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Radiocarbon and U-series dating of the endemic deer *Praemegaceros cazioti* (Depéret) from "Grotta Juntu", Sardinia

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Abstract

Radiocarbon and U-series methods (^{230}Th/U and ^{231}Pa/^{235}U) for absolute age determination have been applied to some fossil samples from Grotta Juntu, in North Eastern Sardinia (Italy). The remains belong to the endemic deer species *Praemegaceros cazioti*, which is here represented by an almost complete skeleton. The three dating methods lead to concordant ages of about 7500 years BP, indicating that the skeleton was maintained as closed system after burial. Taking into consideration these results, *Praemegaceros cazioti* from Grotta Juntu is now the youngest representative of this species in Sardinia.

Keywords: Radiocarbon; U-series dating; Bones; Teeth; Cervidae; Quaternary; Sardinia

1. Introduction

The Juntu Cave is a karstic cavity opened at 900 m above sea level, on the Northwest side of Monte Albo, Sardinia (Fig. 1). The cave was discovered in 1986, in the context of explorations made during a hydrogeological study of Monte Albo epikarstic system.

A near complete skeleton, belonging to an adult specimen of a middle-sized deer, was found in the cave. The skull and the antlers of this specimen show the diagnostic morphological features of the endemic species *Praemegaceros cazioti* (Depéret, 1897), which represents one of the most typical elements of the Middle–Late Pleistocene insular faunas in Corsica and Sardinia. The ancestry of this cervid has been identified in the Early-Middle Pleistocene continental species *Praemegaceros verticornis* (Azzaroli, 1961; Caloi and Palombo, 1995 and references therein) which dispersed towards the Corsican - Sardinian paleobioprovince close to the Early–Middle Pleistocene boundary, at a regressive phase of the sea level. Previous studies point to an extinction of *P. cazioti* around 9000 yBP due to the arrival of Mesolithic humans on the Sardinian island (Sondaar, 2000; Sondaar and Van der Geer, 2002; Vigne et al., 2002), as suggested by the remains found in the Corbeddu Cave (Klein Hofmeijer et al., 1987; Klein Hofmeijer, 1997). Accurate dating of fossils in the Juntu cave would be therefore of noticeable importance in order to better understand this extinction event in the Sardinia region.

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The age of the fossil remains from Grotta Juntu was supposed to be in the time range covered by radiocarbon and by two U-series methods, ^{230}Th/U and ^{231}Pa/^{235}U, therefore we applied all three dating methods to fossil bones and teeth of the deer specimen.

Radiocarbon dating has been routinely applied to bones during last years (see e.g. Law et al., 1991; Stäuble, 1995; Yuan et al., 1995), since bones and teeth are the most resistant tissues in a dead organism. In the living state, they contain leaked proteins, the marrow constituents and an organic matrix in which the inorganic constituents of bone are contained. Bones contain mainly hydroxyapatite crystals, which are laid down in a matrix of type-I collagen fibres that make up to 90% of the organic residues of dried bones.

Although Uranium-series dating methods are routinely and successfully applied to carbonatic samples, as corals and speleothems (Esposito et al., 1998), its application to bones and teeth often lead to erroneous results (Esposito et al., 2002), because living bones do not contain Uranium, whereas fossil bones often show high Uranium concentration. The *post mortem* Uranium uptake mechanisms are not yet completely understood (Millard and Hedges, 1995).

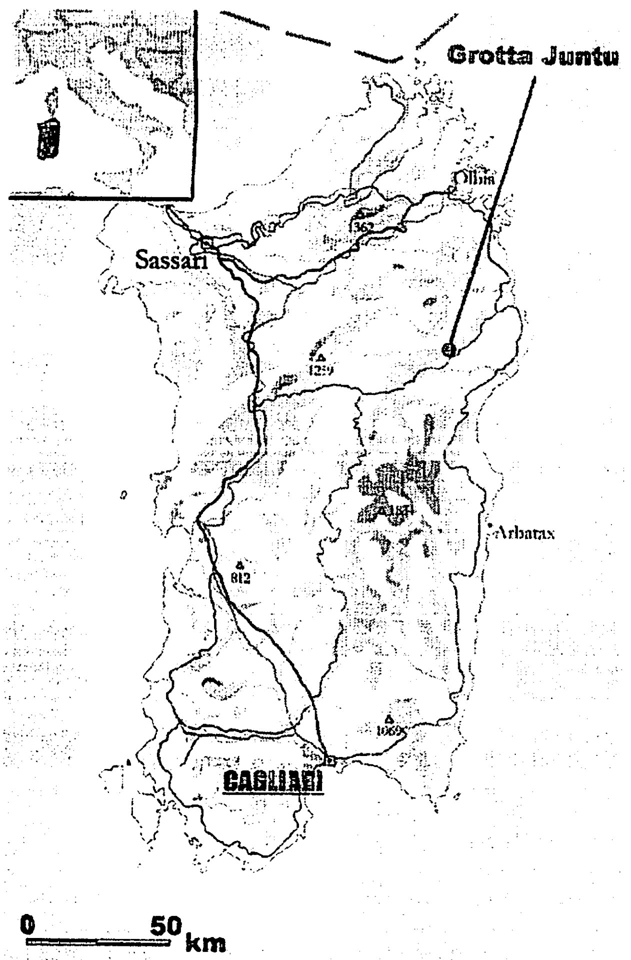

Fig. 1. Location of the Juntu cave in Sardinia, Italy.

In the ideal case Uranium is assimilated into bone soon after burial (Early Uptake model), and the bone remains as a closed system thereafter. Such is sometimes the case for younger samples, for which concordance between U/^{230}Th and radiocarbon dates can be demonstrated (Bischoff and Rosenbauer, 1981; Leitner-Wild and Steffan, 1993). The EU behaviour was also demonstrated for some older samples (Chen and Yuan, 1988). In other cases bones yield dates that are consistently too young, indicating later Uranium assimilation with time (Bischoff et al., 1988). Moreover, Uranium assimilation in bones can be discontinuous and episodic, and the processes cannot be quantified in a simple way. For example, Chen and Yuan (1988) suspected that an early Uranium uptake was followed by a later secondary uptake in a two-stage process. In addition, Uranium may be lost from bone, giving a ^{230}Th activity in excess to ^{234}U (Esposito et al., 2002). In this last case, the radiometric age would be older than the real age. Finally, Ayliffe and Veeh (1988) noticed that many fossil bones were relatively enriched in ^{234}U compared to coeval speleothems and the modern cave waters, a relation also recognised by Leitner-Wild and Steffan (1993). By noting that the matrix sediments were relatively depleted in ^{234}U, they concluded that bones preferentially accumulate ^{234}U with time from the sediment pore fluids. The agreement between radiocarbon dates and U-series ages is thus crucial for testing the validity of these radiometric methods, when applied to bones and teeth.

2. Geological and palaeontological setting

The spelaeo-genesis of the Juntu cave may be related to an evident tectonic fault whose subterranean erosion has given rise to the formation of an originary cavity which was later partially closed by collapses, witnessed by landslide debris, and by concretions which stopped the development of the cave. Small dolines, caused by the static collapse of pre-existent subterranean cavities, have given rise to the formation of a large subplanar area, which evidently interrupts the carbonatic walls of the cave.

The fossil deer of Grotta Juntu has been found in anatomical position, thus excluding an accidental fall or a *post mortem* flow of the skeleton inside the cave. It consists of an almost complete skeleton belonging to a male individual (Fig. 2). The neurocranium is complete, splanchnocranium is lacking, praemaxillary and zigomatic bones are incomplete. Antlers are almost complete. Only some smaller bones lack the postcranial skeleton.

Two different species of cervids are known during the Quaternary of Sardinia, the endemic species *Praemegaceros cazioti* (Depéret) (Comaschi Caria, 1955; Caloi and Malatesta, 1974), well documented during the Middle and Late Pleistocene within the faunal assemblages referred to the so-called *Tyrrhenicola-Praemegaceros* faunal complex (Sondaar et al., 1984; Sondaar and Van der Geer, 2002; Abbazzi et al., 2004), and the red deer *Cervus elaphus* (Linnaeus) which is documented in Holocene deposits with the endemic subspecies *C. elaphus corsicanus*. *C. elaphus corsicanus* has been described at Domu de

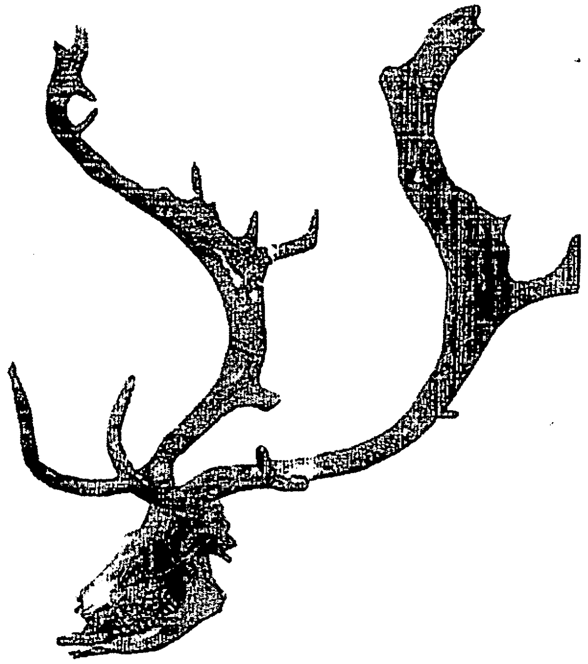

Fig. 2. Skull of the *Praemegaceros cazioti* specimen found in the Juntu cave.

Danas near S. Caterina di Pittinuri (Cuglieri, Oristano) which date to the third millenary B.C. (Cocco and Usai, 1988). Thereafter red deer has been often found in inhabited context since the Middle Bronze Age (1900–1300 B.C.). Data obtained until now do not permit an exhaustive description of this species in prehistoric times (Fonzo, 1987; Fonzo and Gallin, 1992).

Morphological features of skull and mandibles allow us to refer the specimen from Grotta Juntu to the genus *Praemegaceros*. Moreover, the smaller size respect to the continental species of this genus and the morphology of antlers indicates that it belongs to the Sardinian endemic species *P. cazioti*. As observed in other representatives of the *Praemegaceros* genus, the skull of the specimen from Grotta Juntu shows a short muzzle; pedicles are divergent and lie on the same plane as the forehead; pedicles are set laterally above the orbits, which are not very large. In the proximal tract of antlers a first tine set at some distance from the burr (I segment measured on the left antler = 130 mm), and a second tine in middle position (II segment measured on the left antler = 115 mm) occur. The proximal tract of the beam is almost sub-horizontal, then it becomes sub-vertical. At this change of beam disposal, a posterior tine springs. The distal sub-vertical tract of the beam is fairly flattened and brings many small points.

In size of lower teeth row and of the skull the specimen of Grotta Juntu is comparable to *P. cazioti* from Dragonara (Caloi and Malatesta, 1974). From this site, late Pleistocene in age, a rich sample of this megacerine has been found and well described in the literature (Caloi and Malatesta, 1974; Caloi and Palombo, 1991, 1995).

As reported in the Introduction, the Sardinian–Corsican endemic deer has evolutionary relationships with the well known megacerine of the so-called *verticornis* group. The Systematics of this "giant deer" are widely discussed and at present a main disagreement among authors regards whether it must be included in the same genus as *Megaloceros giganteus* (cf. Lister et al., 2005 and reference therein). On the other hand, *verticornis* species has been shown on morphological ground to be distinct respect to *Megaloceros giganteus* and it has been suggested it belongs to a different phyletic lineage (Abbazzi, 2004). Accordingly, *Praemegaceros* is the genus name available for indicating the *verticornis* species and related forms, as the endemic *P. cazioti* (Abbazzi, 2004).

3. Experimental procedure

The well-preserved bone samples contained a sufficient amount of collagen. A triple soft treatment acid–alkali–acid was implemented in order to extract purified collagen and remove humic contamination (Arslanov and Svezhentsev, 1993). The results were in good agreement with expected yields (about 15%) and purity. Collagen was burned in chromatographic oxygen and then converted in benzene for liquid scintillation counting, performed using quartz vials in a Wallac 1220 Quantulus.

For the U-series measurements, the tooth surfaces were cleaned of detritus by careful scraping. Dentine was separated from the enamel. The bone was analysed as a whole.

The samples were combusted at 800 °C for 12 h to remove organic matter. The ashen samples were dissolved in 2 M HNO_3, then Al nitrate carrier and $^{232}U-^{228}Th$ tracer solution were added. The adopted method for separation of U and Th, using ion exchange column, is discussed in full in Wild and Steffan (1991). Thorium and Uranium were plated on an aluminium foil and counted by alpha spectrometry.

4. Results and discussion

Two replicates analysis on a bone sample (laboratory code BO472L) of the cervid were made to obtain radiocarbon dates. The first ^{14}C age obtained, calculated using a measured $\delta^{13}C$ value of -28.1 ± 0.1‰, was 6460 ± 130 years BP, while the second analysis, with the same $\delta^{13}C$ value, gives a radiocarbon age of 6790 ± 80 years BP. The better precision of the second measurement is due to the larger size of the sample and to the longer counting time (about 9000 min). The calibrated age of the sample, calculated with the CALIB3 computer program (Stuiver and Reimer, 1993), is in the range of 7650–7530 years cal BP. All errors (1σ) are based on counting statistics and include a laboratory error multiplier.

In Table 1 the results of the Uranium-series dating of bone and tooth samples of *Praemegaceros cazioti* are shown. The measured activity ratios with 1σ errors are listed together with U/Th ages and for bone sample with the U/Pa age. The ^{231}Pa activity of the bone has been determined through the ^{227}Th activity, assumed to be at secular equilibrium. Errors of the Uranium-series ages were calculated as described by Ivanovich (1982).

Both bone and dentine did not contain ^{232}Th, so that contamination of the samples with detrital ^{230}Th can be excluded. The U/Th and the U/Pa ages of both samples are not contradictory

Table 1
U-series analysis with radiometric age of a bone and a tooth of the *Cervidae* from the Juntu cave

Sample	^{238}U dpm/g	(^{234}U; ^{238}U)	(^{230}Th; ^{232}Th)	(^{230}Th; ^{234}U)	(^{231}Pa; ^{235}U)	Age ^{230}Th	Age ^{231}Pa
Bone	6.8 ± 0.3	1.03 ± 0.03	27 ± 4	0.075 ± 0.007	0.18 ± 0.03	8.5 ± 0.7	9.3 ± 0.8
Enamel	0.060 ± 0.005	1.26 ± 0.13	2.5 ± 1.1	0.39 ± 0.07	n.d.	52 ± 13	n.d.
Dentine	11.7 ± 0.4	1.03 ± 0.02	34 ± 11	0.063 ± 0.004	n.d.	7.1 ± 0.5	n.d.

Errors are at 1 standard deviation.

with the radiocarbon date, about 7500 years. Even though the comparison of U/Th and U/Pa ages is not a very reliable check of the closed system condition for young samples (Bischoff et al., 1988), the radiocarbon date seems to be a strong validation of the Uranium-series results. The U/Th age of the enamel (52,000 ± 13,000 years) is obviously incorrect because of the contamination by detrital ^{230}Th. The large uncertainty of the enamel age results from the low Uranium content of this sample.

5. Conclusion

Radiocarbon dating and U-series methods have been successfully applied to faunal remains of Juntu Cave (Sardinia, Italy). The results are in good agreement indicating an age of about 7500 years Bp.

Even though the application of the U/Th dating to bones and teeth always demands great caution, in this case the radiocarbon dates seem to support the assumptions of the methods.

The radiometric dating of the deer form Grotta Juntu at 7500 years BP makes it the youngest record of the *cazioti* species in Sardinia. The mode, tempo and the causes of the extinction events of the endemic late Pleistocene Sardinian fauna are a discussed issue. Many mammals survived during the Holocene, in particular the smaller ones, e.g. insectivores, rodents and lagomorphs, while the large mammals vanished during the latest Pleistocene–ancient Holocene. As already pointed out, the arrivals of Mesolithic hunters from the mainland has been considered the main factor in causing the extinctions, due to the introduction of predators or competitors.

P. cazioti survived on Sardinia for about 1 Ma and therefore it is a clear example of a species well adapted to the ecological conditions of the island: in fact it successfully overcomes the numerous climatic-environmental crises of Middle and Late Pleistocene, which on the other hand provoked many extinction events in the mainland (Masini et al., 2002; Sondaar and Van der Geer, 2002).

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