

MONK SEAL (*MONACHUS MONACHUS*) BONES IN BEL TORRENTE CAVE (CENTRAL-EAST SARDINIA) AND THEIR PALEO GEOGRAPHICAL SIGNIFICANCE

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Abstract: Fragments of monk seal bones (*Monachus monachus*) discovered 7–12 m below water level in Bel Torrente Cave (central-east Sardinia) in 2004 have been AMS radiocarbon dated. The bones, probably of different individuals, have calibrated ages ranging from 5000–6500 calendar years B.P. and allow reconstruction of the paleogeography of the cave and the surrounding area during this time period. Monk seals living in large numbers along the Sardinian coast used the cave for shelter and to give birth to their pups. The lower sea level of the mid-Holocene, combined with cave morphology, allowed them to reach far into the main tunnel of the cave. The large number of bones found of approximately the same age seems to indicate that the monk seals used caves either to shelter from storm waves or to escape from natural predators during periods when human disturbance of the coast was minor. This could suggest the monk seals had other predators they were also trying to avoid.

INTRODUCTION

During the summer of 2004, scuba divers exploring Bel Torrente Cave, one of the most interesting submarine karst resurgences in the Gulf of Orosei, central-east Sardinia, discovered several skeletons of monk seals (*Monachus monachus*) in an underwater passage. The skeletons were 750 m from the cave entrance and 8–12 m below the water surface (Sgualdini, 2004). A geomorphic study of the cave and AMS radiocarbon dating of some monk seal finger and toe bones were undertaken in an attempt to reconstruct the environmental conditions at the time this remarkable concentration of seal bones accumulated in what are now submerged passages.

MONK SEAL BIOGEOGRAPHY

Recent genetic studies suggest that monk seals (genus *Monachus*) originated in the Tethys region during the Tortonian age (ca 12 Ma), and since have occupied the temperate waters of the Mediterranean (Mediterranean monk seal, *Monachus monachus*). They then spread from east to west to the Caribbean first (Caribbean monk seal, *Monachus tropicalis*, now extinct), and then to the Pacific Ocean (Hawaiian monk seal, *Monachus schauinslandi*, endemic to the Hawaiian Islands) (Fyler et al., 2005).

In the recent past, Mediterranean monk seals were present along coasts from the Black Sea through the entire Mediterranean to the Atlantic shores of Morocco and reaching as far south as Gambia and westwards to the Azores (Johnson et al., 2008). Monk seals were often mentioned during the Greek and Roman Periods as occurring along rocky shorelines and also on beaches. Since ancient times, the animal was hunted for its skin, meat, fat, and oil, but it was only in Roman times that the

seal population was seriously depleted. There was a partial recovery in numbers after the fall of the Roman Empire, but monk seals were again endangered during the Middle Ages where they sought shelter along inaccessible coasts and often in sea caves, some only with underwater entrances. The inaccessible coasts of Sardinia must have been ideal places for important populations of monk seals to settle (Bareham and Furreddu, 1975). The vast territory formerly occupied by monk seals was rapidly limited by the increasing use and occupation of coastal areas by humans. Consequently, the animal has almost completely disappeared from France, Italy, Spain, Egypt, Israel, and Lebanon. Although there are still sporadic sightings of monk seals along some parts of these coasts, there do not appear to be permanent populations (Johnson et al., 2008).

Today, the major monk seal populations are found along the Cabo Blanco peninsula (Western Sahara-Mauritania) (Samaranch and Gonzaléz, 2000; Aguilar et al., 2007; Borrell et al., 2007), the Desertas Islands of Madeira archipelago (Karamandlidis et al., 2004; Pires et al., 2007), the Mediterranean coast between Morocco and Algeria (Borrell et al., 1997), the Cilician basin in Turkey (Gucu et al., 2004), and in Cyprus and the Greek Islands (Dendrinos et al., 2007a; 2007b). Monk seals are still occasionally sighted along the Sardinian coast, but the last permanent residents date back to at least 30 years ago. Before World War II monk seals were regularly hunted by local fishermen, but during the 1950s there were still tens of seals along the coast (Altara, 1995; Johnson, 1998). This number continued to decrease due to hunting, but also

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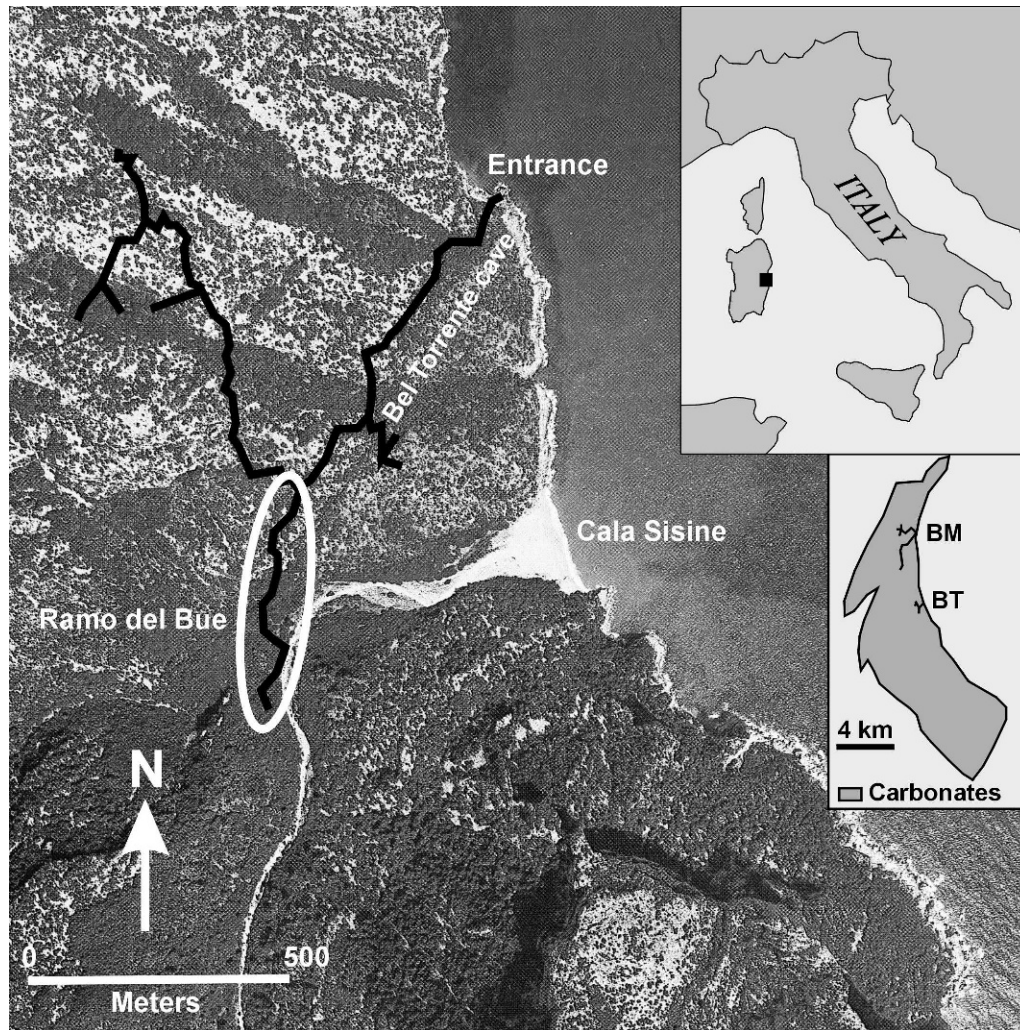


Figure 1. Aerial photograph of the Bel Torrente Cave area. Cave passages are shown in black; the ellipse marks the Ramo del Bue area.

because of increased tourism, with the famous Bue Marino Cave opening for visits in 1960 (Arisci et al., 2000). Tourism is one of the most important disturbances in karst areas in the central-eastern part of Sardinia and monk seals have been among the first to suffer (De Waele, 2008). The last monk seal reported in the Bue Marino Cave was killed by a fisherman in 1970, and about ten individuals were seen at the Grotta del Fico, a few kilometers south of Bue Marino, in the early 1970s (Bareham and Furreddu, 1975).

BEL TORRENTE CAVE

EXPLORATION

The Bel Torrente Cave is located 0.5 km north of Cala Sisine (Fig. 1). The cave was discovered and explored by Jochen Hasenmayer in the 1970s and the first 500 m was surveyed in the 1990s (Fancello et al., 2000; Morlock and Mahler, 1995). Cave diving expeditions in 2003, 2004, and 2006 explored and mapped the cave to more than 3 km.

The side branch with the largest number of monk seal bones was discovered in the summer by two cave divers (Luca Sgualdini and Enrico Seddone) working for the diving club at Santa Maria Navarrese (Sgualdini, 2004).

The cave was surveyed with a wrist-held compass. Distances were determined using tags on the safety line spaced at 5-meter-intervals. Depth was measured with both analog- and digital-depth gauges. At survey points, distances to the cave floor and roof were estimated with an accuracy of about 1 m. Overall precision of the cave plan and profile is around 1%.

MORPHOLOGY

Bel Torrente Cave is characterised by a 5–20 m wide tunnel with an average height of 5 m and a depth of 12 m (Fig. 2). The cave extends to the southwest for the first 550 m and there are several air-filled passages separated by short sumps. Then the passage has a 22-m-deep sump (Sifone Centrale or Central Sump) that allows access to

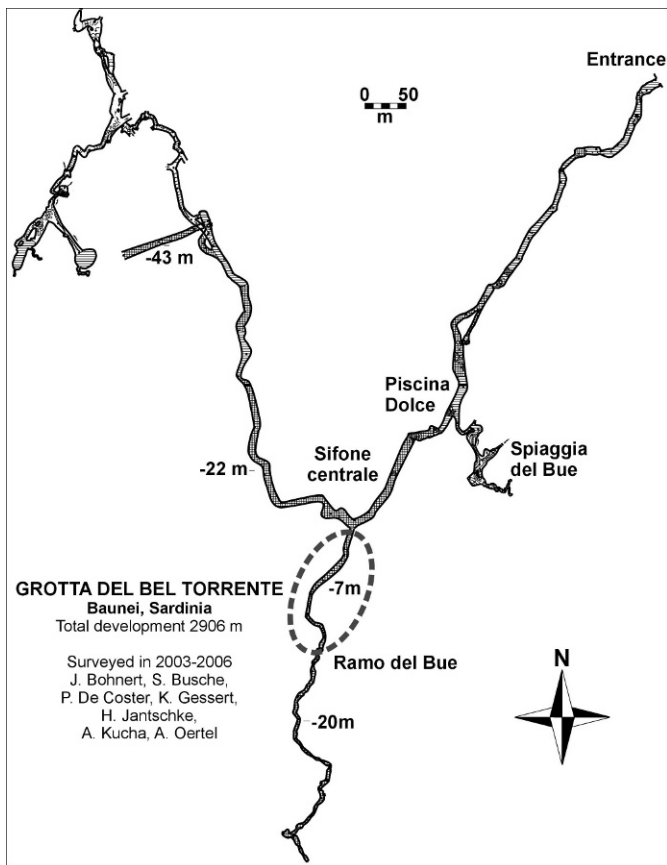


Figure 2. Plan of Bel Torrente Cave. The ellipse defines the area from which monk seal bones were obtained.

another air-filled chamber where a deep and only partially explored sump starts and a by-pass gives access to a series of air-filled galleries. Before the Sifone Centrale, there are two side passages to the left. The first side passage leads to the Spiaggia del Bue (ox beach), where bones of monk seal have been found on the sandy floor at 3–4 m depth and other remains of smaller vertebrates in several places on the rocky floor approximately 1 m above sea level. These bones have not been sampled and dated.

The second side passage, the Ramo del Bue (ox gallery) (Oertel and Patzner, 2007; Sgualdini, 2004), is entirely underwater and departs from the Sifone Centrale at 10 m below sea level. A 3-m-wide tunnel leads to the south and is 7–22-m-deep with the shallower section (–7 m measured at bottom of the gallery) located 50–100 m from the main tunnel and is characterized by a large flowstone entering from above (Fig. 3).

The floors of the main tunnel and the side passages are covered with sands and gravels containing both limestone and granite fragments with few fine sediments so that even after divers have passed through them water in the passages remains relatively clear. The lack of fine sediments is related to the regular flushing of the cave by freshwater floods. During normal conditions, the discharge of freshwater through the cave is only tens of liters per

second so that the water current is hardly noticeable. Near the entrance, and up to 200–400 m inside the cave (depending on sea and climate conditions), there is a halocline at 1–2 m of water depth (Oertel and Patzner, 2007). Freshwater forms a “surface blanket” over brackish and sea water. After heavy rains, the main tunnel is flooded entirely by fresh water and flow velocities are up to 2 m s^{-1} (Morlock and Mahler, 1995). These floods transport clastic deposits (including fine sediments) from the cave and erode/corrode the walls of the tunnel. As a result, the floor, ceiling, and walls display typical phreatic erosion and corrosion features. In several places, speleothems (flowstones, stalagmites, and stalactites) are present above water and also several meters below present sea level. These have been intensively corroded and eroded by flood waters below sea level and also up to at least one meter above sea level.

The morphology of the Bel Torrente Cave generally resembles that of the nearby Bue Marino Cave, except that the passages of Bel Torrente are mainly under water (De Waele and Forti, 2003). This difference may be due to neotectonic activity that resulted in the southwards tilting of the Tyrrhenian tidal notch, dated to 125,000 years B.P. and ranging in height between 10.5 m a.s.l. at Cala Gonone and 7.7 m a.s.l. at Santa Maria Navarrese (Antonioli et al., 1999). This slight tilting could be responsible for the altitude difference between the Bel Torrente and Bue Marino caves (De Waele, 2004; Forti and Rossi, 1991). If true, the Bel Torrente Cave system predates the tilting, and there is evidence suggesting that the main period of cave formation was more than 3 Ma. One convincing piece of evidence is Plio-Pleistocene basalts, dated between 2–3 Ma (Savelli et al., 1979) that fill karst conduits of the Bue Marino main gallery, indicating a karst phase older than this volcanic activity, which is thought to be of Mio-Pliocene age (De Waele, 2004; Mahler, 1979).

During the Quaternary, changes in sea level resulted in periodic drying and flooding of caves along the coast. The most recent drying episode was 22–18 ka B.P. when sea level dropped approximately 125 meters. From recent studies, especially on cave stalagmites, postglacial sea level had already risen to 6–10 m below present by about 6.5 ky B.P. (Antonioli et al., 2004), thus leaving most of the Bel Torrente galleries above water. As a result, 5–6 ka Bel Torrente may have resembled the present Bue Marino Cave, with an underground river flowing out of the mountains and easily accessible for at least 550 meters. Sea level continued to rise in the mid to late Holocene reaching 0.5–1 m below sea level 2 ky B.P. during Roman times.

THE SEAL CEMETERY

Several monk seal skeletons were found in the shallow part of the Ramo del Bue passage, 50–100 m from the main gallery (720–790 m from the entrance). Bones and skulls of at least five monk seals have been found at depths of 8–



Figure 3. Five skulls of monk seal discovered in the Ramo del Bue: **A.** Skull on a sandy floor in the center of the passage (cave diver for scale); **B.** Skull and bones with a black coating deposited in a fissure on the tunnel walls; **C.** Jaw with black coating and some spinal bones on a sandy floor of a side niche; **D.** Small blackened jaw lying on bare rock; other bones can be seen in the back; **E.** Jaw and bones with black coating on the bare rock surface in a lateral alcove.

12 m, resting on the sandy floor or fallen in fissures or holes along the walls (Figs. 3 and 4). The cave divers who explored the passage report seeing the water surface in this area so that there could be an air-filled chamber above the flooded passage. Although only five skulls have been counted, more could be buried beneath sand, trapped in niches along the walls, or in a possible air-filled chamber above.

SEAL BONE AGES

SAMPLING

Four samples of small finger and/or toe bones were collected from skeletal material 20–70 m from the entrance of the Ramo del Bue branch passage (720–790 m from cave entrance), at depths of 7.6–12 m (Table 1 and Fig. 4).



Figure 4. Monk seal bones in the Ramo del Bue: (A) Rib and vertebra on bare rock on the side of the passage; (B) Deposit of long and short bones in a lateral fissure; (C) Small bone, probably toe, in a sandy fissure; (D) Vertebra and other bones in a lateral alcove.

Smaller bones were selected for study as these were large enough to contain enough bone collagen for dating, which allowed leaving the skulls and larger bones to remain intact. When collected, the fragments were labelled and put in plastic bags together with the water. All of the bone fragments had a dark brown patina, and although composed of denser bone material, were relatively fragile. In the laboratory, samples were left to dry for several weeks and often lost consistency.

RADIOCARBON DATING TECHNIQUES

To determine the ages of the monk seal bones, bone apatite (bioapatite) and bone collagen were dated. The bones were cleaned by abrasion and washed using an ultrasonic bath. The crushed bone was treated with diluted 1 N acetic acid to remove surface-absorbed and secondary carbonates. Periodic evacuation ensured that evolved carbon dioxide was removed from the interior of the

sample fragments, and that fresh acid was allowed to reach even the interior micro-surfaces. The chemically cleaned sample was then reacted under vacuum with 1 N HCl to dissolve the bone mineral and release carbon dioxide from bioapatite.

The crushed bone was then treated with 1 N HCl at 4 °C for 24 hours. The residue was filtered, rinsed with deionized water, and under slightly acid conditions (pH = 3) heated at 80 °C for 6 hours to dissolve collagen and leave humic substances in the precipitate. The collagen solution was then filtered to isolate pure collagen and dried out. The purified collagen was combusted at 575 °C in an evacuated, sealed Pyrex ampoule in the presence of CuO.

The resulting carbon dioxide was cryogenically purified from the other combustion products and catalytically converted to graphite using the method of Vogel et al. (1984). Graphite C^{14}/C^{13} ratios were measured using the 0.5 MeV accelerator mass spectrometer at the Center for

Table 1. Location and description of the bone samples.

Sample	Distance from Entrance (m)	Depth (m)	Description
B	770	7.6	Bigger bone (10 cm) found in sand in the passage
C	760	9.5	Small bone (finger?) found on right side of passage in small sand filled cleft
D	720	12	Small bone (finger?) found on the sand in middle of passage
F	760	9	Small bone found in middle of passage on the sand between rocks

Applied Isotope Studies at the University of Georgia. The sample ratios were compared to the ratio measured from the Oxalic Acid I standard (NBS SRM 4990). Sample C¹³/C¹² ratios were measured separately using a stable isotope ratio mass spectrometer and expressed as $\delta^{13}\text{C}$ with respect to PDB, with an error of less than 0.1‰. The $\delta^{13}\text{C}$ of the bone collagen varied between -0.4 and $-2.4\text{‰} \pm 0.1\text{‰}$ relative to the PDB standard, while bone apatite varied between -7.2‰ and $-7.5\text{‰} \pm 0.1\text{‰}$. These values were subsequently used to calculate corrections for isotope fractionation.

The quoted uncalibrated dates are in radiocarbon years before 1950 (years BP), using the ¹⁴C half-life of 5568 years (Table 2). The error is quoted as one standard deviation and reflects both statistical and experimental errors. The dates have been corrected for isotopic fractionation assuming that the samples originally had a $\delta^{13}\text{C}$ composition of -25‰ . The ages shown in Table 2 were calibrated using OxCal version 3.9 (Ramsey, 1995, 2001) and the calibration curve of Stuiver et al. (1998).

RESULTS

Samples B and F were dated using both collagen and bio-apatite for comparison. In both samples the bio-apatite ages are several hundred years older than the collagen ages presumably because of the incorporation of old, dead carbon during accumulation or because of later contamination. Because the cave is a spring, discharging ground water contains significant quantities of old carbon that could explain this observation. The collagen ages are considered more reliable. Collagen samples C and F are statistically of the same age (6447 ± 106 cal yr B.P. and 6698 ± 150 cal yr B.P.) as are samples B and D ($5124 \pm$

211 cal yr B.P. and 4896 ± 194 cal yr B.P.). This means that the samples recovered could have come from two individuals, one dying around 6500 cal yr B.P. and the other around 5000 cal yr B.P., or from several different seals that died at these times.

DISCUSSION

Based on the ages of the bones, and assuming that the seals could not have climbed to ledges in the cave much above water level, sea level was at most 10 m lower than present level by ca. 6.5 ka. In fact, sea level records for the Tyrrhenian show altitudes between 6 and 10 m below present at this time (Antonioli et al., 2004). At Alghero (N-Sardinia), Neolithic burials dated to around 7 ka B.P. have been found in the final sump of Grotta Verde 8–10 m below present sea level (Antonioli et al., 1994).

The longitudinal profile of the Bel Torrente Cave (precision ~ 1 m) shows that when sea level was 6 m lower than today, the monk seals would probably have been able to enter the first 500 meters of the cave (Fig. 5). This would have given them access to Spiaggia del Bue. Beyond this, the deep central sump reaching 22 m depth and completely submerged 6 ka may have been a significant obstacle to the seals. However, the Ramo del Bue gallery, with an initial section of limited depth and then two sumps around 15 m deep, may have been partly accessible. In fact, 6 ka Spiaggia del Bue and the first shallow section of Ramo del Bue, 500 m and 750–800 m from the entrance, respectively, may have been special resting places for monk seals and females giving birth on the sandy beaches alongside the underground river. Supporting this conclusion are observations of similar behavior by monk seals

Table 2. AMS radiocarbon ages on seal bone collagen and bioapatite.

Sample ID	UGA CAIS ID ^a	Libby Age with Background Subtracted	$\delta^{13}\text{C}$	Libby Age with $\delta^{13}\text{C}$ Correction	Calibrated Ages in cal. yr BC (95.4%)	Calibrated Age (cal yr before AD 2000)
B	R01879-B	4957 ± 50	-7.53	5098 ± 50	3989–3774	5881 ± 107
B	R01879-C	4308 ± 54	-11.12	4421 ± 54	3335–2913	5124 ± 211
C	R01880-C	5501 ± 57	-11.19	5613 ± 57	4553–4341	6447 ± 106
D	R01881-C	4192 ± 53	-12.39	4293 ± 53	3090–2702	4896 ± 194
F	R01882-B	6798 ± 55	-7.22	6942 ± 55	5978–5724	7851 ± 127
F	R01882-C	5739 ± 59	-10.44	5857 ± 59	4848–4548	6698 ± 150

^a B=bioapatite, C=collagen.

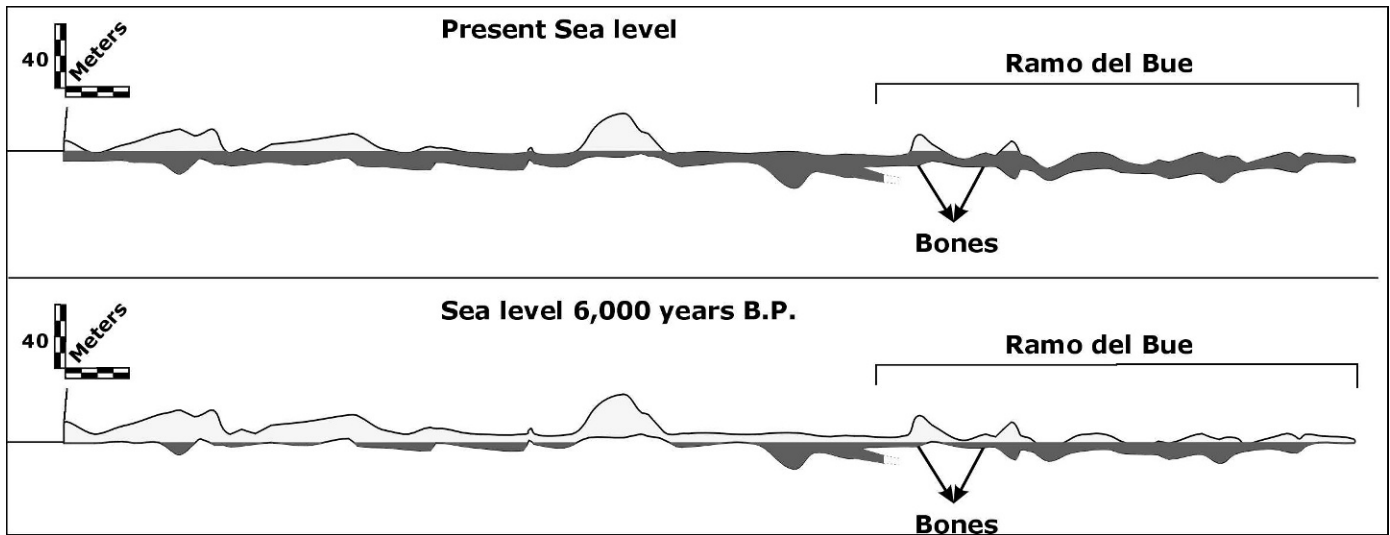


Figure 5. Longitudinal profile of Bel Torrente Cave showing accessibility today and 6 ky B.P. when sea level was much lower.

that used Bue Marino Cave. According to Johnson, these seals sheltered or gave birth almost 1 km from the entrance to this cave (Johnson, 1998).

CONCLUSIONS

It has been suggested that monk seals in the Mediterranean sought out caves as refuges from sea waves during heavy storms, human interference, and killing. Our analysis of seal bones from Bel Torrente Cave suggest that even 6.5 ka, when human pressures were relatively low by modern standards, monk seals were using caves as refuges. The elevation of the bones indicates that by this time sea level was already within 10 m of the present position. The morphology of Bel Torrente Cave confirms that in the mid Holocene it was a coastal cave with an underground river, and monk seals would have been able to penetrate about 800 m without encountering severe difficulties such as deep sumps. Our data reveal that monk seals, even in periods of low human disturbance, had the habit of using coastal caves, penetrating as far as 800 m inside. This suggests that 6.5 ka humans were not the only predators of monk seals.

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