Online Supplementary Information for “Environmental changes in SW France during the Middle-to-Upper Palaeolithic transition from the pollen analysis of an eastern North Atlantic deep-sea core”

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# Pollen analysis

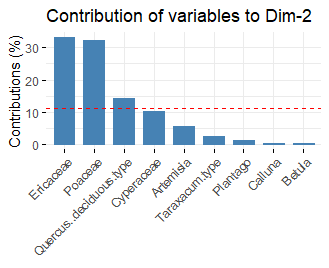
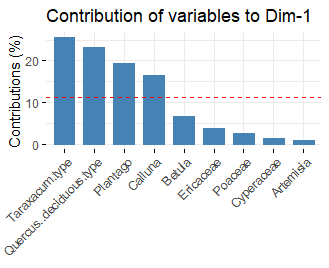


Fig. S1. Contributions of each variable on dimension 1 and dimension 2.

# MD04-2845 chronology

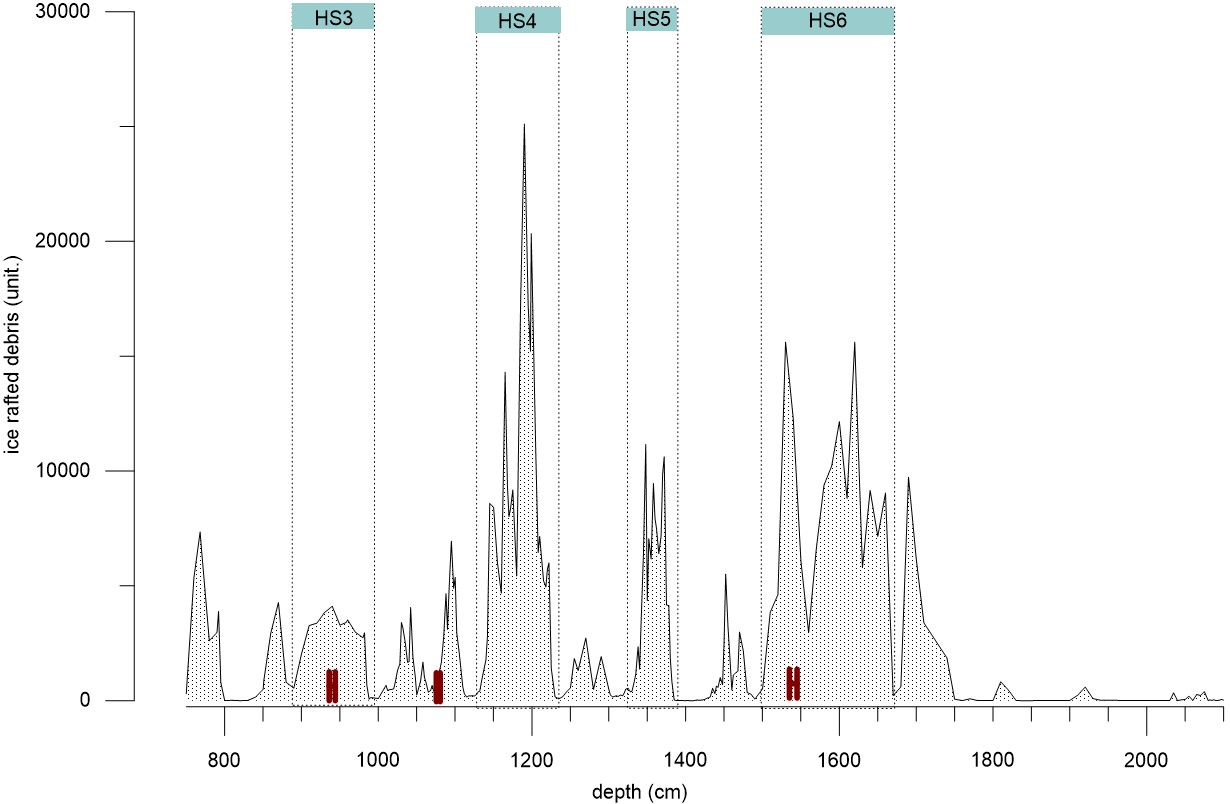
## Luminescence: methods and sampling

Luminescence dating methods determine the time elapsed since the minerals were last exposed to sunlight or heat. The method of the OSL (optically stimulated luminescence) requires the determination of two elements: the determination, based on luminescence measurements, of the equivalent dose (De) corresponding to the total irradiation dose absorbed by minerals since their last zeroing. This resetting can occur when sediments bleached by sunlight, by pressure (Bateman et al., 2012, 2018) or heat independents of the time of the deposition. The dose rate (Dr) corresponds to the dose absorbed per unit time. In general, it is determined by radioelements contents in the sediment itself (usually a CRP2A laboratory thanks to High purity and low background gamma-spectrometry, (Guibert and Schvoerer, 1991) combined with in situ dosimetric measurements (dosimeters or in situ gamma spectrometry), the latter being impossible in the case of deep-sea cores. Dating feldspars by IRSL (Infrared stimulated luminescence) with commonly used protocols (IR at 50°C for example) requires, contrary to quartz OSL dating, to consider a loss of charge from stable traps called anomalous fading (Huntley and Lamothe, 2001), or to use protocols to overcome it. The post-IR-IR signal (pIR-IR), measured at high temperature (e.g 290°C) can be used to avoid anomalous fading and determine an age (Thiel et al., 2011a, 2011b; Thomsen et al., 2011; Buylaert et al., 2012).

Sampling

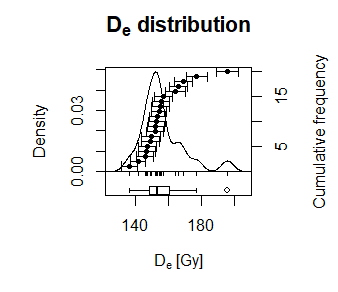
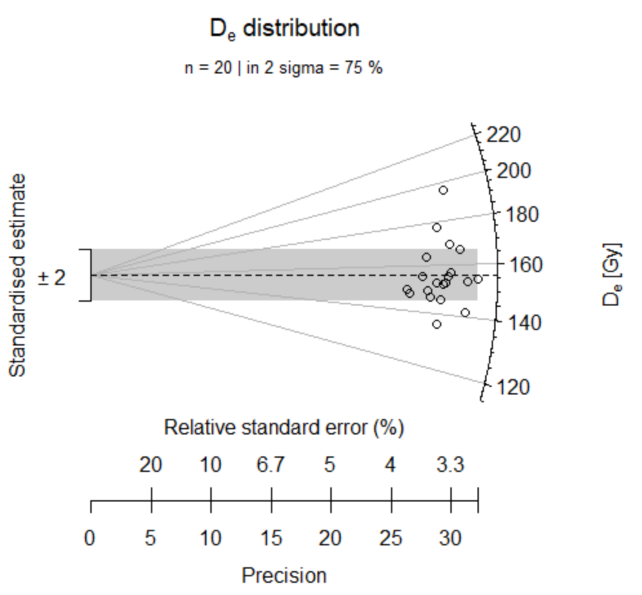
The samples were collected according to the protocols described by Armitage and Pinder (2017) and Nelson et al., (2019). The first few external centimetres of sediment (exposed to light after sampling) were sampled for Dr determination. Below these first few centimetres, internal sediment was sampled for De measurements. Approximately 50 g of material was required for both De and Dr measurements.

Each measured aliquot contained approximately 1 mg of material (polymineral extract averaging 250 grains, estimated with the function “calc\_AliquotSize” in the Luminescence package (v. 0.9.10, Kreutzer et al., 2020) in RStudio environment).



**Fig. S2:** Ice Rafted Debris curve (unit) according to depth (centimeters) from MD04-2845 deep-sea core. The quantity of IRD are used to identify the HEs. The Heinrich Stadials (HS) are delimited by both the IRD and the Sea Surface Temperatures. Vertical dashed lines represent the depth limits of the four HSs (HS3 to HS6) in MD04-2845 deep-sea core. The red dots represent the three sampling between 936-944, 1076-1081 and 1535-1545 cm depth for the luminescence dating. The grains were sampled over a width of ~10 cm.

**Fig. S3**: Radial and Kernel plots of pIR-IR290 measurements on BDX24931 sample (n=20), using the Luminesncence package V. 0.9.10 in RStudio environment

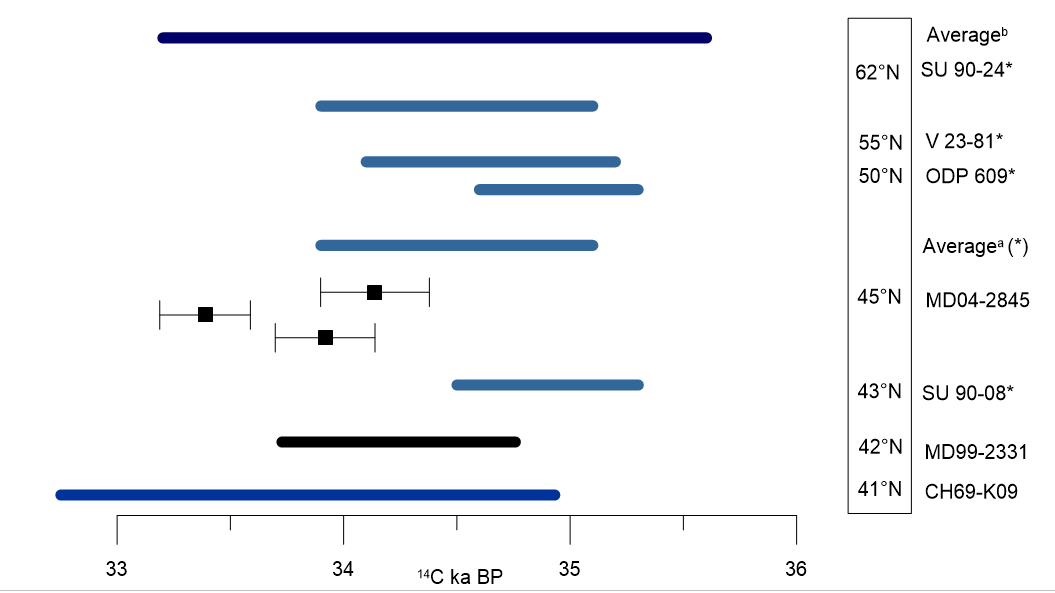


|  |  |
| --- | --- |
| **Step** | **pIR-IR290** |
| 1  2  3  4  5  6  7  8  9  10 | Irradiation  Preheat, 60s at320°C  IRSL, 280s at 50°C  IRSL, 280s at 290°C  Dose test  Preheat (TL) 60s at 320°C  IRSL, 280s at 50°C  IRSL, 280s at 290°C  IRSL, 280s at 325°C  Return step 1 |

**Table S1:** Single-aliquot regenerative-dose (SAR) protocols used for feldspars *De* determinations (pIR-IR290)(Murray and Wintle, 2003)

# Chronologies of HS 4

1. **Chronological comparison of several deep-sea cores: HS 4 and calibration curves**

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**Fig. S4**: Dates of HS 4 from six North Atlantic deep-sea cores between 62°-42°N.

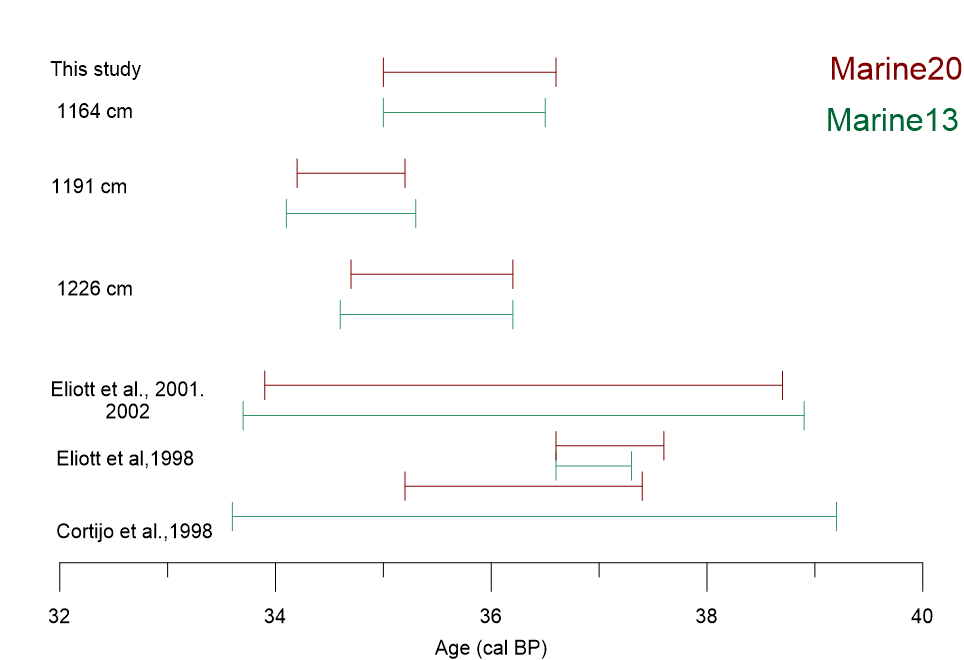
The duration of HS 4 in each deep-sea core (at the right) is given by the 14C dating of the interval containing high abundance of coarse grains (IRD). The three new 14C age of core MD04-2845 within the HS 4, are represented with the age and its uncertainties. Furthermore, for the other ages of HS 4, the duration of this same event are estimated from different cores. Are represented HS 4 in MD99-2331 (Naughton et al., 2009). “Averagea” (light blue) represents the HS 4 temporal lapse,calculated from the correlation of several cores: SU-90-08 (3 ages), ODP 609 (1 age), V 23-81 (1 sample), SU 90-24 (7 ages) (Elliot et al., 1998). “Averageb” (dark blue, Eliott et al.,2001; 2002) was estimated using SU90-24, V23-81 and ODP 609, Na 87-22 (2 ages from Cortijo et al., 1997) , CH69-K09 (from correlation with NA 87-22), SU 90-08 (light blue) and cores.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Area** | **Core names and localisation** | **Depth (m)** | **Method** | **Grain size**  **(µm)** | **Water content**  **(%)** | **Cosmic rate** | **References** |
| North Pacific | TT28-14  (33°26’N 173°38’E) | 5079 | TL | 4-11 | 57 ± 5 | negligible (> 4km) | Wintle and Huntley, (1980, 1979) |
| Antarctic | RC8-39  (42°53’S 42°21’E) | 4330 | TL | 4-11 | 59 ± 2 | negligible (> 4km) | Wintle and Huntley, (1980, 1979) |
| Gulf of Carpentaria (Australia) | MD32  (12°S32’, 139°98’)  MD-33  (12°39’, 140°34’) | 60 | TL-OSL | 106–150  63–106 | 20 ±5 |  | Chivas et al., (2001), Reeves et al., (2008) |
| Arabian Sea | 70KL  (17°52’N 61°71’E)  74KL  (14°32’N 57°36’E) | 3810  3212 | OSL | 4-11 | 65 à 135 | n.d. | Stokes et al., (2003) |
| Arctic Ocean | 96/24-1sel (87°183’N,144°60’E) | 980 | OSL (MG) | >63 | 28 - 46 | negligible | Jacobson,(2003) |
| East Indian Ocean | FR10/95-GC17 (22°05’ S 113°50 E) | 1093 | OSL | 60-70 | 80 à 105± 10 | (Prescott et Hutton, 1994) | Olley et al., (2004) |
| Arctic Ocean | LLF03(-SM1A,  8 cores | 449 (min)  960 (max) | TL – IRSL  (polyminieral) | 4-11 ; 62-105 ; 105-185 | 28± 4 to 100±2 | Négligeable (=0) | (Berger, 2009) + Berger, (2006) |
| Baltic Sea, Arkona basin | 242790  (54°951’N 13°780’E) | n.d. | OSL | 63-106 | 27-237 | n.d. | Kortekaas et al., (2007) |
| Mediterrannean Sea, Peloponese | 36°37.5’N 21°34.6’E | 5200 | TL - OSL | 30-60  (polymineral) | 52-57 ratio w/mineral | negligeable | Polymeris et al., (2009) |
| North Sea | 21VC  26VC  14VC  35VC  06VC  41VC  49VC |  | OSL - IRSL | 100-150  150-200 | 40 ± 10 | 0.3 mGy/a | Alappat et al., (2010) |
| Okhotsk Sea | MR0604-PC07A (51°16.54’ N, 149°12.54’ E) | 1249 | OSL (quartz) | 4 - 11 | n.d. | negligible | Sugisaki et al., (2010) |
| Shiretoko Peninsula | MR0604-PC04A (44°31.65′N, 145°00.25′E) | 1215 | OSL | 4 - 11 | 61-114 | negligible | Sugisaki et al., (2012) |
| Baltic Sea | C06 (55°3'02"N, 13°7’47"E)  D03 (55°2'39"N, 13°9'31"E)  E02 (55°2'44"N, 13°1'01"E) |  |  |  | 30±5 |  | Anjar et al., (2012) |
| China East Sea | ECS-DZ1 (30°29'N, 112°03'E) | 1200 | OSL | 4-11100-200 | 20 ± 5  40± 10 | Prescott & Hutton, 1994  <0.04 ± 0.004 mGy/a ± 10% | Yi et al., (2014)  Wang et al., (2015) |
| Atlantic Ocean, Cap Blanc | ODP 658 (20°45’N, 18°35’W) | 2263 | OSL | 4-11  40-63 | 48±5.0 | negligible | Armitage, (2015); Armitage and Pinder, (2017) |
| Japonese Sea | LV53-18-2 (42°56'N, 134°44'E) | 551 | pIR-IRSL  MET-pIRIR  OSL | 4-11 | 40-50±10 | negligible | Yang et al., (2015) |
| Monterey Canyon (California) | DR 584 VC 328 (36°59’N, 122°44’W)  DR 584 VC 329 (36°59’N, 122°43’W)  DR 584 VC330 (36°59’N, 122°44’W)  DR 39 – VC3  DR 39 – VC9  DR 38 – VC1 | 2920  3612  3555  3456 | IRSL  OSL (SA) | 200-250  150-250  74-250 | Saturated  0.04±0.04 à 0.57±0.06 | Prescott & Hutton, 1994  0 | Heerema, (2016)  Steven et al., (2014) |
| East Mediterranean Sea (Israel coast) | K20  (34°49’N, 31°62’E)  K38  (34°51’N, 31°63’E) | 2540  950 | OSL – IRSL  KF et Q | 150-200  105-250 | 20±10 | 35±5 µGy/a | Porat et al., (2003) |

**Table S2**: Deep-sea cores dated by luminescence dating (OSL, IRSL, TL). The locations, depths of the cores, granulometric fractions, water contents and cosmic doses rates are shown, associated with bibliographic references.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Top  14C ka BP | Bottom  14C ka BP | 14Cages  (average or date) | Calibrate ages (ka Cal BP)  Marine13 | Calibrate ages  (ka Cal BP)  Marine20 |
| Cortijo et al., 1998 | 33.2 ±0.3 | 35.1 ± 1.1 |  | 33.6-35.2  34.2-39.2 | 33.8-35.2  34.3-38.8 |
| (Elliot et al., 1998) | 33.9 | 35.1 | 35.2±0.13 | 38.4-39.1 | 36.8-37.4 |
| (Elliot et al., 2001, 2002) | 33.9 ± 0.7 | 34.9 ± 1.1 |  | 33.7-36 .9  33.9-38.9 | 33.9-37.2 (top)  34.1-38.7 (bottom) |
| Naughton et al., 2009 | 33.73 | 34.74 |  |  |  |
| This study |  |  | 33.92±0.22 | 34.6-36.2- | 34.7-36.2- |
| This study |  |  | 33.39±0.20 | 34.1-35.3- | 34.2-35.2- |
| This study |  |  | 34.14±0.24 | 35.0-36.5- | 35.0-36.6- |

**Table S3**: 14C and calibrated ages of estimated HS4 in several North Atlantic cores (see Figure S2 above). The 14C ages and their uncertainties were calibrated with Marine13 with Calib 7.0.4 and with Marine20 (Calib. 8.20).

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**Fig. S5:** Comparison of calibrated ages of HS 4 (Table 3 above) using Marine13 (Calib v.7.0.4) and Marine20 (Calib v.8.20).

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