STABLE OR MOBILE SEA-LEVEL, STABLE OR MOBILE SARDINIA DURING THE HOLOCENE: EVIDENCE FROM THE CAGLIARI GULF

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1. INTRODUCTION

The new Sheet "557" Cagliari (CARG Project) produced a map of the Quaternary Syntems, however the results of the new radiometric datings were not exhaustive and sometimes contradictory. The groups working on continental and marine areas reached different conclusions on the chronology of the deposits: some coastal deposits have been included in the subsynthem of Cala Mosca (Tyrrhenian) although we should refer them to the Holocene. However, the distribution of the Tyrrhenian deposits was reduced and the Is Arenas beach ridge grouped within the Holocene. We report the elements supporting a Holocene age for the coastal deposits.

2. GEOLOGICAL SETTING

The Campidano is a Plio-Pleistocene NNW-SSE oriented subsiding basin. Early Pliocene marine sediments crop out on the western side at Capo Frasca and Capo S.Marco up to 50 m asl. Early Pliocene sediments with *Globorotalia margaritae*, *puncticulata* and *crassaformis* have been found at depth in the Cagliari Gulf (Murru, 1983) and in the Oristano 1 and 2 boreholes (-727 and -666 m respectively; (Pomesano-Cherchi, 1971) (Fig.1a). In the Oristano 1, these sediments are covered with basalts, similar to those dated at 3 Ma in the Sinis Peninsula. They are in turn overlaid by continental deposits suggesting a great mobility of the Campidano. Along the Cagliari coast, NNE-SSE normal faults, that in the nearby Villacidro Sheet cut Late Pleistocene alluvial fan deposits, drove the river network.

3. LITHO-, MORPHO-, BIO- AND PEDO-STRATIGRAPHIC CHARACTERISTICS

The quaternary deposits have been subdivided into the Late Pleistocene Porto Vesme Sinthem (PVM), comprising the Cala Mosca (PVM1; "Tyrrhenian" *Auct.*) and the Portoscuso Subsynthem (PVM2a), and the Holocene Sinthem. The PVM2a consists of gravelly alluvial fans, up to ca 10 m in thickness, that are truncated by marine cliffs and river incision. The top of the Late Pleistocene Rio Corongiu terraced alluvial fan, to the east of the Poetto beach, is preserved for ca 10 km from the apical zone (205 m), to the rear of the coastline (m. 28). Soil with well developed argillic horizons and with profiles A-Bt-C, A-Btc-C and A-Btg-Cg (Typic, Ultic e Aquic Paleoxeralf, APAT, 2005) are locally preserved. The argillic horizons in places overlie carbonate-rich horizons but the latter develop also on top of the argillic horizons (A-Bt-Ck e A-Btk-Ckm, Calcic and Petrocalcic Paleoxeralf). These are Early Holocene soils because their degree of weathering is not comparable with the Last Interglacial soils of the Apennines (Coltorti & Pieruccini, 2005). The PVM1, crop out only at Cala Mosca (Capo S.Elia), that is the type locality of the "Tyrrhenian", the penultimate high standing marine stage (Issel, 1914; Spano, 1980; Ulzega *et alii*, 1982) and at Marina Piccola (Fig.1a). A few decimetres of gravels and bioclastic sands, including *Strombus bubonius*, lay unconformably on a rocky marine platform whose elevation varies from ca + 1 m to + 4 m asl. They are sealed with over 7 m of debris and aeolian sands. At Cala Mosca, these sediments are also found inside a coastal cave with mussel boreholes up to 3.8 m asl.

The Holocene deposits that after the recommendations of geologists dealing with the marine areas, have been mapped as "Tyrrhenian" in age, crop out at Sa Illetta and at Foxi (Fig. 2). At Sa Illetta sands and calcarenites constitute the remains of an inner beach ridge up to ca. 1,5 m asl while at Foxi they crop out along the beach. Molluscs are typical of coastal and lagoon environments. Small colonies of *Cladocora coespitosa* in living position are present in both sites.

Incised into the Pleistocene terraced deposits, there is a Holocene alluvial gravelly terrace locally containing polmonates and thin buried soil (A1C or A1Ck profile). It is cut by a coastal cliff sealed with alluvial or beach deposits. Nowadays, most rivers are bordered by artificial levees but in the past they had a braided pattern associated with a high solid load due to accelerated slope erosion. Laterally, they interlayer with alluvial fan deposits. Prior to this braided pattern, air-photos reveal that meanders occupied the plain. Close to the coastline the Riu Corongiu create a small fan delta whilst the Flumini Mannu generated cuspidate deltas inside the S.Gilla lagoon. In the Quartu bay the rivers enter the Molentargius swamp, originated by the Is Arenas beach ridge made with even laminated sands and gravels up to ca. 5 m asl,. Organic lagoon mud has recently been dredged at a depth of 8 m. We recognised only present-day mollusc fauna but Ulzega *et alii* (1982) mention the presence of *Strombus bubonius*, although it is possible that it was reworked from older layers.

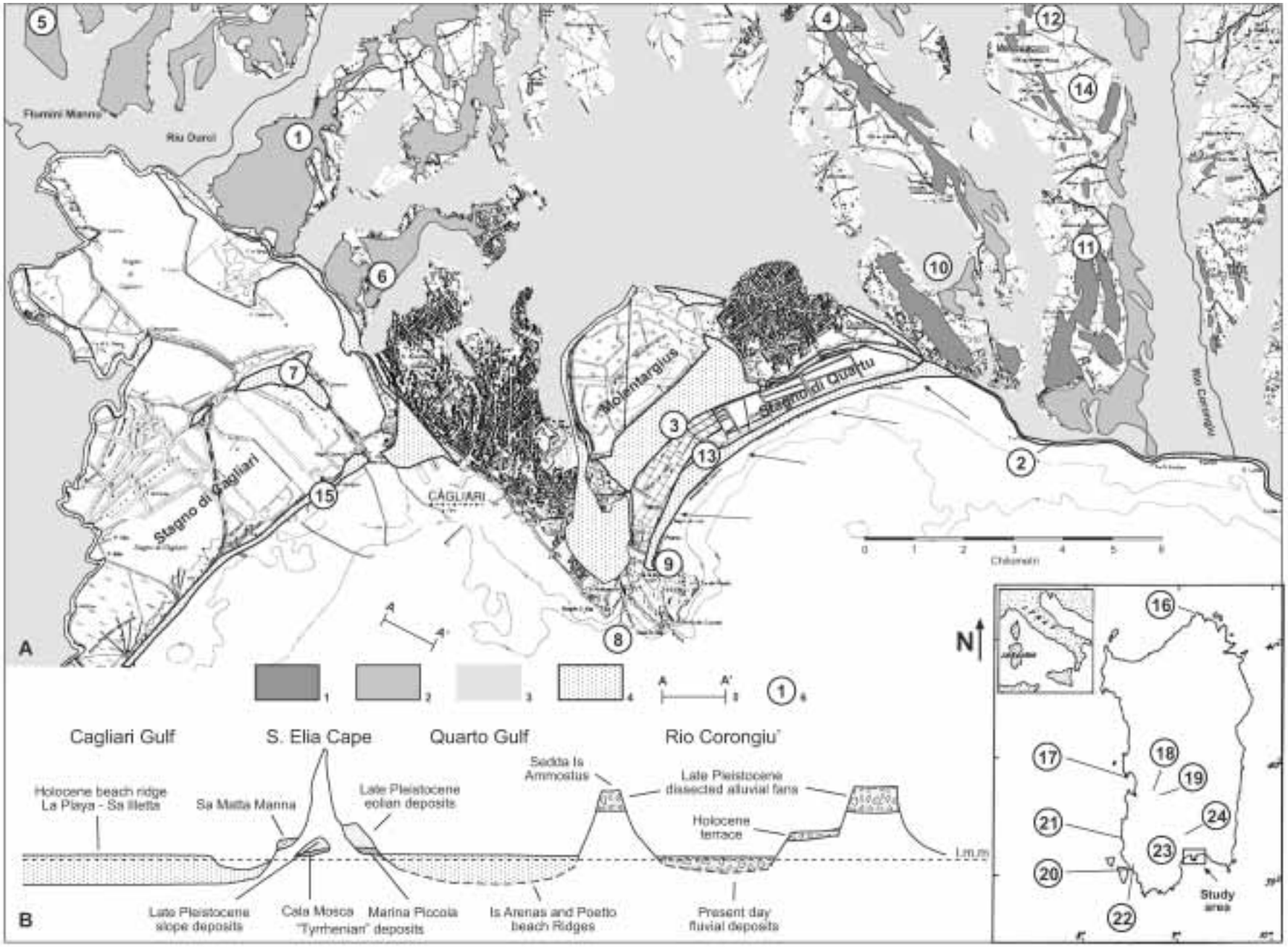

Fig.1a - *Sketch map of the sinthems of the Cagliari Sheet; 1. Late Pleistocene terraced alluvial fan; 2. Holocene terraced alluvial plain; 3. Holocene alluvial deposits; 4. Holocene beach deposits; 5. location of the seismic profile of fig.2; 6. main sites in the text: 1. S.Lorenzo; 2. Foxi; 3. Is Arenas; 4.Pran'e Silli; 5. Sa Manna Matta (not in the map but reported in the closer area over the same unit); 6. S.Michele Cemetery; 7. Sa Illetta; 8. Cala Mosca; 9. Marina Piccola; 10. Stagno di Simbirizzi; 11. Sedda is Ammostus; 12, Prani 'e Silli; 13. Poetto; 14; Arcu Maini; 15, La Playa; 16. Santa Reparata: 17. Cala Spinosa; 18. Capo S.Marco; 19; Capo Frasca; 20 S.Antioco; 21. Porto Vesme; 22. Matzaccara; 23. Cixerri Basin; 24. Samassi; B, Stratigraphic relationship between the different sinthems.*

4. CHRONOSTRATIGRAPHIC DATA

A new U/Th dating on *Cladocora* found in Cala Mosca gave 122,11+5,3/-5,01 ka (EM-216-6375) but the low isotopic $230^{Th}/232^{Th}$ratio suggests contamination. A date of 138 ± 8 ka was obtained by HEARTHY *et alii* (1986) but the sample had a percentage of calcite exceeding 9%. When calcite exceeds 5%, the $230^{Th}/234^{U}$ratio or the $230^{Th}/238^{U}$ratio ratio are not measured, samples have to be rejected (KAUFFMANN, 1986). BELLUOMINI *et alii* (1986) utilising the isoleucine epimerization, report an age of over 250 ka. HEARTY *et alii* (1986) utilises the ratio between *Arca/Glicimeris*, because the results from a single species are unreliable. The Last Interglacial shells would have a ratio close to 1,31 but at Cala Mosca it varies between 1,37 (lower part) and 0,86 (top). However, this method is unreliable because the decaying ratio varies with the temperature (MCCARROLL, 2002; WALKER, 2005).

The chronology of the PVM2a fluvial deposits is based on a date of 34.810 + 2880/-2120 BP (AMS-KIA24070) of organic material found 10 m below terraced alluvial fan gravels at Samassi. The Holocene terraced deposits have been dated at Sa Matta Manna. Polmonate shells found in silty layers in the lower part of the sequence gave 8.680 ± 60 BP (AMS, Beta-150624). In the S.Lorenzo area and at S.Michele Cemetery (Fig.1a) rolled fragments of pottery testify that the incision occurred after the Early Neolithic. At Foxi the whole rock dating of calcarenites gave 23.140 ± 90 BP (Beta-138678) while a U/Th of corals gave 53,3 +0,8/-0,7 ka (EM-130-6376). At Sa Illetta, a sample of

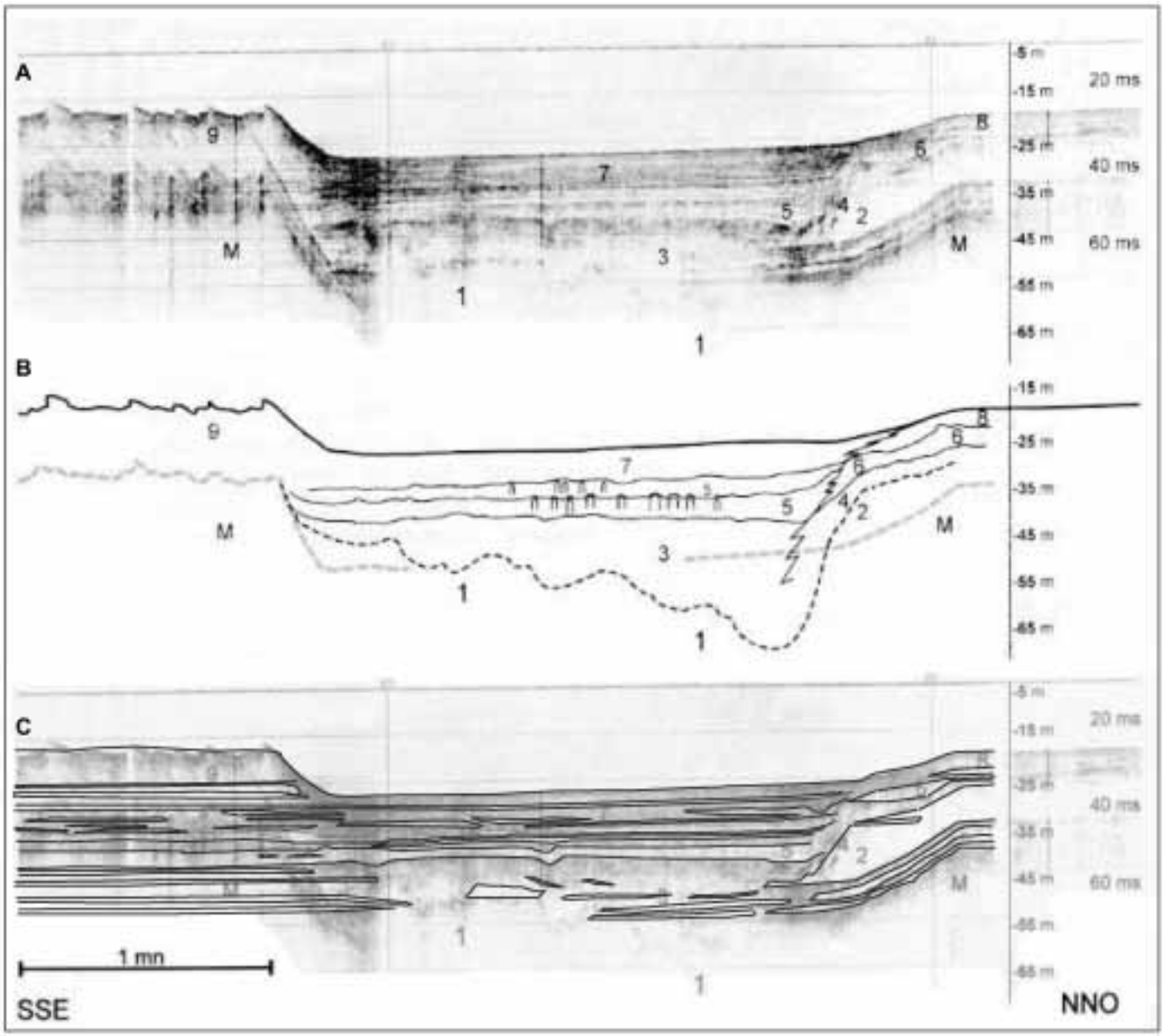

Fig. 2 - *The seismic profile (A) located to the south of La Playa beach ridge (Fig.1) used by* ORRÙ et al. *(2004) to establish an unconformity between Holocene and Tyrrhenian deposits (B). Interlayering is evident in our interpretation (C).*

shell was dated at 40.420 ± 1.120 BP (AMS, Beta-138680) while the whole rock was 18.880 ± 50 BP (AMS, Beta-138675). ULZEGA & HEARTHY (1986) also obtained an unreliable U/Th dating of *Cladocora* of 149 ± 10 ka because stratigraphy, calcite content and isotopic ratios are unknown. At Is Arenas a sample of shells was dated at 26.740 ± 360 BP (AMS, Beta-138676). Isoleucine epimerization allowed BELLUOMINI *et alii* (1986) and HEARTHY *et alii* (1986) to attribute the deposits to the Neo-Tyrrhenian. ULZEGA & HEARTHY (1986) report corals, never published in a comprehensive way, coming from the Poetto and La Playa beaches, dated respectively at 6,5 and 7 ka. Holocene datings also come from marine shells found in the clay filling in front of the Cagliari port (ORRÙ *et alii*, 2004).

5. DISCUSSION AND CONCLUSIONS

Cala Mosca and Marina Piccola constitute the older units cropping out below debris and aeolian deposits (Fig.1b). Terraced Late Pleistocene alluvial fans are the older deposits inland. Their incision was filled with alluvial deposits later incised and filled with the actual fluvial sediments. The latter unit shows a transition to coastal deposits subdivided into a number of beach ridges and lagoon deposits similar to the Adriatic (COLTORTI, 1997) and Tyrrhenian coasts (BOSCHIAN *et al*., 2006). The reliability of radiometric dates of organic matter and polmonates in Late Pleistocene and Holocene alluvial deposits is confirmed by the rolled pottery. The dating of the shell remains at Sa Illetta, Is Arenas and Foxi is evidently unreliable. These are Holocene beach ridges lying at the base of marine and fluvial escarpments that affect the Late Pleistocene terraced deposits (Fig.1b). Aeolian deposits or paleosoils are absent. Shells found in lagoon deposits at + 6 m asl at the Vascone site (Matzaccara, Carbonia Sheet) dated to 36.220 ± 730 B.P. (Beta-138698) but at the same layer with a few pieces of rolled pottery confirm a systematic error for these Holocene deposits. The older ages of the shells could be due to the hard water effect or diagenetic processes. Also the marine deposits of Santa Reparata (Fig.1a), attributed to Last Interglacial with isoleucine epimerization (ULZEGA & HEARTHY, 1986), are Holocene in age. In fact, they overlie (and not underlie) aeolian deposits that in the nearby Cala Spinosa contain polmonate shells dated to 20.010 ± 60 BP (AMS; Beta 138687). The Sa Illetta and Is Arenas beach ridges were attributed to the "Tyrrhenian" also because, following an eustatic model, a series of deep narrow valleys would have cut the "Tyrrhenian" deposits during the Last Glaciation. However, a deposition dominated by climatic processes follows an eventual erosion as a consequence of sea level fall (PLINT *et al*., 1992) and seismic profiles demonstrated a strong sedimentation before 18 ka down to the shelf break (LECCA *et alii*, 1998). In particular Is Arenas beach ridge completely dams the valley and if it is Tyrrhenian in age, no later erosion and limited sedimentation occurred in the basin. The erosional valleys that in the model of PECORINI (1986) and ORRÙ *et alii* (2004) were carved during the cold period in our idea were modelled during the Late Glacial/Early Holocene, after the reduction of the solid load resulting from reforestation while the sea level was still low. This is confirmed by the Holocene age of the valley filling and by the interlayering visible in our reinterpretation of the Orrù's seismic profile (Fig. 2). Barrier beaches are the result of long-shore drifting of river sediments after Neolithic soil erosion.

The high elevations of the Sa Illetta and Is Arenas coastal deposits was also used to support a "Tyrrhenian age because Holocene storm deposits are not expected above 4 m asl (ISSEL, 1914; ULZEGA *et alii*, 1982). However, elevation must not aprioristically represent a proof. If elevation and not stratigraphy should be the criteria, new discoveries are impossible. Stratigraphy suggests that the Holocene sea-level rose higher than the present day and/or that some parts of Sardinia are affected by positive tectonic movements. Sardegna is considered a stable region but the geological setting and the faults cutting the Late Pleistocene deposits suggest otherwise. The "Tyrrhenian" tidal notches in the Orosei Gulf (CAROBENE & PASINI (1973) also demonstrated differential uplift. Moreover, if the dating of *Cladocora* found at the sea level and dated ca 7 ka at La Playa and Poetto (ULZEGA & HEARTHY (1986) are reliable they confirm a higher sea level during the Early Holocene or tectonic movements. In fact, today *Cladocora* grow between 4 and 10 m bsl. If the Holocene sea level never exceeded the present day one (LAMBECK *et alii*, 2004) the Cagliari area is affected by uplift. However, it is our opinion that the curve of the Holocene sea level rise is still far from resolved.

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