedogenic horizon constraint. Albani et al. (2014) estimated bulk flux of 242 $\text{g/m}^2/\text{yr}$
14 for St. Pierre-lès-Elbeuf, 412 $\text{g/m}^2/\text{yr}$ for Harmignies, 560 $\text{g/m}^2/\text{yr}$ for Remicourt, 2,114 $\text{g/m}^2/\text{yr}$
15 for Nussloch and 758 $\text{g/m}^2/\text{yr}$ for Dolni Vestonice for the 25-12ka interval. Based on a
16 different timescale, a similar conclusion could be proposed for these reconstructions, though
17 these MARs seem underestimated compared to ours.

18 **4. Comparison with Chinese loess sequences**

19 Millennial variations are identified from high-sedimentation-rate loess sequences
20 located on the northwestern Chinese loess Plateau, but without any paleosol identified in the
21 LCC as observed in Europe (Sun et al., 2012). Based on numerous OSL dates of the Gulang
22 and Jingyuan sequences, Sun et al. (2012) suggested that variations of the East Asian winter
23 monsoon as inferred from loess grain size are well correlated with millennial climate changes
24 recorded in the Chinese Hulu/Wulu speleothems and the Greenland ice core. Generally, GSs
25 correspond to coarser loess units whereas, GIs are characterized by increased contribution of
26 finer dust materials originated from northern Chinese deserts, mostly the neighboring Tengger
27 Desert (Fig. 5). This result supports the previous observations performed all over the Chinese
28 Loess Plateau (e.g. (Ding et al., 1999; Porter and An, 1995; Yang and Ding, 2014). Therefore,

1 our methodology used for European sequences about the dust deposition does not apply to
2 these records, which are interpreted as having dust deposition also during Gl's, as observed
3 also in modern conditions through continental dust storms (Sun et al., 2001).

4 To compare our results from European sequences with Chinese loess records, we
5 have used the correspondences between the published age model and the measured depth
6 of the Chinese equivalents of the Greenland GSs and Gl's in Gulang and Jingyuan loess
7 sequences from Sun et al. (2012), and the time boundaries of the GSs and Gl's from the
8 Greenland ice-cores as defined by Rasmussen et al. (2014). Strong similarity in millennial-
9 scale changes in mean grain size variations from the Gulang and Jingyuan loess series and
10 $\delta^{18}\text{O}$ record from the Hulu Cave and Greenland ice core yields precise correlation of these
11 DO cycles during the 60-23 ka (Rasmussen et al., 2014; Sun et al., 2012; Wang et al., 2001) .
12 Such correlation was lately extended to the last two climatic cycles by a 249 ka stack of eight
13 loess grain size records from northern China (Yang and Ding, 2014), Bulk SR and MAR of
14 these two Chinese sequences are therefore estimated to compare with those from our
15 European sequences, during BCA and BCB (Fig. 6; Tab. 3).

16 SRs at Gulang and Jungyuan always show values lower than our European
17 sequences, consistent with those obtained for St. Pierre-lès-Elbeuf which is less than 100
18 cm/kyr. Interestingly, Jingyuan always shows higher values than Gulang, but also coarser
19 material according to Sun et al. (2012). This result probably relates to the location of the two
20 sites with regard to the dust source. Gulang is protected by the mountain range bordering
21 westwards the Tengger desert while Jingyuan is very close to the Yellow River where coarser
22 material can be easily transported by the East Asian monsoon wind. Estimated MARs at
23 Gulang and Jingyuan are lower by a factor of 2-3 than those computed for the European
24 sequences for BCA and BCB. Jingyuan shows higher values than Gulang, probably because
25 of its downwind location from the proximal dust sources The Chinese loess plateau is
26 worldwide known as a remarkable record of the Tertiary and Quaternary eolian deposits,
27 yielding a unique continental archive to document changes in East Asian paleomonsoon and
28 dust deposition over the last 25 Ma (Guo et al., 2002; Qiang et al., 2011). Estimated MARs
29 from loess sequences in the central Chinese Loess Plateau, ranging between 111.5 and

1 758.9 g:m²/yr during the last glacial maximum (An et al., 1991; Liu et al., 2019) are much
2 lower than those from the northern western Chinese Loess Plateau.

3 Our comparison between European and Chinese loess sequences shows that the dust
4 loading of the atmosphere, was much higher in Europe than in China by a factor of 3, at least
5 during BCA and BCB, and therefore during mostly the LGM, with the dustiest conditions of the
6 last climate cycle. However, this difference in dust loading between the two regions does not
7 imply that the frequency of the dust events, transport and deposition was lower in China.
8 Rather, as continuous dust deposition prevailed in Asia, one could assume that dust storms
9 were more frequent than in Europe, similar to today between the Gobi and Taklamakan
10 deserts showing higher frequencies of dust storm for the former but a high dust amount
11 emitted for the latter (Laurent et al., 2006). The difference in MAR is likely attributed to
12 different source-to-sink dust systems between Europe and East Asia, since Asian dust is
13 mainly transported from distant provisional sources such as the Gobi and sandy deserts in
14 northwest China and southern Mongolia (Sun et al., 2020).

15 **5. Comparison with Earth System Model estimates**

16 When modeling the LGM dust deposition worldwide, Mahowald et al. (Mahowald et al.,
17 2011; Mahowald et al., 2006) indicated much lower values for European loess deposits than
18 our estimates. Indeed, in the region corresponding to Harmignies, Remicourt and St. Pierre-
19 lès-Elbeuf, Mahowald et al. (Mahowald et al., 2011; 2006) indicate MAR of 5-10 g/m²/yr, of
20 10-20 g/m²/yr for the Nussloch area, 50-100 g/m²/yr for the Zlota area, and finally 100-200
21 g/m²/yr for the area including Dolni Vestonice, Stayky and Surduk. These estimates fit with
22 other LGM deposition rates for Europe, proposed most recently by Albani et al. (2014) and
23 Lambert et al. (2015) indicating MAR values higher than 50 g/m²/yr (Kageyama et al., 2018).
24 On the contrary, Hopcroft et al. (2015) rather indicated even lower deposition rates of about 1
25 g/m²/yr for the same region.

26 The differences between these model estimates and our reconstructions, which could
27 be considered as significant, rely on the fact that models only consider the fine-grained
28 mineral component of the dust deposits, up to about 10µm. In contrast, our initial

1 reconstructions were based on bulk material, which includes grain size categories coarser
2 than the mineral aerosol size used in climate models. The assignment of every sample taken
3 from the outcrop into four main grain-size classes allows a slightly different MAR computation,
4 with particle sizes $<4.6\mu\text{m}$ for clays, between $4.6\mu\text{m}$ and $26\mu\text{m}$ for fine silts, between $26\mu\text{m}$
5 and $63\mu\text{m}$ for coarse silts and $>63\mu\text{m}$ for sand (Tab. 4). When taking into account the clay
6 fraction, which is closer to the mineral aerosol size used by the models, Nussloch loess
7 sequence yields, MAR varying between 181 and 126 $\text{g}/\text{m}^2/\text{yr}$ for BCA, and between 109 and
8 66 $\text{g}/\text{m}^2/\text{yr}$ for BCB, which are values closer to the estimates from Albani et al. (2014) and
9 Lambert et al. (2015) for the LGM encompassed in BCA. Interestingly, considering the clay
10 fraction, the MAR estimates for BCA in Dolni Vestonice and Stayky are higher than in
11 Nussloch, between 240 and 145 $\text{g}/\text{m}^2/\text{yr}$, in agreement with the average $<10\mu\text{m}$ fraction flux
12 estimated for BCA and BCB, 269 and 157 $\text{g}/\text{m}^2/\text{yr}$ respectively, from southern Hungary
13 (Ujvari et al., 2017), but also the MAR range for the area grouping these three sites by Albani
14 et al. (2016).

15 Using the grain size results for Nussloch, Dolni Vestonice and Stayky, the respective
16 contributions of the four main categories to the bulk MARs can be evaluated (Tab. 4).
17 Although the highest values are obtained for BCA and for the coarse silt fraction, $26\mu\text{m}$ -
18 $63\mu\text{m}$, no particular pattern prevails. BCB reveals lower, but still high values for Nussloch
19 compared to the other sequences.

20 **6. Conclusions and outlook**

21 The Greenland Interstadials described in the Last Climate Cycle from ice core records
22 have their equivalent in the European loess sequences as paleosols, tundra gleys or
23 embryonic soils. These loess series also show a complicated evolution in time duration as the
24 pedogenic units developed downward into the top of the eolian units when dust deposition
25 stopped. The observation leads to a reconsideration of the time interval corresponding to the
26 real dust deposition in terms of the thickness of the observed loess units, and that of the
27 overlying paleosols in contrast to other records of continuous deposition.

28 We applied this new stratigraphical and chronological concept to the Nussloch

1 sequence as a reference record of the LCC, and then compared this record to other
2 European high-resolution loess sequences located at about 50°N. By correlating with the
3 Greenland ice core timescale, we assigned ages to the continental equivalents of GSs and
4 GIs. Doing so, we have grouped GS and GI European equivalents according to the definition
5 of the Bond Cycles, which represent long-term cooling cycles gathering several interstadial-
6 stadal cycles. Our study shows that two Bond Cycles are well preserved in the European
7 loess sequences, namely BCA between GI4 and GS3 (i.e., 29-23ka b2k), and BCB between
8 GI8 to GS5 (i.e. 38.2-29ka b2k), BCA shows the highest SRs and MARs in all the studied
9 sequences. Due to the new methodology we applied to the age model, our estimates differ
10 from previous investigations which show relatively lower values. Our study also shows that a
11 longitudinal gradient in the bulk estimates prevailed with the highest values in western
12 European sequences and that the dustiest conditions were not necessarily linked to Heinrich
13 stadials ending all Bond cycles.

14 Comparison of European loess records with two Chinese loess sequences reveals that
15 while millennial scale variability is evident in these loess profiles, no pedogenic unit is
16 punctuating the rather continuous dust deposition on the Chinese Loess Plateau. The
17 comparison between the Chinese and the European sequences shows that bulk SR and MAR
18 estimates are much higher in Europe than in China, indicating that during the last Glacial
19 Maximum stadials, the atmosphere may have been dustiest in western Eurasia compared to
20 East Asia. However, proposing a dustier Europe does not imply that the dust storm
21 frequencies were higher in Europe but rather the dust amount emitted during one particular
22 dust storm in Europe was higher than in Asia.

23 A final validation of our study has been performed by a comparison of our estimates
24 with dust deposition rates computed from Earth System models. We assigned grain size
25 results of the loess samples into four main categories for better comparison with the model
26 results. The clay-sized fractions of the loess samples is close to the grain size of mineral
27 aerosol considered by Earth System models. The comparison between our MAR estimations
28 and the model results shows similar values, yielding a promising result for further Model-data
29 assimilations.

1 **Author Contributions**

2 D.-D. R. designed and performed research; D.-D. R., P. A., and Y. S. analyzed data; and D.-
3 D. R. wrote the paper with contributions from P. A. and Y. S.

4 **Declaration of interest**

5 The authors declare no competing interests

6 **Data and materials availability**

7 Correspondence and material request should be addressed to D.-D. R.

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3

4

1

2 **Figures and Tables**

3

4 **Fig. 1.** Map of the European loess deposits with indication of the location of studied records in
5 this paper, of the depth of the last glacial maximum sea level low stand and of the expansion
6 of the Greenland, Iceland, British, and Fennoscandian ice sheets. Map drawn by P. Antoine in
7 Rousseau et al. (2014) modified.

8

9 **Fig. 2.** Nussloch bulk sedimentation rate (SR) and mass accumulation rate (MAR) over the
10 interval 60 ka to 23 ka b2k (age before 2000 AD). From left to right, stratigraphy with the
11 identification of the loess and paleosol units as discussed in the text (from (Antoine et al.,
12 2016) modified). Arrows indicate the direction of the evolution of the time during the dust
13 depositions (in blue), paleosol developments (in red) after the stop in the dust sedimentation
14 (in green) (from (Rousseau et al., 2017b) modified). Correlation with NGRIP interstadials. SR
15 and MAR as estimated from NGRIP $\delta^{18}\text{O}$ timescale (Rasmussen et al., 2014). On the right
16 hand side, identification of Bond cycles according to Bond et al. (1993), labels a to d are from
17 the present study. The insert at the bottom of the figure explains how time should be read
18 when considering European loess sequences

19

20 **Fig. 3.** Maximum and minimum sedimentation rates estimated from our European key
21 reference sequences for:

22 a) "Bond Cycle A" (between GI4 and GS3, i.e., 29-23ka b2k) and "Bond Cycle B"
23 (between GI8 to GS5, 38.2 to 29ka b2k).;

24 b) "Bond Cycle A" (between GI4 and GS3, i.e., 29-23 ka b2k);

25 c) "Bond Cycle B" (between GI8 to GS5, 38.2 to 29 ka b2k).

26 Same caption as in Fig. 1.

27

28 **Figure 4.** Maximum and minimum mass accumulation rates estimated from our key reference
29 sequences for:

30 a) "Bond Cycle A" (between GI4 and GS3, i.e., 29-23 ka b2k) and "Bond Cycle B"
31 (between GI8 to GS5, 38.2 to 29 ka b2k);

32 b) "Bond Cycle A" (between GI4 and GS3, i.e., 29-23 ka b2k);

1 c) "Bond Cycle B" (between GI8 to GS5, 38.2-29 ka b2k).

2
3 **Fig. 5.** Map of the Chinese records. A. Map from Google Earth locating the two loess
4 sequences discussed in the present study. B. Schematic map of the Chinese Loess plateau
5 and the surrounding main deserts. (from (Hao et al., 2010) modified)

6
7 **Fig. 6.** Map of the maximum extension of the last climate cycle ice sheets in Northern
8 Hemisphere, with indication of maximum and minimum

9 a) Sedimentation Rates (right)

10 b) Mass Accumulation Rates (left)

11 for "Bond Cycle A" (BCA) and "Bond Cycle B" (BCB).

12 Schematic location of the polar jet stream with location of regions or areas (in black) and of
13 sites (in red) discussed in the text. $\delta^{18}\text{O}$ (‰, in blue) and the dust concentration (part/ μL , in
14 brown) records in the NGRIP ice core over the interval between 60 and 15ka b2k with
15 mention of BCA and BCB (in green). Dust concentrations are shown on a logarithmic scale.

16 The map was compiled by Jürgen Ehlers available at
17 <http://www.qpg.geog.cam.ac.uk/lgmextent.html>.

18

19 **Table 1.** Nussloch data. From left to right, Stratigraphy expressed in terms of thickness of the
20 eolian deposits, including the paleosol development from the top of the loess units. NGRIP
21 correspondence, Nussloch individual GS bulk SR and MAR estimates for the four Bond
22 cycles comprised between 60 and 15ka b2k (Rasmussen et al., 2014).

23

24 **Table 2.** Individual GS bulk SR and MAR estimates for Bond Cycle a (29-23ka b2k) and Bond
25 Cycle b (38.2-29ka b2k) from European sequences with reference to their original stratigraphy
26 and NGRIP timescale (Rasmussen et al., 2014) as reference.

1

2 **Table 3.** Bulk SR and MAR estimates for "Bond Cycle A" (29-23ka b2k) and "Bond Cycle B"
3 (38.2-29ka b2k) from Gulang and Jingyuan Chinese sequences with reference to their original
4 stratigraphy (Sun et al., 2012) and the NGRIP timescale

5

6 **Table 4.** MAR estimates for "Bond Cycle A" (29-23ka b2k) and "Bond Cycle B" (38.2-29ka
7 b2k) from Nussloch, Dolni Vestonice and Stayky after decomposing the bulk value according
8 to the four grain size categories measured in the sediment samples taken on the studied
9 outcrops. Data from Antoine et al. (2009b), Rousseau et al. (2011), Antoine et al. (2013).

10

11

1 **Supplementary figure**

2

3 **Fig. S1.** Correlation of the studied European sequences plotted on the same depth scale
4 according to (Antoine et al., 2016; Antoine et al., 2013; Antoine et al., 2009a; Antoine et al.,
5 1999; Antoine et al., 2009b; Antoine et al., 2001; Moska et al., 2018; Moska et al., 2015;
6 Rousseau et al., 2011). The different colored boxes corresponds to the various Bond Cycles
7 (BCx) discussed in the manuscript with BCA, lasting between 28,900 yr and 23,340 yr
8 b2k, BCB, lasting between 38,220 yr and 28,900 yr b2k, BCC, lasting between
9 46,860 yr and 38,220 yr b2k, and BCD, lasting between 54,220 yr and 46,860 yr b2k
10 using Rasmussen et al (2014) chronology.

11

Fig1

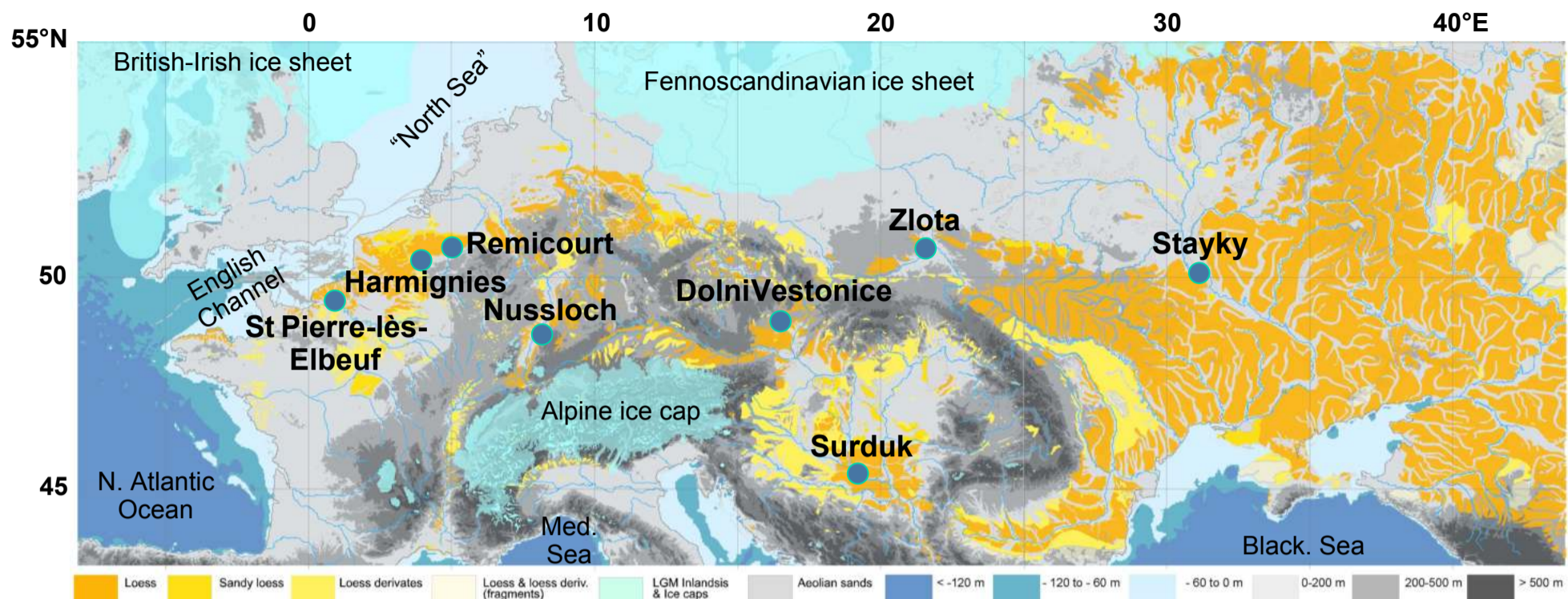


Fig2

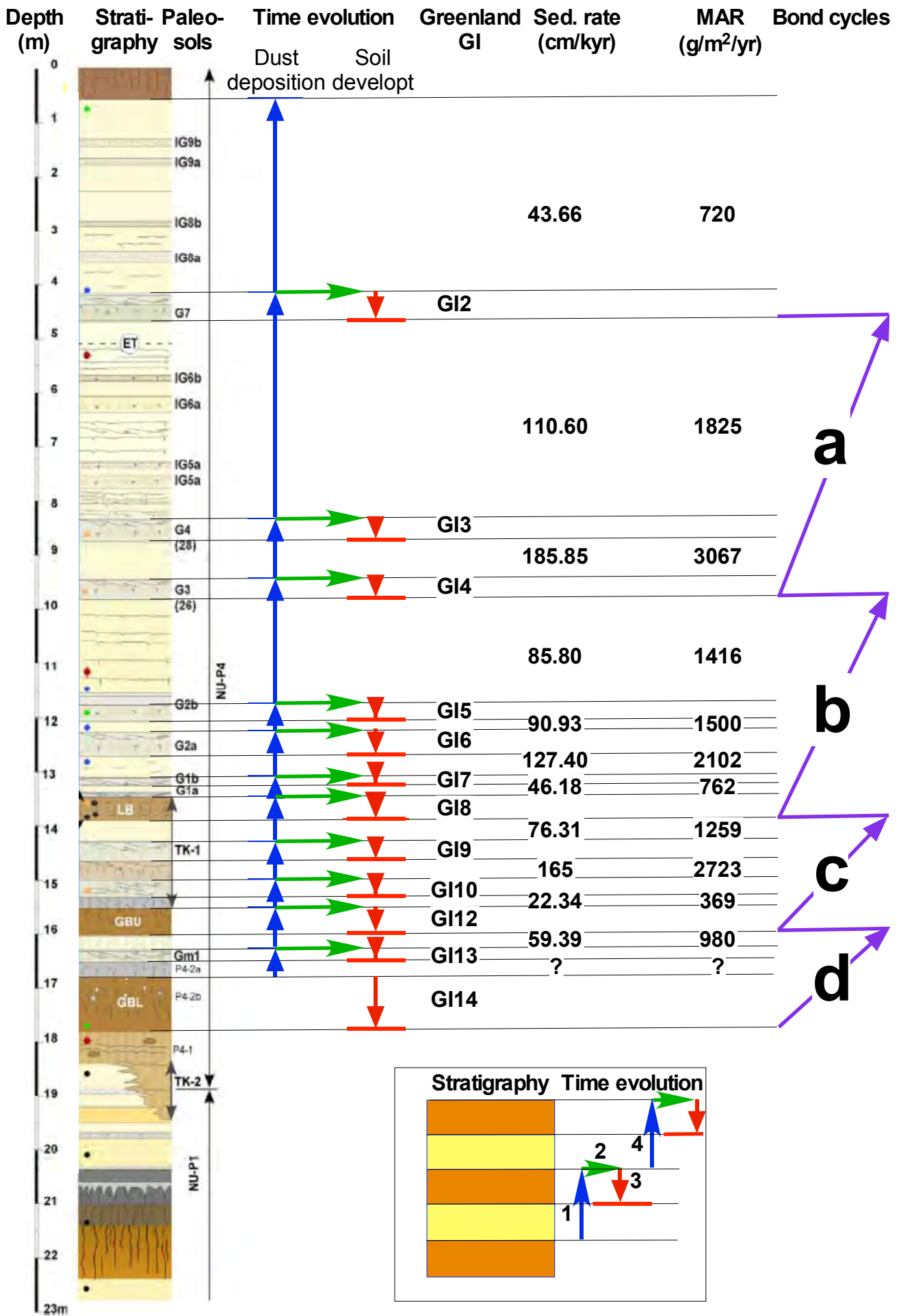


Fig3

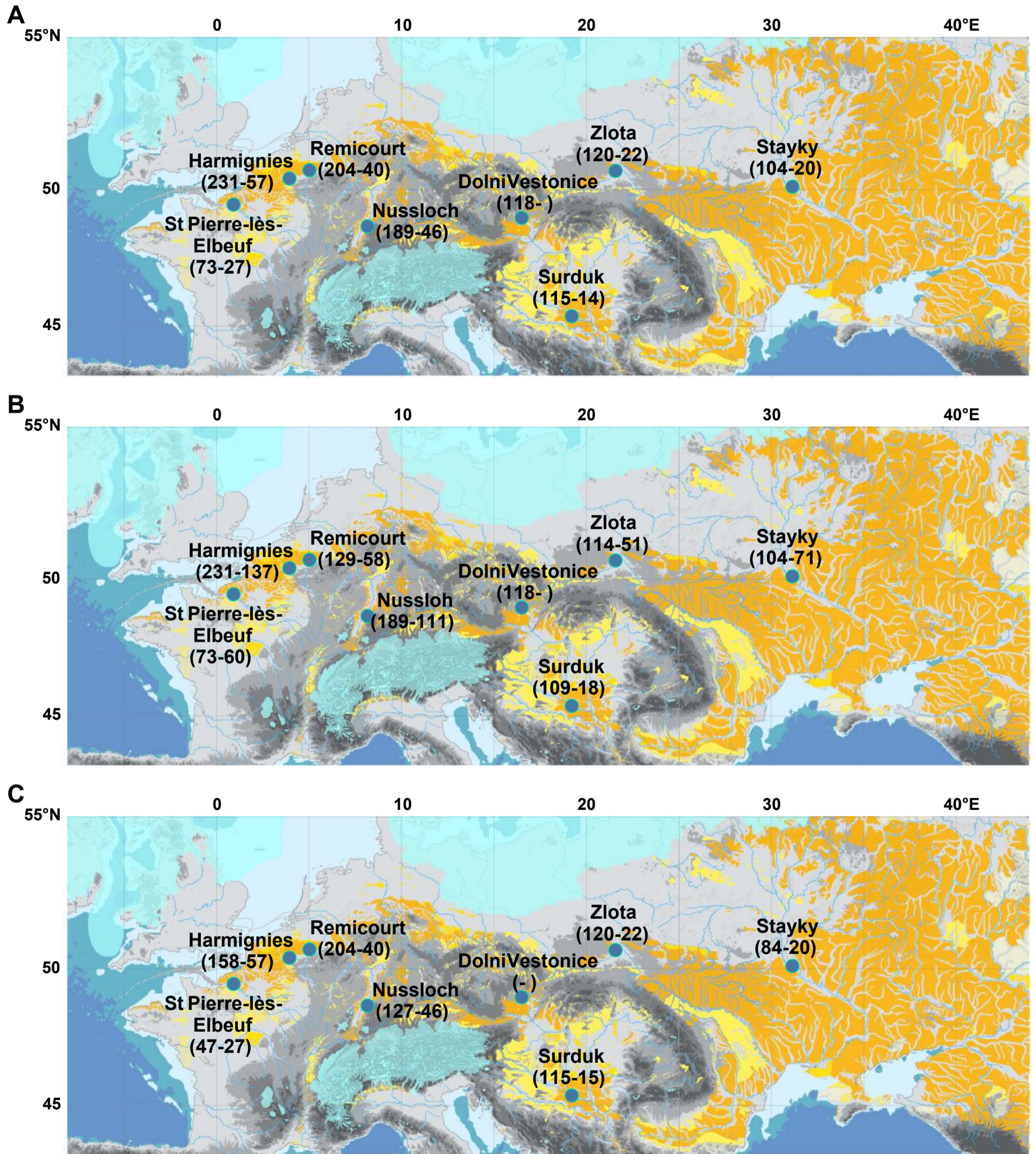


Fig4

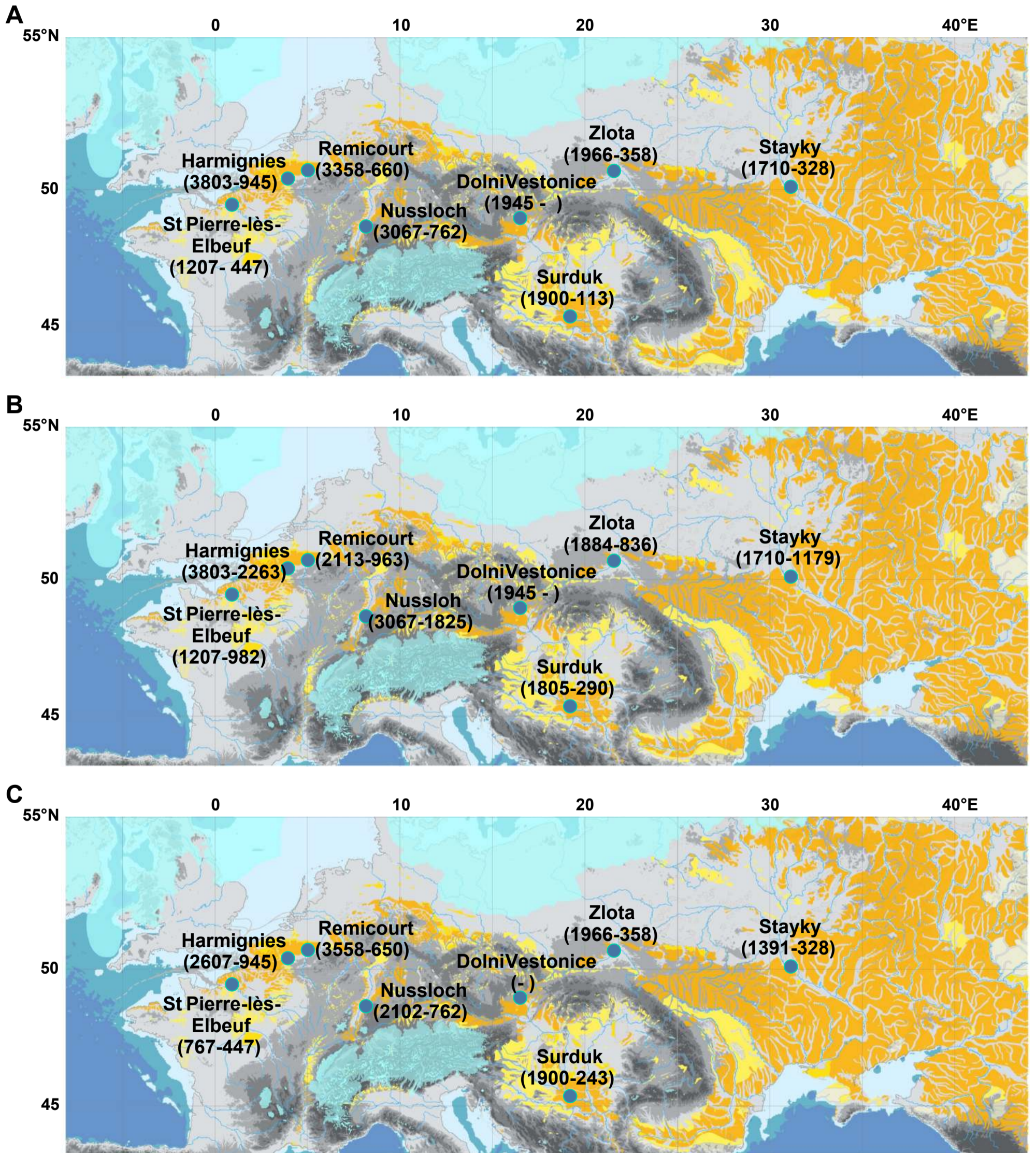


Fig5

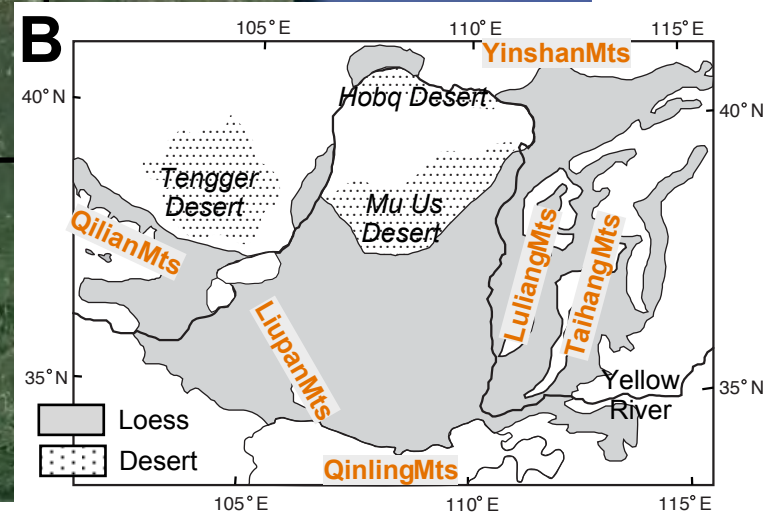
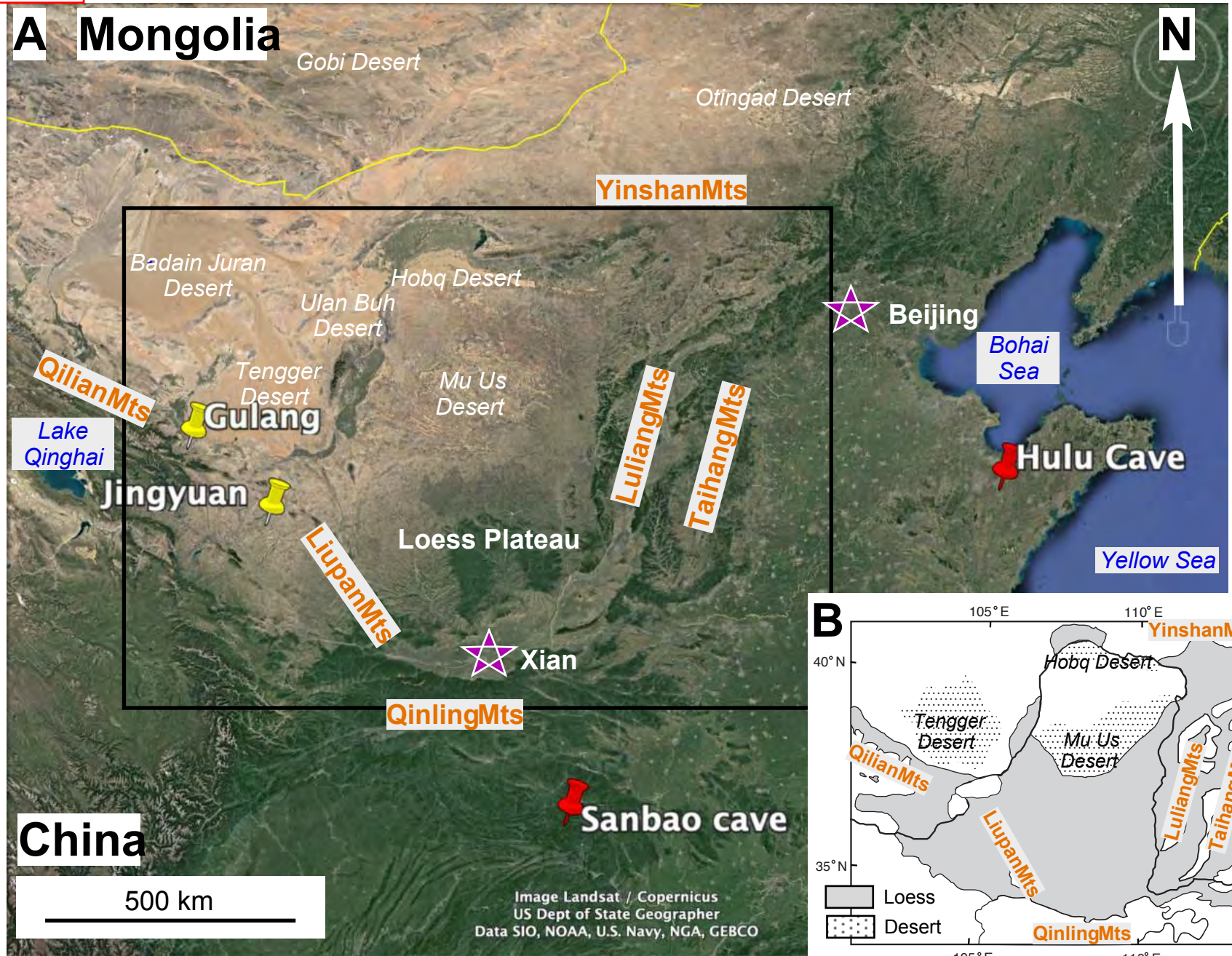
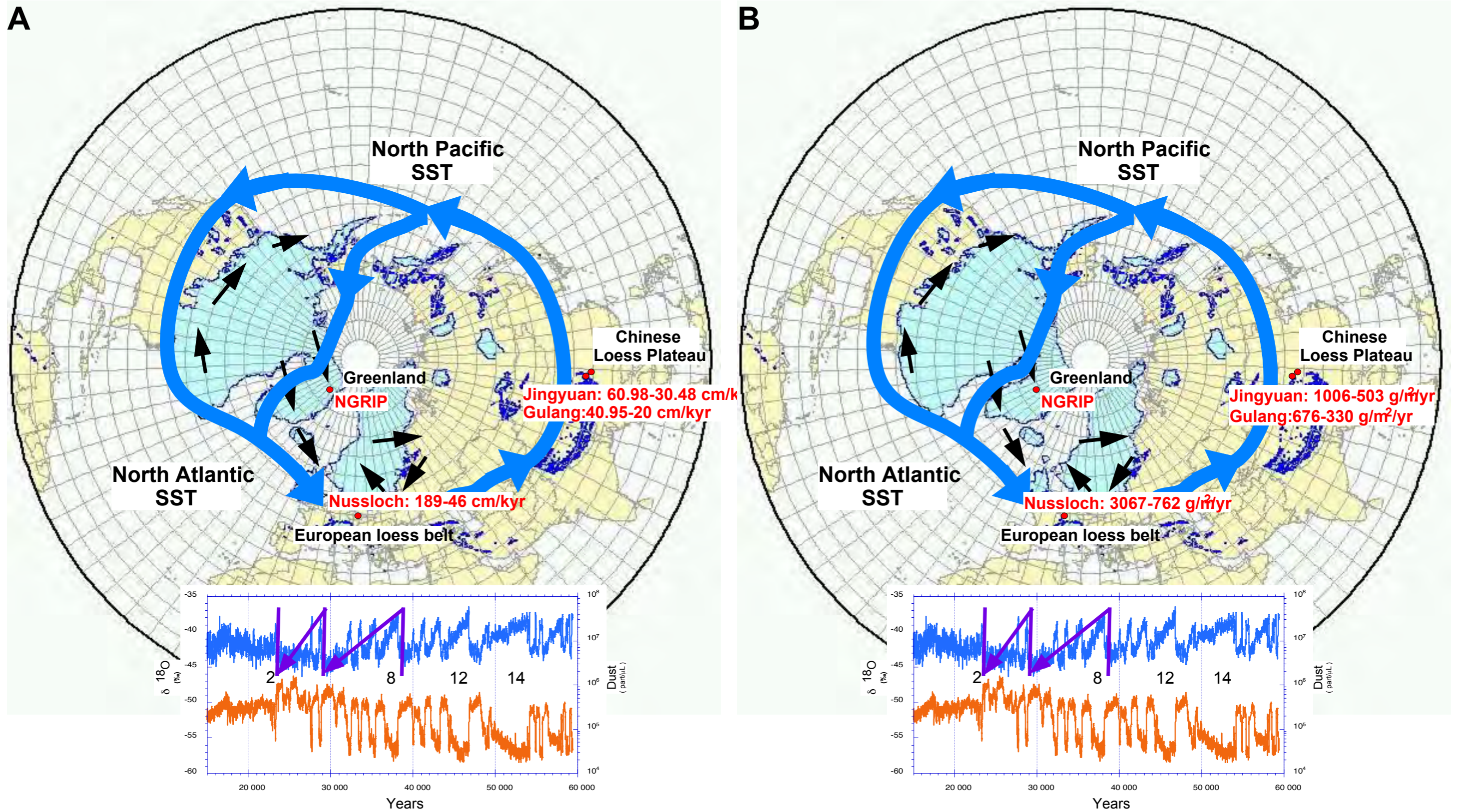
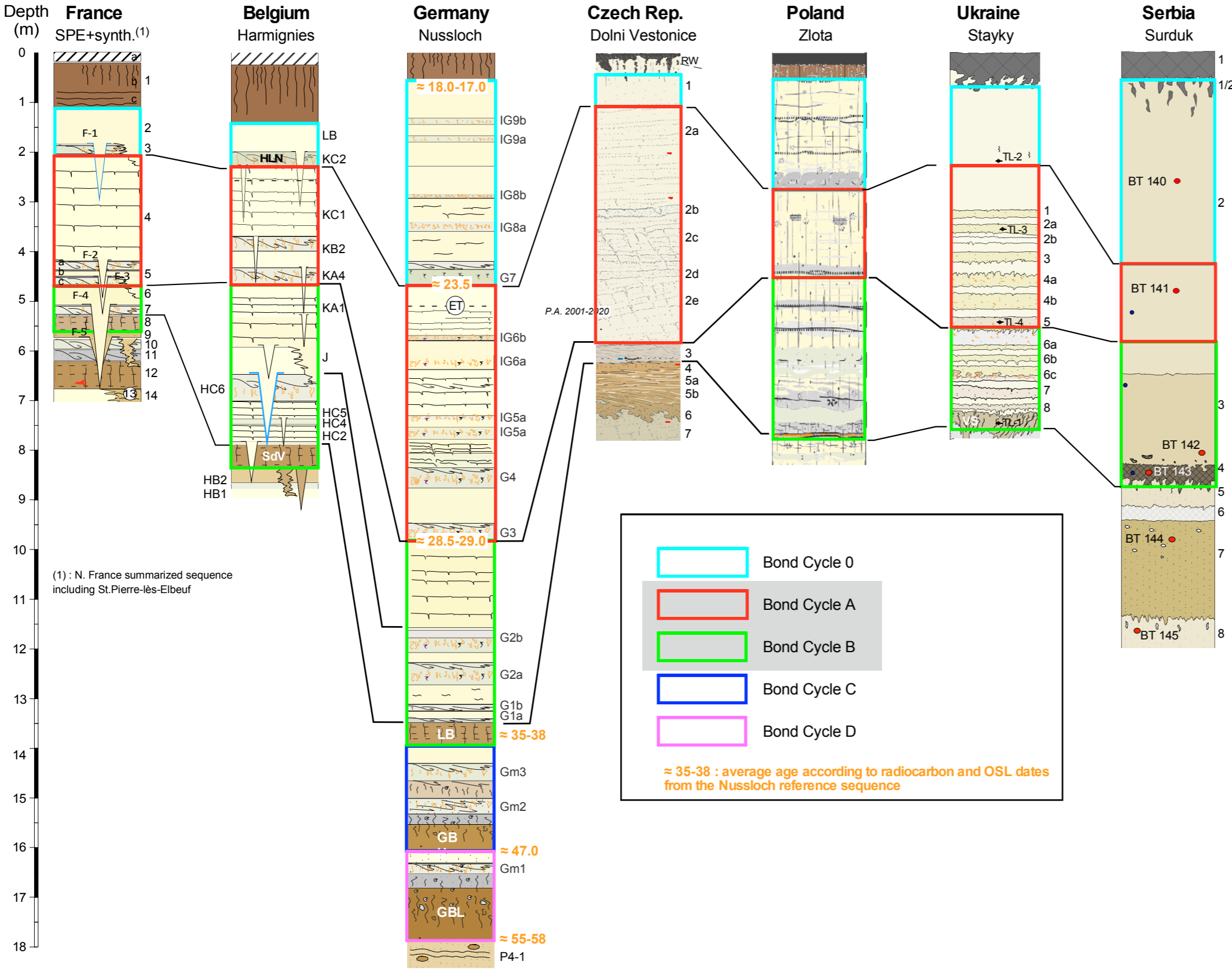


Fig6





suppl. Fig1

Eolian sedimentation	Paleosols	Thickness depth (m)	Thickness for MAR/SR	Age end Rasmussen (yr)	Age start Rasmussen (yr)	Duration Rasmussen (yr)	Sedimentation rate Rasmussen (mm/yr)	Age end dust (yr)	MAR Rasmussen (g/m ² /yr)	MAR dust (g/m ² /yr)	SR Rasmussen cm/kyr	sed rate dust cm/kyr	
Top sequece - Top G7 (GI2)		3.589	3.589	15000	23220	8220	0.44	15000	720	723	43.66	43.82	Bond cycle 0
	G7 (GI2)	0.508		23220	23340	120		23190					
Top G7 - Top G4 (GI3)		4.137	4.645	23340	27540	4200	1.11	23370	1825	1851	110.60	112.20	Bond cycle a
	G4 (GI3)	0.411		27540	27780	240		27510					
Top G4 - Top G3 (GI4)		1.113	1.524	27780	28600	820	1.86	27800	3067	3445	185.85	208.77	Bond cycle a
	G3 (GI4)	0.387		28600	28900	300		28530					
Top G3 - Top G2b (GI5)		2.306	2.694	28900	32040	3140	0.86	28910	1416	1507	85.80	91.32	Bond cycle b
	G2b (GI5)	0.290		32040	32500	460		31860					
Top G2b - Top G2a (GI6)		0.492	0.782	32500	33360	860	0.91	32500	1500	1593	90.93	96.54	Bond cycle b
	G2a (GI6)	0.444		33360	33740	380		33310					
Top G2a - Top G1b (GI7)		0.831	1.274	33740	34740	1000	1.27	33750	2102	2416	127.40	146.44	Bond cycle b
	G1b (G7)	0.145		34740	35480	740		34620					
Top G1b - Top LB (GI8)		0.363	0.508	35480	36580	1100	0.46	35490	762	798	46.18	48.38	Bond cycle b
	LB (GI8)	0.452		36580	38220	1640		36540					
Top LB - Top Gm3 (GI9)		0.831	1.282	38220	39900	1680	0.76	38220	1259	1259	76.31	76.31	Bond cycle c
	Gm3 (GI9)	0.347		39900	40160	260		39900					
Top Gm3 - Top Gm2 (GI10)		0.710	1.056	40160	40800	640	1.65	40180	2723	2904	165.00	176.00	Bond cycle c
	Gm2 (GI10)	0.298		40800	41460	660		40780					
?			0.298	41460	42240	780		41490					Bond cycle c
	TK1 (GI11)			42240	43340	1100		42200					
unitX - Top GBU (GI12)		0.210	0.210	43340	44280	940	0.22	43360	369	417	22.34	25.30	Bond cycle c
	GBU (GI12)	0.508		44280	46860	2580		44190					
Top GBU - Top Gm1 (GI13)		0.371	0.879	46860	48340	1480	0.59	46870	980	936	59.39	56.71	Bond cycle d
	Gm1 (GI13)	0.218		48340	49280	940		48420					
Top Gm1 - Top GBL (GI14)		0.500	0.718	49280	49600	320	2.24	49300	3702	1669	224.38	101.13	Bond cycle d
	GBL (GI14)	1.016		49600	54220	4620		50010					
mean						1508.46	1.03		1702	1627	103.15	98.58	
standard dev						1798.86	0.62		1024	915	62.09	55.44	
Max						8220.00	2.24		3702	3445	224.38	208.77	
Min						120.00	0.22		369	417	22.34	25.30	

(G12)		15000	23220	8220	3.589	3.589	43.66	/20		0.900	0.9
	G7 (G12)	23220	23340	120	0.508				pseudogley=G7 (G12)	0.150	
Top G7 - Top G4 (G13)		23340	27540	4200	4.137	4.645	110.60	1825		4.800	4.9
	G4 (G13)	27540	27780	240	0.411				unit3=G4 (G13)	0.350	
Top G4 - Top G3 (G14)		27780	28600	820	1.113	1.524	185.85	3067			
	G3 (G14)	28600	28900	300	0.387				G3 (G14)		
Top G3 - Top G2b (G15)		28900	32040	3140	2.306	2.694	85.80	1416			
	G2b (G15)	32040	32500	460	0.290				G2b (G15)		
Top G2b - Top G2a (G16)		32500	33360	860	0.492	0.782	90.93	1500			
	G2a (G16)	33360	33740	380	0.444				G2a (G16)		
Top G2a - Top G1b (G17)		33740	34740	1000	0.831	1.274	127.40	2102			
	G1b (G7)	34740	35480	740	0.145				G1b (G7)		
Top G1b - Top LB (G18)		35480	36580	1100	0.363	0.508	46.18	762			
	LB (G18)	36580	38220	1640	0.452				unit4=LB (G18)	0.200	

Reference strati (Nussloch)		NGRIP (Greenland)			Nussloch (Germany)				Surduk (Serb)		
Eolian sedimentation	Paleosols	Age end (yr)	Age start (yr)	Duration (yr)	Thickness depth (m)	Thickness for MAR/SR	SR (cm/kyr)	MAR (g/m2/yr)	Paleosols	Thickness depth (m)	Thickn for MAR/
Top sequece - Top G7 (G12)		15000	23220	8220	3.589	3.589	43.66	720		0.563	0.56
	G7 (G12)	23220	23340	120	0.508				base LE4-baseG12 (G12)	0.313	0.31
Top G7 - Top G4 (G13)		23340	27540	4200	4.137	4.645	110.60	1825		1.063	1.06
	G4 (G13)	27540	27780	240	0.411				baseLE3-base G13 (G13)	0.188	0.18
Top G4 - Top G3 (G14)		27780	28600	820	1.113	1.524	185.85	3067		0.125	0.12
	G3 (G14)	28600	28900	300	0.387				top G14-base G14 (G14)	0.438	0.43

Reference strati (Nussloch)		NGRIP (Greenland)			Nussloch (Germany)				Gulang (China)					Jingyuan (China)			
Eolian sedimentation	Paleosols	Age end (yr)	Age start (yr)	Duration (yr)	Thickness depth (m)	Thickness for MAR/SR	SR (cm/kyr)	MAR (g/m2/yr)	Loess strati	Thickness depth (m)	Thickness for MAR/SR	SR (cm/kyr)	MAR (g/m2/yr)	Thickness depth (m)	Thickness for MAR/SR	SR (cm/kyr)	MAR (g/m2/yr)
Top G7 - Top G4 (GI3)		23340	27540	4200	4.137	4.645	110.60	1825	GS3	1.720	1.720	40.95	676	2.400	2.400	57.14	943
	G4 (GI3)	27540	27780	240	0.411				GI3	0.060	0.060	25.00	413	0.140	0.140	58.33	963
Top G4 - Top G3 (GI4)		27780	28600	820	1.113	1.524	185.85	3067	GS4	0.200	0.200	24.39	402	0.500	0.500	60.98	1006
	G3 (GI4)	28600	28900	300	0.387				GI4	0.060	0.060	20.00	330	0.140	0.140	46.67	770
Top G3 - Top G2b (GI5)		28900	32040	3140	2.306	2.694	85.80	1416	GS5	0.920	0.920	29.30	483	1.820	1.820	57.96	956
	G2b (GI5)	32040	32500	460	0.290				GI5	0.160	0.160	34.78	574	0.200	0.200	43.48	717
Top G2b - Top G2a (GI6)		32500	33360	860	0.492	0.782	90.93	1500	GS6	0.300	0.300	34.88	576	0.400	0.400	46.51	767
	G2a (GI6)	33360	33740	380	0.444				GI6	0.140	0.140	36.84	608	0.160	0.160	42.11	695
Top G2a - Top G1b (GI7)		33740	34740	1000	0.831	1.274	127.40	2102	GS7	0.320	0.320	32.00	528	0.440	0.440	44.00	726
	G1b (G7)	34740	35480	740	0.145				GI7	0.240	0.240	32.43	535	0.320	0.320	43.24	714
Top G1b - Top LB (GI8)		35480	36580	1100	0.363	0.508	46.18	762	GS8	0.360	0.360	32.73	540	0.400	0.400	36.36	600
	LB (GI8)	36580	38220	1640	0.452				GI8	0.940	0.940	57.32	946	0.500	0.500	30.49	503

Mean grain size				MAR by grain size				Eolia
/ %	M fine silt (4.6-26um) %	M coarse silt (26-63um) %	M sand (>63um) %	MAR clay (g/m2/yr)	MAR fine silt (g/m2/yr)	MAR coarse silt (g/m2/yr)	MAR sand (g/m2/yr)	
	27.95	47.81	14.71	69	201	344	106	betwe
	27.44	50.59	14.25	126	446	822	232	betwe
	26.97	50.77	14.16	181	604	1137	317	betwe
	26.96	52.39	13.24	90	327	635	160	betwe
	35.16	47.40	8.33	86	332	447	79	betwe
	34.16	47.16	10.76	109	468	646	148	betwe
	37.64	40.74	9.50	66	205	222	52	betwe

	29.52	40.39	17.26	41	95	130	55	betwe
	33.03	40.11	14.11	145	376	457	161	betwe
	36.36	34.96	13.64	166	402	387	151	betwe
	36.7	33.56	12.7	43	92	84	32	betwe
	37.05	34.3	11.6	131	284	263	89	betwe
	42.4	28.14	10.2	167	367	244	88	betwe
	43.7	18.5	12.7	151	262	111	76	betwe

	29.52	40.39	17.26	23	53	73	31	Top se pseud
	33.03	40.11	14.11	240	623	756	266	Top ps unit3 (