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A key site for inferring the timing of dispersal of giant deer in Sardinia, the Su Fossu de Cannas cave, Sadali, Italy

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ABSTRACT

Su Fossu de Cannas (SFC) cave is one of several known cavities in the Sadali plateau in Sardinia, Italy. The evolution of the cave is the result of complex erosional and depositional processes that occurred during the Neogene and Quaternary. A fossiliferous cemented conglomerate, containing various deer remains, now forms the ceiling of a cavity (tunnel). The faunal remains belong to a large cervid, which show some morphological affinity with large deer that have an endemic Sardinian lineage (*Praemegaceros sardous –Praemegaceros cazioti*). Palaeoecological data based on some peculiar features and the large size of the SFC deer suggest that it is the most primitive Megacerine found in Sardinia to date, and the first representative of the endemic lineage. The 450 ka U–Th age for the flowstone capping the fossiliferous layer defines: the end of sedimentation in which Sadali deer remains are preserved; and the dispersal from the mainland of the ancestor of the endemic Sardinian Megacerini. Stratigraphic and micromorphological analyses of the cave deposits allow the reconstruction of the timing of the cave's development throughout the Pliocene to the Holocene.

Introduction

Caves are particularly important to Quaternary paleoenvironmental reconstructions and paleontological analyses, as they may contain deposits that often span multiple millennia (e.g., Sasowsky, 2007; Cuenca-Bescos et al., 2009). Clastic sedimentary fills are typically studied, because they can produce information concerning the evolution of the surrounding territory (e.g., Auler et al., 2004; Bosch and White, 2004; Springer, 2005; White, 2007). Caves also provide stable conditions for the long-term preservation of the skeletal remains of both large and small vertebrates (Nielsen-Marsh, 2000). Vertebrate deposits in caves are sometimes associated with calcium carbonate precipitates (speleothems). These can be dated and provide minimum/maximum ages of the sediment and fossil remains filling a cave (e.g., Burney et al., 2001; Carrión et al., 2003; Auler et al., 2006). Sardinia, which is the second largest island in the central Mediterranean area, is characterized by karst areas that are developed in carbonate rocks of various ages ranging from the Cambrian to the Quaternary and comprise ~9% of the island's area (De Waele, 2009, Fig. 1). Many of these caves provide evidence for past phases of sedimentation and erosion. Remnants of sediment fills and fossil remains are frequently present on the walls and ceilings of the caves, and testify to former sediment infilling episodes followed by one or more phases of sediment removal (De Waele et al., 2005, 2012; Melis et al., 2013). Caves with fossiliferous sediment are mainly located in the Cambrian limestone and Mesozoic dolomitic limestone areas (De Waele et al., 2005; Melis et al., 2013).

Although many of these caves have been studied and explored, geochronological data on the deposits are still scarce (Corbeddu cave, Eisenmann and Van der Geer, 1999; Klein Hofmeijer, 1996; Juntu cave, Benzi et al., 2007 and Grotta dei Fiori, Melis et al., 2013). Accordingly, despite their richness, vertebrate fossil records from Sardinian caves are of little help in decoding the complex chronological framework of the Pleistocene/early Holocene terrestrial fauna of the area (e.g., Palombo, 2009; Palombo and Rozzi, 2014 and references therein). In particular, little is known about the actual timing of arrival in Sardinia of the ancestor of the endemic deer *Praemegaceros cazioti*, the remains and tracks of which are found in

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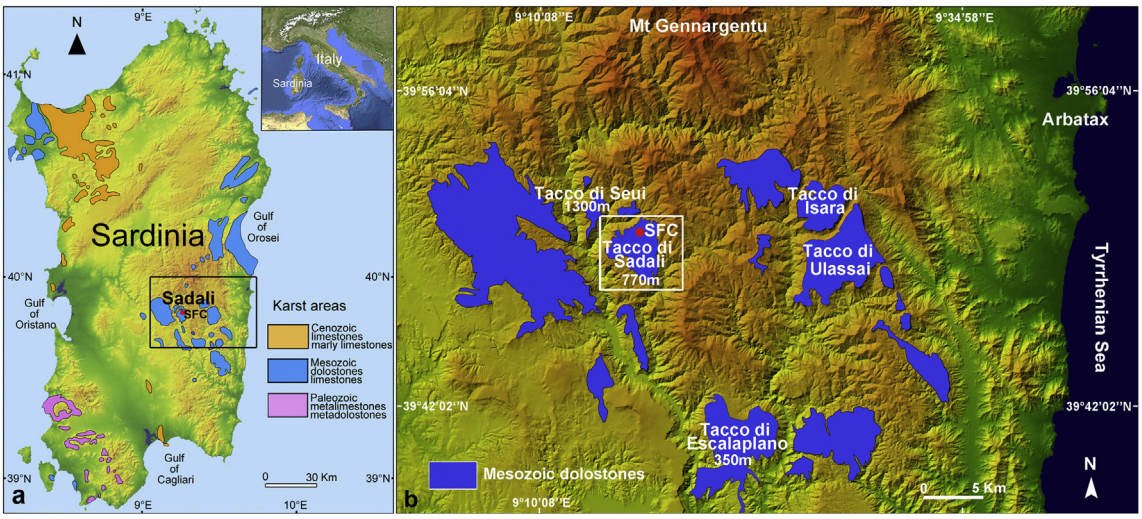

Figure 1. Location of the study area: a) Schematic map of karst areas of Sardinia; b) Location map of the limestone plateaus ("Tacchi") in central-eastern Sardinia. The box shows the location of the geomorphological map of the Sadali plateau in Fig. 2a.

aeolian deposits (e.g., Palombo, 2006, 2009; Fanelli et al., 2007 and references therein).

Various remains of a large deer were discovered during a speleological survey in an eroded conglomerate that nowadays constitutes the ceiling of a narrow tunnel in the Su Fossu de Cannas (SFC) cave, which opens in the Sadali limestone plateau in Barbagia of Seulo, central-eastern Sardinia. The large size of the SFC deer suggests that it may be the most primitive Megacerine hitherto found in Sardinia and the first representative of the endemic lineage (Palombo et al., 2003; Palombo and Melis, 2005; van der Made and Palombo, 2006; Palombo, 2009).

Sardinia has experienced a long history of alternating phases of complete isolation and mainland connections since its separation from the Iberian Peninsula since about 30 Ma. The island was also part of an archipelago of the Tusco-Sardinian palaeobioprovince during the Late Miocene, and then became a complete isolate insular district by the end of the Messinian.

Sardinia experienced several episodes of colonization by European mammals from the Pliocene to the Late Quaternary. These gave rise to successive endemic faunas. The biodiversity progressively decreased from the impoverished, but balanced, Pliocene/earliest Pleistocene fauna (*Nesogoral* Faunal Complex, FC) to the Late Pleistocene–early Holocene version (*Microtus* (*Tyrrhenicola*) FC) (Palombo, 2009; Palombo and Rozzi, 2014 and references therein). The latter is disharmonic, strongly impoverished, and highly unbalanced compared to the fauna inhabiting similar continental ecosystems. This meets the expectations of an insular system that remained completely isolated due to quite severe barriers for long time intervals. The fauna is characterized by the appearance of more evolved species within a number of endemic, small mammal lineages, the diachronous disappearance of the large mammals recorded in the previous Faunal sub-Complex (FsC), and the discrete appearance of alien small and large mammals. Some large mammals (i.e., the ancestors of the *Cynotherium* and *Praemegaceros* lineages) may have reached the Corso-Sardinian massif and arrived on the island by way of a sweepstake overseas dispersal during the late Early Pleistocene. At that time the increased amplitude of sea-level fluctuations in the glacial cycle linked to the so-called Mid-Pleistocene Revolution (e.g. Maslin and Ridgwell, 2005) possibly led to the temporary emergence of limited areas of the platform. This reduced the width of the sea-arms that separated the Corso-Sardinian massif from the mainland (Palombo, 1985). This proposition is fairly consistent with the phylogenetic relationships proposed for both of the endemic lineages, suggesting that the wild canid and giant deer on Sardinia (independent of other authors' contrasting opinions about its putative ancestor) stemmed from the late Early Pleistocene continental stock (Croitor et al., 2006; van der Made and Palombo, 2006; Madurell-Malapeira et al., 2015). Nonetheless, the actual time of this dispersal is unknown, due to the lack of consistent geochronological constraints for a number of local faunal assemblages. This makes it challenging to test any hypothesis on the timing and dynamics of the evolutionary process undergone by endemic lineages.

This is particularly the case when it comes to comparing the evolutionary patterns of insular Quaternary deer from Mediterranean islands. During the Middle–Late Pleistocene and early Holocene, endemic deer, descended from different mainland ancestors (Megacerini, *Cervus*, *Dama*), were a common component of a number of insular Mediterranean fauna (Eastern Mediterranean: Crete, Kassos, Karpathos, Amorgos and Tilos; Western Mediterranean: Sardinia and Corsica, Capri, Pianosa, Sicily and Malta). Each species on each island has it own evolutionary history, and it is therefore difficult to identify a dominant factor in insular deer evolution. The endemic deer from Sardinia and Crete, for instance, although generally regarded as stemming from closely related ancestors (i.e., the Megacerini tribe), underwent different evolutionary processes. The sympatric speciation and radiation process of Cretan deer led to the presence of several species that differed in size and ecological behavior (e.g., De Vos, 2000). Meanwhile, in Sardinia, endemic deer probably underwent a progressive reduction in size from the large, slender deer recorded at the SFC cave to the smallest and stouter deer (unknown age), the *Praemegaceros sardus* from Santa Lucia (450 ± 20 ka; Motoji Ikeya, fide van der Made, 1999 and the *P. cazioti* from Medusa-Dragonara [LGM, Palombo et al., in press], Corbeddu [Tardiglacial, Palombo et al., in press] and Juntu cave [~7.0 ka, Benzi et al., 2007] [see, e.g., van der Made and Palombo, 2006 for a fuller discussion]).

Crucial for testing the hypothesis concerning the time of dispersal of the ancestor of the Sardinian *Praemegaceros* lineage, and providing clues to enable a better understanding to be achieved of the time and patterns of evolution of the Corso-Sardinian Pleistocene is to provide a firm chronological constraint for the largest specimens, i.e., *Praemegaceros* from the SFC cave, which is