

SHORT PAPER

Holocene Sea-Level Rise Recorded by a Radiocarbon-Dated Mussel in a Submerged Speleothem beneath the Mediterranean Sea

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Fossil shells of the boring mussel *Lithophaga lithophaga* provide a means for dating changes in relative sea level. These bivalves, being among the first colonizers of bare calcareous substrates, can mark the earliest stages of marine submergence of caves. Here we report data concerning the deepest submerged speleothem presently sampled in a temperate area, at 48 m below present sea level off the west coast of Italy (Mediterranean Sea). A fossil mussel shell beneath encrusting layers from later marine colonists gave an AMS age of 9580 ± 35 ^{14}C yr B.P. ($10,253 \pm 72$ cal yr B.P.).

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Radiometric dating of submerged speleothems provides a means for reconstructing past changes in relative sea level (Richards *et al.*, 1994; Lundberg and Ford, 1994). A possible drawback of this procedure is that it provides only an upper limit for past sea levels: the ages refer to time before the sea rose to the level of the speleothem. Furthermore, speleothem growth may have stopped before marine submergence. These problems have been partly addressed through dating of marine organic material encrusted on submerged speleothems. Such dating yielded a sea-level curve for the late Pleistocene and Holocene of the central Tyrrhenian region of Italy (Alessio *et al.*, 1992). The new methodology (involving the use of an *ad hoc* mathematical model to extrapolate radiocarbon data that are temporally punctiform from the continuous layers) partially resolves the problem of the lack of coral-like continuity.

Such use of speleothems in sea-level studies can be furthered by dating shells of marine bivalves that bored into the speleothems soon after marine submergence. Here we

report an age on such a mussel, collected in 48 m of present water depth (pwd) in the Mediterranean Sea.

The sample site is the Capo Palinuro Promontory (Fig. 1), which has a large system of karstic cavities located mostly below sea level. The area has a long-term subsidence rates of about $3\text{--}4 \times 10^{-3}$ m kyr $^{-1}$ (Alessio *et al.*, 1992).

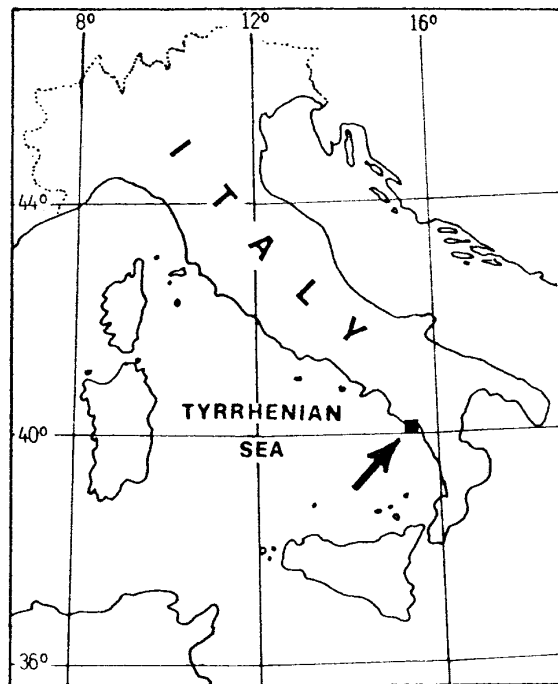


FIG. 1. Location map of the study area. Arrow points to the Capo Palinuro Promontory.

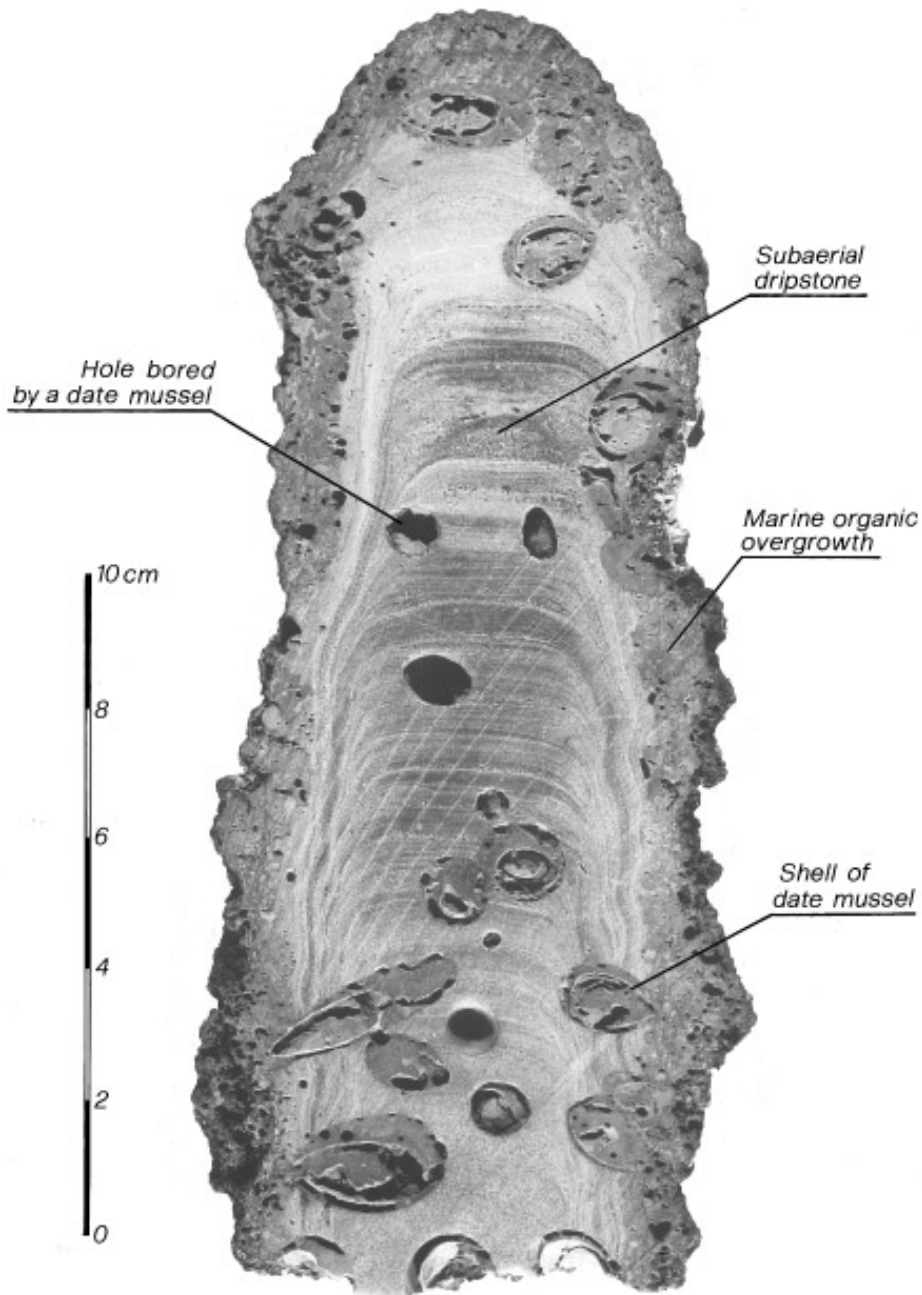


FIG. 2. Longitudinal section of the -48-m stalagmite. The holes bored by the date mussels are all sealed by the earliest layers produced by the encrusting organisms.

Several speleothems have been located and sampled between 27 and 48 m p.w.d. in the cave complex "Scaletta-Punta Iacco," which probably originated in the middle Pleistocene. Depths were measured with a digital gauge (± 0.1 m); corrections were made for water density, but not for sea tide which has a range of 0.2 m.

The dated mussel came from a stalagmite 42 cm long (Fig. 2). Organic material encrusting this speleothem has an

average thickness of 1.5 cm. The formerly subaerial core of the speleothem contains many fossil specimens of the date mussel *Lithophaga lithophaga* (L.). This mussel was among the first marine colonizers of the speleothem, as shown by encrusting organic material that covers the holes that had been bored by the mussels.

The modern benthic community settled on the speleothem consists exclusively of animals, due to the total

lack of light. The sessile community is composed of Porifera, Cnidaria, Annelida, Mollusca, Brachiopoda, and Bryozoa (dominated by Bryozoa Gymnolemata). The structure of the communities settled on submerged speleothems is controlled by many factors, the main one being currents (Oliverio, 1992). On the sampled speleothems the modern community is dominated by Bryozoa Gymnolemata. Nearly all the animals encountered in the living community leave remnants of their skeletons on the speleothem, resulting in encrusting layers of organic material. Caves (and especially their inner portions) are commonly considered stable environments; there is little reason to think that communities very different from those living may have been supported by the speleothem during its submerged life. The sole exception is related to the very earliest stages of submersion, when the speleothem was colonized by the date mussel (*L. lithophaga*). This bivalve mollusk settles only on calcareous rocks, from low tide level, usually to no more than -20 m, with a preference for the uppermost few meters (up to 1600 specimens per square meter at $0-2$ m). It invariably and continuously bores holes on the substrate. Growth is relatively slow; according to Kleeman (1973a), 8-cm lengths are attained in 80 years. Our sample contains only specimens of less than 4 cm, suggesting that the date mussels were no more than a few tens of years old when they died. Settling on the definitive substrate takes place at the larval (veliger) stage, preferably on bare substrates (*L. lithophaga* is considered a pioneer species) (Kleemann, 1973b).

Lyell (1877) correlated the presence of date mussel holes on the pillars of a building at Pozzuoli (Napoli, Italy) with sinking and subsequent elevation of the land. Imamura (1926) correlated the presence of holes by the Japanese date mussel *Lithophaga nasuta* Philippi on uplifted bands, with a series of earthquakes. In both cases the emerged remains were correlated with tectonic uplift. Here we use fossil submerged remains as markers of the very earliest stages of land submersion during relative sea-level rise.

In the Scaletta-Punta Iacco cave complex, fossil date shells are common in the formerly subaerial cores of the sampled speleothems. No living *L. lithophaga* have been encountered either on the speleothems or on the walls of the caves below 10 m of depth. On the sampled stalagmite all the fossil shells are preserved in holes drilled entirely in the subaerial core and subsequently sealed by the earliest encrusting marine layers. Such specimens probably colonized the bare (or nearly bare) speleothem at the earliest, shallow-water stage of submersion. A date shell was sampled in the speleothem in a hole entirely within the subaerial core and sealed by successive (including the inner) encrusting layers. The shell has been ^{14}C AMS

dated (OS-3532) at 9580 ± 35 ^{14}C yr B.P. ($10,253 \pm 72$ cal yr B.P.; calibration after Stuiver and Reimer (1993) with an apparent age of sea water of 400 yr). This age is consistent with the results (8200 ± 132 and 8550 ± 59 cal yr B.P.) of analyses of speleothems from the same cave at -27 and -41 m pwd, respectively (Alessio *et al.*, 1994).

Fairbanks' (1989) reconstruction of the Holocene sea-level rise, based on ^{14}C dating of corals from Barbados, produced at 48 m pwd an estimated age of about 9600 yr B.P. Bard *et al.* (1990), using Th/U dating, obtained for the same altitude an estimate of about 11,000 yr B.P. In both studies the authors had to make corrections due to the tectonic instability of the Barbados area. Aloisi (1993) produced a curve of the sea level change for a Mediterranean area (Lion Gulf), with an estimate of ca. 9800 yr B.P. at 48 m pwd.

According to our data, the Tyrrhenian sea required about 2000 yr ($10,253$ to 8200 cal yr B.P.) to rise 21 m—a mean submergence rate of about 10 mm/yr. This estimate has an uncertainty of perhaps $\pm 10\%$ from possible delay between initial marine submergence of the speleothem and subsequent colonization by the mussels.

Our underwater speleological approach opens new opportunities for studies of past sea levels in temperate areas. Fossil date shells are present on most of the speleothems that we have sampled at many sites in the Mediterranean Sea (e.g., the Aegean Sea, the central Tyrrhenian Sea, and the Sardinian and the Balearic coasts). Moreover, species of date mussel, all with similar ecological requirements, are distributed nearly world wide; their fossil shells can be expected on submerged speleothems in karstic caves along coasts beyond the Mediterranean. Dating of the shells should produce sea-level data complementary to, and probably more accurate than, directly dating the speleothems themselves.

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REFERENCES

- Alessio, M., Allegri, F., Antonioli, F., Belluomini, G., Ferranti, L., Improta, S., Manfra, L., and Proposito, A. (1992). Risultati preliminari relativi alla datazione di speleotemi sommersi nelle fasce costiere del Tirreno Centrale. *Giornale di Geologia* **54**(2), 165–193.
- Alessio, M., Allegri, F., Antonioli, F., Belluomini, G., Improta, S., Manfra, L., and Preite, M. (1994). La curva di risalita del Mare Tirreno negli ultimi 40 ka tramite datazioni di speleotemi e dati archeologici. "International Meeting of Underwater Geology GEOSUB'94," pp. 74–75.
- Aloisi, J. C. (1993). Holocene sea level data from the Mediterranean coast

- and shelf of France. In "Holocene Sea Level Change Workshop," European Science Foundation, Rennes, France, 2–4 December 1993.
- Bard, E., Harmelin, B., and Fairbanks, R. (1990). U–Th ages obtained by mass spectrometry in corals from Barbados: Sea level during the past 130,000 years. *Nature* **346**, 456–458.
- Fairbanks, R. (1989). A 17,000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature* **342**, 637–642.
- Imamura, A. (1926). On the recurrence of destructive earthquakes. *Proceedings of the Imperial Academy, Tokyo* **2**, 264–267.
- Kleemann, K. H. (1973a). *Lithophaga lithophaga* (L.) (Bivalvia) in different limestone. *Malacologia* **14**, 345–347.
- Kleemann, K. H. (1973b). Der Gesteinsbau durch Atzmuscheln an Kalkküsten. *Oecologia* **13**, 377–395.
- Lundberg, J., and Ford, D. C. (1994). Late Pleistocene sea level change in the Bahamas from mass spectrometric U-series dating of submerged speleothem. *Quaternary Science Reviews* **13**, 1–15.
- Lyell, C. (1877). "Principles of Geology," 12th ed. Appleton, New York.
- Oliverio, M. (1992). Aspetti ecologici del popolamento bentonico di speleotemi sommersi. In "Seminario di Geologia Subacquea, Naples, Italy, 30 June 1992," pp. 24–25.
- Pirazzoli, P. A. (1991). "World Atlas of Holocene Sea-Level changes," Elsevier Oceanographic Series, Vol. 58. Elsevier, Amsterdam.
- Richards, D. A., Smart, P. L., and Edwards, R. L. (1994). Sea levels for the last glacial period based on ^{238}U – ^{234}U – ^{230}Th ages of submerged cave deposits from the Bahamas. *Nature* **367**, 357–360.
- Stuiver, M., and Reimer, P. J. (1993). Radiocarbon calibration program. *Radiocarbon* **35**, 215–230.