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U/TH DATING OF A *CLADOCORA CAESPITOSA* FROM CAPO SAN MARCO MARINE QUATERNARY DEPOSITS (SARDINIA, ITALY)

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ABSTRACT: A whole specimen, not reworked and well preserved of *Cladocora caespitosa* has been found within the marine Quaternary deposits, outcropping along the eastern coast of the Capo San Marco Promontory. The U/Th dating of this sample has provided a minimum age of 70 ± 4 ka B.P. This dating allows to state that these marine deposits, containing the coral, are not Holocene in age.

Keywords: marine Quaternary deposits, *Cladocora caespitosa*, U/Th dating, Tyrrhenian, Sardinia.

1. INTRODUCTION

The Geological Survey of Italy, concerning the institutional activities related to the realization of the Geological Map of Italy at 1: 50.000 scale (CARG Project), has done quick geological surveys to check and monitoring some sample areas of the 528 Oristano Geological Sheet (middle-western Sardinia), still in progress. In particular, marine and continental Quaternary deposits were taken into account. In the middle-western Sardinia, Sinis Peninsula and eastern coast of the Capo San Marco Promontory, these deposits occurred in peculiar outcroppings which have been studied in detail by several Authors (Maxia & Pecorini, 1968; Ulzega et al., 1982; Carboni & Lecca, 1985; Davaud et al., 1991; Kindler et al., 1997; Melis et al., 2001; Lecca & Carboni, 2007; Andreucci et al., 2009; Coltorti et al., 2010; Thiel et al., 2010).

The research has especially addressed marine Quaternary deposits, in relation with a scientific debate which has recently risen about the chronological attribution of these deposits (AIQUA, 2007; Bartolini et al., 2008; Catto, 2010). In the 528 Oristano Geological Sheet "the beach and beach ridge deposits" have been chronologically attributed to Holocene age, instead of the Upper Pleistocene age (Tyrrhenian) reported in literature and in the official Geological Map of Italy (Regione Autonoma della Sardegna, 1989).

During the field activity many fossils have been collected including a specimen of *Cladocora caespitosa* which has been dated with the U-series method.

The aim of this note is to give a additional element to dating the Quaternary deposits outcropping in this area of the Sardinia Region, and to provide a useful contribution to the scientific debate in progress.

2. GEOLOGICAL SETTING

The Capo San Marco Promontory, which from a

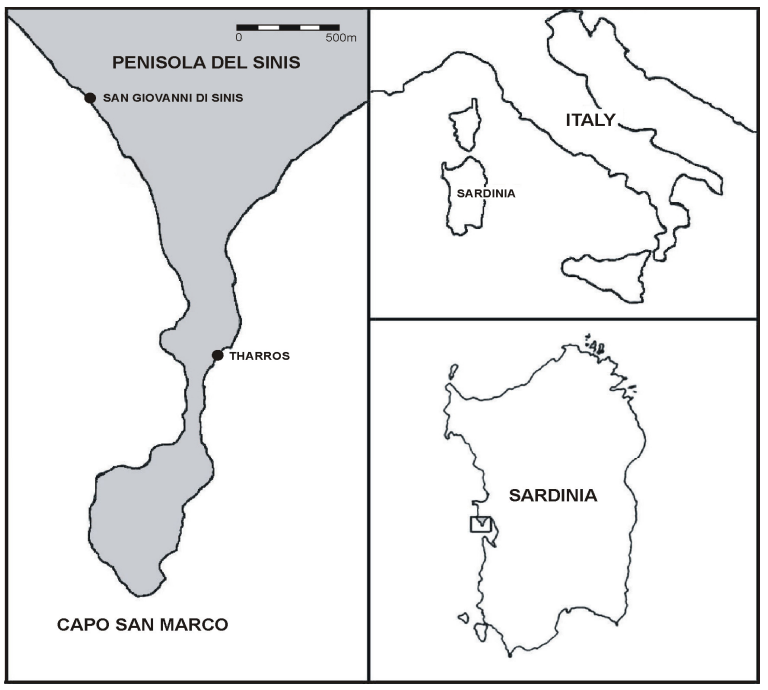

Fig. 1 - Location map of the Sinis Peninsula (Melis et al., 2001; modified).

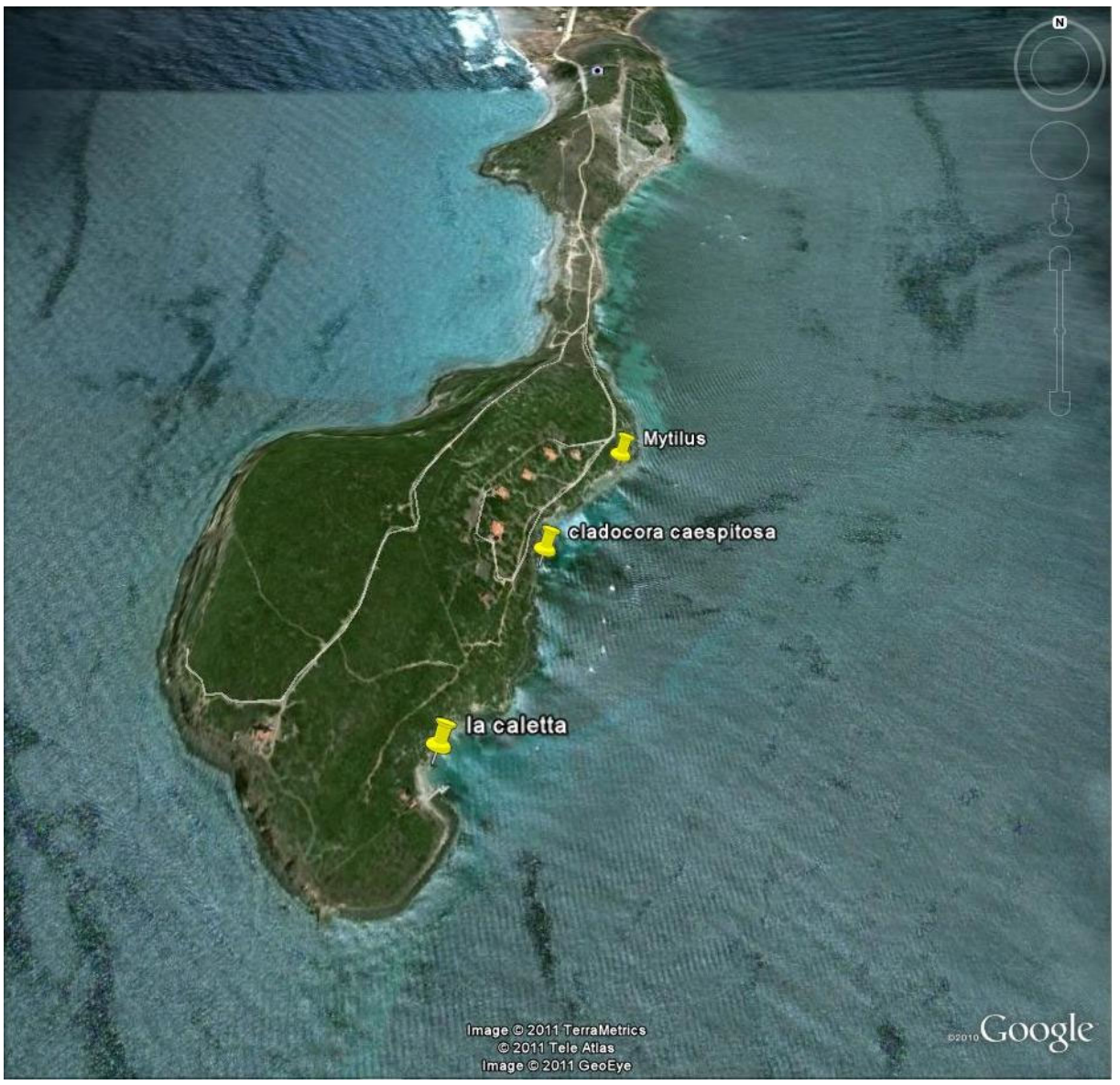

Fig. 2 - Satellite view (from Google Earth) with location of outcrops and sampling point of the *Cladocora caespitosa*.

geomophological point of view extends a few kilometers offshore, represents the end of the Sinis Peninsula (Fig. 1). The western coast consists of an high and steep Miocene-Pliocene cliff, while the eastern coast, gently dipping seaward, is mainly made of marine and continental Quaternary deposits. In this area, in fact, the pre-Quaternary bedrock crops out only in a few sites along of the coast where the Quaternary deposits were dismantled by the intense wave action.

The basal portion of the substrate is represented by the Capo San Marco Formation (Cherchi et al., 1978), divided into two facies: the lower one consists of "dark grey clays" and the upper one is made of "marly - calcareous deposits". The outcropping thickness is about 50 m, the age is Upper Tortonian – Lower Messinian.

The Nuraghe Baboe Formation (Spano, 1989) overlies the marly - calcareous deposits of the Capo San Marco Formation, with a transgressive unconformity surface. This unit consists of a marine succession made of breccias, conglomerates, sandstones, calcareous sandstones, silty-marly clays, calcarenites and marly

Sample	ppm U	$^{230}Th/^{232}Th$	$^{234}U/^{238}U$	$(^{234}U/^{238}U)_i$	$^{230}Th/^{234}U$	Age (ka)
Capo San Marco	3.099 ± 0.088	51.298 ± 2.306	1.124 ± 0.024	1.151 ± 0.029	0.478 ± 0.018	70 ± 4

Table 1 - Uranium content, uranium and thorium activity ratios and age of the coral.

Fig. 3 - La Caletta Site. Geometrical relationships between aeolian and marine deposits. a) Front view of the outcrop and present-day tidal notch in the aeolian deposits. b) Detail of the marine deposit. c) Lateral view of the outcrop. d) Detail of the marine deposit clearly capped by aeolian deposit.

mudstone. The thickness is about 35 m, the age is Lower Pliocene.

The Golfo di Oristano basalt Formation (Costa Randata facies), unconformably overlying on the previous formations, represents the top and the southern cliff of the promontory. These basalts, dated 3.12 Ma (Beccaluva et al., 1985), are made of several superimposed flows and their maximum thickness is about 30 m; the occurrence of columnar structures suggests a slow cooling of the lavas.

3. OBSERVATIONS ON QUATERNARY DEPOSITS

The Quaternary deposits widely crop out in the area of the 528 Oristano Geological Sheet. The best and more complete stratigraphic sections occur near the San Giovanni di Sinis area, within which some Authors recognize different facies (Maxia & Pecorini, 1968; Ulzega et al., 1982; Carboni & Lecca, 1985; Davaud et al., 1991; Kindler et al., 1997; Melis et al., 2001; Lecca & Carboni, 2007; Andreucci et al., 2009; Coltorti et al., 2010; Thiel et al., 2010). Quaternary deposits have been also recognized along the fossil beach ridge that closes the Cabras lagoon. These deposits are formed by Thyrrenian bioclastic calcarenites (Forti & Orrù, 1995).

The Quaternary deposits crop out without interruption all over the eastern coast of the Capo San Marco Promontory, from the southernmost end up to 1 km to the north of Tharros archeological site.

These deposits are often fractured, disrupted and prone to fall and topple landslides due to the intense marine erosive processes acting along the coasts of the promontory.

At the tip of the promontory the basalts are overlapped by aeolian deposits, made of well cemented

Fig. 4 - View of the *Mytilus galloprovincialis* layer.

quartz-sandstone, characterized by high angle cross stratification with foresets landward dipping.

The aeolian deposits continue below sea level and are characterized by a recently formed tidal notch.

These deposits are modelled by a flat marine erosional surface, gently sloping seaward, located at about 4 m above sea level, delimited upslope by a notch of about 50 cm of height.

This surface is capped by 1 m-thick marine deposit. The lower portion consists on huge prevailing basalt blocks, well rounded, with a diameter up to 50 cm, in a well cemented, gravelly-sandy matrix, with abundant fossils. The upper part consists of a well cemented level of coarse to medium fossiliferous sandstone. The fossils are mostly bivalves (*Anomia ephipphium*, *Arca noe, Fissurella italica*, *Glycimeris* sp., C*ardium* sp., ostreids) and gastropods (*Murex taurinensis*, *Trochocochlea turbinata*, *Purpura haemastoma*, *Patella ferruginea*).

The age of the aeolian deposits, assigned using OSL dating on a sample collected just above the notch, is 174 ± 13 ka, thus referable to the Middle Pleistocene (Thiel et al., 2010).

At La Caletta Site (Fig. 2) a marine deposit crops out at present-day sea level. This deposit is composed by huge meter-sized, well rounded basaltic boulders, in a gravelly-sandy supporting matrix, rich in fossils (*Ostrea* sp., *Arca noe, Glycimeris* sp., *Patella ferruginea*, etc.). This sedimentary body, dipping 10° seaward, rise upward for a few meters along the slope. It is completely capped by Upper Pleistocene aeolian quartz-sandstones which deep below sea level. In this site the geometrical relationships between these deposits can be observed in a three-dimensional view. In fact, it is possible to observe the marine deposits underlying the aeolian sandstones through several joints expanded by marine erosion (Fig. 3). Northward, in the direction of Tharros (Figs.1-2), a peculiar beach deposit has been found. This 50 cm-thick layer is made of medium to coarse-grained, well cemented sandstone, rich in *Mytilus galloprovincialis* and other bivalves (Fig. 4)**.** This marine deposit is very similar to that described by Lecca et al. (2007) and by Andreucci et al. (2009) in the Sinis Peninsula, about 1 km away. In this site a planar bedded sandstone overlying the *Mytilus galloprovincialis* layer has been dated using OSL method, providing an age of 120 ± 10 ka (Andreucci et al., 2009).

During the field survey it was noteworthy the finding of one whole specimen of *Cladocora caespitosa* at about 2.5 m above sea level. This fossil has been collected from marine Quaternary deposits unconformably lying on the bedrock with an articulated erosional surface. The specimen not reworked and well preserved has been considered suitable for an isotopic dating according to the U/Th method.

4. U/TH DATING

Corals are considered excellent samples to be dated with U-series disequilibria methods because in most cases they consist of pure calcium carbonate, free from a detrital component that makes problematic the dating of dirty carbonates.

The $^{230}Th/^{234}U$ method is the most widely used dating technique applied to corals and is based on the extreme fractionation of the parent isotopes ^{238}U and ^{234}U from their long-lived daughter ^{230}Th in the hydrosphere. Uranium, markedly more soluble than Th in the surface and near-surface environments, is readily mobilised as the highly soluble uranyl ion (UO_2^{2+}) and its complexes, whereas Th is easily hydrolyzed and precipitated or adsorbed on detrital particles. Uranium is co-precipitated with $CaCO_3$ on exsolution of CO_2,

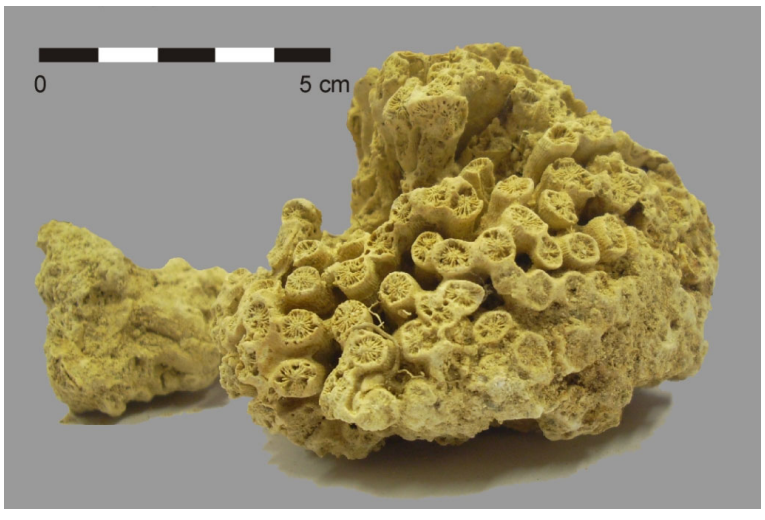

Fig. 5 - The specimen of *Cladocora caespitosa* which has been dated using U/Th method.

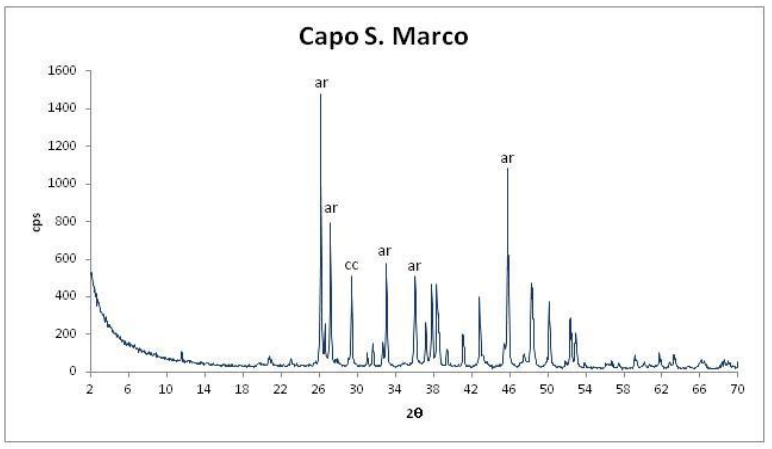

Fig. 6 - Diffractogram showing the aragonitic (ar) nature of the coral with moderate calcite amount (cc) and detrital fraction: quartz , halite gypsum.

while Th is generally negligible. In the absence of detrital Th, ^{230}Th only forms in situ by radioactive decay of co-precipitated U. In a closed system the extent to which the ^{230}Th/^{234}U activity ratio has returned towards unity is a function of time, taking into account also the state of disequilibrium between ^{234}U and ^{238}U (Kaufman & Broecker, 1965). Moreover, it is important to verify the original aragonitic nature of the coral and check the eventual presence of calcite. The occurrence of relevant calcite indicate that weathering processes have affected the coral after its burial, with consequent opening of the chemical system. In this case, semi-quantitative X-ray diffractometry analysis has evidenced the aragonitic nature of the coral with the presence of moderate calcite amount (Fig. 6) that can be estimated around approximately 10%.

About 3 g of coral were ultrasonically washed in deionized water and dissolved in nitric acid. Few milliliters of hydrogen peroxide were added and heated at 100 °C in order to destroy organic matter. Isotopic complexes of uranium and thorium were extracted according to the procedure described in Edwards et al. (1986) and alpha-counted using high resolution ion implanted Ortec silicon surface barrier detectors. The age, 70 ± 4 ka, was calculated by means of Isoplot/Ex (version 3·0), a plotting and regression program designed by Ludwig (2003) for radiogenic-isotope data. U-series data are reported in Table I. Errors are quoted as 1σ.

^{230}Th/^{232}Th activity ratio, higher than 50, indicates that the coral does not contain a significant detrital fraction. Furthermore, the uranium content, about 3 ppm, approaches the average value of uranium abundance in corals and the initial ^{234}U/^{238}U activity ratio (^{234}U/^{238}Ui) of the carbonate correspond to that of the marine water. These three data are an evidence of the good quality of the obtained age.

5. CONCLUSIONS

The U/Th dating on a sample of *Cladocora caespitosa* has provided an age of 70 ± 4 ka B.P. The specimen of *Cladocora caespitosa*, not reworked and well preserved, was sampled at about 2.5 m above sea level within the marine Quaternary deposits, overlying the Miocene-Pliocene bedrock, along the eastern coast of the Capo San Marco Promontory.

The diffractometric analysis showed the sample is mainly composed by aragonite. For the U/Th dating must be taken into account the occurrence of the calcite which could cause the rejuvenation of the samples. In this case study, considering the modest quantities of calcite, the age of 70 ± 4 ka B.P. represents the minimum age of the sample.

Based on these considerations and with reference to the isotopic curve related to the last 300 ka (Martinson et al., 1987) the examined sample can be located at the end of the Isotopic Stage 5 even assuming the rejuvenation of the sample for the presence of moderate calcite amount (Fig. 6).

This finding agrees with the results reported in Dorale et al. (2010) and Tuccimei et al. (2010), inferred from phreatic overgrowths on speleothems in coastal caves of Mallorca (Balearic Islands - Spain). These Authors assert that the western Mediterranean relative sea level stood at about 1m above present sea level during marine Isotope Stage (MIS) 5a, between ~ 82 and 80 ka ago. Furthermore, the data of Mallorca coastal caves, show good coherence with those observed from Tuccimei et al. (2012) in the Capo Caccia area (north-western Sardinia), located not far from Capo S. Marco.

The U/Th dating of *Cladocora caespitosa* allows to state that the marine deposits outcropping along the eastern coast of the Capo San Marco Promontory are not Holocene in age, as reported in the documents and maps up to now realized for the 528 Oristano Geological Sheet, still in progress.

REFERENCES

AIQUA (2007) - Notizie d'interesse. Il Quaternario, 20 (1), 85.

Andreucci S., Pascucci V., Murray A.S., Clemmensen L.B (2009) - Late Pleistocene coastal evolution of San Giovanni di Sinis, west Sardinia (Western Mediterranean). Sedimentary Geology, 216, 104-116.

Bartolini C., Bonfiglio L., Carrara C.,Carraro F., Ciaranfi N., Girotti O., Vai G. (2008) - Commenti e Repliche. Il Quaternario, 21 (1B), 375-376.

Beccaluva L., Civetta L., Macciotta G.P., Ricci C.A. (1985) - Geochronology in Sardinia: results and problems. Rend. Soc. It. Min. Petr., 40, 57-72.

Carboni S., Lecca L. (1985) - Osservazioni sul Pleistocene medio-superiore della penisola del Sinis (Sardegna occidentale). Boll. Soc. Geol. It., 104, 459-477.

Catto N. (2010) - Geomorphology, stratigraphy and facies analysis of some Late Pleistocene and Holocene key deposits along the coast of Sardinia (Italy)," and "Geochronology for some key sites along the coast of Sardinia (Italy)": A note from the Editor-in-Chief. Quaternary International, 222, 17-18.

Cherchi A., Marini A., Murru M., Robba E. (1978) - Stra-

tigrafia e paleoecologia del Miocene superiore della penisola del Sinis (Sardegna occidentale). Riv. It. Paleont. Strat., 84(4), 973-1036.

Coltorti M., Melis E., Patta D. (2010) - Geomorphology, stratigraphy and facies analysis of some Late Pleistocene and Holocene key deposits along the coast of Sardinia (Italy). Quaternary International, 222, 19-35.

Davaud E., Kindler P., Martini R., Strasser A. (1991) - Enregistrement des variations eustatiques dans des dépôts littoraux du Pleistocéne supérieur San Giovanni di Sinis (Sardaigne occidentale). Bull. Soc. Géol. Fr., 162, 523-533.

Dorale J.A., Onac B.P., Fornós J.J., Ginés J., Ginés A., Tuccimei P., Peate D.W. (2010) - Sea-Level Highstand 81,000 Years Ago in Mallorca. Science, 327, 860-863.

Edwards R.L. (1988) - High precision thorium-230 ages of corals and the timing of sea level fluctuation in the Late Quaternary. Ph.D. Thesis, California Institute of Technology, Pasadena California, USA.

Edwards R.L.,Chen, J.H., Wasseburg G.J. (1986) - ^{238}U-^{234}U- ^{230Th}-^{232}Th systematics and the precise measurement of time over the past 500 000 years. Earth Planet. Sci. Lett. 81, 175-192.

Forti S., Orrù P. (1995) - Geomorfologia costiera e sottomarina della Penisola del Sinis (Sardegna occidentale). Boll. Soc. Geol. It., 114, 3-21.

Kaufman A, Broecker W.S. (1965) - Comparison of 230Th and 14C ages of carbonate materials from Lakes Lahantan and Bonneville. Journal of Geophysical Research 70, 4039-4054.

Kindler P., Davaud E., Strasser A. (1997) - Tyrrhenian coastal deposits from Sardinia (Italy): a petrographic record of high sea levels and shifting climate belts during the last interglacial (isotopic stage 5e). Pal. Pal. Pal., 133, 1-25.

Lecca L., Carboni S. (2007) - The Tyrrhenian section of San Giovanni di Sinis (Sardaigne): stratigraphic record of an irregular single high stand. Riv. It. Paleont. Strat., 113(3): 509-523.

Ludwig K.R. (2003). - Using Isoplot/Ex, Version 3. A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Ctr. Spec., Pub. 4.

Maxia C, Pecorini G. (1968) - Il Quaternario della Sardegna. Atti X° Congresso Internazionale di Studi Sardi, 247-266.

Melis R.T., Palombo M.R., Mussi M. (2001) - Mammuthus lamarmorae (Major, 1883) remains in the pre-Tyrrhenian deposits of S. Giovanni di Sinis (Western Sardinaia, Italy). In: G. Cavaretta, P. Gioia, M. Mussi & M.R. Palombo (Eds.). "The World of Elephants", pubbl. CNR, Roma, 2001, 481-485.

Martinson D.G., Pisias N.G., Hays, J.D., Imbrie, J.D., Moore T.C., Shackleton N.J. (1987) - Age Dating and the Orbital Theory of the Ice Ages: Development of a High-Resolution 0 to 300,000-year Chronostratigraphy. Quaternary Research, 27, 1-29.

Regione Autonoma della Sardegna (1989) - Carta Geologica d'Italia alla scala 1:100.000: Fogli 216-217 "Capo S. Marco – Oristano".

Spano C. (1989) - Macrofauna circalitorale del Pliocene inferiore di capo S. Marco (Sardegna Occidentale). Riv. It. Paleont. Strat., 95(2), 137-172.

Thiel C., Coltorti M., Tsukamoto S., Frechen M. (2010) - Geochronology for some key sites along the coast of Sardinia (Italy). Quaternary International, 222, 36-47.

Tuccimei P., Onac B.P., Dorale J.A., Fornós J.J., Ginés J., Ginés À., Spada G., Ruggieri G., Mucedda M. (2012) - Decoding Last Interglacial sea-level variations in the Western Mediterranean using speleothem encrustations from coastal caves in Mallorca and Sardinia: A field data - model comparison. Quaternary International. doi: 10.1016/j. quaint 2011.10.032, article in press

Tuccimei, P., Soligo, M., Ginés, J., Ginés, A., Fornós, J., Kramers, J., Villa, I.G. (2010) - Constraining Holocene sea levels using U-Th ages of phreatic overgrowths on speleothems from coastal caves in Mallorca (Western Mediterranean). Earth Surface Processes and Landforms 35 (7), 782-790.

Ulzega A., Ozer A., Lecca L., Leone F., Pecorini G. Spano C., Cordy M.J. (1982) - Comptes-rendus de l'excursion-tablr ronde sur le Tyrrhenien de Sardaigne. Cagliari 21-28 avril 1980/ INQUA (livret-Guide), 88 pp.

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