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# Age of the final Middle Palaeolithic and Uluzzian levels at Fumane Cave, Northern Italy, using $^{14}\text{C}$ , ESR, $^{234}\text{U}/^{230}\text{Th}$ and thermoluminescence methods

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## Abstract

This article presents and discusses the chronological layout of the final Mousterian and Uluzzian levels of Fumane Cave in northern Italy using  $^{14}\text{C}$ , ESR and TL methods. Given its complex sedimentary and cultural succession, Fumane is a key site to assess the Middle–Upper Palaeolithic transition in Southern Europe and to explore Neanderthal behaviour and to compare it with the first Aurignacians. Large ranges defined by the ESR and TL dates cover the radiocarbon ages for units from A11 to A4, respectively, from 42.8 to 32.5 ka BP become progressively younger in agreement with the stratigraphy, despite high dispersions within the same unit. Our estimates using chronometric data seem to support the hypothesis that the sequence may cover almost 10,000 radiocarbon yr and that from comparison with the sedimentological and palaeoecological data, the late Middle Palaeolithic and the early Upper Palaeolithic at Fumane occur in sediments formed under moderately cool to mild climatic conditions correlated to the Hengelo-Interstadial, shifting towards cooler and drier conditions. Finally, comparisons between the Fumane data set and other sites in the North-Adriatic region are discussed.

## Keywords

U/Th, Electron spin resonance, Radiocarbon, Thermoluminescence, Middle Paleolithic, Italy

## 1. Introduction and general background

A fine chronological framework is strongly needed in studies on biological and cultural dynamics at the crucial period that spans the final Middle Palaeolithic to the Early Upper Palaeolithic in Europe. This interval involves the so-called transitional period with its notably complex human-behavioural evidence. For a long time “Transitions” have been complicated to investigate due to difficulties encountered in separating evidence imputable to long-term local traditions from those attributable to the external influences produced by ecological shift, population movements, contacts and timing.

Specifically at the 50–30 ka interval, timescale precision is strongly affected by problems of a different nature.

Within this controversial period, we present a new contribution for temporally assessing the Middle–Upper Palaeolithic (MP–UP) transition in Southern Europe starting with the chronometric set of dates from the Pre-Aurignacian levels of Fumane Cave, a key site (Bartolomei et al., 1992, Broglio et al., 2003) in which it is possible to explore Neanderthal behaviour in terms of subsistence and lithic technology (Peresani and Sartorelli, 1998, Fiore et al., 2004).

Fumane Cave is located at 350 m altitude on the right slope of the Fumane Valley, the Western Monti Lessini, Veneto Pre-Alps (Fig. 1). Already known since the XIX century, this important site was firstly investigated in 1964 then in 1982 by the Natural History Museum of Verona and secondly in 1988, when new investigations started under the patronage of the Soprintendenza per i Beni Archeologici del Veneto. The cave belongs to a fossil karst complex system probably of tertiary age – still not completely surveyed – composed of several cavities excavated in dolomitic limestone of the Jurassic undifferentiated dolomitic complex. Explored only in recent times, this complex preserves a sedimentary sequence of more than 10 m in thickness divided into four main macro-units differentiated on the basis of their lithological features and the intensity of archaeological evidence. Tens of Middle and Upper Paleolithic levels, including several Mousterian and Aurignacian living floors and some traces left by Gravettian occupations, represent the rich cultural layout. The sequence (Fig. 2) documents the main climatic events, which occurred during the last glacial cycle – from the Early Weichselian to the second half of the Middle Weichselian – which conditioned pedo-sedimentary processes (Ferraro, 2002) and human settlement.

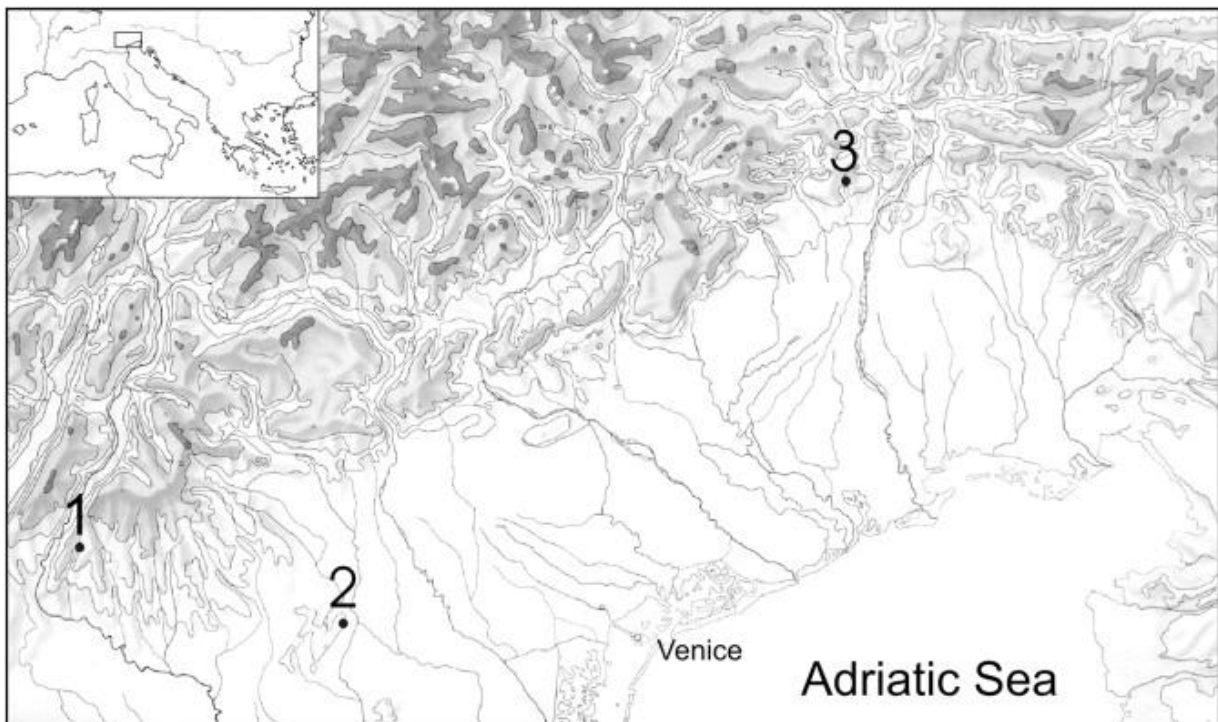


Fig. 1. The North-Adriatic region, indicating the location of Fumane Cave (1), Broion Cave (2) and Rio Secco Cave (3).

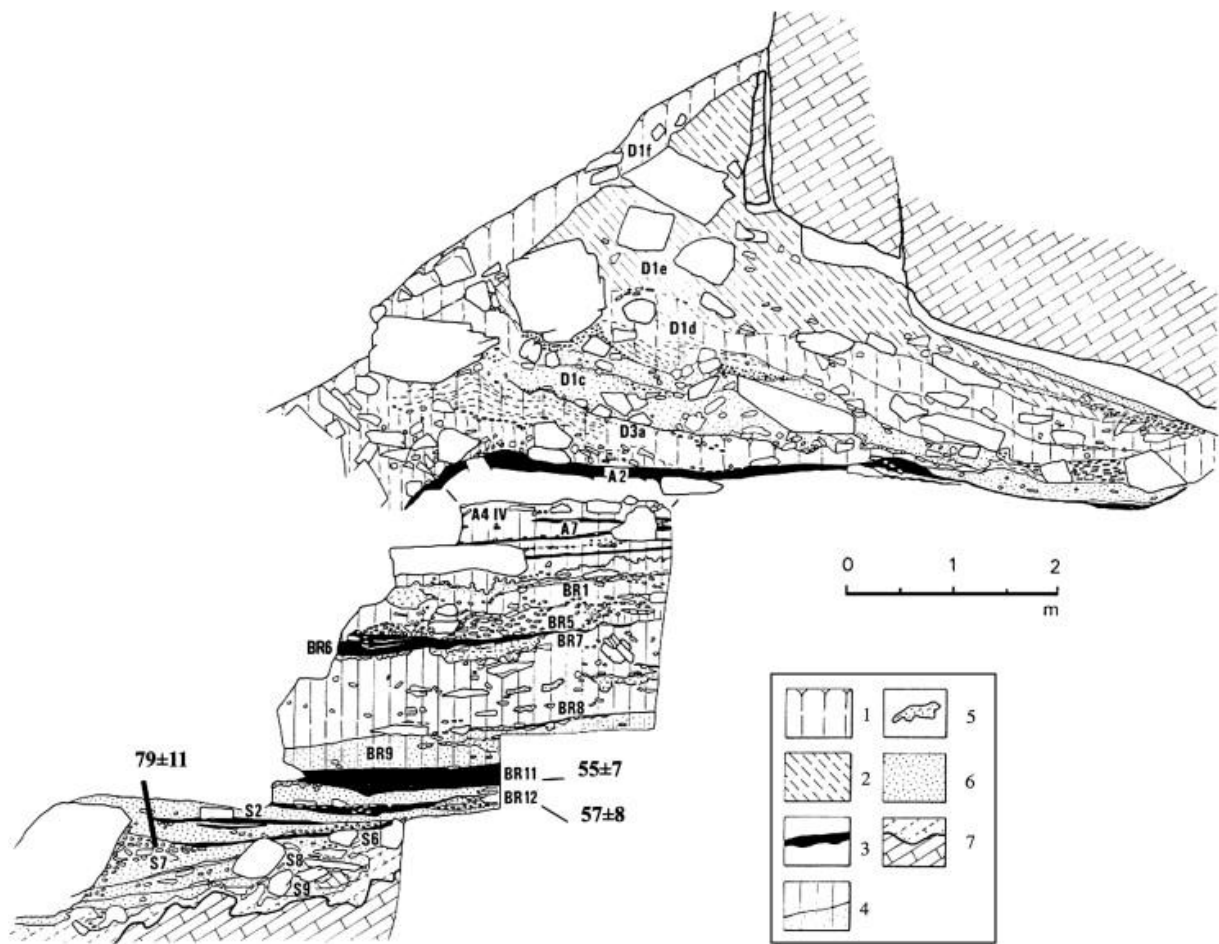


Fig. 2. Stratigraphic sequence of Fumane Cave reported for the main sagittal section running from outside the cave (right). Lithological features of the most significant units within the S, BR, A and D complexes are reported. Key: 1 – rendzina, upper soil; 2 – slope deposits with boulders; 3 – living floors, with high concentration of organic matter or charcoal; 4 – loess and sandy loess; 5 – CaCO<sub>3</sub> cemented layers; 6 – sandy deposits; 7 – unweathered and weathered bedrock. TL dates (after Martini et al., 2001) are reported for units S7, BR12 and BR11.

The basal units, which are arranged in horizontal layers and grouped in the macro-unit S, originated from run-off of residual dolomitic sands, the falling-down of some partially weathered boulders and formation of human living floors. TL data for unit S7 demonstrates that it was deposited at the end of Marine Isotope Stage 5 (MIS 5) (Martini et al., 2001). The overlying macro-unit BR marks a clear lithological change, with a dramatic decrease in sand content and a predominance of aeolian loam associated with breccia. Except for a thick living floor containing a high concentration of anthropic materials in BR11, Mousterian archaeological evidence in macro-unit BR is represented only by a few dispersed lithic artefacts, faunal remains and in some cases hearths with associated scatters of artefacts and bones interpretable as remains of specific tasks carried out during short-term occupations (Cremaschi et al., 2005). Evidence of a much more intense human occupation is documented in macro-unit A which includes several horizontally layered units from A13 to A1 composed of residual sands disturbed by frost heaving (A13–A12), cryoclastic breccia and aeolian loamy matrix (A11–A1) with varying content of organic matter and locally affected by faunal bioturbation. Mousterian living floors are found in A11, A10, A9 (+A8), A6 (+A5), Uluzzian industries in units A4 and A3, Proto-Aurignacian in units A2 and A1. The macro-unit D occurs at the top of the sequence. It consists of large blocks, which collapsed from the roof of the cavity at different moments, as a consequence of macroglaciation processes, which occurred during the last pleniglacial (MIS 2). Human presence is

still notable in the lowermost layers D3d, D3b and D3a, documenting the latest Aurignacian units, but it becomes sporadic in the middle level D1d, where some Gravettian artefacts have been found.

This paper aims to present and discuss the time-span during which the last Middle Paleolithic deposits (layers A11–A4) formed, as revealed by radiocarbon and non-radiocarbon (TL, ESR, U/Th) dating methods. Previous chronological assessments inferred from sedimentological analyses (Bartolomei et al., 1992), palaeontological analyses (Cassoli and Tagliacozzo, 1994) and thermoluminescence dating of heated flint (Martini et al., 2001) have been published elsewhere. Several <sup>14</sup>C dates have been reported already in other publications dealing with various aspects of the archaeological record, but not strictly focused on the chronometric sequence (Peresani, 2001, Peresani, 2003). Further TL as well as ESR model ages dates on tooth enamel have also been presented in a preliminary form elsewhere (Grupponi et al., 2005).

## **2. The late Middle Paleolithic layers: general information**

### **2.1. Excavation, stratigraphy and lithology**

The late Mousterian layers from A11 to A5 and the Uluzzian layers A4 and A3 have been excavated at different times since 1989 and to a different degree outside the present-day drip-line and inside the cave. The first complete stratigraphy was exposed in 1989 and 1990 in the southernmost sector, from where a NW-SE trench was opened in 1990 towards a central zone right in front of the cave entrance. After the layers of unit D were excavated, units A9–A4 were further exposed in 1995 and 1996 in two narrow trenches excavated inside the cave, the longest one running NE-SW along the morphological axis of the cavity at the base of the main section, the shortest one perpendicularly oriented with respect to the former (Fig. 3). A very limited sector was dug in 1992 still outside the cave, whereas more extensive investigations have been recently (2000–2001) carried out on the left side of the cave entrance and scattered ungulate bones, flint and non-flint artefacts have been brought to light in the A5 + A6 and A6 stratigraphic group. The above-mentioned units, from A13 to A3 (Fig. 4), are composed of freezing–thawing breccia, colluvial sands (A13–A12) and an aeolian matrix (A11–A4) that gradually replaces stones from the inner to the outermost zone of the cavity where it becomes almost exclusive. The overall sedimentary sequence displays varying amounts of these basic lithological components as well as in the density of cultural remains. More specifically, layers A13 and A12 are composed of loose breccia with prevalent sandy matrix, mostly vertically arranged stones and affected by densely spaced deformations incorporating the overlying unit A11. This latter unit and the overlying unit A10 mark the units with the highest content of cultural and organic remains; they are thin levels and some stone-lines are interbedded and sediment includes loose, partially open-worked breccia, with slabs often vertically arranged as a consequence of freeze–thaw action. A11 was excavated during the 1988 and 1989 field seasons. Various levels were recognized within this unit, such as A11a and A11c (organic levels with dwelling structures), A11d (ephemeral occupation level) and A11base (thin layer overlying unit A12). Similarly, unit A10, excavated in the 1990 trench, was subdivided into five fine levels as a function of interbedding and limited prevalence of gravel, aeolian loam, charcoal, ash and organic matter.

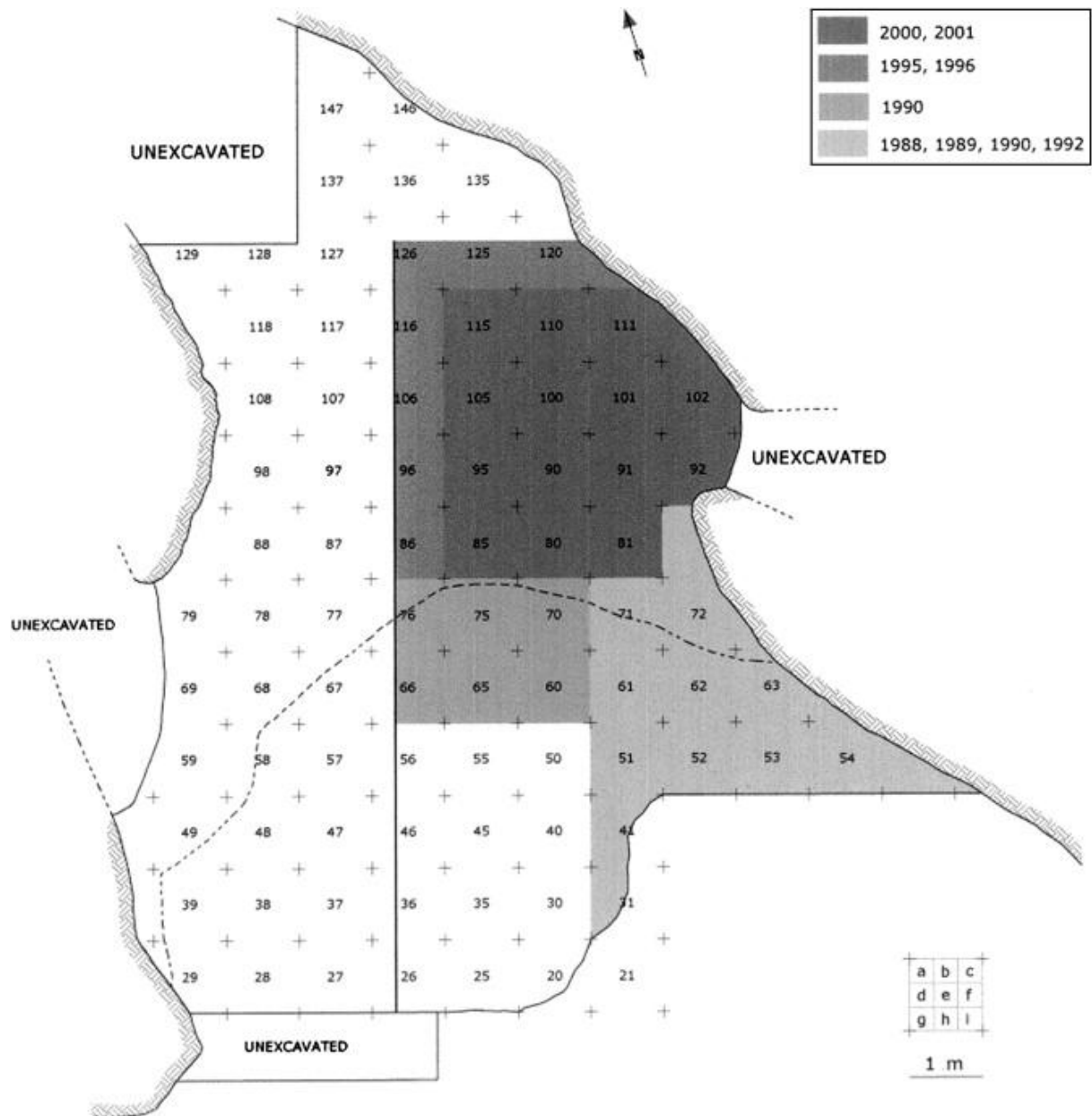


Fig. 3. Plan of the cave entrance and the lateral tunnels at Fumane Cave showing the grid and the sub-grid (below, right) with numbers and letters, respectively, the excavated and unexcavated sectors, years of excavation and sub-grid (below, right). The solid line in squares from 26 to 126 corresponds to the NE-SW longitudinal section drawn in Fig. 2, Fig. 4. Projection of the present-day drip-line is indicated by the dotted line (drawn by M. Peresani and S. Muratori).

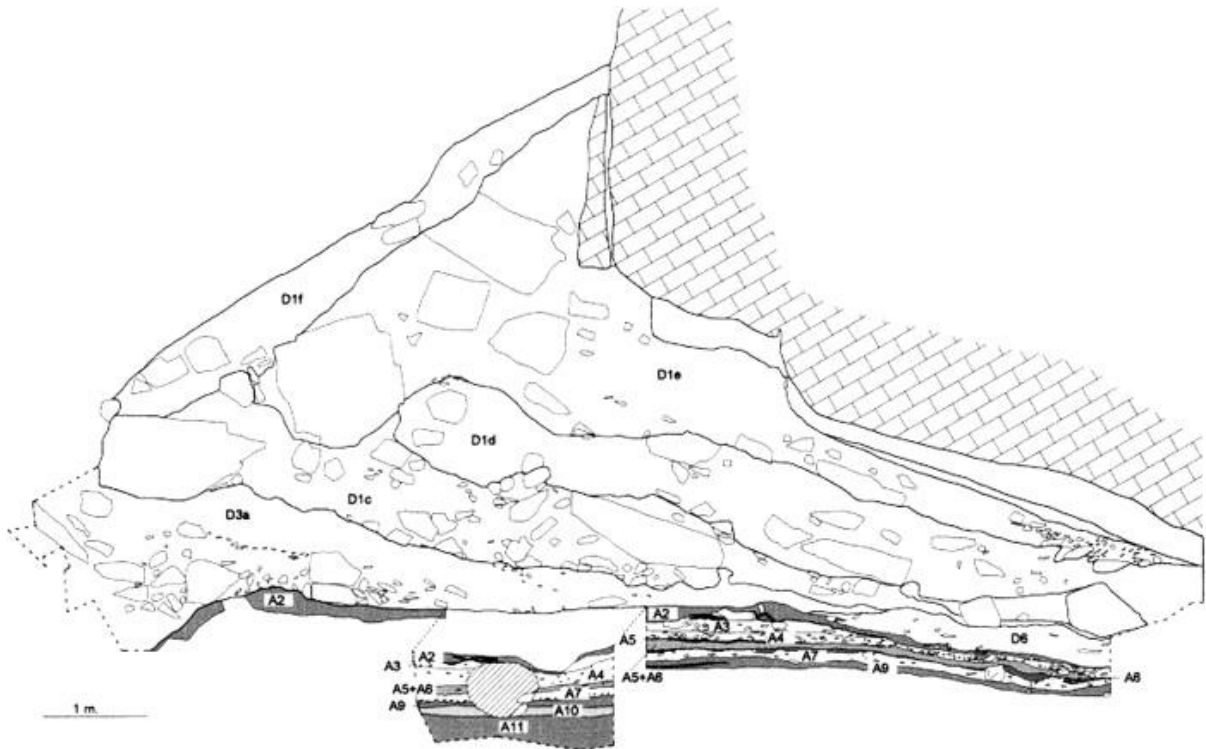


Fig. 4. Sketch section with evidence of the late Mousterian (A11–A5), Uluzzian (A4 and A3) and the earliest Aurignacian layer (A2) and on the variable content in archaeological remains (increasing from light gray to dark gray and black). Centre below, a section drawn 0.6 m east of the main one. A large faunal bioturbation is indicated by oblique lines in the middle between A11 and A2 levels (by M. Cremaschi and M. Peresani, redrawn by S. Muratori).

Unit A9 and sub-unit A8, the dispersed portion of A9 upper part, are stony layers with various amounts of aeolian dust. Unit A7 is completely lacking in primary cultural traces and thus marks an interruption in human occupation. The latter unit clearly contrasts with unit A6 with its dense amount of organic matter, charcoal, faunal and lithic remains and some remains of combustion structures such as the one we have labelled A6base SI, discovered in squares 95 and 105. Regarding A5 + A6, during excavation a thin discontinuous anthropic horizon gradually vanishing in the upper portion of A6 emerged, which we labelled A5, but given that there was no clear boundary between the two levels, we have labelled it as A5 + A6. The uppermost units A4 and A3 are stony or sandy layers with few cultural remains and with slabs (A4I–A4III) progressively substituted by aeolian dust outside the present-day drip-line (i.e. A4IV).

## 2.2. Palaeoecological setting and archaeological content

The palaeoecological setting related to the sequence described above is provided by palaeontological and charcoal diagrams. Pollen is rare and data on micromammals and other palaeoecological proxies are not yet available macromammals, and specifically hunted ungulates found from units A12 to A4, reveal moist-cool climatic phases that favoured the expansion of forests in favour of alpine grasslands. Nevertheless, the presence of *Capra ibex*, *Rupicapra rupicapra* and *Marmota marmota* in addition to some birds – *Pyrrhocorax graculus* and *Lagopus mutus* – indicates that open alpine environments still characterized the cave surroundings. In units A11–A10 cervids progressively and clearly increase relative to caprids revealing a moist–temperate climatic shift in parallel with forest expansion. Aside from a certain tendency towards cooler conditions observable towards the top of the sequence (units A2 and A1), such a moist–temperate situation seems to have been quite stable until level A3 (Cassoli and Tagliacozzo, 1994).

Charcoal analysis reveals that the prevalence of *Pinus sylvestris/mugo* (probably the former) is high in A11–A10 and decreases in A9 to then disappear from A7 upwards. Except in A11, the percentage of *Larix decidua* remains high throughout the sequence and is indicative of persistent cool climatic conditions. Units A7–A4 also include a few broad leaves (Maspero, unpublished data). The charcoal samples associated with units A11–A4 provide evidence for the long-term presence of microthermal species at lowlands, while the observed variations are likely to represent light timber-line shifts occurring under the influence of cool and continental climatic conditions. As a whole, humans reached the cave in a context of open forests with species adapted to poor soils colonized by a sort of parkland which was variably closed during the late Mousterian. Such conditions were transitional to discontinuous alpine grasslands or pioneer vegetation on carbonate rocks on the high plateau over the cave.

The final Mousterian levels, which were investigated on surface areas of 6–20 m<sup>2</sup> in size, are usually characterized by lithic and faunal remains which are densely scattered on the living floors as is the case in units A11, A10, A5 + A6 and A6. Flints were locally provisioned and in units A11, A10, A6, A5 and A4 were exploited through Levallois technology. Levallois blades were obtained using the unidirectional recurrent modality, whereas some flakes were obtained through the centripetal modality at the final stages of the reduction sequence. Formal tools like most scrapers and some points, as well as denticulates, remain invariable in morphology throughout these levels (Peresani and Sartorelli, 1998, Broglio et al., 2003).

An abrupt technological change occurs in unit A9 and sub-unit A8, with the appearance of an exclusive discoid industry, with its complete reduction sequence (Peresani, 1998) and typical implements like pseudo-Levallois points, backed flakes with thin opposite edge, subcircular, quadrangular or triangular flakes shaped into lateral or transverse scrapers, points and denticulates. Functional analyses show that these tools were being used for scraping or cutting wood, as well as humid or dry skins (Lemorini et al., 2003). The so termed Uluzzian occurrences of units A4 and A3 are also characterized by specific lithic tool sets (Peresani, in press). Technology was aimed towards the production of flakes by means of the Levallois method (still used in unit A4), the production of flakes by means of a variety of methods and of few blades and bladelets. Tools include backed knives and lunates opposite to a thin edge as well as lateral–transverse scrapers, some of which were thinned on the ventral surface.

### **3. The dates: sampling, methodology and results**

#### **3.1. U/Th-ESR combined dating**

##### **3.1.1. Samples and methodology**

The samples under investigation are five herbivore teeth found in levels A4I, A5 + A6, A6, A9 and A11a. We used combined U-series (see details in Ivanovich and Harmon, 1992) and ESR methods (Grün, 1989, Ikeya, 1993, Rink, 1997). The U-series method is based on the measurement of the isotopic ratio between <sup>230</sup>Th and <sup>234</sup>U (<sup>230</sup>Th/<sup>234</sup>U) and depends on the difference of solubility between these two elements. Percolating water contains a certain amount of uranium but no thorium. Thus uranium can be incorporated into different sample materials during their formation (stalagmite, stalactite, etc...) or during their burial (bones and teeth) while the measured <sup>230</sup>Th in the sample is created from the radioactive decay of uranium. In the case of the Fumane sample, there is no evidence of a detrital contamination (<sup>230</sup>Th/<sup>232</sup>Th > 100).

The ESR method is based on the detection of natural radiation effects in minerals resulting from environmental radioactivity. The age is calculated by estimation of the total amount of radiation



received by the sample during its history, called the palaeodose, and of the annual dose rate that the sample accumulates in 1 yr. For a fossil tooth, the palaeodose, also called equivalent dose ( $D_E$ ), is the total radiation accumulated in the sample from the time of burial to its discovery.

Both U-series and ESR methods are dependent on the mode of uranium uptake in the fossil teeth. Several mathematical models have been proposed to describe the effects of uranium accumulation. The early uptake (EU) model assumes that uranium is incorporated shortly after burial (Bischoff and Rosenbauer, 1981). The linear uptake (LU) model supposes that uranium was incorporated at a constant rate since the time of burial (Ikeya, 1982). The combined U-series and ESR data permit us to determine, for each dental tissue, a U-uptake parameter  $p$  (Grün et al., 1988). This parameter describes more accurately the geochemical history of the tooth (Grün and McDermott, 1994, Falguères et al., 1997). However, this procedure does not apply to situations for which uranium has been leached. To use this procedure, the EU–ESR age should be older than the EU–U-series age (Falguères et al., 1999).

### 3.1.2. Analytical procedure

The analyses were performed in the Department of Prehistory of the Museum national d'Histoire Naturelle, Paris, France.

The various tissues of the teeth (enamel, dentine and cementum) were separated mechanically, then the outer surface of the enamel was removed using an electric drill in order to eliminate the effect of external alpha contribution dose. Nine enamel aliquots were irradiated using a calibrated  $^{60}\text{Co}$  gamma-ray source with doses of 32, 63, 125, 250, 400, 630, 900, 1200 and 1500 Gy.

The ESR measurements were performed on an EMX Bruker ESR spectrum (X-band, 9.85 GHz) with the following parameters: 10 mW microwave power, 0.1 mT modulation amplitude, and room temperature. The equivalent doses ( $D_E$ ) were determined from the  $g = 2.0018$  enamel signal with the additive method using an exponential fitting (see details in Yokoyama et al., 1985). Each ESR measurement was repeated three times for every dose.

For the U-series analyses in this work, samples were dissolved in nitric acid and artificial spikes of  $^{232}\text{U}$  and  $^{228}\text{Th}$  were added. Uranium and thorium isotopes were then isolated via ion-exchange resins and measured by alpha-ray spectrometry, following the method described by Bischoff et al. (1988).

The calculation for ESR ages was made using the following parameters:

- A  $k$ -value (alpha efficiency factor) of  $0.13 \pm 0.02$  determined by Grün and Katzenberger-Apel (1994) was used according to Grün and Schwarcz (2000).
- The water content was estimated to be 3, 7 and 15 wt% (with an error of  $\pm 33\%$ ) in the enamel, dentine, and sediment, respectively.
- The initial thickness of the enamel layers corresponds to the measurement of the enamel thickness before preparation. A part of each side of the enamel layer was removed during the sample preparation with a electric drill. So, the  $\beta$ -dose rate was calculated taking into account this fact and using “One Group” beta attenuations in the enamel (Brennan et al., 1997).
- The cosmic dose was evaluated using the formula given by Prescott and Hutton (1994).
- In computing the annual dose, the external dose rate values deduced from the  $\text{CaSO}_4$  TL dosimeters placed *in situ* in the different layers were used with all associated measurements errors. When these data were not available, the  $\gamma$  dose rate (and its error) was calculated from the U, Th and K contents of the sediment measured by  $\gamma$ -rays spectrometry using a high purity germanium detector.
- The effect of Ra and Rn losses in enamel, dentine and cement was determined by combining alpha-ray and gamma-ray results (Bahain et al., 1992).
- All the calculations were performed using the program “Data-IPH” provided by courtesy of Rainer Grün.

### 3.1.3. Results

Table 1 summarizes the ESR/U-Series data of the late Mousterian level samples. The U content in enamel varies between 0.12 and 0.65 ppm and in dentine from 14 to 25 ppm. The equivalent doses range between 18 and 38 Gy.

Unit	U (ppm)	Th (ppm)	K (%)	Sample	$D_E$ (Gy)	Tissue	U content (ppm)	Enamel thickness ( $\mu\text{m}$ )			Annual dose rate ( $\mu\text{Gy/an}$ ) ( $d_a$ )				$p$	Ages (ka)
								Initial	Removed side dent.	Removed side sed.	( $\alpha + \beta$ ) enamel	$\beta$ dentine	$\beta$ sediment	$\gamma + \text{cosm}$		
A4-1	$2.56 \pm 0.11$	$5.76 \pm 0.08$	$0.85 \pm 0.02$	FU0003	$25.10 \pm 1.43$	Enamel	0.18	1269	93	142	$37 \pm 6$	$51 \pm 13$	$85 \pm 12$	$395 \pm 30$	-1.00	$44 \pm 7$
						Dentine	18.23								-0.28	
A5 + A6	$2.95 \pm 0.09$	$3.06 \pm 0.06$	$0.50 \pm 0.06$	FU9606	$17.71 \pm 1.06$	Enamel	0.24	1600	100	100	$48 \pm 9$	$28 \pm 6$	$54 \pm 8$	$322 \pm 30$	-1.00	$38 \pm 6$
						Dentine	14.06								1.61	
A6	$2.55 \pm 0.01$	$6.43 \pm 0.08$	$1.10 \pm 0.02$	FU9607	$37.57 \pm 2.56$	Enamel	0.53	1656	75	75	$82 \pm 23$	$75 \pm 20$	$87 \pm 14$	$746 \pm 35$	-0.78	$38 \pm 6$
						Dentine	24.28								-0.59	
A9	$2.72 \pm 0.09$	$2.98 \pm 0.06$	$0.47 \pm 0.01$	FU0004	$2450 \pm 1.29$	Enamel	0.65	954	116	88	$44 \pm 15$	$80 \pm 26$	$90 \pm 15$	$306 \pm 30$	-1.00	$46 \pm 7$
						Dentine	20.56								-0.15	
A11a	$2.72 \pm 0.09$	$2.98 \pm 0.04$	$0.99 \pm 0.02$	FU0005	$30.50 \pm 0.89$	Enamel	0.12	1269	93	142	$25 \pm 4$	$8 \pm 25$	$78 \pm 15$	$440 \pm 30$	-1.00	$49 \pm 7$
						Dentine	17.50								-1.00	

Table 1. The combined ESR/U-series data set

The contribution of the external dose rate to the total dose rate is more than 90% and so its estimation has to be very precise. The data recorded using TL dosimeters are considerably lower than the gamma-ray spectrometry determinations. At Fumane where layers are composed of loamy and coarse sediments, the data obtained by TL dosimeters are more representative of the real external dose and were used for the age calculation. The five teeth date between  $38 \pm 6$  ka and  $49 \pm 7$  ka.

### 3.2. TL dating

One burnt flint taken from the layer A6 in trench 1990 has been submitted to thermoluminescence measurements (Aitken, 1985) that have been carried out using the fine-grain technique (Zimmermann, 1976). The verification of the heating in the past was performed following Valladas, 1992. The system used for measurements, home-made, consisted of an oven for controlled heating, where the glow-curves were measured in ultra pure N<sub>2</sub> atmosphere, at a heating rate of 15 °C/sec, using a photon counting technique (EMI 9635QB photomultiplier tube coupled to Corning BG12 blue filters). Artificial irradiations were performed using a 1400 MBq <sup>90</sup>Sr-<sup>90</sup>Y beta source (dose rate: 1.62 Gy/min) and a 37 MBq <sup>241</sup>Am alpha source (dose rate: 14.8 Gy/min).

The radioactivity analyses of the flint and its associated 2sediment were carried out using ZnS (Ag) scintillators for thick source total alpha counting, and flame photometry for potassium concentration measurements. The dose absorbed by the flint since its heating was 90 ± 10 Gy. The results of radioactivity measurements are presented in Table 2. The corresponding dose rate was 1.78 ± 0.12 mGy/yr. The age of the flint is 50,000 ± 8000 yr BP (±1σ) but it should be considered a preliminary result, due to the fact that *in situ* evaluation of the γ dose rate and the measurements of the seasonal variations in the humidity at the site have still not been measured. The quoted overall error takes into account a fluctuation of 25–100% of saturation water in soils.

Sample	<sup>238</sup> U (ppm)	<sup>232</sup> Th (ppm)	Th/U ratio	K <sub>2</sub> O (%)
Flint	0.6	0.5	0.8	0.09
Sediment	2.2	7.0	3.2	0.48

Analytical procedures are explained in the text.

Table 2. Radioactivity measurements of flint and sediment for the burnt flint collected in unit A6

### 3.3. <sup>14</sup>C dates

#### 3.3.1. Samples and methodology

Radiocarbon measurements were carried out on charred wood samples taken at variable positions from the surface of the Mousterian layers from A11 to A4II. The use of different protocols for recovering charred wood samples and other specimens during the 10-yr span of fieldwork explains the reason for the diverse provenience reported for each stratigraphic unit in Table 3. During the first season of excavation, several charcoal pieces were collected from layers A10 (LTL-377A) and A11 (LTL-378A) in the southernmost zone, from the section wall exposed in the pit. It is important to mention that the A11 assemblage has been subjected to repeated bulk sampling from surfaces exposed during the several seasons of excavation again in the southern sector currently outside the cave. These different samples were selected and grouped together for charcoal analyses.

Unit	Lab. number	Square	<sup>14</sup> C date	Converted <sup>14</sup> C date (cal BP, 1σ)
A4II	OxA-8021	95	33,300 ± 400	37,851 ± 857
A4II	OxA-6462	85	33,150 ± 600	37,736 ± 1032
A4II	LTL-566A	86–96–106	33,700 ± 350	36,912 ± 1287
A5	OxA-6463	*	33,700 ± 600	38,875 ± 1497
A6	OxA-11331	90h	34,400 ± 800	39,522 ± 1099
A6	OxA-6464	*	34,950 ± 700	39,956 ± 968

A6	LTL-569A	100i°	35,450 ± 1180	40,148 ± 1296
A6	LTL-568A	90	37,300 ± 450	42,007 ± 382
A6base-SI	LTL-570A	95	37,750 ± 400	42,274 ± 381
A5 + A6	OxA-8022"	90	38,800 ± 750	43,145 ± 712
A5 + A6	OxA-8023"	90	38,250 ± 700	42,800 ± 694
A8	LTL-571A	31–41–51	36,650 ± 350	41,686 ± 327
A9I	LTL-573A	86	36,450 ± 400	41,591 ± 333
A9	LTL-574A	70b	38,550 ± 540	43,004 ± 650
A9	OxA-11346	31–41–51	39,950 ± 550	43,725 ± 662
A9	LTL-572A	61d	40,150 ± 550	43,849 ± 700
A9	LTL-376A	**	42,750 ± 700	46,304 ± 1295
A10	LTL-377A	nn	41,350 ± 750	44,855 ± 901
A10I	LTL-575A	***	37,100 ± 450	41,903 ± 376
A11	LTL-577A"	+	36,850 ± 350	41,781 ± 336
A11	LTL-378A	nn	42,000 ± 750	45,478 ± 968
A11a	LTL-578A	++	39,850 ± 500	43,667 ± 633
A11base	LTL-579A	++	38,100 ± 600	42,621 ± 576

Column 1 lists the units described in the text; column 2 lists the laboratory number with samples OxA-8022" and OxA-8023", having been divided into two, each half having been pretreated separately and measured independently; column 3 reports the square, the group of squares (\*85,86,95,96; \*\*85–86,95–96,105–106,115–116; \*\*\*60,61,65,66,70,71,75,76; +31,41,51–54,61–64,71–72,82; ++51–54,60–66,70–72,75–76,82) and the sub-squares (letters) where the samples were collected, the spatial reference number for a single charcoal (° = 539) and no indication (nn) for samples LTL-377A LTL-378A; <sup>14</sup>C ages have been converted to calendar ages by using CalPal2007-HULU Calibration Curve in the CalPal calibration software.

Table 3. The radiocarbon data set of the final Mousterian and the Uluzzian layers at Fumane

Charred wood was taken from level A10I and from level A10, as this unit was labelled during the first survey carried out in 1988–1989. The five samples from unit A9 and the single sample from A8 were taken at different places and at different times. Three samples (LTL-376A, LTL572A, and LTL574A) come from the 8 m<sup>2</sup> sector explored in 1990 just in front of the cave entrance. The OxA-11346 and LTL571A samples are from a different 3 m<sup>2</sup> sector explored in 1992 outside the present-day cave. The abundance of charred material in the latter sector suggested the existence of hearths or accumulation of residual combustion products. A similar concentration, A9I (LTL573A), was discovered in 1995 in the trench in the cave behind the drip-line.

One of the latest Mousterian stratigraphic assemblages was explored on the largest surface area exploited outside and inside the cave. The dated charcoals listed in Table 3 come mostly from the southern sector at the cave entrance and are spatially positioned according to each square or sub-square except for two samples (OxA-6463 and OxA-6464), which were taken from a 4 m<sup>2</sup> area around the present-day drip-line, where level A5 is differentiated from the underlying level A6. During the more recent excavation (2001) of level A6, three-dimensional coordinates were recorded for the largest embedded charred wood pieces. The pieces selected were embedded in the organic sediment,

well isolated both from the upper and the lower boundaries of the layer. Each charcoal (as for example the dated one LTL569A) was kept separate and preserved for archaeobotanical analyses and radiocarbon dating.

Likewise, level A4II was dated on material collected at the cave entrance and kept distinct per square metre. The sample used for LTL-566A was found in a 3 m long trench opened behind the drip-line. The results of the radiocarbon date are reported in Table 3.

The charcoal samples submitted for  $^{14}\text{C}$ -AMS dating at CEDAD, University of Lecce, Italy underwent a multi-step sample processing intended to remove the contamination from the sample and consisting first of a mechanical cleaning under optical microscope, followed by a chemical procedure consisting of alternate Acid/Alkali/Acid treatments. The purified sample material was dried in an oven and then combusted to  $\text{CO}_2$  at  $900\text{ }^\circ\text{C}$  in sealed quartz tubes together with copper oxide and silver wool. The tubes were then broken under vacuum and the sample  $\text{CO}_2$  was cryogenically transferred to the graphitisation reactors where it was converted at  $600\text{ }^\circ\text{C}$  to graphite by using hydrogen as a reducing medium and iron powder as a catalyst (D'Elia et al., 2004). The graphite was then pressed into the sample holders of the accelerator mass spectrometer where the carbon isotopic ratios were measured by comparing the  $^{12}\text{C}$  and  $^{13}\text{C}$  ion beam currents and the  $^{14}\text{C}$  counts measured for the unknown samples with those obtained for reference materials of known  $^{14}\text{C}$  concentration supplied by IAEA (International Atomic Energy Agency) (Calcagnile et al., 2005). The measured isotopic ratios were then corrected for mass fractionation by using the  $\delta^{13}\text{C}$  term measured on-line with the accelerator and for accelerator and sample processing background and used to calculate the radiocarbon age by the exponential radioactive decay law (Stuiver and Polach, 1977). The measurement uncertainty is given, conservatively, as the larger between the radioisotope counting error (*Poisson Statistics*) and the standard deviation of the nine repeated measurements carried out on each sample.

### 3.3.2. Comments

The three dates obtained for level A4 are consistent with each other. The only date obtained for level A5 of  $33,700 \pm 250$ , is consistent with its stratigraphic position, inserted between level A4 and 1–2 cm above level A6, and is statistically indistinguishable from the age of the uppermost level (A4). The set of dates for A6 presents dispersed values in the 34.4–37.8 radiocarbon ky BP range despite the relatively constrained spatial position of the samples. These have all been taken at the cave entrance in order to avoid the risk of pollution determined by trampling and other perturbations that affected the living floors in the inner zone inside the cave. Thus, no correlation can be found between the measured radiocarbon ages and the square from which the samples come: marked differences can occur within the same square, whereas equivalent dates can be found between adjacent squares.

The single date obtained for horizon A8 fits with its stratigraphic position at the top of unit A9. As a whole, for the A9 assemblage, the dates are highly dispersed and range from 36.5 to 42.8 ky BP in uncalibrated radiocarbon ages. This is regardless of the spatial distribution of the samples, which were taken from different places, such as in the cave entrance, around the drip-line and in the outermost area. In order to avoid pollution risks due to post-depositional disturbance, no charcoal samples were taken for dating from inside the cave, which is currently being excavated. The oldest dated bulk sample comes from the 1990 trench. No correlation can be established between the radiocarbon age and the stratigraphic and spatial position of the samples, with different dates coming from different squares, but also equivalent dates from different squares.

Highly dispersed dates are also recorded for levels A11 and A10 and this is not, in our opinion, imputable to the different horizontal and vertical positions of the samples. The earliest date of A11 comes from an unknown horizontal position, presumably the outermost zone surveyed in 1988,

whereas the LTL-578A and LTL-579A values define an inverted shift with respect to the stratigraphy. The latest date for the A11 group is from the outermost area of the cave. Likewise, both dates obtained from A10 and A10I are from samples taken in the outermost area.

#### 4. Discussion

Current hypotheses about the Middle Palaeolithic–Upper Palaeolithic “transition” in Western Eurasia are still almost exclusively based on  $^{14}\text{C}$  dates (e.g. Bocquet-Appel and Demars, 2000, Conard and Bolus, 2003, d’Errico and Sanchez Goñi, 2003, Jöris et al., 2003, Mellars, 2006), but conspicuous and significant uncertainties in the radiocarbon timescale beyond its present calibration limit of *c.* 26,000  $^{14}\text{C}$  yr BP (NotCal04, IntCal Working Group and Stuiver et al., 1998, and updated on-line data set) still persist and affect the timing of this crucial bio-cultural phase (Conard and Bolus, 2003, Hughen et al., 2004, Jöris et al., 2003, Giaccio et al., 2006).

At Fumane, despite the fine stratigraphic resolution, the chronological reconstruction of the human occurrences is inevitably coarse. This is because the errors (and, therefore, precision) being a function of the mean age of a sample, are not homogeneous but “decrease” towards the upper boundary of the range (Pettitt, 1999). Moreover, the data set obtained for this final Middle Palaeolithic and transitional series overlaps with a considerable portion of the  $^{14}\text{C}$  data set of the earliest Aurignacian layer A2 (Table 4; Cremaschi et al., 2005). As is the case for the Aurignacian data set, the relevant question for the Mousterian data set here relates to the scatter in the dates within a layer. Being taphonomy excluded, different effects can explain this scatter, such as variation in sample processing techniques and contamination by exogenous carbon material. Contamination and the success of radiocarbon pre-treatment chemistry in removing it is a key influence in dating accuracy and for samples of 30 ka or greater, contamination with modern carbon is significant in affecting dates which, as they creep closer to the limit of the technique, tend to cluster and reach an asymptote (at around 40 ka, Chappell et al., 1996), resulting in ages that are more likely to be erroneous and underestimate the true age. Even if it is usually assumed that pre-treatment methods are sufficient to remove the majority of contamination within the dated material, a re-examination of the Middle Palaeolithic–Upper Palaeolithic Fumane sequence using remaining charcoal from previously dated contexts archived at the Oxford Radiocarbon Accelerator Unit and subject them to the ABOx-SC pre-treatment. Further measurements will probably make clearness on the absence of correlation between the radiocarbon age and the stratigraphic and spatial position of the samples, viewed in terms of pedo-sedimentary conditions.

Unit	Lab. number	$^{14}\text{C}$ date	Converted $^{14}\text{C}$ date (cal BP, $1\sigma$ )
A2	UtC-2047	32,100 ± 500	36,556 ± 928
	OxA-11347	30,650 ± 260	34,839 ± 369
	OxA-11360	31,830 ± 260	35,813 ± 437
	UtC-2048	36,500 ± 600	41,597 ± 419
	OxA-8054	33,160 ± 400	37,638 ± 793
	OS-5999***	32,000 ± 90	–
	OS-5871***	32,700 ± 140	–
A2R	LTL-375A	34,312 ± 347	39,695 ± 847

A2 – str. 9	UtC-2044	31,600 ± 400	35,570 ± 562
A2 – str. 10	UtC-2051	32,800 ± 400	37,292 ± 756
A2 – str. 10	UtC-1774	40,000 + 4000/–3000	–
A2 – str. 16	Ly-9920*	31,300 ± 395	35,309 ± 479
A2 – str. 19	Ly-1286 OxA	32,415 ± 1045	36,992 ± 1384
A2 – str. 19	Gr-16231**	33,140 ± 460	37,629 ± 843
A2 – str. 14 top	OxA-6566	31,900 ± 1100	36,506 ± 1438
A2 – str. 14 top	OxA-8052	34,120 ± 460	39,557 ± 954
A2 – str. 14 lev. A	UtC-2688	36,800 + 1200/–1400	41,175 ± 1338
A2 – str. 14 lev. B	UtC-2689	35,400 + 1100/–1300	40,100 ± 1310
A2 – str. 14 lev. B2	UtC-2690	34,200 + 900/–1100	39,052 ± 1496
A2 – str. 14 base	OxA-6465	31,620 ± 500	35,670 ± 669
A2 – str. 14 base	OxA-8053	33,640 ± 440	38929 ± 1467

A complete data set for the Aurignacian sequence has been reported in [Cremaschi et al. \(2005\)](#) and will be discussed in specific upcoming contributions (in preparation). Notes: \*\*date on collagen; \*\*\*date on marine shell; the remaining dates are on charred wood; samples have also been collected from combustion structures 9, 10, 16 and 14 (different levels) and from a concentration of ochre with dispersed charcoals;  $^{14}\text{C}$  ages have been converted to calendar ages by using CalPal2007-HULU Calibration Curve in the CalPal calibration software.

Table 4. The radiocarbon data set of the lowermost Aurignacian layer at Fumane

It also should be pointed out that important breakthroughs emerged recently from studies regarding the variation in the atmospheric  $^{14}\text{C}$  concentration over the past 50,000 yr (Voelker et al., 1998, Voelker et al., 2000, Beck et al., 2001, Van der Plicht et al., 2004, Fairbanks et al., 2005, Hughen et al., 2004, Giaccio et al., 2006). Special relevance is given to the marked changes in geomagnetic field intensity, which occurred during the second half of OIS3. Before Mono Lake, one of the most marked geomagnetic minima was the Laschamp which took place roughly between Greenland Interstadial 10 (GI10) and Heinrich Event 4 (HE4), *c.* 41,000–39,000 GISP2 yr B.P. and which markedly biased the radiocarbon timescale. It is assumed that at the Middle Palaeolithic–Upper Palaeolithic “Transition” this event produced radiocarbon signal ramification, as has been pointed out at Geißenklösterle in the Swabian Jura, where the “Middle Paleolithic Anomaly”, readable in the high variability in the  $^{14}\text{C}$  dates obtained from bones, has been explained by appealing to natural fluctuations in atmospheric radiocarbon (Conard and Bolus, 2003, Conard et al., 2003) rather than invoking taphonomic processes about the mixing and reworking of finds.

Along the sequence from units A4 to A11, dates appear consistent in A4 and A5 units, even if largely overlapped with a part of the Aurignacian data set (see Table 4), and begin to disperse in layer A6 and A5 + A6, A9, A10 and A11. In spite of these scatters, each unit records progressively older ages consistent with the stratigraphic order if we exclude LTL-376A. Although no general agreement exists regarding the extension of the radiocarbon calibration curve beyond the current limit ( $\sim 26$  cal ky BP) of the last internationally accepted calibration data set (IntCal04) (Blackwell et al., 2006), the obtained  $^{14}\text{C}$  ages have been converted to calendar ages by using the CalPal2007-HULU Calibration Curve of the CalPal calibration software with the results being listed in Table 3. A much closer agreement exists between the calibrated radiocarbon ages and the U/Th-ESR combined and TL dates. Furthermore, the

scatter in the data within each layer is much reduced for the calibrated dates compared to the uncalibrated ages.

## **5. Considerations and implications for the Middle Palaeolithic–Upper Palaeolithic bio-cultural scenario in the Northern Adriatic region**

Our estimates using chronometric, lithological and biological data seem to support the hypothesis that the entire late Mousterian stratigraphic sequence from A11 to A4 may cover 10,000 radiocarbon yr. Moreover, a combination of numeric ages with sedimentological and palaeoecological data suggests that the Late Middle Palaeolithic at Fumane is interbedded in sediments formed under moderately cool to mild climatic conditions likely corresponding to the Hengelo-Intersadial, the most significant warm interval in the second half of OIS 3. According to radiocarbon measurements available for Hengelo-Intersadial deposits, this warm interval most likely correlates with interstadial 12 of the Greenland ice cores (GI 12; Jöris et al., 2003; cfr. Dansgaard et al., 1993) and possibly continues until GI 11. At present no pollen data are available from long-term complete sequences in Northern Italy. Recent results from the Azzano × pollen record, a core from the Friulian plain, indicate continuous oscillations in the percentage values of *Pinus*, *Picea*, *Betula*, Graminae and xerophytes, possibly resulting from alternating steppe and taiga environments. According to Donegana et al. (in press), the climate never reached temperatures supporting broad-leaf forests.

In a wider archaeological setting of the northern Adriatic region, Mousterian industries are recorded in the 40–30 ka BP radiocarbon interval in Northern Italy, in Slovenia and Croatia by a variety of radiometric methods ( $^{14}\text{C}$ , U/Th, TL, racemization). Furthermore, the revised direct radiocarbon dates on human remains from Vindjia demonstrate that Neanderthals were present in that region until 32–33 radiocarbon ka BP (Higham et al., 2006) and contribute to drawing the bio-cultural scenario of this region at the very end of the Middle Palaeolithic. Old and new discoveries of human deciduous teeth in Southern Italy seem to suggest that Neanderthals were the makers of the Uluzzian (Gambassini et al., in press), a technocomplex, which might share some typological and technological features with the industry recovered in levels A4 and A3 at Fumane (Peresani et al., in progress).

In the Eastern Italian Pre-Alps a handful of sites have been dated to this interval. At Broion Cave in the Berici Hills the  $^{14}\text{C}$  date of  $40,600 \pm 1270$  BP was obtained for layer I, and a date of  $46,400 \pm 1500$  BP was obtained for the base of the same unit (Leonardi and Broglio, 1966). In the same prealpine fringe, at the Pradis high plateau, the recently discovered Rio Secco Cave provides evidence of final Middle Palaeolithic occupation dated to  $37,790 \pm 360$  radiocarbon yr BP (Peresani and Gurioli, 2007). Further to the south-east, the dated sequence at Fumane is almost contemporaneous with layers B through E1 and E1/E2 of Mujina Pećina, dated between 45 and 34  $^{14}\text{C}$  ka BP (Rink et al., 2002) and with level G3 of Vindija cave in northwestern Croatia, which contains a Mousterian industry and Neanderthal remains (Karavanić and Smith, 1998). This latter level has been recently dated by AMS to over 42  $^{14}\text{C}$  ka BP (Ahern et al., 2004). Recently revised from the technological and typological points of view, the G3 lithic assemblage reveals different features than do earlier Middle Paleolithic assemblages from the same site. In spite of dominant flake technology, there is also evidence of blade and bifacial (retouch) technology, while the Levallois method was not used in this level. This latter method indeed occurs in older Mousterian levels at Vindija (unit K) and at the nearby early Neanderthal site of Krapina (Simek and Smith, 1997). Although some lithic elements and the pattern of raw material use indicate cultural continuity between levels G3 and G1, the abrupt appearance of bone points does not (Karavanić and Smith, 1998). Still, at present, this well-known association in layer G1 of Mousterian artefacts with one leaf-point and Upper Paleolithic tools, including bone points, remains a highly debated and controversial subject (Montet-White, 1996, Kozłowski, 1996, Karavanić and Smith, 1998, Karavanić and Smith, 2000, Zilhão and



D'Errico, 1999, Ahern et al., 2004). Moreover, in terms of lithic raw material, layer G1 comprises less quartz and more chert than do earlier Vindija Middle Paleolithic assemblages. This foreshadows the pattern of raw material use in the Vindija Upper Paleolithic, which is dominated by chert. At Mujina Pécina a cultural sequence including Levallois artefacts in the lower levels E–D and small tools like notches and denticulates in the upper ones C and B found similarities with other sites in the same region and in Montenegro at Crvena Stijena (Rink et al., 2002).

Some scholars (Palma Di Cesnola, 1996, Peretto, 1992, Montet-White, 1996) described the evolution of the final Mousterian industries in the Northern Adriatic region and in the Dalmatian Coast as a continuous process leading to the progressive increase in denticulates vs. the traditional tools in the context of a decreasing utilization of Levallois technology. Advancements and a diverse approach to this type of evidence reveals a cultural mosaic that can be ascribed to the human societies at the very end of the Middle Palaeolithic (Peresani, 2003). Fumane shows how the temporal chronological overlap between Late Middle Palaeolithic and Early Upper Palaeolithic (Broglio and Dalmeri, 2005) contrasts with the site's stratigraphic evidence, which shows no clear indication of contact, exchanges or relationship between Mousterian, Uluzzian and Aurignacian contexts, nor any interstratifications between different cultural types in sequences bracketing the 40–30 ka temporal range (Palma Di Cesnola, 1996).

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## **References**

- J.C.M. Ahern, I. Karavanić, M. Paunović, I. Janković, F.H. Smith. New discoveries and interpretations of hominid fossils and artifacts from Vindija Cave, Croatia. *Journal of Human Evolution*, 46 (2004), pp. 25-65
- M.J. Aitken. *Thermoluminescence Dating*. Academic Press, Oxford (1985)
- J.J. Bahain, Y. Yokoyama, C. Falguères, M.N. Sarcia. ESR dating of tooth enamel: a comparison with K-Ar dating. *Quaternary Science Reviews*, 11 (1992), pp. 245-250
- G. Bartolomei, A. Broglio, P. Cassoli, L. Castelletti, M. Cremaschi, G. Giacobini, G. Malerba, A. Maspero, M. Peresani, A. Sartorelli, A. Tagliacozzo. La Grotte-Abri de Fumane. Un site Aurignacien au Sud des Alps. *Preistoria Alpina*, 28 (1992), pp. 131-179
- J.W. Beck, D.A. Richards, R.L. Edwards, B.W. Silverman, P.L. Smart, D.J. Donahue, S. Herrera-Osterheld, G.S. Burr, L. Calsoyas, A.J.T. Jull, D. Biddulph. Extremely large variations of atmospheric <sup>14</sup>C concentration during the last glacial period. *Science*, 292 (2001), pp. 2453-2458
- J.L. Bischoff, J. Robert, R.J.V. Rosenbauer. A test of Uranium-series dating of fossil tooth enamel: result from Tournal Cave, France. *Applied Geochemistry*, 3 (1988), pp. 145-151
- J.L. Bischoff, R.J. Rosenbauer. Uranium-series dating of human skeletal remains from the Del Mar and Sunnyside sites, California. *Science*, 213 (1981), pp. 1003-1005
- P.G. Blackwell, C.E. Buck, P.J. Reimer. Important features of the new radiocarbon calibration curves. *Quaternary Science Reviews*, 25 (2006), pp. 408-413

- J.P. Bocquet-Appel, P.Y. Demars. Population kinetics in the Upper Palaeolithic in western Europe. *Journal of Archaeological Science*, 27 (2000), pp. 551-570
- B.J. Brennan, W.J. Rink, E.L. McGuirl, H.P. Schwarcz, W.V. Prestwich. Beta doses in tooth enamel by "One Group" theory and the Rosy ESR dating software. *Radiation Measurements*, 27 (1997), pp. 307-314
- A. Broglio, G. Dalmeri (Eds.), *Pitture paleolitiche nelle Prealpi Venete: Grotta di Fumane e Riparo Dalmeri*, Memorie Museo Civico di Storia Naturale di Verona, Sezione Scienze dell'Uomo, vol. 9 (2005)
- A. Broglio, C. Lemorini, M. Peresani, P. Rossetti. Modifications culturelles et comportementales entre Moustérien et Aurignacien au sud des Alpes. J. Brůžek, B. Vandermeersch, M.D. Garralda (Eds.), *Changements biologiques et culturels en Europe de la fin du Paléolithique moyen au Néolithique*, Laboratoire d'Anthropologie des Populations du Passé. Université Bordeaux 1 (2003), pp. 39-59
- L. Calcagnile, G. Quarta, M. D'Elia. High resolution accelerator-based mass spectrometry: precision accuracy and background. *Applied Radiation and Isotopes*, 62/4 (2005), pp. 623-629
- P.F. Cassoli, A. Tagliacozzo. Considerazioni paleontologiche, paleoecologiche e archeozoologiche sui macromammiferi e gli uccelli dei livelli del Pleistocene superiore del Riparo di Fumane (VR) scavi 1988-91. *Bollettino del Museo Civico di Storia Naturale di Verona*, 23 (1994), pp. 85-117
- J. Chappell, J. Head, J. Magee. Beyond the calibration limit in Australian archaeology and Quaternary research. *Antiquity*, 70 (1996), pp. 543-552
- N.J. Conard, M. Bolus. Radiocarbon dating the appearance of modern humans and timing of cultural innovations in Europe: new results and new challenges. *Journal of Human Evolution*, 44 (2003), pp. 331-371
- N.J. Conard, G. Dippon, P. Goldberg. Chronostratigraphy and archaeological content of the Aurignacian deposits at Geißenklösterle. J. Zilhão, F. D'Errico (Eds.), *The Chronology of the Aurignacian and of the Transitional Technocomplexes*, *Trabalhos de Arqueologia*, vol. 33 (2003), pp. 165-176
- M. Cremaschi, F. Ferraro, M. Peresani, A. Tagliacozzo. Il sito: nuovi contributi sulla stratigrafia, la cronologia, le faune a macromammiferi e le industrie del paleolitico antico. *Memorie Museo Civico di Storia Naturale di Verona*, 2<sup>a</sup> serie, Sezione Scienze dell'Uomo, 9
- A. Broglio, G. Dalmeri (Eds.), *Pitture paleolitiche nelle Prealpi Venete: Grotta di Fumane e Riparo Dalmeri* (2005), pp. 12-22
- W. Dansgaard, S.J. Johnsen, H.B. Clausen, D. Dahl-Jensen, N.S. Gundestrup, C.U. Hammer, C.S. Hvidberg, J.P. Steffensen, J. Jouzel, G. Bond. Evidence for general instability of past climate from 250-Kyr ice-core record. *Nature*, 364 (1993), pp. 218-220
- M. D'Elia, L. Calcagnile, G. Quarta, A. Rizzo, C. Sanapo, M. Laudisa, U. Toma. Sample preparation and blank values at the AMS radiocarbon facility of the University of Lecce. *Nuclear Instruments and Methods in Physics Research B*, 223-224 (2004), pp. 278-283
- Donegana, M., Banino, R., Pini, R., Ravazzi, C., Vavassori, E. The Late Pleistocene pollen record of Azzano Decimo (southeastern alpine foreland). In: Pini, R., Ravazzi, C. (Eds.), *Quaternary Stratigraphy and Evolution of the Alpine Region in the European and Global Framework*. *Proceedings of the INQUA-SEQS Meeting*. Quaternary International, in press.

- F. D'Errico, M.F. Sanchez Goñi. Neandertal extinction and the millennial scale climatic variability of OIS 3. *Quaternary Science Reviews*, 22 (2003), pp. 769-788
- R.G. Fairbanks, R.A. Mortlock, T. Chiu, L. Cao, A. Kaplan, T.P. Guilderson, T. Fairbanks, A.L. Bloom, P.M. Grootes, M.J. Nadeau. Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired  $^{230}\text{Th}/^{234}\text{U}/^{238}\text{U}$  and  $^{14}\text{C}$  dates on pristine corals. *Quaternary Science Reviews*, 24 (2005), pp. 1781-1796
- C. Falguères, J.-J. Bahain, H. Saleki. U-series and ESR dating of teeth from Acheulian and Mousterian levels at la Micoque (Dordogne, France). *Journal of Archaeological Science*, 24 (1997), pp. 537-545
- C. Falguères, J.J. Bahain, Y. Yokoyama, J.L. Arsuaga, J.M. Bermudez de Castro, E. Carbonell, J.L. Bischoff, J.M. Dolo. Earliest Humans in Europe: the age of Atapuerca fossils, Spain. *Journal of Human Evolution*, 37 (1999), pp. 343-352
- Ferraro, F., 2002. I riempimenti sedimentari delle cavità carsiche e dei ripari sottoroccia come memoria storica delle variazioni climatiche e paleoambientali del tardo Pleistocene. Unpublished PhD Thesis, XV Cycle, University of Milano.
- I. Fiore, M. Gala, A. Tagliacozzo. Ecology and subsistence strategies in the Eastern Italian Alps during the Middle Palaeolithic. *International Journal of Osteoarchaeology*, 14 (2004), pp. 273-286
- Gambassini, P., Mallegni, F., Ricci, S. Grotta del Cavallo: the finding of a Neanderthal deciduous tooth associated to uluzzian industry. In: *Proceedings of the XV U.I.S.P.P. Congress*, in press.
- B. Giaccio, I. Hajdas, M. Peresani, F. Fedele, R. Isaia. The Campanian Ignimbrite (c. 40 ka BP) and its relevance for the timing of the Middle to Upper Palaeolithic shift: timescales and regional correlations. N.J. Conard (Ed.), *When Neanderthals and Modern Humans met*, International Workshop, Tübingen Publications, Verlag (2006), pp. 343-375
- R. Grün. Electron spin resonance (ESR) dating. *Quaternary International*, 1 (1989), pp. 65-109
- R. Grün, O. Katzenberger-Apel. An alpha irradiator for ESR dating. *Ancient TL*, 12 (1994), pp. 35-38
- R. Grün, F. McDermott. Open system modeling for U-series and ESR dating of teeth. *Quaternary Science Reviews (Quaternary Geochronology)*, 13 (1994), pp. 121-125
- R. Grün, H.P. Schwarcz. Revised open system U-series/ESR age calculations for teeth from Stratum C at the Hoxnian Interglacial type locality, England. *Quaternary Science Reviews*, 19 (2000), pp. 1151-1154
- R. Grün, H.P. Schwarcz, J. Chadam. ESR dating of tooth enamel: coupled correction for U-uptake and U-series disequilibrium. *Nuclear Tracks and Radiation Measurements*, 14 (1988), pp. 237-241
- Gruppioni, G., Falguères, C., Bahain, J.-J., Cremaschi, M., Peresani, M., 2005. ESR and U-series dates of Mousterian and Aurignacian levels at the Fumane Cave (Veneto, Italy) – comparison with radiocarbon and thermoluminescence results. LED05, Cologne, Abstract book.
- K. Hughen, S. Lehman, J. Southon, J. Overpeck, O. Marchal, C. Herring, J. Turnbull.  $^{14}\text{C}$  activity and global carbon cycle changes over the past 50,000 years. *Science*, 303 (2004), pp. 202-207
- T. Higham, Ch. Bronk Ramsey, I. Karavanić, F.H. Smith, E. Trinkaus. Revised direct radiocarbon dating of the Vindija G<sub>1</sub> Upper Paleolithic Neandertals. *Proceedings National Academic of Sciences of the United States of America*, 103/3 (2006), pp. 553-557
- M. Ikeya. A model of linear uranium accumulation for ESR age of Heidelberg (Mauer) and Tautavel bones. *Japanese Journal of Applied Physics*, 22 (1982), pp. L763-L765

- M. Ikeya. *New applications of Electron Spin Resonance: Dating, Dosimetry and Microscopy*. World Scientific, Singapore (1993)
- M. Ivanovich, R.S. Harmon. *Uranium-series Disequilibrium: Application to Earth, Marine and Environmental Science*. (second ed.), Clarendon Press, Oxford (1992)
- O. Jöris, E.Á. Fernández, B. Weninger. Radiocarbon evidence of the Middle to Upper Palaeolithic transition in southwestern Europe. *Trabajos de Prehistoria*, 60 (2) (2003), pp. 15-38
- I. Karavanić, F.H. Smith. The Middle/Upper Paleolithic interface and the relationship of Neanderthals and early modern humans in the Hrvatsko Zagorje, Croatia. *Journal of Human Evolution*, 34 (1998), pp. 223-248
- I. Karavanić, F.H. Smith. More on the Neanderthal problem. *Current Anthropology*, 41 (2000), pp. 838-840
- Kozłowski, J.K., 1996. Cultural context of the last Neanderthals and Early Modern Humans in central-Eastern Europe. In: *Actes XIII Congrès UISPP, Colloquium X The origin of Modern Man*, pp. 205–218, Forlì.
- C. Lemorini, M. Peresani, P. Rossetti, G. Malerba, G. Giacobini. Techno-morphological and use-wear functional analysis: an integrated approach to the study of a discoid industry. M. Peresani (Ed.), *Discoid Lithic Technology. Advances and Implications*, British Archaeological Reports, International Series, vol. 1120 (2003), pp. 257-275
- P. Leonardi, A. Broglio. Datazione assoluta di un'industria musteriana della Grotta del Broion. *Rivista di Scienze Preistoriche*, XXI/2 (1966), pp. 397-405
- M. Martini, E. Sibilia, S. Croci, M. Cremaschi. Thermoluminescence (TL) dating of burnt flints: problems, perspectives and some example of application. *Journal of Cultural Heritage*, 2 (2001), pp. 179-190
- P. Mellars. A new radiocarbon revolution and the dispersal of modern humans in Eurasia. *Nature*, 439 (23) (2006), pp. 931-935
- A. Montet-White. Le Paléolithique en ancienne Yougoslavie. Millon (Ed.), *Préhistoire d'Europa* (1996) 4
- A. Palma Di Cesnola. Millon (Ed.), *Le Paléolithique inférieur et moyen en Italie* (1996) 1
- M. Peresani. La variabilité du débitage Discoïde dans la Grotte de Fumane (Italie du nord). *Paléo*, 10 (1998), pp. 123-146
- M. Peresani. An overview of the Middle Palaeolithic settlement system in North-Eastern Italy. N.J. Conard (Ed.), *Settlement Dynamics of the Middle Palaeolithic and Middle Stone Age*, Tübingen Publications in Prehistory, Verlag (2001), pp. 485-506
- M. Peresani. An initial overview of the middle Palaeolithic discoid industries in Central-Northern Italy. M. Peresani (Ed.), *Discoid Lithic Technology. Advances and Implications*, British Archaeological Reports, International Series, vol. 1120 (2003), pp. 209-223
- Peresani, M. A new cultural frontier for the last Neanderthals: the Uluzzian in Northern Italy. *Current Anthropology*, in press.
- Peresani, M., Gurioli, F., 2007. The Rio Secco Cave, a new final Middle Palaeolithic site in North-eastern Italy. *Eurasian Prehistory*, 5/1, 85–94.

- Peresani, M., Sartorelli, A., 1998. The lithic assemblages at the Cave of Fumane. New evidence of technological variability in the Middle palaeolithic of northern Italy. In: Proceedings of the XIII Congress of the International Union of Prehistoric and Protohistoric Sciences, Forlì, Italy, 2, pp. 269–278.
- C. Peretto. Il Paleolitico medio. A. Guidi, M. Piperno (Eds.), *Italia Preistorica* (1992), pp. 170-197. Laterza
- P. Pettitt. Neanderthal extinction: radiocarbon chronology, problems, prospects and an interpretation of the existing data. J. Evin, C. Oberlin, J.P. Daugas, J.F. Salles (Eds.), *Archéologie et <sup>14</sup>C. Actes du 3ème Congrès International, Revue d'Archéométrie, suppl. 1999* (1999). *Bulletin Société Préhistorique Française, Mémoire*, 26, 165–170
- J.R. Prescott, J.T. Hutton. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. *Radiation Measurements*, 23 (1994), pp. 497-500
- W.J. Rink. Electron spin resonance (ESR) dating and ESR applications in Quaternary science and archaeometry. *Radiation Measurements*, 27 (5–6) (1997), pp. 975-1025
- W.J. Rink, I. Karavanic, P.B. Pettitt, J. Van Der Plicht, F.H. Smith, J. Barstoll. ESR and AMS-based <sup>14</sup>C dating of Mousterian levels at Mujina Pécina, Dalmatia, Croatia. *Journal of Archaeological Science*, 29 (2002), pp. 943-952
- J. Simek, F.H. Smith. Chronological changes in stone tool assemblages from Krapina (Croatia). *Journal of Human Evolution*, 32 (1997), pp. 561-575
- M. Stuiver, H.A. Polach. Discussion: reporting of <sup>14</sup>C data. *Radiocarbon*, 19 (1977), pp. 355-363
- M. Stuiver, P.J. Reimer, E. Bard, J.W. Beck, G.S. Burr, K.A. Hughen, B. Kromer, G. McCormac, J. Van der Plicht, M. Spurk. INTCAL98 Radiocarbon Age Calibration, 24,000–0 cal BP. *Radiocarbon*, 40 (1998), pp. 1041-1083
- H. Valladas. Thermoluminescence dating of flint. *Quaternary Science Review*, 11 (1992), pp. 1-5
- J.W. Van der Plicht, J.W. Beck, E. Bard, M.G.L. Baillie, P.G. Blackwell, C.E. Buck, M. Friedrich, T.P. Guilderson, K.A. Hughen, B. Kromer, F.G. McCormac, C. Bronk Ramsey, O.J. Reimer, R.W. Reimer, S. Remmele, D.A. Richards, J.R. Southon, M. Stuiver, C.E. Weyhenmeyer. NOTCAL04-comparison/calibration <sup>14</sup>C records 26–50 cal kyr BP. *Radiocarbon*, 46 (2004), pp. 1225-1238
- A.H.L. Voelker, P.M. Grootes, M.J. Nadeau, M. Sarthein. Radiocarbon levels in the Iceland Sea from 25–53 kyr and their link to the earth's magnetic field intensity. *Radiocarbon*, 42 (2000), pp. 437-452
- A.H.L. Voelker, M. Sarthein, P.M. Grootes, H. Erlenkeuser, C. Laj, A. Mazaud, M.J. Nadeau, M. Schleicher. Correlation of marine <sup>14</sup>C ages from the Nordic seas with the GISP2 isotope record: implications for radiocarbon calibration beyond 25 ka. *Radiocarbon*, 40 (1998), pp. 517-534
- Y. Yokoyama, C. Falguères, J.P. Quaegebeur. ESR dating of quartz from quaternary sediments: first attempt. *Nuclear tracks*, 10 (1985), pp. 921-928
- J. Zilhão, F. D'Errico. The Neanderthal problem continued: reply. *Current Anthropology*, 40 (1999), pp. 355-364.
- D.W. Zimmermann. Thermoluminescence dating using fine grains from pottery. *Archaeometry* 13, 29–52.