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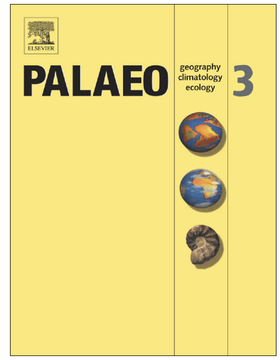

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The De Nadale Cave (Zovencedo, Berici Hills, northeastern Italy): a small-mammal fauna from near the onset of Marine Isotope Stage 4 and its palaeoclimatic implications

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Abstract

Marine Isotope Stage 4 (MIS 4; ca. 71-57 ka) is not well documented in European continental contexts and is characterized mainly by minimum summer insolation, producing a maximum extension of the polar ice caps during the Late Pleistocene together with a lowering of the sea level in the Northern Hemisphere. The De Nadale Cave site, located at an altitude of 130 m a.s.l. in the Berici Hills in northeastern Italy, contains a single archaeological layer (Unit 7) dated to MIS 4. In this paper, we present a palaeoenvironmental and palaeoclimatic reconstruction based on small-mammal (insectivore, bat and rodent) assemblages from this layer. Habitat Weighting and Bioclimatic Model methods were used in order to reconstruct the palaeoenvironmental and palaeoclimatic conditions. The results identify a cold climatic period with a landscape dominated by open woodland formations and open-dry habitats, dating to near the beginning of MIS 4. The findings are consistent with studies of large mammals and previously reported pollen studies in terrestrial sequences of this age in Italy and in cores from the offshore Mediterranean basin. Given the scarcity of terrestrial data for MIS 4, the De Nadale Cave constitutes an important site for our knowledge of the environment and climate of this period.

Keywords: Insectivores, Bats, Rodents, Palaeoenvironment, Palaeoclimate, Neanderthals

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1. Introduction

Marine Isotope Stage 4 (MIS 4) is a stage of short duration, lasting about 14 kyr between ca. 71-57 ka (Obrochta et al. 2014). It began with a cooling episode called MIS 5/4 or the D-O 19 transition, which commenced with a rapid increase in $\delta^{18}O$ isotope values, followed by a gradual cooling (Boch et al. 2011). In general, this period is characterized by minimum summer insolation in the Northern Hemisphere, which produced a maximum extension of the polar ice caps during the Late Pleistocene, together with a lowering of the sea level a hundred metres beneath current levels and ocean temperatures up to 10 ºC lower than current temperatures (Sánchez-Goñi and d'Errico 2005). It is reflected in the western Mediterranean sea core of the Alboran Sea by a progressive decrease in sea-surface temperatures (SST) and a progressive increase in semi-desert plants detected in pollen samples (Sánchez-Goñi and d'Errico 2005). Even though MIS 4 is characterized by a predominately stable cold climate (Rasmussen et al. 2014) and was a stage of short duration, at least one interstadial period has been detected, Greenland Interstadial 18 (GI 18), around 64 ka (Landais et al. 2004, 2007). This interstadial is characterized by a warming of the sea surface, probably related with an increase in humidity, but this is not reflected in an increase in temperatures on the continent (Sánchez-Goñi and d'Errico 2005).

The De Nadale Cave, located in the northeastern region of Italy, is one of the few terrestrial caves believed to be associated with MIS 4. The present paper aims to undertake an environmental and climatic reconstruction based on the small-mammal assemblages (insectivores, bats and rodents) in the cave site. The findings are compared with previous ecological studies based on large mammals (Jéquier et al. 2015; Livraghi 2015) and pollen studies undertaken at continental lakes in northeastern Italy (Pini et al. 2009, 2010). Finally, although there are no other sites with small-mammal assemblages for this chronological time span, we also draw comparisons with the micromammal assemblages recovered from two sites located in the close vicinity (Berici Hills) of the De Nadale Cave with a chronology falling immediately beforehand (MIS 5; Grotta Maggiore di San Bernardino) (López-García et al. 2017) and afterwards (MIS 3; Grotta del Broion) (Colamussi 2002; Berto 2013).

2. De Nadale Cave

The De Nadale Cave is located at 130 m a.s.l., with geographical coordinates of 45º 26’ N and 11º 30’ E, and opens to the south on a small cliff oriented west-east in the middle of the Berici Hills, a karst plateau in the sub-alpine region of northeastern Italy (Fig. 1A-B). The present-day landscape is an ensemble of markedly different morphological zones. Above the cave at an average elevation of 250 m, the karst plateau forms a gentle honeycomb with sinkholes and depressions (including *ponors* and limestone pavements), delineating an extremely uneven topography with peaks and blockkarst affected by surface dissolution. The De Nadale Cave is situated in an area where the plateau is dissected by the Calto valley-bottom, a depressed system with pocket-valleys where two ephemeral streams temporarily produce a swampy environment and fed mills in historical times (Fig. 1A). The slopes are steep all around. To the east, the Pozzolo depression is a wide trench cutting through the plateau in a NW-SE direction and with an elevation of 150 metres at both the SE and NW ends (Fig. 1A). It is the relict segment of a previous valley crossing the relief, cut by a river during the first uplift phases of this morphological unit. The ancient karst surface is covered with palaeosols and thick red clayey residual deposits (Sauro 2002).

Archaeological excavations started at the De Nadale Cave site in 2013, following the discovery of bones and lithics scattered over the surface by burrowing animals. In 2014, two excavation campaigns were undertaken, and a 1.5 x 1.5 m pit was opened in the western zone of the cavity. These excavations exposed a short stratigraphic sequence, including a single Middle Palaeolithic anthropic layer (Unit 7) sandwiched by archaeologically sterile levels (Units 3, 6 and 8) (Fig. 1C). Unit 3 is a thick layer alternating between a stone-supported layer and stony loamy textured layers; Unit 6 is a stone-supported breccia composed of large sub-angular and tabular blocks, with a sub-horizontal disposition; Unit 7 comprises dark brown-grey silt loam with a crumbly aggregation and medium- to small-sized stones (Fig. 1D) and has yielded a deciduous Neanderthal tooth (Arnaud et al. 2017), as well as a large-mammal assemblage mainly composed of herbivores such as giant deer (*Megaloceros giganteus*), red deer (*Cervus elaphus*) and bovids (*Bos primigenius* and *Bison priscus*), with scarce carnivores. Knapped flint in association with the abundant bone tools recovered from this layer have been attributed to the Quina-Mousterian culture. Uranium-series (U-Th) dating of a bison tooth provides a minimum age of 70.2 +1/-0.9 ka for Unit 7 (Jéquier et al.

2015); Unit 8 is a loose stone-supported breccia with a silt-clay matrix and stones coated with blackish iron and manganese stains on their upper faces. Contact with the bedrock is affected by active dissolution and limited by residual clay.

3. Material and methods

3.1. Small-mammal sorting and the palaeontological and taphonomic study

The small-mammal fossil remains used for this study are disarticulated bone fragments and isolated teeth collected by water-screening the sediments from the excavation campaigns performed in 2014-2015 and 2017 using a 2-mm mesh screen. The material was processed, sorted and classified in the following research institutions, where it is also accessioned: the Sezione di Scienze Preistoriche e Antropologiche, Università degli Studi di Ferrara (Ferrara, Italy) and the Institut de Paleoecologia Humana i Evolució Social (IPHES, Tarragona, Spain). The assemblage includes a total of 201 identified specimens, corresponding to a minimum of 112 individuals, representing at least 13 taxa (Table 1; Fig. 2).

The fragments were identified following the general criteria given by Berto (2013) and López-García (2011) for insectivores and rodents, and by Felten et al. (1973), López-García (2011) and Sevilla (1988) for bats. The specific attribution of this material is based principally on the most diagnostic elements (Sevilla 1988; López-García 2011; Berto 2013): mandible for shrews; mandible, isolated teeth and humerus for Talpidae; humerus for bats; first lower molars for Arvicolinae; and mandible and isolated teeth for *Apodemus* spp. (Appendix A1). Moreover, the fossils were grouped using the minimum-number-of-individuals (MNI) method, by means of which we determined the sample by counting the most represented diagnostic elements (Sevilla 1988; López-García 2011; Berto 2013).

The preliminary taphonomic study of the small mammals is based on the descriptive and systematic method for studying the changes resulting from predation (Andrews 1990; Fernández-Jalvo et al. 2016). For this preliminary study, the alterations caused by digestion present in the first lower molars of the arvicoline rodent species were observed and described (Table 2), allowing us to identify and recognize the action of predation.

3.2. Palaeoenvironmental reconstruction

In order to reconstruct the palaeoenvironment at the De Nadale Cave, we used the method of habitat weightings (Evans et al. 1981; Andrews 2006), distributing each small-mammal taxon in the habitat(s) where it can be found at present in the Italian Peninsula. Habitats are divided into six types, five of them in accordance with Cuenca-Bescós et al. (2005, 2009), Blain et al. (2008) and López-García et al. (2010): open land, in which dry and wet meadows are distinguished, woodland and woodland margin areas, rocky areas and areas surrounding water; finally, a new habitat type is included, open woodlands (López-García et al. 2014). These types are detailed as follows (Table 1): open dry denotes meadows under seasonal climate change; open humid, evergreen meadows with dense pastures and suitable topsoil; open woodland, woodland margins and forest patches, with moderate ground cover; woodland, mature forest; water, areas along streams, lakes and ponds; and rocky, areas with a suitable rocky or stony substratum.

3.3. Palaeoclimatic reconstruction

The Italian Peninsula extends between 35ºNand 47ºN, within the range of a humid-temperate mesothermal climate. Italy is one of the most mountainous areas in Europe, and these mountains play a major role in the characterization of its climatic diversity. Climatic conditions can change abruptly over a few tens of kilometres, from the mildness of the marine coast to the harshness of coastal mountain summits, and from the temperate semi-continental conditions of the Po Plain to the harshness of the inner Alps. The taxonomic composition of the rodent assemblage allows us to evaluate the climatic conditions despite this high variability. In order to assess the palaeoclimatic data from the De Nadale Cave, we used the bioclimatic model established by Hernández-Fernández (2001a, 2001b). This method is based on the hypothesis that a significant correlation exists between climate and mammal communities. According to Hernández-Fernández (2001a, 2001b), Hernández-Fernández and Peláez-Campomanes (2005) and Hernández-Fernández et al. (2007), mammal assemblages can be assigned to ten climate types, five of which are represented by the rodent assemblage of the De Nadale Cave. This assemblage was analysed using the Climatic Restriction Index (CRIi= 1/n, where “n” is the number of climatic zones where the species are represented and “i” is the climatic zone where the species appears) (Table 3). The climate types in question are: IV Subtropical with winter rains and summer droughts; VI Typical temperate; VII Arid temperate;VIII Cold-temperate (boreal) and IX Polar. After obtaining this distribution, the Bioclimatic Component (BC; representation by level of each of the five available climates) was calculated using the following formula: BCi= (∑CRIi) X 100/S, where S is the number of species per unit at the De Nadale Cave (Table 3). From the BC, a mathematical model was elaborated using a multiple linear regression (Hernández-Fernández and Peláez-Campomanes 2005); by means of a seriesof functions, this allows various climatic parameters to be estimated (Appendix A2). On the basis of this method, four climatic factors are estimated: the mean annual temperature (MAT), the mean temperature of coldest month (MTC), the mean temperature of warmest month (MTW) and the mean annual precipitation (MAP). These parameters are compared with the present-day data (from over a period of 30 years) from the meteorological station of Barbarano Vicentino (45º 25' N,11º32'E), which is situated at 135 m a.s.l. For the area around the De Nadale Cave, the current data show that MAT =12.9ºC, MTC = 2.2 ºC, MTW = 23.2 ºC and MAP =902 mm (Climate-Data.org).

4. Results and discussion

4.1.Taphonomic remarks

A total of 162 arvicoline first lower molars from Unit 7of the De Nadale Cave were studied, representing 80.6 % of the total number of identified specimens (NISP)for this unit. A significant percentage of the molars analysed (i.e. 22 %) show an abnormal morphology due to digestion, indicating that the accumulation is associated with predation (Table 2). The high percentage of teeth without alteration shows that the main agent responsible for the accumulation was probably a category 1 or 2 predator, with a light to intermediate capacity for modification. Several nocturnal birds of prey, according to Andrews (1990), fall within these categories. Unfortunately, at present there are no birds of prey identified among the avifauna recovered from Unit 7, and it is not possible to ascribe the small-mammal accumulation to a specific predator. However, in general these kinds of predator do not display a specific prey consumption pattern (Andrews 1990). Thus, palaeoecological interpretations based on the relative abundance of the small-mammal taxa from Unit 7 are reliable indicators of the habitat where the hunting predators consumed their prey.

4.2.Small-mammal composition of the De Nadale Cave

The small-mammal assemblage of Unit 7 is dominated by the common vole *Microtus arvalis* (38 individuals), the field vole *Microtus agrestis* (21 individuals), the northern water vole *Arvicola amphibius* (14 individuals),and to a lesser extent by the snow vole *Chionomys nivalis* (9 individuals) and the common-Apennine shrew *Sorex* gr. *araneus-samniticus* (6 individuals). These five taxa represent 78.6 % (88 individuals) of the total minimum number of individuals (112 individuals) (Table 1). *M. arvalis* is the most abundant species. Unfortunately, there are no reliable data on small-mammal assemblages from MIS 4 in Italy. However, an abundance of *M. arvalis* is well reported in periods immediately before and after MIS 4. In MIS 5 *M. arvalis* is abundant in the Caverna degli Orsi in the Trieste Karst (Berto and Rubinato 2013), Ciota Ciara in Piedmont (Berto et al. 2016) and Grotta Maggiore di San Bernardino (López-García et al. 2017). Subsequently, large numbers of this species are observed at MIS 3 in Grotta del Broion (Colamussi 2002), Grotta Maggiore di San Bernardino (López-García et al. 2017), Grotta Minore di San Bernardino (Bartolomei and Broglio 1964) and Fumane cave (López-García et al. 2015), Riparo Mochi in the Ligurian Alps (Berto 2013) and Grotta di Castelcivita (Massini and Abazzi 1997), Grotta Paglicci (Berto et al. 2017) and Grotta Reali (Sala et al. 2012) in the southern Apennines. The presence of *M. arvalis* is currently reported to be higher in open areas and relatively drier regions of northern Italy (Amori et al. 2008).It is also remarkable that of the most abundant species identified in Unit 7 of the De Nadale Cave, *C. nivalis* and *M. agrestis* are currently found at altitudes over 1000 m in the Veneto region (Bon et al. 1996), suggesting that harsh climatic conditions prevailed at the time when the accumulation of the small-mammal association of Unit 7 of the De Nadale Cave was being formed.

4.3.Palaeoenvironmental and palaeoclimatic reconstructions

By comparison with current climatic data (Table 4), the bioclimatic model characterized the climate as colder (ΔMAT = -5.04 ºC) and relatively humid (ΔMAP = +560.11 mm), yet with a more pronounced continentality: the winters were rather similar to present-day winters (ΔMTC = -1.73 ºC) but the summers were colder (ΔMTW = -6.94 ºC).Taking into account the chronological placement of Unit 7 (70.2 +1/-0.9 ka), this could correspond to the end of MIS 5a and the beginning of MIS 4 (Fig. 3).These data are also concordant with the predominance of species associated with climate categories VI (typical temperate, related with a temperate deciduous forest) and VIII (cold-temperate, related with a boreal coniferous forest), representing more than 80% of BC (Table 3).

The habitat weighting reconstruction suggests a landscape dominated by open woodland formations (ca. 35%),as represented by all the species identified, and rocky-open dry habitats (ca. 35%), mainly represented by two of the most abundant species, *M. arvalis* and *C. nivalis* (Appendix A3). These data are also corroborated by the most abundant large-mammal taxa represented from this layer, bison and large-sized cervids, which are commonly found in open grasslands (Jéquier et al. 2015). Despite this, a good representation of open humid meadows (ca. 16%) and water streams (ca. 13 %) is observed (Appendix A3), mainly shown by the presence of the vole species *M. agrestis* and *A. amphibius*. This landscape reconstruction fits with the present-day surroundings of the cave, where dry karst areas are interspersed with humid valley bottoms and rocky areas and slopes. The low temperatures of the warmest months (ΔMTW= -6.94 ºC) in relation to current temperatures ($MTW_{BarbaranoVicentino}$= 23. 2 ºC) and the high percentage of open dry habitats (ca. 35%) detected in Unit 7 of the De Nadale Cave are in accordance with the general trend of MIS 4 detected in the western Mediterranean cores of the Alboran sea, with minimum values for summer insolation and a progressive increase in semi-desert plants detected in pollen samples (Sánchez-Goñi and d'Errico 2005).

Moreover, our data fit with the Italian terrestrial pollen sequences from Fimon Lake core in Berici Hills (Pini et al. 2010) and Azzano Decimo core in Friuli (Pini et al. 2009), revealing for MIS 4 in general a mosaic of open forest and steppe with a predominance of *Pinus-Picea* (pine-fir tree) and an abundance of *Betula* (birch) and herbaceous plants of the genus *Artemisia*.

Although all the data expounded above are consistent with MIS 4, it cannot be ruled out that Unit 7, given its chronological range, may belong to the end of MIS 5. In fact, the environmental and climatic results obtained for Unit 7 are very similar to those obtained for Unit IV of Grotta Maggiore di San Bernardino, with a predominance of open woodland formations and open dry meadows in a cold climate; the species abundance of the two units is also coincident, with *M. arvalis, M. agrestis* and *A. amphibius* dominating the small-mammal association (López-García et al. 2017). Unit IV of Grotta Maggiore di San Bernardino is located at the end of MIS 5 or beginning of MIS 4, with an ESR-dating to 83 ±18 ka (Gruppioni 2003).

Finally, although there are no reliable small-mammal data for MIS 4, the micromammal assemblages from the MIS 3 layers of the Grotta del Broion (Berto 2013), which is also in the close vicinity of the De Nadale Cave, show a predominance of *M. arvalis* and *M. agrestis* in cold periods. This is also consistent with the abundance in Unit 7 of the open grassland large-mammal species *Bison priscus* (steppe bison) and *Megaloceros giganteus* (giant deer) (Jéquier et al. 2015; Livraghi 2015).

5. Conclusions

The De Nadale Cave constitutes an important site for our knowledge of the environment and climate of MIS 4, taking into account the scarcity of terrestrial data for this period. On the basis of an assemblage composed of insectivores, bats and rodents, our analysis enables the following conclusions to be drawn:

1) The assemblage includes a total of 201 identified specimens, corresponding to a minimum of 112 individuals, representing at least 13 taxa: 4 insectivores (*Talpa* cf. *T. europaea*, *Sorex* gr. *araneus-samniticus*, *Sorex minutus* and *Neomys* cf. *anomalus*); one bat (*Myotis* sp.) and 8 rodents (*Arvicola amphibius*, *Microtus arvalis*, *Microtus agrestis*, *Microtus* (*Terricola*) gr. *multiplex-subterraneus*, *Chionomys nivalis*, *Clethrionomys glareolus*, *Apodemus sylvaticus* and *Apodemus flavicollis*).

2) The preliminary taphonomic data based on the digestive alterations present in 162 first lower molars of arvicoline rodent species suggest that the main agent responsible for the bone accumulation was probably a category 1 or 2 predator with a light to intermediate capacity for modification.

3) The palaeoenvironmental and palaeoclimatic data identify a phase associated with a cold climate, with a landscape dominated by open woodland formations and open dry meadows. Taking into account the chronology of the site, this could be associated with the end of MIS5 or the beginning of MIS 4.

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Figure 1. Geographic and stratigraphic context. A) Location of the De Nadale Cave (Jéquier et al. 2015), Italy, and the other sites mentioned in the manuscript: 1) Grotta di San Bernardino (López-García et al. 2017), 2) Grotta del Broion (Berto 2013), 3) Fimon lake, pollen core (Pini et al. 2010), 4) Grotta di Fumane (López-García et al. 2015), 5) Azzano Decimo, pollen core (Pini et al. 2008). Shades of grey indicates the altitudinal range above sea level; white (0-600 m), grey-light (600-1000 m), grey-dark (+ 1000 m); B) Picture of the De Nadale Cave positioned at mid-elevation on the southern slope of Monte Spiadi, indicated by the black arrow (taken by Prof. Peresani); C) N-W section of the De Nadale Cave showing Unit 7 sandwiched by non-fossiliferous deposits (according to Jéquier at al. 2015); D) Drawing of the W stratigraphic section; dotted lines indicate the roof and the bedrock of the cave (according to Jéquier et al. 2015).

Figure 2. Some small mammals identified from Unit 7 at the De Nadale Cave. A. *Neomys* cf. *N. anomalus* left mandible (CN2015/P12d/US7), posterior (1) and lingual (2) views; B. *Sorex* gr. *araneus-samniticus* left mandible (CN2014/N11b/US7),buccal view; C. *Sorex minutus* right mandible (CN2017/P13e/US7), lingual view; D. *Arvicola amphibius* left m1 (CN2014/N11i/US7), occlusal view; E. *Clethrionomys glareolus* left m1 (CN2014/N10c/US6-7), occlusal view; F. *Microtus arvalis* left m1 (CN2014/O11e/US7), occlusal view; G. *Chionomys nivalis* left m1 (CN2015/P10i/US7-8), occlusal view; H. *Microtus agrestis* right m1 (CN2014/N11e/US7), occlusal view; I. *Microtus* (*Terricola*) gr. *multiplex-subterraneus* right m1 (CN2014/M12b/US7), occlusal view; J. *Apodemus* cf. *flavicollis* right m1 (CN2014/M12h/US7), occlusal view. All scale bars = 1mm. Small-mammal material is deposited at Sezione di Scienze Preistoriche e Antropologiche dell'Università degli Studi di Ferrara (Ferrara, Italy)

Figure 3. Position of Unit 7 of the De Nadale Cave (grey bar) in relation to the benthic ^{18}O curve (modified from Lisiecki and Raymo 2005). GI represents the Greenland Interstadials. ΔMAT is the mean annual temperature; ΔMTC is the mean temperature of the coldest month; ΔMTW is the mean temperature of the warmest month; ΔMAP is the mean annual precipitation, all in relation to the present mean values as measured at the Barbarano Vicentino meteorological station. O. Woodland is the percentage representation of open woodland landscape in Unit 7 of the De Nadale Cave. Ro+O.Dry is the percentage representation of rocky and open dry habitats in Unit 7 of the De Nadale Cave.

Table 1. Representation of the number of identified specimens (NISP), minimum number of individuals (MNI) and the percentage of the MNI (%) for the small vertebrates from Unit 7 of the De Nadale Cave and the small-vertebrate distribution by habitat. OD, open dry; OH, open humid; OW, open woodland; Wo, woodland/woodland-edge; Ro, rocky; Wa, water.

Table 2. Percentages of arvicoline lower first molars from Unit 7 at the De Nadale Cave showing different degrees of digestion.

Table 3. Distribution of the rodent species identified from Unit 7 at the De Nadale Cave according to their climate preferences, in accordance with Hérnandez-Fernández (2001b) and Hérnandez-Fernández et al. (2007).IV Subtropical with winter rains and summer droughts; VI Typical temperate; VII Arid-temperate; VIII Cold-temperate (boreal); IX Polar. CRI: Climatic Restriction Index; Bc: Bioclimatic component.

Table 4.Relation of temperature and precipitation for Unit 7 of the De Nadale Cave; MAT, mean annual temperature; MTW, mean temperature of warmest month; MTC, mean temperature of coldest month; MAP, mean annual precipitation; r^2, determination coefficient; SE, standard error; current values from Barbarano Vicentino meteorological station; Δ: difference between the values obtained by analysing rodents from Unit 7 of the De Nadale Cave and the present-day mean.

Table 1

	NISP	MNI	%	OD	OH	OW	Wo	Ro	Wa
Talpa cf. *T. europaea*	4	1	0.89		0.5	0.5			
Sorex gr.*araneus-samniticus*	14	6	5.36		0.75	0.25			
Sorex minutus	2	2	1.79		0.25		0.75		
Neomys cf. *N. anomalus*	1	1	0.89						
Myotis sp.	1	1	0.89						
Arvicola amphibius	23	14	12.50						1
Microtus arvalis	70	38	33.93	0.75		0.25			
Microtus agrestis	41	21	18.75		0.5	0.5			
Microtus arvalis-agrestis	2	2	1.79						
Terricola gr. *multiplex-subterraneus*	3	2	1.79		0.5	0.5			
Chionomys nivalis	16	9	8.04					1	
Clethrionomys glareolus	7	5	4.46			1			
Apodemus sylvaticus	6	3	2.68			1			
Apodemus flavicollis	6	4	3.57			1			
Apodemus gr.*sylvaticus-flavicollis*	5	3	2.68			1			
Total	**201**	**112**	**100**	**0.75**	**2.5**	**6**	**0.75**	**1**	**1**

Table 2

	A. amphibius	*M.arvalis*	*M.agrestis*	*M. arvalis-agrestis*	*M. (T.) multiplex-subterraneus*	*C. nivalis*	*C.glareolus*	**Total**	**%**
Absent	13	62	27	1	3	14	7	**127**	**78.4**
Light-moderate	5	6	8	0	0	1	0	**20**	**12.3**
Severe	4	1	6	0	0	1	0	**12**	**7.4**
Extreme	1	1	0	1	0	0	0	**3**	**1.9**
Total	**23**	**70**	**41**	**2**	**3**	**16**	**7**	**162**	**100**

Table 3

	IV	VI	VII	VIII	IX
Arvicola amphibius	0.25	0.25	0.25	0.25	
Microtus arvalis		1			
Microtus agrestis		0.5		0.5	
Terricola gr. *multiplex-subterraneus*		1			
Chionomys nivalis	0.25	0.25		0.25	0.25
Clethrionomys glareolus		0.5		0.5	
Apodemus sylvaticus	0.5	0.5			
Apodemus flavicollis		1			
Σ CRI	**1**	**5**	**0.25**	**1.5**	**0.25**
Bci=(Σ CRIi)100/S	**12.5**	**62.5**	**3.125**	**18.75**	**3.125**

Table 4

	Nadale Cave	r^2	SE	Current	Δ
MAT	7.86	0.93	3.637	12.9	-5.04
MTW	16.26	0.746	4.754	23.2	-6.94
MTC	0.47	0.932	5.081	2.2	-1.73
MAP	1462.11	0.746	470.615	902	560.11

Highlights

MIS 4 is a short duration stage that is not well documented in continental contexts

The De Nadale Cave is a site with a single archaeological layer dating to MIS 4

Small-mammal used for the palaeoenvironmental and palaeoclimatic reconstruction

The results enable us clearly to identify a cold climatic period in the MIS 4

And a landscape dominated by open woodland formations and open-dry habitats

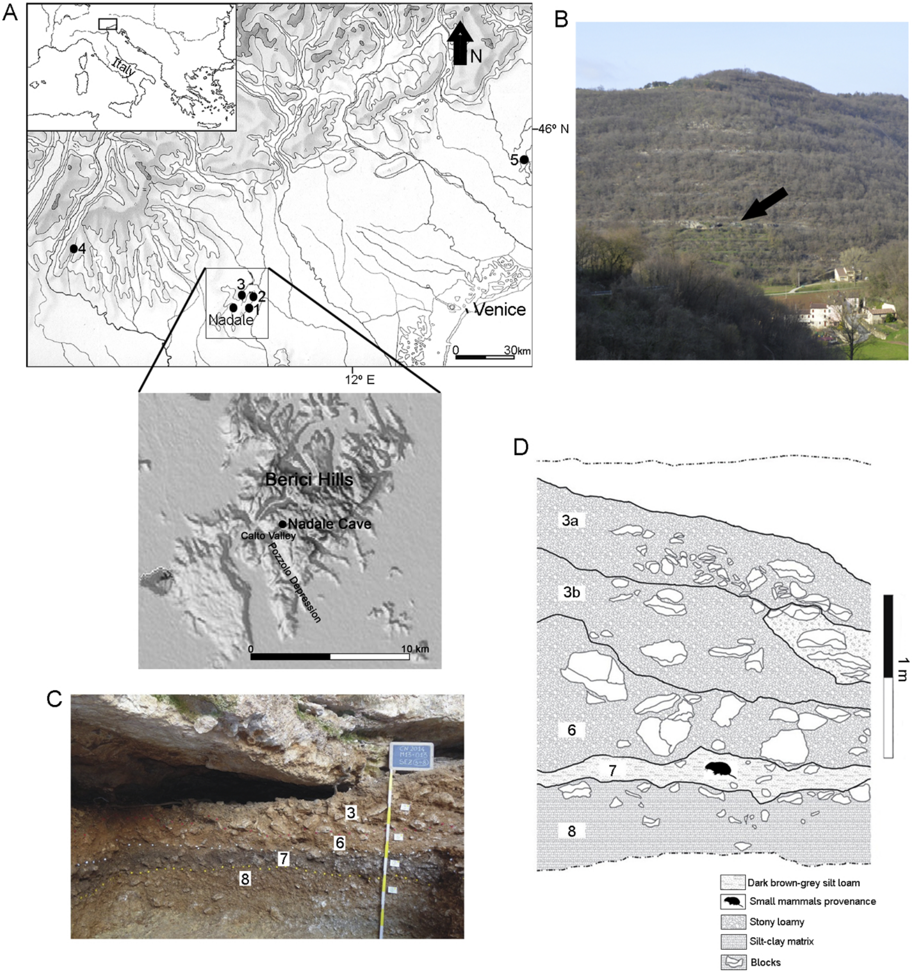

A
Italy
N
46° N
5
4
3
2
1
Nadale
Venice
0
30km
12° E
Berici Hills
Nadale Cave
Calto Valley
Pozzolo Depression
0
10 km
B
C
3
6
7
8
D
3a
3b
6
7
8
1 m
Dark brown-grey silt loam
Small mammals provenance
Stony loamy
Silt-clay matrix
Blocks

Figure 1

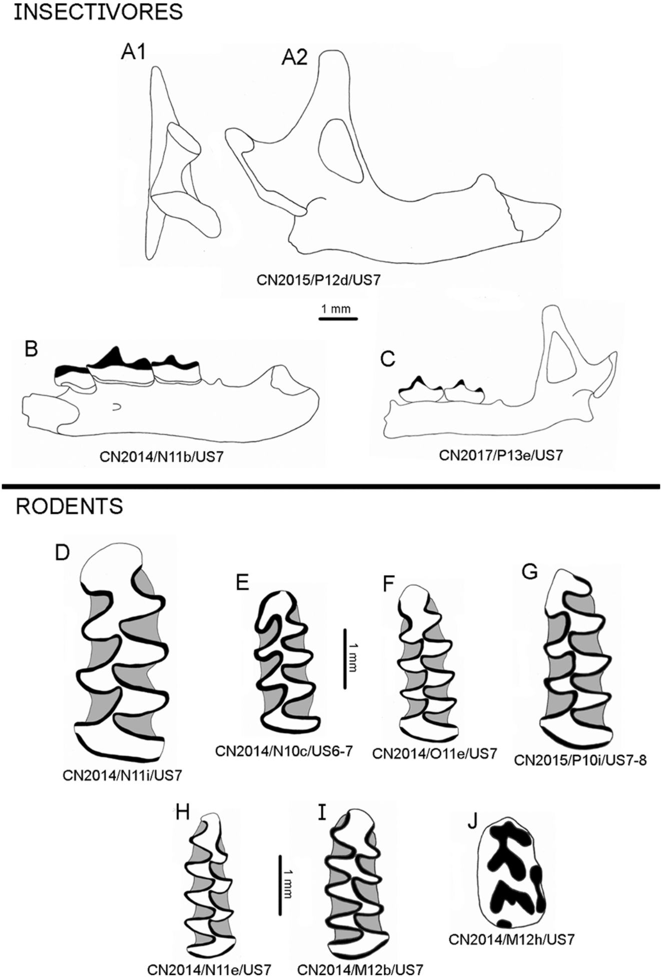
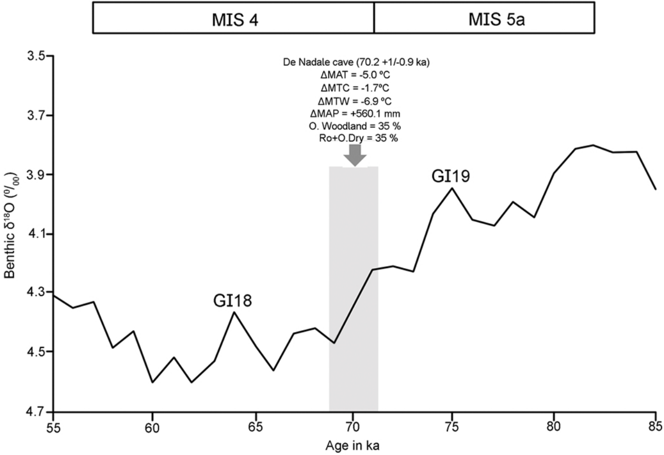

INSECTIVORES
A1
A2
CN2015/P12d/US7
1 mm
B
CN2014/N11b/US7
C
CN2017/P13e/US7
RODENTS
D
CN2014/N11i/US7
E
CN2014/N10c/US6-7
1 mm
F
CN2014/O11e/US7
G
CN2015/P10i/US7-8
H
CN2014/N11e/US7
1 mm
I
CN2014/M12b/US7
J
CN2014/M12h/US7

Figure 2



MIS 4
MIS 5a
De Nadale cave (70.2 +1/-0.9 ka)
ΔMAT = -5.0 ºC
ΔMTC = -1.7ºC
ΔMTW = -6.9 ºC
ΔMAP = +560.1 mm
O. Woodland = 35 %
Ro+O.Dry = 35 %
GI19
GI18
Benthic δ18O (0/00)
3.5
3.7
3.9
4.1
4.3
4.5
4.7
55
60
65
70
75
80
85
Age in ka

Figure 3