Scientific Report on the COST-STSM-ES0701-6735

The mission took place, as scheduled, between 29 July and 8 August 2010. The aim of the STMS was to study sea level indicators in Cyclades (Aegean sea) wider area. The idea of the STSM came from the discovery by the Host, in April 2010, of submerged notches corresponding to former shorelines along the coast of the island of Naxos, indicating rapid subsidence movements probably of co-seismic origin. The initial idea of the STSM was to extend the investigation to other islands around Naxos in an attempt to delimit the wider area affected by the tectonic movements.

During the first three days of the mission, however, wind was strong enough to make the access to the coast of the Cyclades Islands difficult and risky. An alternative programme to study sea-level indicators in the Gulf of Corinth was therefore organized by using a car and a boat provided by the Host. This made possible on 30 July, on the south coast of the Gulf, a comparison between Lechaion [west harbour of ancient Corinth, excavated in a marshy area around 600 BC (Stiros et al. 1996), where an uplift of ca. 1.2 m occurred between 500 and 200 BC (Stiros and Pirazzoli, 1998)] and the beginning of the Diolkos, which appears capped by slightly emerged beachrock slabs (Fig. 1).

Fig. 1. Undated beachrock slabs capping displaced slabs at the beginning of the Diolkos.

The date of construction of the Diolkos is not known (Werner, 1997). Its initial part was probably situated in a bay (to make access by boats possible) and was partly submerged (to make the loading up of boats and their transportation easier). The uplift indicated by the beachrock is about the same that can be estimated at Lechaion. Because the beachrock is developed above some Diolkos stones, it may be assumed that a displacement of beach sediments occurred in the bay of access to the Diolkos, with partial accumulation and beachrock formation also above part of the Diolkos construction. Finally, between 500 and 200 BC, both the base of the Diolkos and the beachrock capping it were affected by about 1-m uplift.

Contrary to the south coast of the Gulf of Corinth, which has been uplifting during the Quaternary, the northern coast is considered to be subsiding, though subsidence rates generally remain to be determined. During our underwater observations of the northern coast of the Corinth gulf, submerged notches were measured and photographed at various depths.

The meteorological conditions having improved at the end of July, it became possible to move to the Cyclades and carry out underwater observations between 2 and 7 August. The

coasts of the following islands could be visited in detail: Koufonissia, Keros, Iraklia, Paros, Antiparos, together with other minor islets (Fig. 1).

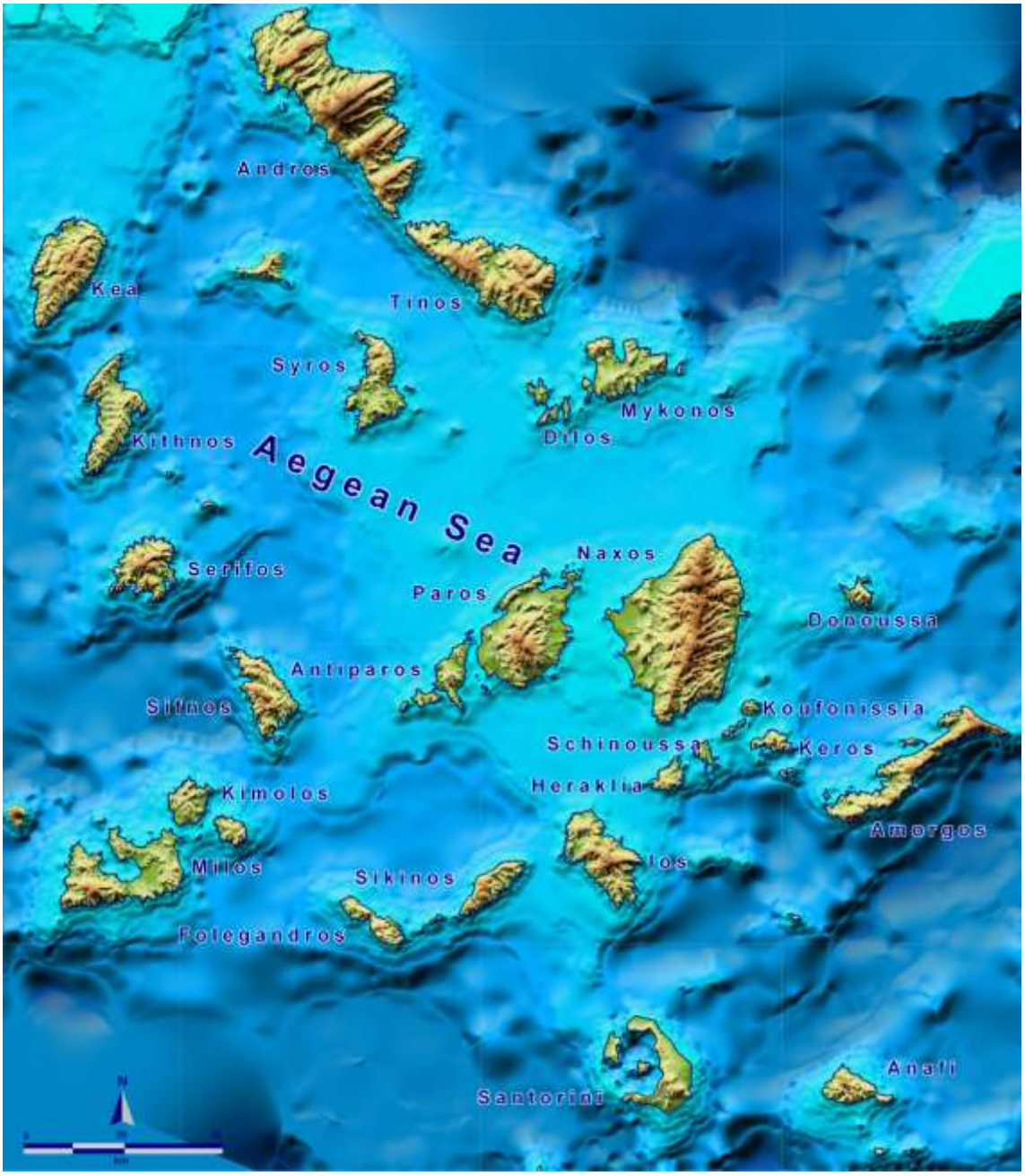

Fig. 1. The Cyclades area

Boat facilities provided by the Municipalities of Koufunissia, Iraklia and Paros have been essential for the success of our survey. It has been also possible to complete at Site 13 in Naxos the survey already carried out in last April by the Host in this island and to check the possibilities of survey in Mykonos, Dilos and Rhinia.

Though underwater observations were carried out at many sites, marks of submerged shorelines could be identified only when the rock was not too stratified and favourable to bioerosion in the midlittoral zone, which is submerged at regular intervals by waves and tides. In this vertical zone (very narrow in the Mediterranean), parallel vegetational belts are more developed. Eroding Cyanobacteria, patellaceous gastropods (limpets) and chitons are more

abundant (Laborel and Laborel-Deguen, 2005). They all contribute, by eating the vegetational belts, to erode the underlying rock and make possible the development (in sites sheltered from wave action) of a reclined U-shaped or V-shaped intertidal notch, with a vertex located near MSL, the base of the notch near the lowest tide level and the top near the highest tide level (Pirazzoli, 1986). The profile of a tidal notch is an excellent sea-level indicator, because it provides qualitative information on the duration during which MSL remained at the level of the notch vertex and, if the notch is emerged or submerged, on the speed (slow, or even sudden) of its emergence or submergence (Pirazzoli, 2005). Carbonate rocks are generally favourable to the development and preservation of tidal notches, while gneisses, schists, amphibolites, terrestrial deposits and volcanic rocks are less affected by bioerosion. During our survey, we had therefore to take into account the local lithology of the Cyclades (Fig. 2).

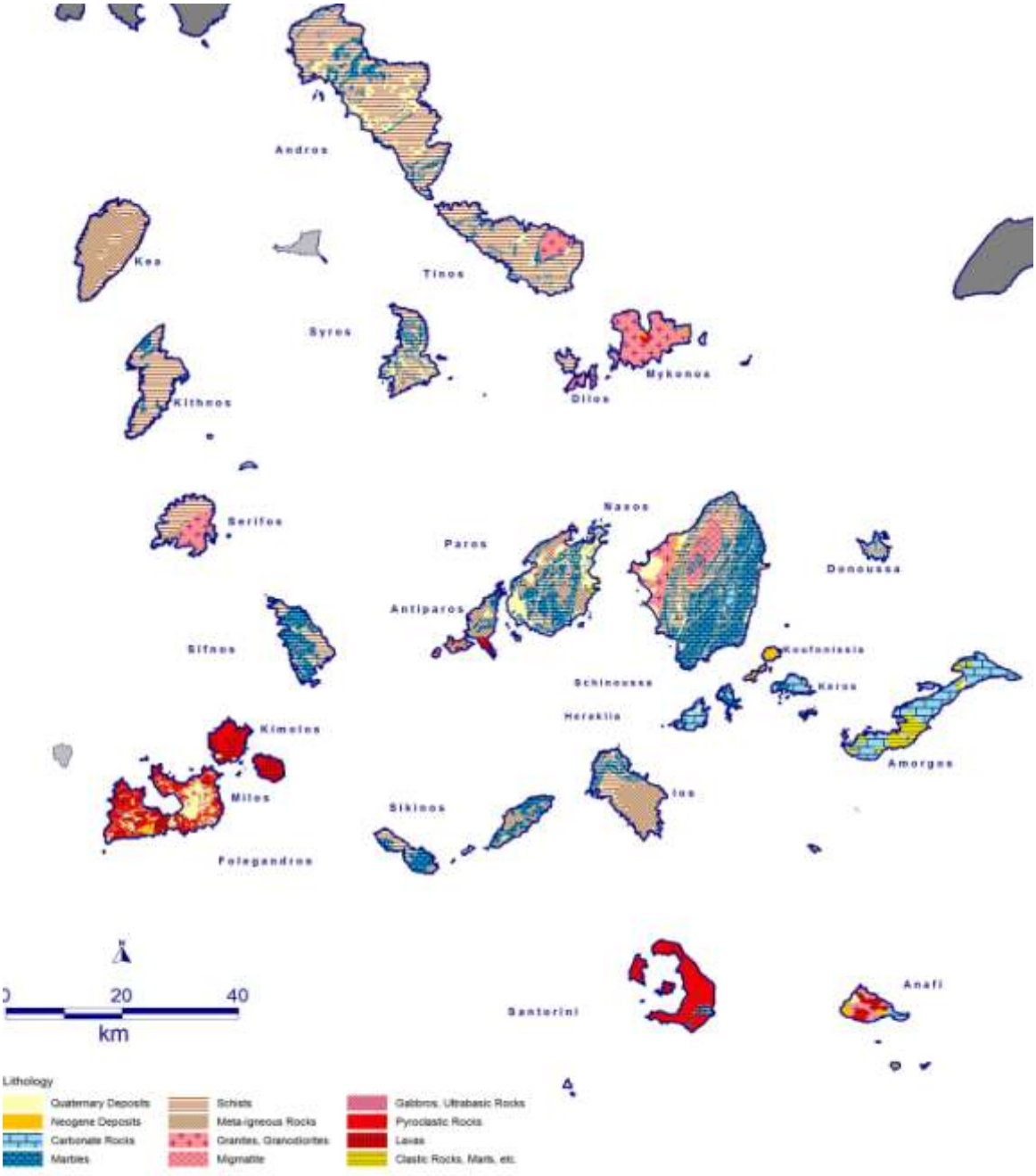

Fig. 2. Lithology of the Cyclades

Results

One dozen immersions were made along the northern coast of the Gulf of Corinth and 25 in the Cyclades (four in Kofounissia-Keros on 3 August, eight in Iraklia on 4 August, eight in Paros, four in Antiparos and one in Naxos (Site 13) on 5-6 August. In all the sites considered, no clear marks of a tidal notch were observed in the present intertidal zone. This suggests that all the area has been affected by a gradual subsidence or by relatively recent co-seismic subsidences. For each immersion, the time and the GPS coordinates were noted and, underwater, the observed features were measured in relation to sea level (with an accuracy that, due to waves, can be estimated at about ±10 cm) and photographed by the Host. For 20 of the 24 stations considered, one or two submerged notches were observed.

The vertex of the upper submerged notch is most often 30 to 40 (±10) cm below the present sea level, suggesting that it could have been submerged by a co-seismic subsidence movement of about the same amount. The horizontal depth the first notch profile varies between 5 and 28 cm (18 cm on average; this variability can be due, at least in part, to irregularities in the rock surface) and could correspond to an almost stable relative MSL lasting one or few centuries before the co-seismic event.

The shape of the second submerged notch is locally more variable, with an average depth of the retreat point (vertex) between 100 and 280 cm (185 cm on average), and its height may vary locally between 20 and 120 cm, suggesting that wave action or a gradual subsidence may have increased the height of the notch in some cases. As concerns the horizontal depth of its profile, between 15 and 60 cm (27 cm on average), it suggests the occurrence of an almost stable relative MSL at the level of the notch during at least a few centuries. Our survey was as accurate, systematic and detailed as possible at each site (see e.g. Fig. 3 and Table 1 for the observations made at the Site 2 of Iraklia). In total, about 600 photos have been taken.

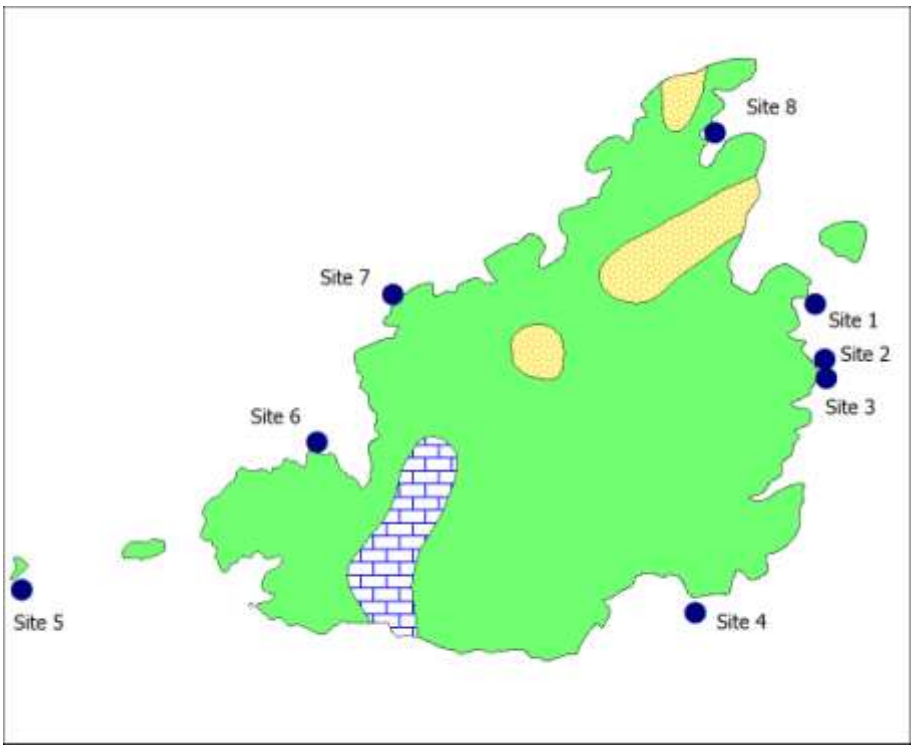

Fig. 3.Location map of the underwater observations made at Iraklia. Green colour = Alpine Paxi zone

Table 1. Underwater measurements made at the Site 2 of Iraklia.

Place Name: Site 2 Date: 04/08/2010 Time: 10:12-10:27 X=25,48 Y= 36,84515 Comments:	
Notch 1	Measurements
Roof depth from SL	20 cm
Retreatment point depth	5 cm
Height	15 cm

Notch 2	Measurements
Roof depth from SL	90 cm
Retreatment point depth	15 cm
Height	30 cm

Fig. 4. View of the two underwater notches (arrows) at the Site 2 of Iraklia. A Host assistant gives scale (photo N. Evelpidou).

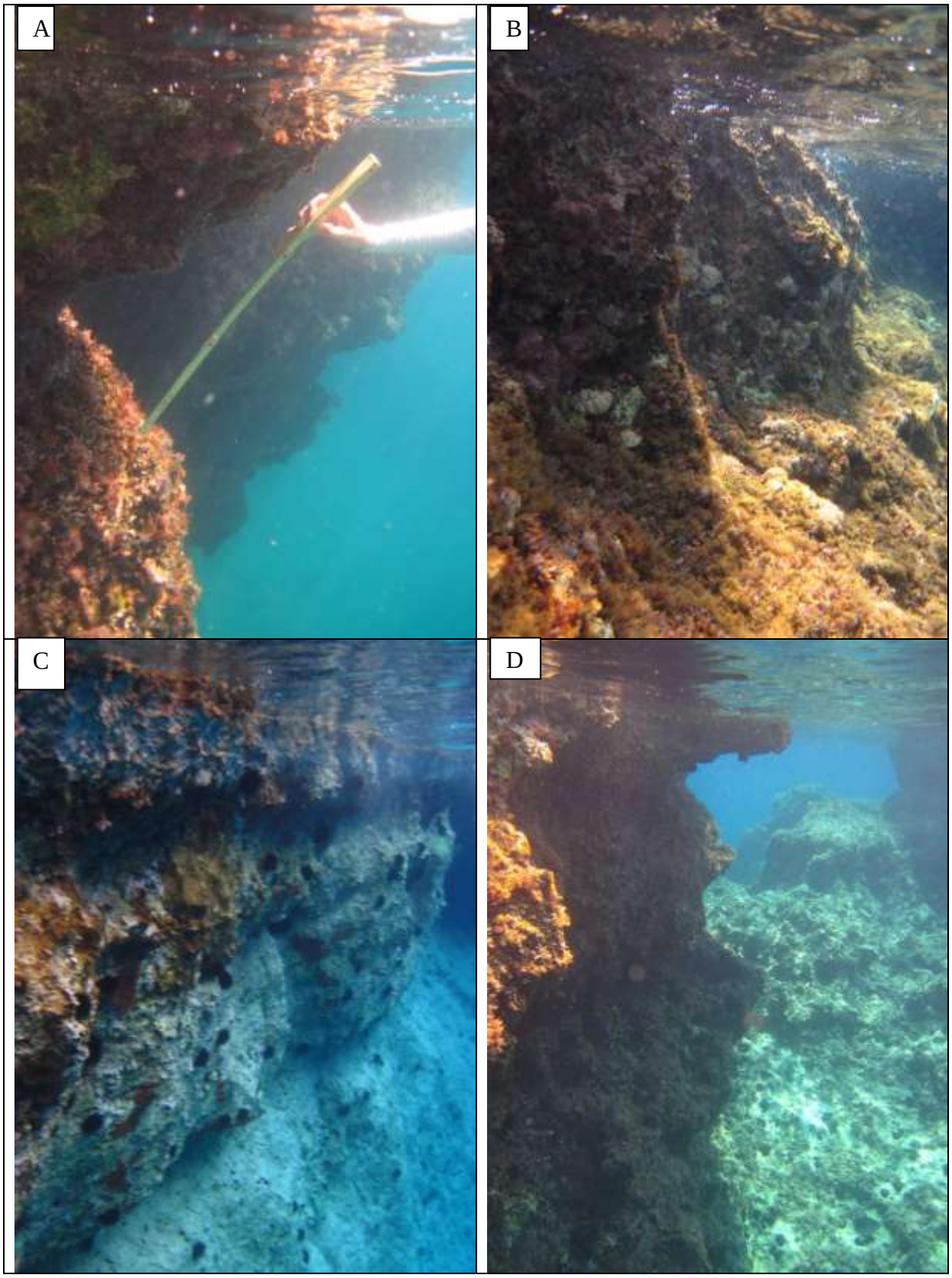

Fig. 5. Examples of underwater notches. A: measurement of the upper submerged notch at Paros (Site 2); B: the upper notch at Antiparos (Site 3); C: double notch at Keros; D: double (or even triple?) notch at Site 13 of Naxos (photos N. Evelpidou).

Conclusion

The STSM was a full success, both in the Gulf of Corinth and in the Cyclades, thanks to the excellent organization by the Host and in spite of difficulties created by unfavourable meteorological conditions and by strikes (e.g. of petrol stations) in Greece.

Future collaboration and foreseen publications to result from the STSM.

The alternative fieldwork carried out in the Gulf of Corinth during the first three days of the STMS seems worth of further developments for comparisons between indicators of former sea levels and archaeological remains, to attempt new estimates of subsiding rates along the north coast and of uplift in the Diolkos area.

In the Cyclades, a statistical comparison between the underwater profiles observed, their variable exposure to wave action and the local lithology (that can easily deduced from geological maps) will probably improve our understanding of the relationship between marine bioerosion and lithology and make easier the preparation of future fieldwork on sea-level indicators.

An extension of the area investigated to nearby islands (e.g. Amorgos, Ios, Skinos, Folegandros and Sifnos) would be useful in order to delimit the areas that have been affected by co-seismic subsidence movements. To date such movements, two ways seem worth being investigated:

i) historical accounts on past earthquakes, and
ii) results of borings in coastal sediments that could be of help in identifying and date periods of relative sea-level stability at depths corresponding to those of submerged notch levels.

Paolo Antonio Pirazzoli
Emeritus research director at the CNRS

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