Phreatic Overgrowths on Speleothems as Indicators of Sea Level Fluctuations Between 150-60 ka in Coastal Caves of Mallorca (Balears, Spain)

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Abstract

Phreatic Overgrowths on Speleothems (POS) form around pre-existing supports at the surface of brackish pools located in littoral caves along the coast of Mallorca (Balearic Islands, Western Mediterranean). Sampled POS alignments, occurring both above and below present sea level and recording past sea stands at the corresponding elevations, have been dated by U-series method. As the most outstanding results of this dating programme, a detailed Western Mediterranean eustatic curve for the period 150-60 ka BP is presented. The periods of high and low sea stands recorded in Mallorca have been preceded and followed by rapid sea level changes, more than 18 metres in magnitude which happened during temporal intervals less than 10 ka. The deduced minimum rates of sea level shift are about 1.5 m/ka, with average values of about 4 m/ka.

Resumen

Espectaculares recubrimientos freáticos sobre espeleotemas (Phreatic Overgrowths on Speleothems, POS) se han formado en la superficie de los lagos salobres que ocupan muchas cuevas costeras de Mallorca (Islas Baleares, Mediterráneo Occidental), creciendo sobre cualquier soporte adecuado, como estalagmitas, estalactitas y coladas parietales. Se han datado, mediante el método de las series de Uranio, muestras de bandas de recubrimiento (POS) localizadas tanto por encima como por debajo del actual nivel freático, en asociación con antiguos niveles del mar. El resultado más destacable del programa de dataciones efectuado, que aquí se presenta, ha consistido en la obtención de una curva detallada de las oscilaciones eustáticas del nivel marino para el intervalo 150-60 ka BP. Las estabilizaciones del mar registradas en las cuevas de Mallorca, tanto las que se encuentran sobre el nivel actual como las que se observan varios metros por debajo del mismo, aparecen insertas dentro de una pauta general de rápidos cambios de nivel del mar, de más de 18 metros de magnitud, que se produjeron en breves intervalos de tiempo, inferiores a 10 ka. Las tasas mínimas de fluctuación del nivel del mar se sitúan en torno a 1,5 m/ka, con un valor medio de 4 m/ka.

Phreatic Overgrowths on Speleothems (POS) in the Coastal Caves of Mallorca

Phreatic Overgrowths on Speleothems (POS) are a common feature in the coastal endokarst of Mallorca (Balearic Islands, Western Mediterranean). POS form around pre-existing supports at the surface of the brackish pools frequently found in many littoral caves in Mallorca. The vast majority of caves located along the southern and eastern coastline of the island are partially drowned by phreatic waters, whose peculiar chemistry allows for oversaturation and subsequent precipitation of carbonates in the close proximity of the water table. The position of today’s sea level determines the presence and the current water-plane elevation of these underground brackish pools, the surfaces of which respond to minor fluctuations such as tides. Consequently, eustatic variations control the elevation of the POS-coatings whose growth takes place mainly during sea level stands.

Most of the POS-coatings develop on different types of previously formed vadose speleothems, thus adopting bulky shapes. Sometimes they are belt-like speleothems formed around stalagmites and columns.

In many cases, especially when the POS affect the tip of partially submerged stalactites, the former straw morphology can be modified substantially giving rise to some rather flask-like appearances (Figure 1). The bands of subaqueous coatings, marked by such POS alignments on the walls of the caves, permit an easy and accurate identification of high sea paleolevels (GINÉS & GINÉS, 1974; GINÉS *et al*., 1981a). Furthermore, POS alignments are also found by scuba diving below the water table, in the submerged parts of several caves (GRACIA, *et al*., 1998). Obviously, the main interest of these carbonate precipitates is that they record ancient positive and/or negative stabilisation of the sea, as indicated by means of the strictly horizontal alignments of the POS that can be recognised inside the caves (Figure 2).

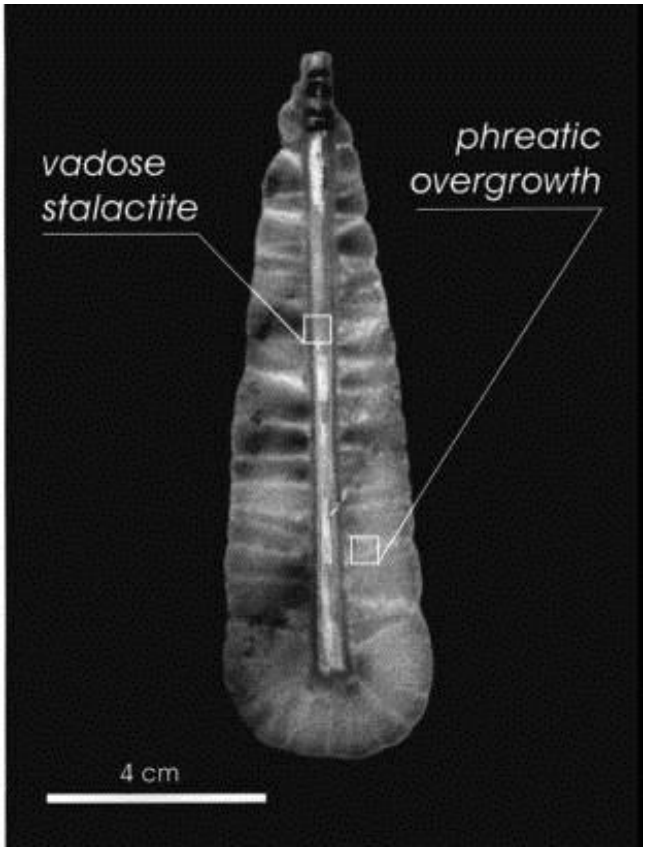

Figure 1: Delicate stalactite coated by an aragonite POS (Phreatic Overgrowth on Speleothem) collected at the surface of a brackish cave pool (Cova des Pas de Vallgornera, southern Mallorca)

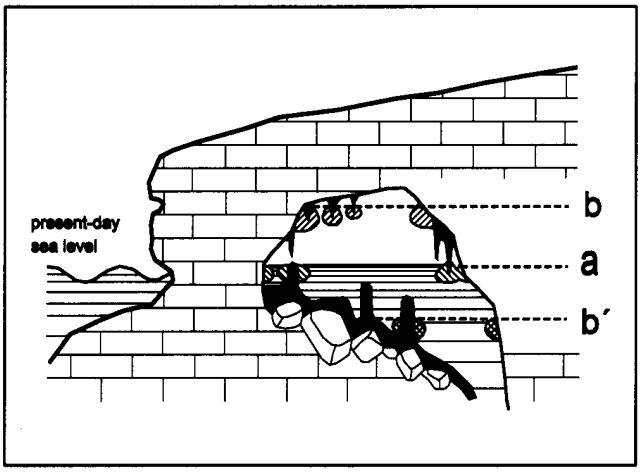

Figure 2: Sketch of a karstic littoral cave containing POS paleolevels.
a: POS alignment to the current water table; b: POS paleolevel located above present sea level; b': submerged POS paleolevel.

Although there is still much that needs to be understood about the geochemistry of coastal karst, it appears that these phreatic overgrowths on speleothems originate preferentially within the range of daily fluctuations of the ground water table (POMAR *et al*., 1979). Generally, coastal POS from Majorcan caves are roughly similar to other subaqueous speleothems but their morphology, texture and mineralogy show a remarkable diversity (POMAR *et al*., 1976; GINÉS *et al*., 1981b). Calcite, low Mg-calcite, high Mg-calcite and aragonite mineralogy is present. On the other hand, depending on their external appearance and textural patterns, they can be classified into several groups: smoothed, globular, coralloidal, branching and macrocrystalline (GINÉS, 2000). Such differences call for additional research on the ancient hydrological and climatic controls involved in this particular geochemical environment.

In Mallorca, a great number of phreatic-crystallisation paleolevels have been observed between the current sea level and +40 metres. GINÉS & GINÉS (1974) have considered the possibility of correlating these deposits altimetrically with Middle and Upper Pleistocene shorelines as identified by means of the stratigraphic and paleontological study of the Pleistocene beach deposits (BUTZER, 1975; CUERDA, 1975). These authors suggested that the POS situated 30 metres above present sea level should date back at least to OIS 9.

Since 1981, several dating programmes of Majorcan POS located above the present sea level were realised (GINÉS *et al*., 1999). The analysis carried out using the Uranium series method confirmed the previously established chronological model, with regard to altimetric correlation between POS paleolevels and Pleistocene beach deposits. The results of the dating programmes show ages that range from present-day to more than 350 ka, the limit of this method. The overgrowths less than 250 ka old are well correlated with the climatic events that involve a sea level similar to, or slightly higher, than the present one (OIS 1, 5 and 7, which correspond to warm periods). The samples which are more than 300 ka old (paleolevels higher than 30 m a.s.l.) have to be assigned tentatively at least to OIS 9 or 11.

In 1994 the study of POS was extended to new caves and new samples. Until now, 16 coastal caves have been investigated and 51 samples have been dated. Some of them were also analysed for O and C isotopic composition in order to collect information about past climate changes (VESICA *et al*., 2000). However, research dealing with submerged POS alignments had not been started until very recently (1999 and 2000 sampling campaigns). In spite of the difficult sampling, POS located below the current water table represent a very promising field of research, because they bring new information on the regressive marine fluctuations associated with the cold pulsations that affected sea level in the past. In fact most of the benchmarks of the eustatic curve for the last interglacial, that follows, correspond to data yielded by submerged POS.

An eustatic curve for the last interglacial obtained from U-series dating of POS

U-series dating of phreatic overgrowths on speleothems (POS) are a good tool in order to improve the knowledge of Pleistocene sea level change, as has been demonstrated in the case of Mallorca by a widespread background of available publications (HENNIG *et al*., 1981; POMAR *et al*., 1987; GINÉS & GINÉS, 1989; TUCCIMEI *et al*., 1997; GINÉS *et al.*, 1999; TUCCIMEI *et al*., 2000a; VESICA *et al*., 2000).

Near the coastline, owing to the easy porosity-connections with the sea, phreatic waters flooded the caves in accordance with contemporaneous sea level. Such brackish karst waters precipitated POS close to their surface as a consequence of enhanced CO_2 outgassing. As explained before, the occurrence of this kind of speleothems, both above and below the current sea level, gives evidence of the height attained by the top of the brackish pools that occupied the lower part of the caves during the rises and falls of the sea. For this reason, POS alignments are excellent indicators of coastal paleo-watertables when located above the current sea level (GINÉS & GINÉS, 1974; GINÉS *et al*., 1981a) and, on the other hand, become rather unique evidence in the case of the paleo-watertables recorded below it.

U-series dating of POS collected at different depths below present sea level provides new information about poorly known aspects of the sea level history in the Western Mediterranean. Conventional marine level records (fossil beaches, abrasion platforms and other geomorphological data) do not give precise data about regressive events, except in the case of coasts affected by severe uplift. In tectonically stable coasts, remnants of previous coastlines formed during low stand periods have been submerged and consequently it is very difficult to study them. But in the coastal karstic caves, besides the technical problems regarding the observation and collection of submerged POS, these kinds of crystallisations represent excellent records of the changes in sea level without being disturbed by other successive coastal dynamic processes.

After the data obtained by means of U-series dating on 22 POS samples (12 of them submerged POS) collected in 9 coastal caves of Mallorca (Figure 3), it is now possible to attempt the reconstruction of an eustatic curve for the last interglacial, valid for the Western Mediterranean basin. As documented in the

general reports of the campaigns (GINÉS & GINÉS, 1989; GINÉS *et al*., 1999; TUCCIMEI *et al*., 2000a), the sampling programme was not formerly restricted to the last interglacial. However, in fact the most exciting findings became concentrated around stages 4 and 5 of the oxygen isotope record.

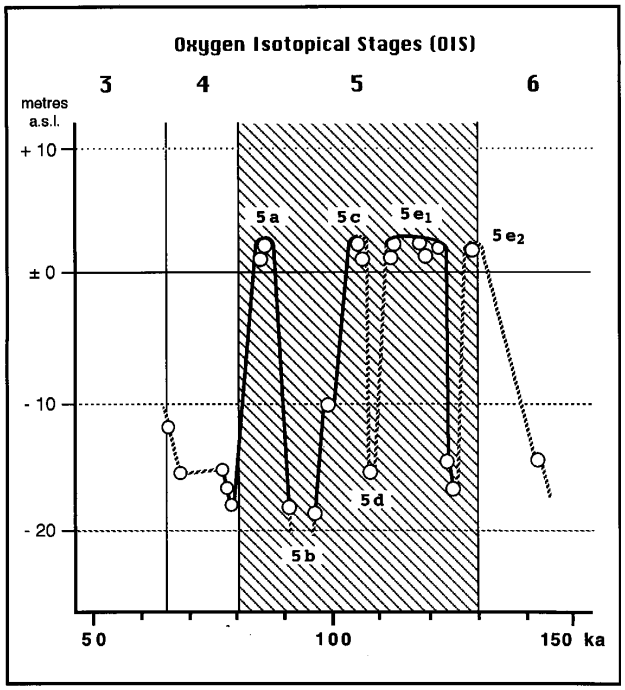

Figure 3: Location map of the caves containing POS whose sampling has documented the last interglacial sea level curve presented here. - BA: Cova de na Barxa, Capdepera; DI: Cova del Dimoni, Manacor; PI: Coves del Pirata, Manacor; FA: Cova de Cala Falcó, Manacor; VB: Cova de Cala Varques B, Manacor; GL: Cova de sa Gleda, Manacor; SE: Cova des Serral, Manacor; PS: Cova den Passol, Felanitx; CS: Cova des Drac de Cala Santanyí, Santanyí.

Obviously, one remarkable feature shown by the collected data corresponds to the information gathered about the sea level stands that occurred at negative elevations (GINÉS, 2000; TUCCIMEI *et al*., 2000a), because no other evidence was previously found on such paleolevels in Mallorca. If chronological data for submerged POS are integrated with those relative to analogous crystallisations located above present sea level, a detailed eustatic curve for the last interglacial can be reconstructed (Figure 4). Even if affected by small recent tectonic activity, littoral areas of eastern and southern Mallorca can be considered substantially stable, being documented a maximum of 1 metre tilting for the time span studied (TUCCIMEI *et al*., 1997). Furthermore, average errors of the U-series dating method for the time range between 60 and 150 ka are about 3%. Thus, the accuracy of the data obtained seems to provide a good estimate of the magnitude of marine level fluctuations as well as of the rapid changes in elevation produced during OIS 4 and 5 in accordance with minor climatic variations.

What emerges from the curve plotted after our research (Figure 4) is that sea level fluctuations during the time range between 60 and 150 ka seem to occur in accordance with the following pattern: periods of sea stands, large enough to produce the formation of POS at a certain elevation (at least 1-2 ka long), alternating with rapid sea level changes, more than 18 metres in temporal intervals shorter than 10 ka. The minimum rates of sea level changes deduced on the basis of the eustatic curve here presented are about 1.5 m/ka, with average values of 4 m/ka. High sea level stands as reported after our research for the substages 5a, 5c and 5e are in good agreement with previously published data by HILLAIRE-MARCEL *et al*. (1996) and ROSE *et al*. (1999).

POS: a Useful Method to Determine Pleistocene Sea Level and Climatic Changes

The new data, obtained from the sampled-POS chronologically associated with the last interglacial sea level pulsations, emphasises the suitability of further studies on this kind of speleothems with regards to Quaternary research. U-series dating, stable isotope investigations, fluid inclusions analysis and

mineralogical studies, coupled with accurate altimetric identification of paleo-watertables, can improve our knowledge on Pleistocene sea level shifts and involved climate changes, as demonstrated in the case of Mallorca.

During the last two years, POS studies have successfully extended to similar coastal-cave features from the Alghero area (eastern coast of Sardinia, Italy). The high correlation found with some preliminary results provided by Sardinian samples (TUCCIMEI *et al*., 2000b) suggests that more coastal karst areas around the world should be the subject of detailed survey with respect to POS-related topics.

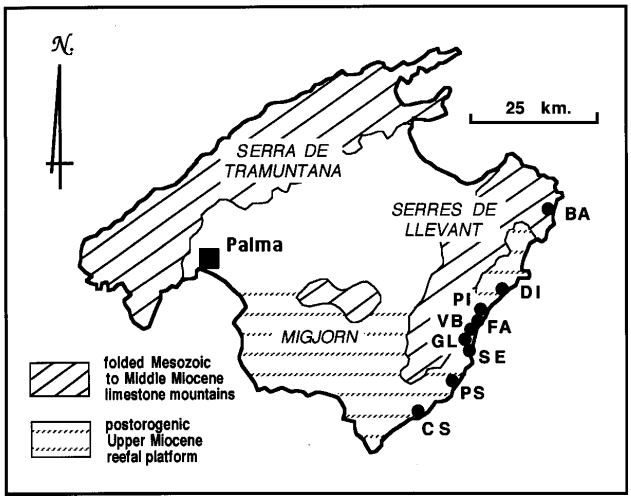

Figure 4: Last interglacial eustatic curve deduced from Th/U dating of POS from coastal caves of Mallorca. Unbroken lines represent sea level fluctuations documented by means of more than one dating.

Acknowledgements

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