OVERVIEW ON THE CAVE BEARS FROM THE "BUCO DEL FRATE" CAVE (BRESCIA PROVINCE, LOMBARDY, ITALY): MORPHOMETRY AND MORPHODYNAMIC OF THE SKULLS, MANDIBLES AND TEETH

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Key words - *Ursus* ex gr. *spelaeus*, Buco del Frate, uni-and multivariate analysis, Late Pleistocene

Abstract - The cave bear populations coming from the Eastern area of Lombardy have not been thoroughly studied. In order to partially fill this gap the skulls, mandibles and teeth from the Buco del Frate Cave (Brescia province) have been analysed with an univariate and multivariate approach and compared with the data from other Italian, European and Caucasian caves. The results are consistent with what can be seen in the other Italian populations, where the cave bears exhibit a mix of primitive (skull and mandible size) and advanced features (teeth shape and indices). In particular, the range of the P4/4 indices of Italian populations is very similar to that of medium-sized species of the Alpine region like *U. s. eremus* and *U. s. ladinicus*. However the lack of genetic analysis makes it impossible to place these bears within a precise taxon.

Parole chiave - *Ursus* ex gr. *spelaeus*, Buco del Frate, analisi univariata e multivariata, Pleistocene superiore

Riassunto - Studio degli orsi delle caverne del Buco del Frate (Brescia, Lombardia, Italia): morfometria e morfodinamica di crani, mandibole e denti. - Gli orsi delle caverne del settore orientale della Lombardia non sono stati, ad oggi, intensamente studiati; per ridurre almeno parzialmente questa lacuna si propone un'analisi univariata e multivariata che ha coinvolto i crani, le mandibole e i denti provenienti dal Buco del Frate (Brescia). La popolazione ad orsi è stata confrontata con altre provenienti da località italiane, europee e caucasiche. Gli orsi del Buco del Frate mostrano, come le altre popolazioni italiane, un mix di caratteri primitivi (specialmente relativi al cranio e alle mandibole) e più moderni nei denti e negli indici corrispondenti. In particolare il range degli indici P4/4 delle popolazioni italiane è molto simile a quello di taxa delle regioni alpine come *U. s. eremus* e *U. s. ladinicus*. La mancanza di analisi genetiche impedisce, purtroppo, di assegnare ad uno o più taxa gli orsi delle caverne dal Buco del Frate.

INTRODUCTION

Cave bears (*Ursus ex gr. spelaeus*, Rosenmüller, 1794) are one of the main components of Middle-Late Pleistocene megafauna from Europe as testified by the large amount of remains found in the caves of the entire continent. Starting from the 2000s the advancements in DNA-analysis technologies has allowed numerous modifications of the phylogenetic tree of the cave bears, uncovering the existence of new taxa: *U. ingressus* in Eastern and Central Europe, *U. spelaeus spelaeus* in Western Europe, *U. s. eremus* and *U. s. ladinicus* in the Alpine region and *U. kanivetz* in Russia (Rabeder, 1991; Rabeder *et al.*, 2004; 2010; Frischauf *et al.*, 2017; Baryshnikov & Puzachenko, 2019; Gimranov *et al.*, 2021 and others). In Italy cave bear fossils have been found in the following regions: Liguria, Piedmont, Lombardy, Veneto, Trentino-Alto Adige, Friuli Venezia Giulia and Tuscany. However only the populations of Cima Conturines (Bolzano, the highest cave in Europe, 2800 meters a.s.l.), Trene and Paina (Vicenza) have had their DNA studied. The lack of DNA analyses stops us from putting Italian cave bears within a precise taxon. The aim of this paper is to give an overview of the anatomical features of the population coming from the Buco del Frate Cave (Brescia Province) through morphometric analysis of skulls, mandibles and teeth and morphodynamic analysis of the teeth surfaces. The importance of this cave is caused by its position as a meeting point between the Northwest and the Northeast of the Italian Alps (Rossi & Santi, 2013).

GEOGRAPHY AND GEOLOGY OF THE BRESCIA PROVINCE AND THE BUCO DEL FRATE

That part of the Lombardian Prealps between the western shore of Lake Garda and the city of Brescia is known as the 'Carso Bresciano' ('Brescian Karst') due to the types of outcropping rocks, mostly Mesozoic limestones (Corna Formation), which over the course of millions of years have developed karst phenomena so intense as to recall the Carso area in Friuli Venezia Giulia (Vailati, 2003). The intense karst activity has acted on different levels, both superficial and deeply underground: the deep phenomena have given rise to a complex system of caves and sinkholes still not fully explored today. The caves and sinkholes of this area function (and, indeed, have so functioned for hundreds of thousands of years) as sedimentary traps (Cremaschi, 2000), trapping huge quantities of sediments and fossils from at least the Middle Pleistocene onwards. Buco del Frate is the first cave of the Speleological Land Register of Lombardy ('Lo1') and

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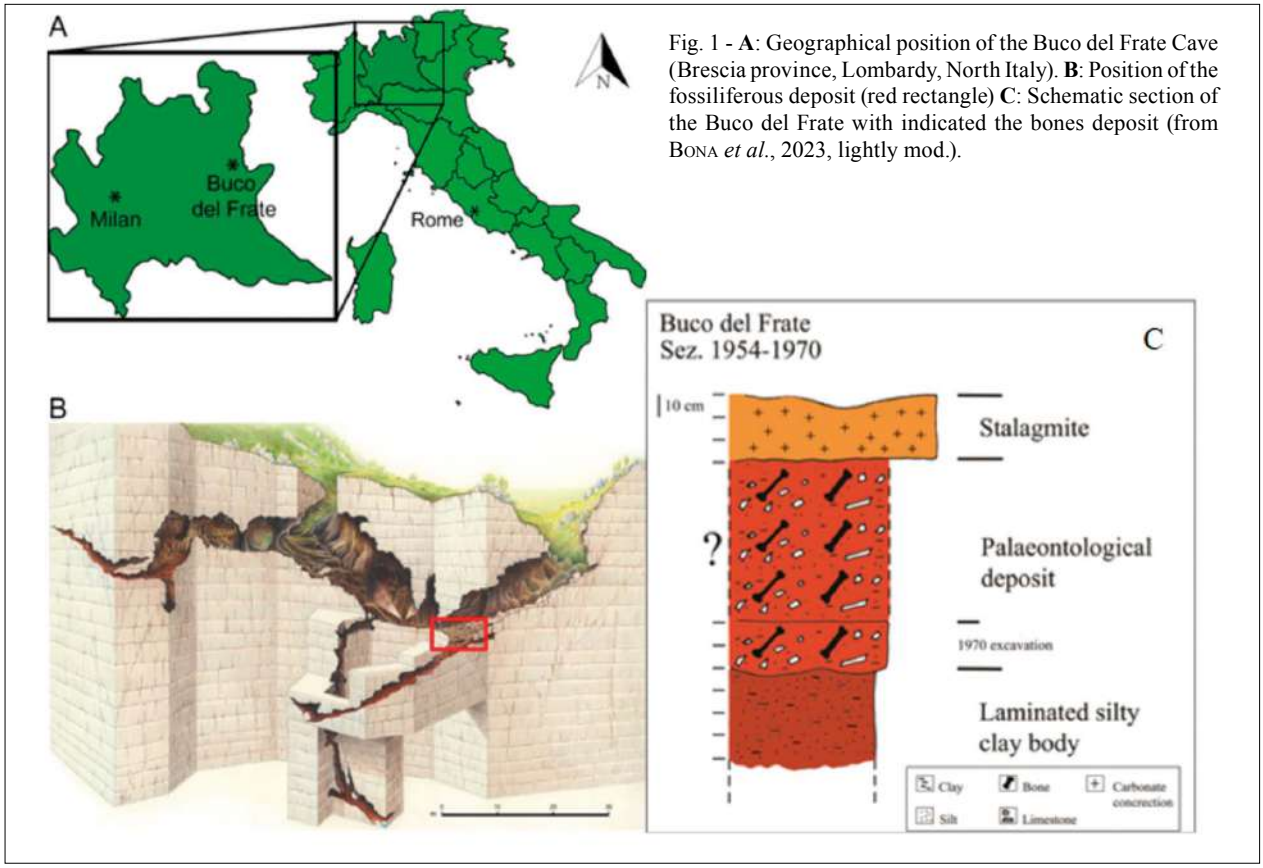


Fig. 1 - **A**: Geographical position of the Buco del Frate Cave (Brescia province, Lombardy, North Italy). **B**: Position of the fossiliferous deposit (red rectangle) **C**: Schematic section of the Buco del Frate with indicated the bones deposit (from Bona *et al.*, 2023, lightly mod.).

the most famous and important one in the 'Carso Bresciano'. It is located in the municipality of Prevalle (Brescia Province, Lombardy) and is characterized by the presence of two entrances (the largest of which opens at 253 m a.s.l.) with downward passages that meet approximately in the middle of the main segment. Overall, the known extent of the cavity is about 230 metres. The deposit consists of a thick and homogeneous red clay sediment, deposited among enormous blocks collapsed from the vault of the cave, forming a room in direct communication with the surface by one or two steeply ascending galleries that function as sinkholes. The list of large mammal remains, partially compiled by Pasa (1958) and Simoni (1971), includes species like cave bear (*Ursus spelaeus*), cave hyena (*Crocuta crocuta spelaea*), wolverine (*Gulo gulo*), alpine marmot (*Marmota marmota*), wolf (*Canis lupus*), red deer (*Cervus elaphus*), beaver (*Castor fiber*) and others (Fig. 1) (Bona *et al.*, 2023).

MATERIALS AND METHODS

The material examined consists of 12 skulls, 37 mandibles and 383 teeth. The fossils are stored in the Museo di Scienze Naturali of Brescia and in the Museo Archeologico della Valle Sabbia of Gavardo (Brescia province). The remains have been measured following the parameters codified by Baryshnikov & Puzachenko (2011) for the skulls, Tsoukala & Grandal-D'Anglade (1997) and Baryshnikov *et al.* (2018) for the mandibles, Grandal-D'Anglade & López-Gonzáles (2004) and Baryshnikov & Puzachenko (2019, 2020) for the teeth. The measurements have been used to compare this population with cave bears coming from Italy, Europe and Russia. The data have been analysed with a univariate and multivariate approach, using the software Past 4.0 (Hammer *et al.*, 2001). Teeth measurements and indices have also been used to determine the sex of the individuals (Rabeder & Withalm, 2014; Baryshnikov & Puzachenko, 2017). A morphodynamic analysis of the teeth has also been undertaken, following Rabeder (1999), Baryshnikov *et al.* (2019) and Gimranov *et al.* (2021).

BRIEF DESCRIPTION OF THE REMAINS

The skull specimens are preserved in varied conditions: some of them are almost complete, with only the frail bones being eroded or absent, whereas others are very partial; in general the zygomatic bones, parts of the condyles and the parietal bones are fractured or damaged. Most of them still preserve traces of the red clay that is typical of the cave (Fig. 2). The same can be written for the mandibles: out of a sample of 37 bones only one is complete, all the others are isolated hemimandibles. Only ten mandibles are complete; in others the distal parts (condyle, coronion) are damaged or missing. In some skulls and mandibles the associated teeth are still present: these are mainly molars, sometimes premolars and canines, but there are no incisors. With the isolated teeth it is possible to observe the full row: the sample includes canines, incisors, premolars and molars. Some teeth are fragmentary or have their masticatory surface eroded. The majority however has been preserved in optimal conditions that allow taking precise measurements and determining the morphodynamic indices.

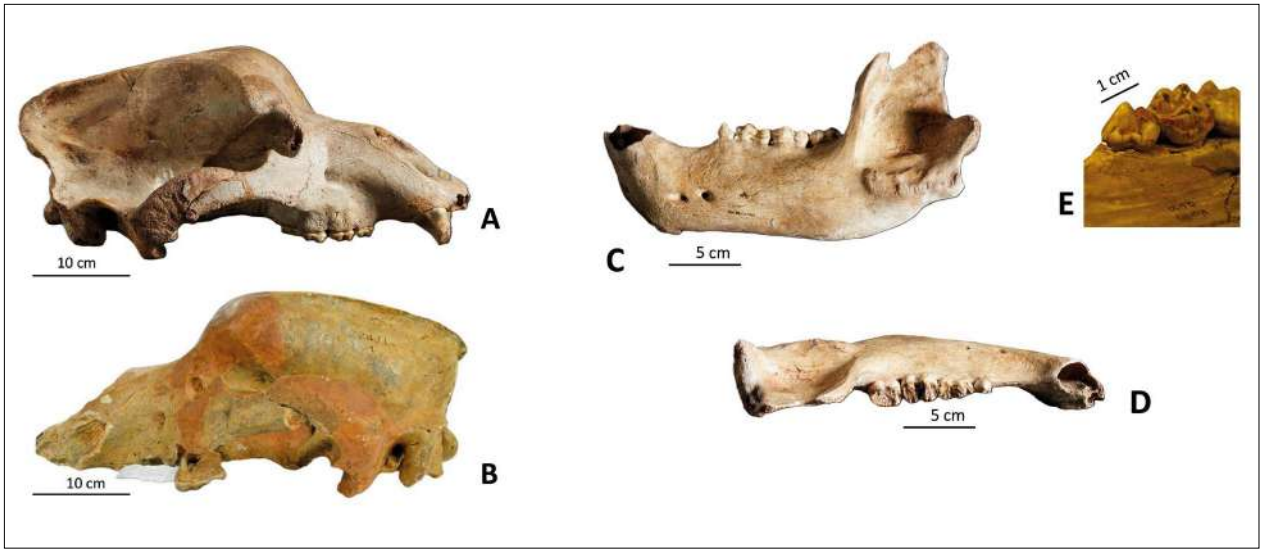


Fig. 2 - **A**: Lateral view of the right side of a skull (MSNBS-PA10248). **B**: Lateral view of the left side of a skull (MSNBS-PA10249). **C**: Lateral view of the left side of a complete hemimandible (MSNBS-PA5129). **D**: Upside view of a partial hemimandible, showing the tooth row and the tooth sockets (MSNBS-PA5129). **E**: Detailed view of a fourth upper premolar and a first upper molar (MSNBS-PA10235).

SEX DIMORPHISM

The main considerations about the sex dimorphism were advanced using the teeth in particular the "Length" and "Width" of the canines (Rabeder & Withalm, 2014); thus for the most important indices the results are: Sex Index (SI) = 75, Sex Ratio (SR) = 3, Sex Dimorphism Index (SDI) = 132,82. In the Buco del Frate population the females are more common than males and this is shown in the P4, M2, p4 and m3. Contrarily when considering M1, males are more abundant than females; with m1 we observe two opposite distributions: one shows a larger number of females while the second shows that males are more abundant than females. Using only m2 the sexual dimorphism results are impossible to define (Fig. 3). Utilising the indices from Baryshnikov & Puzachenko (2017) and Baryshnikov *et al.* (2018) the SSD (Sexual Size Dimorphism) has these results: M1 = 6,08, M2 = 6,95, p4 (L) = 12,16, p4 (W) = 5,92, m3 = 7,11 while the ASSD (Average Sexual Size Dimorphism) shows these results: P4 = 1,37, M1 = 1,21, M2 = 1,158, p4 = 4,87 and m3 = 1,77. It is evident that some teeth are more useful than others when determining the sex dimorphism.

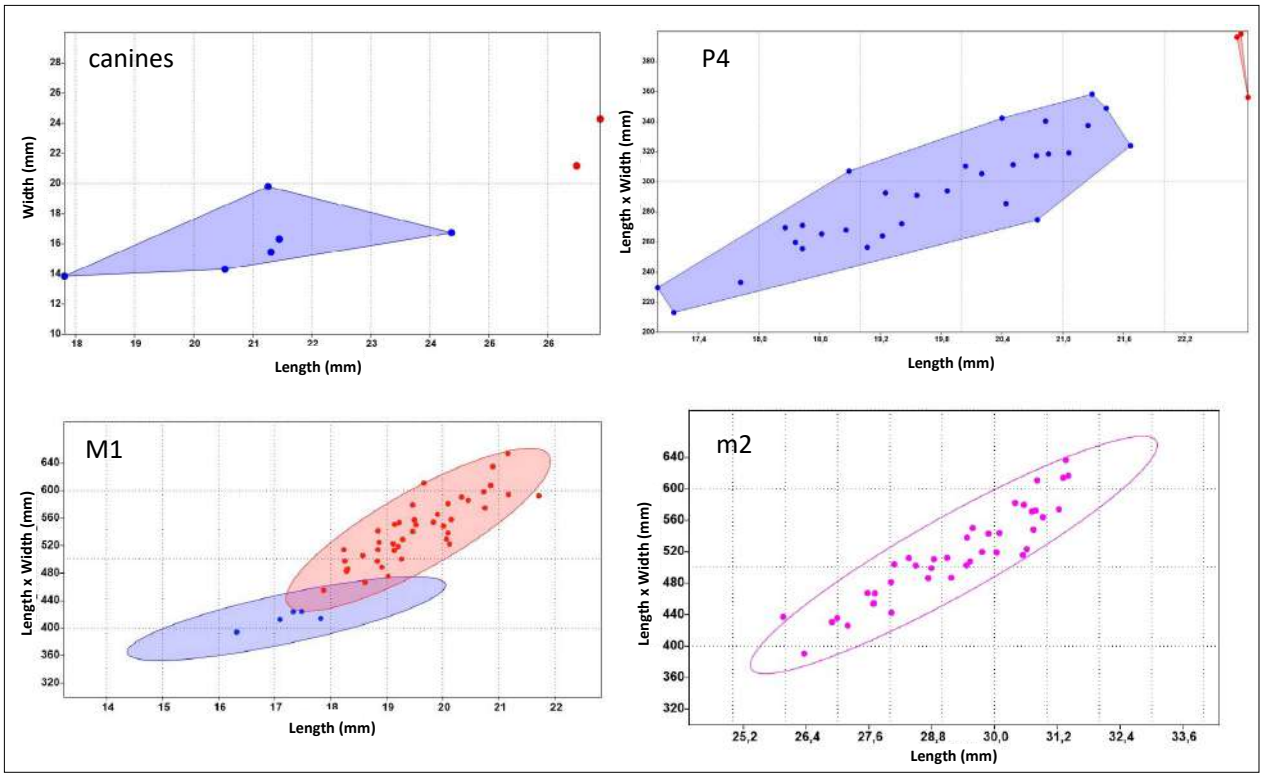


Fig. 3 - Sex dimorphism in the Buco del Frate population utilizing the canines, P4, M1 and m2 respectively. Females (blue), males (red).

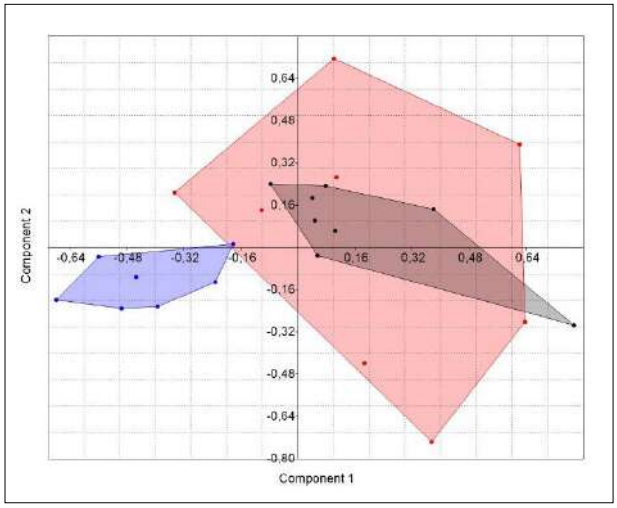


Fig. 4 - Multivariate analysis of cranial measurements of the cave bears from Buco del Frate (red points), Goyet (Belgium) (black dots) and Mischin Kamik (blue dots).

MORPHOMETRIC ANALYSIS

Before analysing the specimens, basic statistical tests were performed. Grubb's test was performed to individuate the outlier values; the measurements are globally homogeneous. A normality test was performed utilising the Shapiro-Wilk test, while the likelihood and the equitability tests were applied to show the similarity of the specimens and the presence (or lack of one) taxon or more taxa inside the amount of the fossils, respectively. Globally, the material has a high likelihood and belongs to one taxon. Kendall's correlation test and Shannon's entropy test were also applied.

Skulls. A first morphometric analysis of the skulls coming from the Buco del Frate cave has been studied in depth by Indelicato *et al.* (2023), however it is still possible to make some more considerations. In Fig. 4 we see the multivariate analysis of the measurements of the skulls of three European cave bear populations: *U. rossicus* from Mishin Kamik Cave (Bulgaria), *U. ex* gr. *spelaeus* from Goyet Cave (Belgium) and *U. ex* gr. *spelaeus* from Buco del Frate. The similarity between the skulls from Italy and Belgium is evident; whereas the skulls from Bulgaria occupy a different spot on the diagram, since *U. rossicus* is a smaller species. In Fig. 5 we see a cluster analysis of the skulls of different populations (data taken from Baryshnikov & Puzachenko, 2011): the skulls from Buco del Frate belong to the middle group with *U. s. eremus*, *U. kanivetz* and *U. deningeri*, with the latter being the closest, and thus the most similar to our population. While the cluster analysis doesn't necessarily reflect a taxonomic affinity, it is interesting to note that the skulls of *U. ingressus* and *U. s. spelaeus* (two closely-related taxa, according to Barlow *et al.*, 2021) are positioned next to each other.

Mandibles. Cluster analysis of the mandibles (Fig. 6) (data taken from Baryshnikov *et al.*, 2018) shows the existence of three branches: one containing the brown bear (*U. arctos*), the primitive *U. etruscus* (often considered the ancestor of all cave bears) and the small-sized *U. rossicus*; one containing all the so-called "advanced" cave bears (*U. s. spelaeus*, *U. ingressus*,

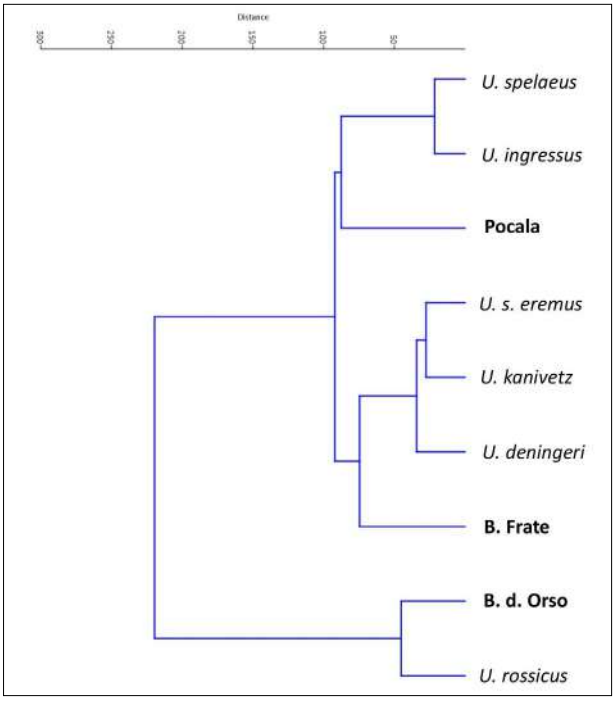


Fig. 5 - Cladogram elaborated with the likelihood between the means of the different measurements of the skulls of the Italian, European and Russian populations.

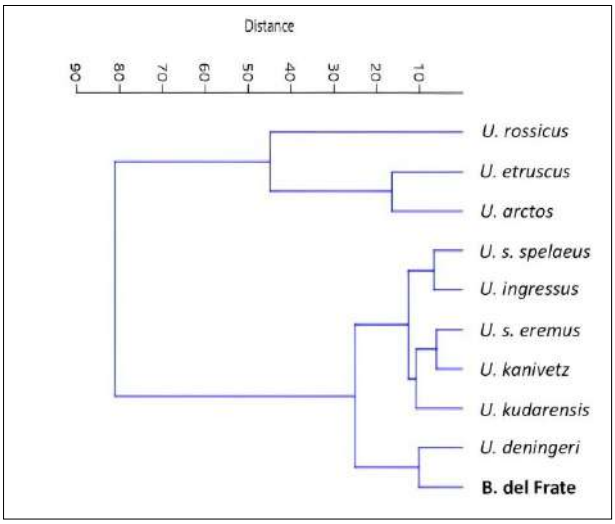


Fig. 6 - Cladogram based on the means of the values of the mandible parameters from Buco del Frate, other cave bear taxa and *U. arctos*.

U. *s. eremus*, *U. kanivetz* and *U. kudarensis*); the last one containing *U. deningeri* and the population from Buco del Frate. Once again the similarity between these two populations is observed; it is interesting to note that our cave bears, despite living during the Late Pleistocene, are morphologically similar to a taxon from the Middle Pleistocene.

Incisors. The lack of published data outside of Italy makes it difficult to compare our measurements with those of other taxa. It is still possible to investigate whether significant differences between Italian populations exist. As seen in Fig. 7, when comparing values from different caves, no significant difference can be observed. The only interesting case can be seen in the distribution of the I1/I2: the teeth from Buco della Noga (Como) seem to be shorter and broader on average, but

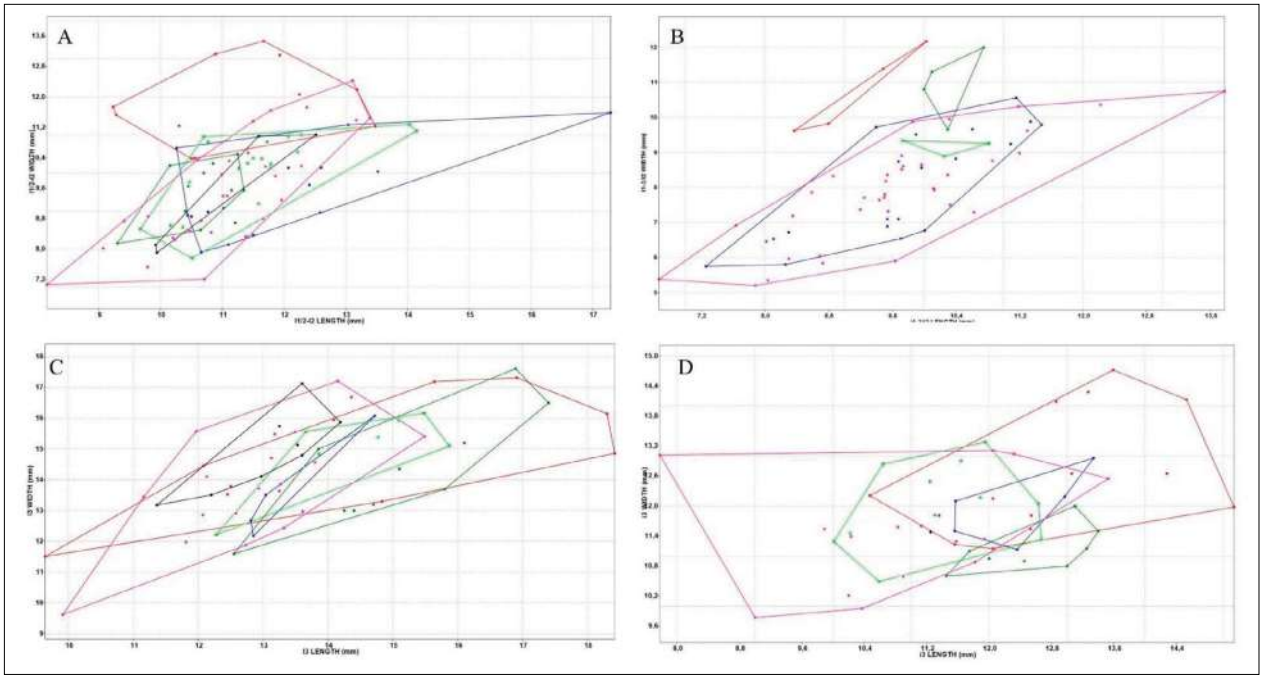


Fig. 7 - **A**: scatterplot of the Length/Width relationships between the I1/I2-I2 of the incisors from Buco del Frate (red dots), Grotta del Bandito -Piedmont (blue dots), Valsolda -Lombardy (green dots), Buco dell'Orso - Lombardy (ligth green dots), Buco del Piombo Cave -Lombardy (black dots) and Mount Fenera caves - Piedmont (fuchsia dots). **B**: scatterplot of the Length/Width relationships between the i1/i2-i2 of the incisors from Buco del Frate, Grotta del Bandito, Valsolda, Buco dell'Orso and Mount Fenera caves. **C**: scatterplot of the Length/Width relationships between the I3 of the incisors from Buco del Frate, Grotta del Bandito, Valsolda, Buco dell'Orso, Buco del Piombo Cave and Mount Fenera caves. **D**: scatterplot of the Length/Width relationships between the i3 of the incisors from Buco del Frate, Grotta del Bandito, Valsolda, Buco dell'Orso and Mount Fenera caves.

this feature can be caused by a bias in the preserved material. The similarity between the size of incisors from different sites can be a proof that Italian bears belonged to the same taxon.

Premolars. Comparing the size of the premolars across different Italian caves gives the same results that were observed in the incisors: there is no significant difference between the size of the premolars of different populations (Fig. 8A-B). In Fig. 9A-B we can see the distribution of the IS for the P4 and the W (width) for the p4 related with the passing of time: for both parameters the age and values of the Buco del Frate population are similar to those of other Late Pleistocene species. The shape analysis elaborated with the Roundness Index (IW = (W/L)*100)) and the Masticatory surface area Index (IS=(L*W)/100)) (Baryshnikov & Puzachenko, 2020) reveals that the lower premolars (p4) from Buco del Frate are very similar to those of other modern cave bear taxa (Fig. 10A).

Molars. The shape analysis using the IS and IW has been elaborated on three molars as well: the first lower molar (m1, IW = (0.5*(WTR+WTAL))/L)*100 and IS = ((WTR*L-TRL)+((L-LTR)*WTAL))/100) (Baryshnikov & Puzachenko, 2020), the first upper molar (M1, IW = (W/L)*100 and IS = (L*W)/100) and the second upper molar (M2, IW = (0.5*(WANT+WPOST))/L)*100 and IS = (WANT*LPA+WPOST*(L-LPA))/100) (Baryshnikov & Puzachenko, 2019).

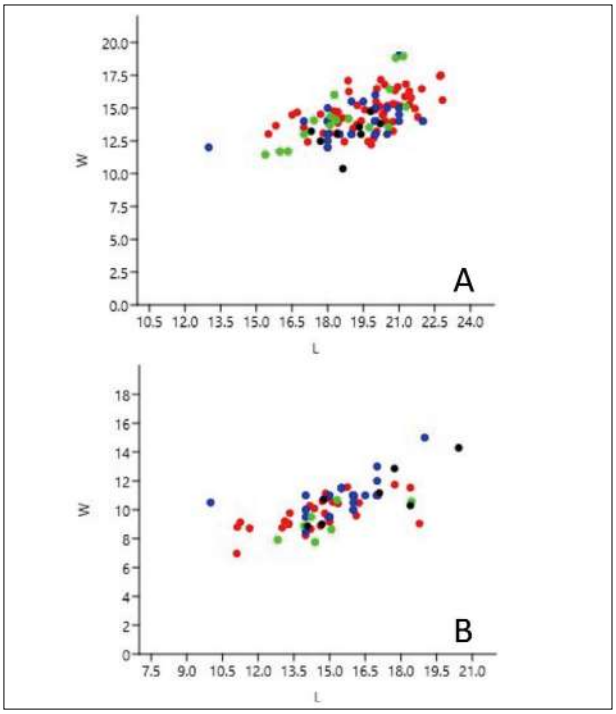


Fig. 8 - Length/Width distribution of the P4 (left) and p4 (right) from the following caves: Buco del Frate (red dots), Grotta della Pocala (blue dots), Monte Fenera (green dots), Grotta del Bandito (black dots).

For the first two types the same case of the p4 is observed again: the values of the population from Buco del Frate are very similar to those of advanced cave bears (like *U. ingressus*, *U. kanivetz*, *U. s. eremus* etc.). Wider differences appear in the analysis of M2: here the values from Buco del Frate don't fit within the range of modern taxa; they also seem to be slightly longer and thinner on average. It is possible that a different diet made this tooth take a unique shape (Fig. 10B-C-D).

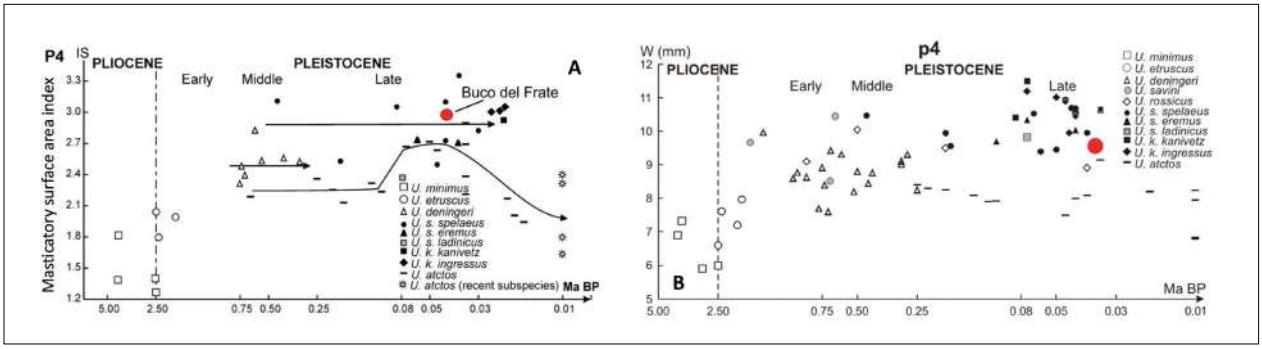
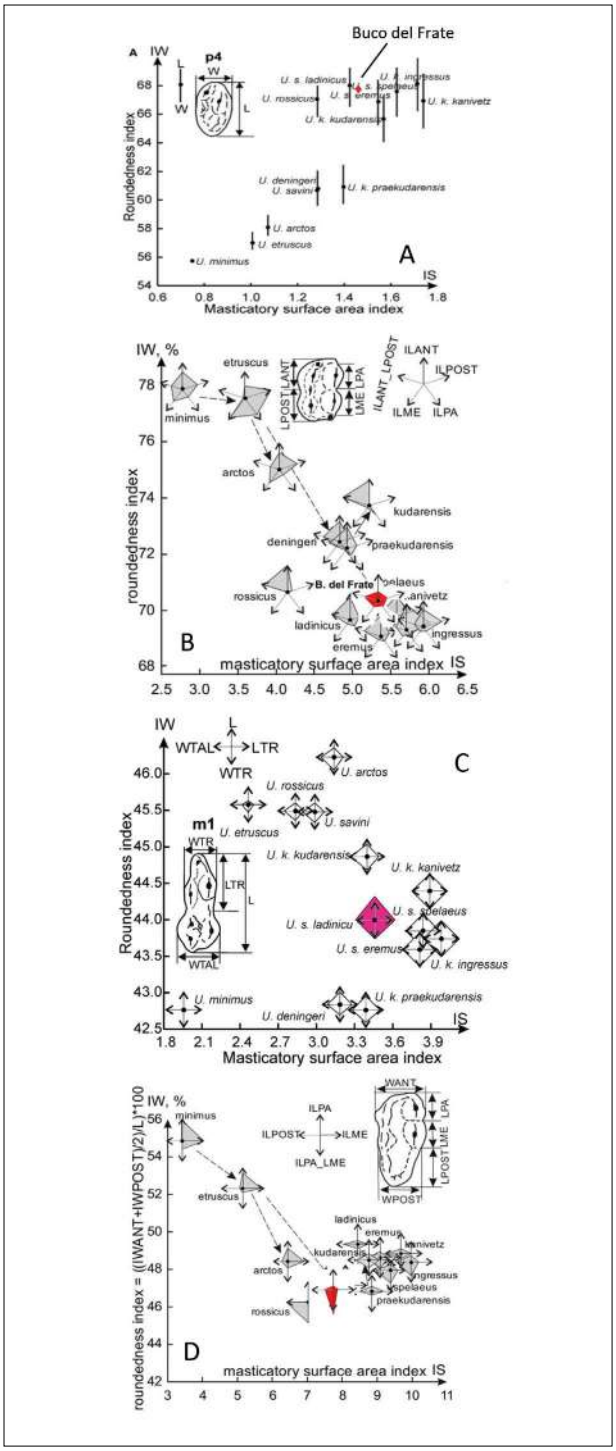


Fig. 9 - **A**: variation of the IS index of the masticatory surface in P4 during the Pleistocene time and **B**: variation of the Width (W) of the p4 during the Pleistocene time (from Baryshnikov & Puzachenko, 2019, 2020 mod.).



MORPHODYNAMIC ANALYSIS

The morphodynamic analysis is based on identifying the morphotypes of the different components of the teeth's masticatory surfaces, following the procedure established by Rabeder (1999) and later expanded by Baryshnikov *et al.* (2019) and Gimranov *et al.* (2021). This type of analysis is based on the fact that there is a relationship between the complexity of the masticatory surface and the evolutionary level reached by the bear. A morphotype (with a set morphodynamic factor) is associated to each morphological variation; then, by using percentage analysis, the Morphodynamic Index is determined and usually standardized to the values from the Gammsulzen Cave (Austria) belonging to the advanced taxon *U. ingressus*. Morphodynamic analysis was first applied to the premolars and later has been extended to incisors and molars.

The morphodynamic analysis in this study is focused only on the fourth premolars since these are the teeth that most precisely allow to distinguish between cave bear taxa (Rabeder, 1999). More in-depth morphodynamic analysis of the incisors and molars will be revealed in future papers. The sample consists of 59 upper premolars (P4) and 32 lower (p4). The masticatory surface, which needs to be well-preserved in order to identify the correct morphotype, is in good conditions in 80% of the P4s and in 100% of the p4s. Broken cusps and surface wear are the most common forms of damage. 25,4% of the P4s is still attached to the skull; 32,25% of the p4s is still attached to the mandible. The rest of the sample consists of isolated teeth.

The morphodynamic index for the P4 from Buco del Frate is 115,56 (45,19 std.); for the p4 it is 109,68 (55,34 std.). The P4/4, obtained with the geometric average of the P4 and p4's indices respectively, is 50,01 when standardized (Rabeder, 1999). This is consistent with the values observed in other Italian caves and it seems to be similar to the values of the taxa that inhabited the Italian Alpine region (*U. s. ladinicus* and probably *U. s. eremus*). There is however a significant difference with the values of *U. ingressus*, the largest and most advanced taxon of cave bear (Fig. 11). Another method to potentially distinguish *U. ingressus* from the other taxa based on tooth morphology is by looking at how the P4/4 index varies with the altitude of the cave: in *U. ingressus* there is a positive correlation between altitude of the cave and the P4/4 index; this correlation however

Fig. 10 - Shape analysis of IS (masticatory surface area index) and IW (roundness index) in p4 (**A**), M1(**B**), m1(**C**), and M2 (**D**) (from Baryshnikov & Puzachenko, 2019, 2020 mod.).

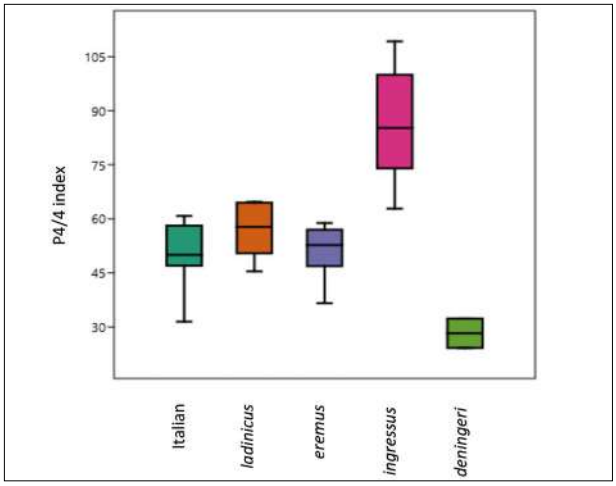


Fig. 11 - Boxplot of the range of P4/4 indices of different taxa: unnamed Italian cave bears (dark green), *U. s. ladinicus* (orange), *U. s. eremus* (purple), *U. ingressus* (fuchsia), *U. deningeri* (light green).

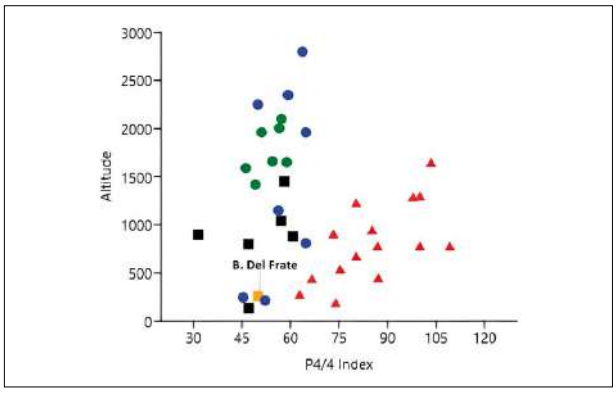


Fig. 12 - Diagram showing the relationship between the P4/4 index and the altitude of the cave across different taxa of cave bears: Buco del Frate (golden square), unnamed Italian populations (black square), *U. s. eremus* (green dot), *U. s. ladinicus* (blue dot), *U. ingressus* (red triangle) (from Laughlan, 2012 mod.).

doesn't exist in *U. s. eremus* and *U. s. ladinicus* (Laughlan *et al.*, 2020). The Italian bears don't show any correlation between these two parameters, once again reducing the possibility that they belong to the *ingressus* taxon (Fig. 12).

DISCUSSION

Like other Italian cave bears, the population of Buco del Frate shows a mix of primitive and advanced features. The skulls are average in size, and even the largest specimens don't reach the maximum sizes of this group (skulls with a length of 50 cm have been found in the Grotta della Pocala Cave, Friuli Venezia Giulia). The cluster analysis also reveals that these skulls were quite different from those of the small-sized *U. rossicus*; instead they are similar to those of *U. deningeri*. The mandibles also appear to be smaller on average when compared to those belonging to the largest cave bear taxa; just like in the case of the skulls, the mandibles are also revealed by cluster analysis to be very similar to those of *U. deningeri*.

Size-wise, the incisors are similar to those from other Italian caves; the shape analysis of the premolars and molars also reveals that these teeth were similar to those of other advanced cave bears from Europe and Russia.

When it comes to the morphodynamic analysis of the premolars the primitive features are very common, with a P4/4 index of 50,01. This value is consistent with those of other Alpine populations like *U. s. eremus* and *U. s. ladinicus*; in particular the index is very similar to the average of *U. s. eremus* (52,25, according to Laughlan *et al.*, 2020). The age of this population (41300-40650 kya according to Bona *et al.*, 2023) corresponds to a time during which *U. ingressus*, a taxon that features the highest morphodynamic indices, was already present in Central Europe (Baca *et al.*, 2014). This seems to indicate that the most advanced cave bear taxa did not establish long-lasting populations in Northern Italy. However, the populations from Covoli di Velo (Verona Province), dated to 32230-29130 kya (Rossi *et al.*, 2023), already shows a higher P4/4 index (60,8). This value is particularly interesting because it corresponds to the higher limit for the indices of *U. s. eremus* and the lower limit for those of *U. ingressus*. Because of this, two hypotheses have been elaborated: 1) the most recent population exhibits higher morphodynamic indices because it was colonized by advanced bears coming from the East (Slovenia, Austria, Croatia); 2) the most recent population exhibits higher morphodynamic indices because its masticatory surfaces evolved with the passage of time, although at a lower pace compared to those of bears from mainland Europe. Unfortunately without genetic data it is impossible both to prove whether these hypotheses are correct, as well as to insert these populations within a specific cave bear taxon.

CONCLUSIONS

The material from Buco del Frate (Brescia Province, easternmost Lombardy) shows once again that Italian cave bears used to have a mix of primitive (skull and mandible morphology, P4/4 index) and more advanced features (teeth morphology and size). The P4/4 index is very similar to the average of *U. s. eremus*; however these remains have been dated to an age (41300-40650 kya) during which the most common cave bears in Europe belonged to the advanced and large-sized *U. ingressus*-*U. s. spelaeus* group, whose presence has never been identified in Italy. Only towards the end of the Late Pleistocene higher indices start to appear in Italian populations, especially in those in the Eastern regions. However, without an analysis of the DNA it is impossible to say if these higher indices were the result of a more intense contact with *U. ingressus* from Mainland Europe or if the Italian specimens belonged to an isolated, relict population that evolved on its own until the extinction of all cave bears.

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