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SURVEYING OF A SUBMERGED FLYSCH OUTCROP AT SISTIANA-DUINO (GULF OF TRIESTE, ITALY)

SUMMARY

Diving geologists surveyed an underwater Flysch outcrop in the northernmost sector of the Gulf of Trieste (Italy). From the Nannoplancton analysis, it results to be Upper Eocene (Lutetian) in age and it seems to be in stratigraphical continuity with Eocene beds of the carbonate sequence. The platform develops at a depth ranging from -1.5 m and -5.0 m and it is 170 m large and about 45 m wide. From a geomorphological point of view, the outcrop represents a relict shore platform due to late-Holocene sea level rise. The platform is interested by various morphologies, as differential erosion on fractures, joints and interbedded interstices and mushroom-like blocks .

RIASSUNTO

RILEVAMENTO DI UN AFFIORAMENTO SOMMERSO DI FLYSCH TRA SISTIANA E DUINO (GOLFO DI TRIESTE, ITALIA)

Vengono studiate le caratteristiche geologiche e geomorfologiche di un affioramento sommerso di flysch del Luteziano medio nel settore nord-orientale del Golfo di Trieste. L'affioramento si sviluppa alla base delle falesie di Sistiana-Duino su una larghezza complessiva di circa 170 m e una distanza verso il largo di circa 45 m, con una profondità variabile da circa -1.5 m a -5.0 m. Da un punto di vista geomorfologico, la struttura può essere considerata una shore platform relitta, interessata da morfologie di vario tipo, tra cui forme di erosione selettiva su fratture, giunti e spaziature d'interstrato e blocchi a fungo.

Introduction

Submarine geological and geomorphological surveying is very useful to study coastal landforms and to evaluate the coastal geohazards (erosion, recent tectonic movements, etc). Despite the importance of the subject, the great difficulty connected to the underwater environment often prevent the possibility of a widespread detailed mapping. The surveying of a submerged flysch outcrop provided interesting insights concerning both the geology and the geomorphological evolution of the coast. Furlani (2003a, 2003b) has provided data on the

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geomorphology of the submerged shore platforms located in the southern part of the Gulf of Trieste.

The main geological features of this sector have been described by D'Ambrosi (1948), Cucchi (1986) and Carulli, Cucchi (1991). Brambati, Catani (1988) have discussed the sedimentological and geotechnical properties of marine sediments in the Gulf of Trieste, while Giorgetti (1967) studied the coastal sediments between Miramare and Duino. However, despite a detailed mapping of the coastal area, no underwater investigations have been performed. Recently, the GeoCGT Project (1:10.000 maps), promoted by the Geological Survey of the Friuli Venezia Giulia Region (scientific responsible, Prof. Franco Cucchi) and the Interreg Project Italia-Slovenia allowed a detailed geological and geomorphological surveying of the Flysch in the Trieste area (Bensi *et al*., 2007, 2009).

This paper aims at providing the geological features of an underwater flysch outcrop discovered by Furlani (2005) at the plunging cliff foot between Sistiana and Duino (fig. 1).

Study area

Geological and geomorphological setting

The Trieste Karst area is characterised by the presence of a thick carbonate sequence (Trieste Karst Limestones Formation) spanning in time from lower Aptian p.p. to middle Cuisian and a turbiditic succession (Flysch of Trieste), dated back at Lutetian p.p.. From a structural point of view, two main patterns interest the Trieste Karst area: the Karst Thrust, developed in Dinaric direction (NW-SE), which forces limestones to overlie the turbidites, and some minor thrusts in the Flysch of Trieste. The contact between them is both tectonic and stratigraphic, depending on the site (Bensi *et al*., 2007, 2009, GeoCGT Project).

The sequence in the northern sector of the Gulf of Trieste is represented by Cretacic Limestones (Upper Cenomanian p.p. – Maastrichtian p.p.), Paleocenic Limestones (Danian – Thanetian p.p.) and Eocenic Limestones (Upper Thanetian – Ypresian) (Cucchi *et al*., 1987; GeoCGT Project).

The top of the carbonate sequence consists of a deepening-upward succession and it is connected to the deep-water marls unit laying at the bottom of the turbiditic sequence. The drowning sequence is composed by limestone marls couplets, organized in thickening and coarsening upward cycles with nodular structures and conglomeratic levels. These are characterized by monogenic rounded pebbles, with a caotic and not organized fabric. Pebbles are fed by the shallow water platform materials. They have been interpreted as diagenetic nodules reworked by resedimentation processes, probably triggered by tectonic movements (Burelli *et al.,* 2008a, 2008b). The contact between the carbonatic and the turbiditic sequences highlight a clear SE-NW tilting versus of the coast of Trieste, probably still active (Braitenberg *et al*., 2005).

The shoreline from Duino to Sistiana (fig. 1), is characterised by 70-meter-high limestone plunging cliffs. Their stratification varies from strongly inclined to sub-vertical, sometimes tending to capsizing. The southeastern shoreline of the Gulf, southwards from Sistiana, is characterized by Eocene marly-sandstone cliffs with small gravel-pebble beaches developed at their base (Brambati, Catani, 1988). Flysch was recognized at the Sistiana Harbour at about -0.5 m s.l.m. (pers. comm., geotechnical technician) and it represents the northernmost one in the Gulf of Trieste. Moreover, the turbiditic sequence was recognized below marine sediments. Morelli, Mosetti (1968), in fact, suggested the occurrence of submerged flysch terraces, inferred from geophysical surveyings, at depths ranging from -20 m to -200 m.

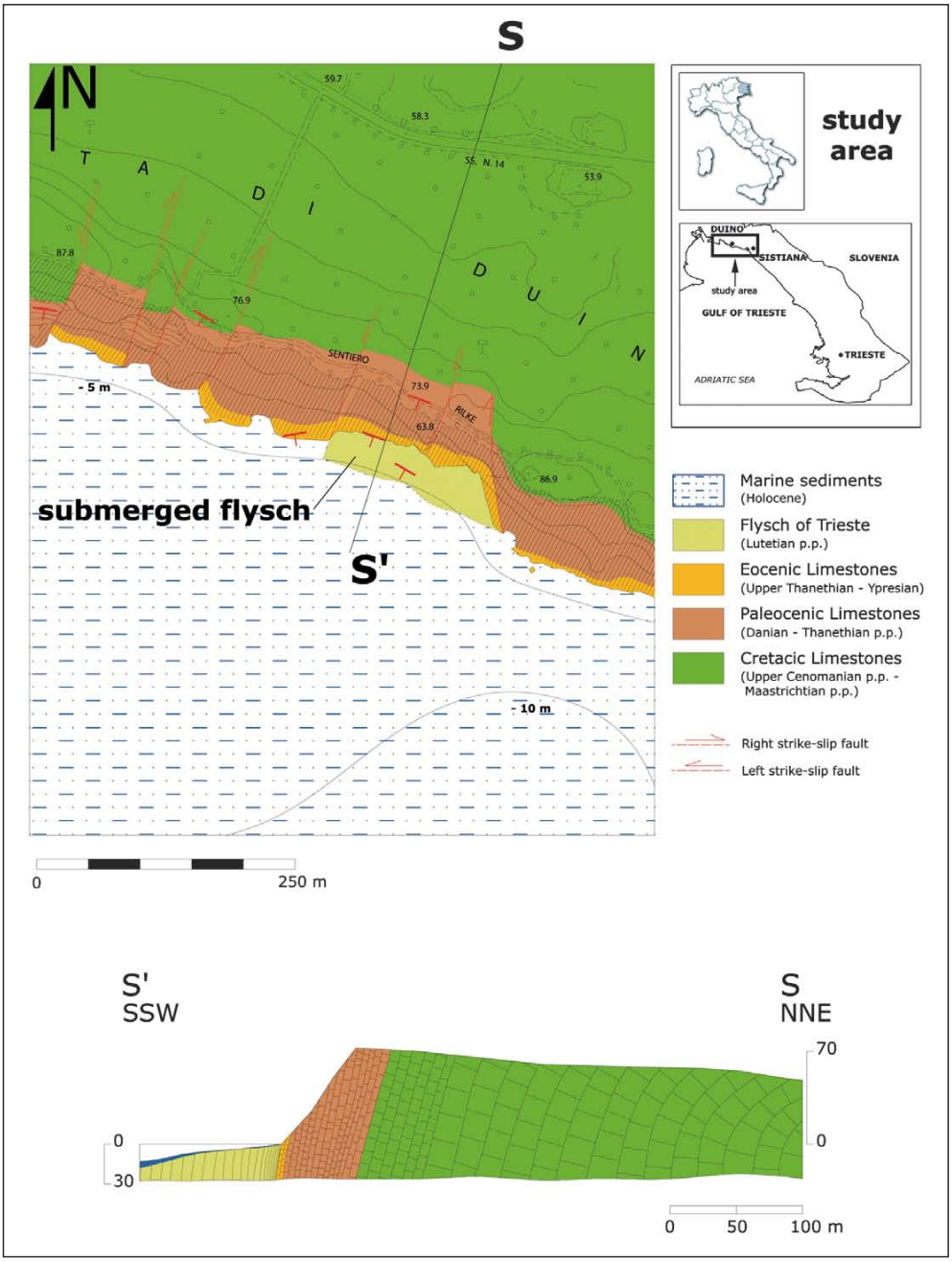

Fig. 1 - Geological sketch and section of the studied area. The geological map is redrawn and improved from the *"Carta di Sintesi geologica GEO-CGT, Foglio 109 – GRADO* (scientific responsible, F. Cucchi; coordinator, R. Marocco), *sezione 109040* (Quaternary series, R. Marocco, A. Fontana; carbonatic series, G. Tunis; structural geology, F. Fanucci; coast and offshore, S. Covelli, F. Fanucci, R. Marocco)".

Material and methods

The collection of submarine data (topographical surveying and photos) concerning the flysch outcrop was carried out by scuba divers (fig. 2a). The uncomfortable location of the outcrop has forced to use a boat as logistic support. Limestone samples have been collected using a geological hammer (fig. 2b, 2c). Measurements were collected using a ruler, while the depth was measured via an electronic scuba depth-meter and corrected with the Trieste tide gauge data, following Antonioli *et alii*. (2007). Sandstone and marlstone beddings were collected using an underwater clinometer (fig. 2d), on purpose made, and an underwater compass (fig. 2e). The rock identification has been carried out through thin sections in the Department of Geology in Trieste, while nannoplankton datings (on marls and silty marls) have been carried out by Prof. Jernej Pavšič of the University of Ljubljana following Pavšič, Peckmann (1996).

Results

Results of the surveying carried out on the plunging cliffs and the submarine flysch outcrop between Sistiana and Duino are discussed. Even if the underwater outcrop is very short in length, because of marine sediments covering, it represents an important geological datum to understand the geological and geomorphological evolution of the studied area.

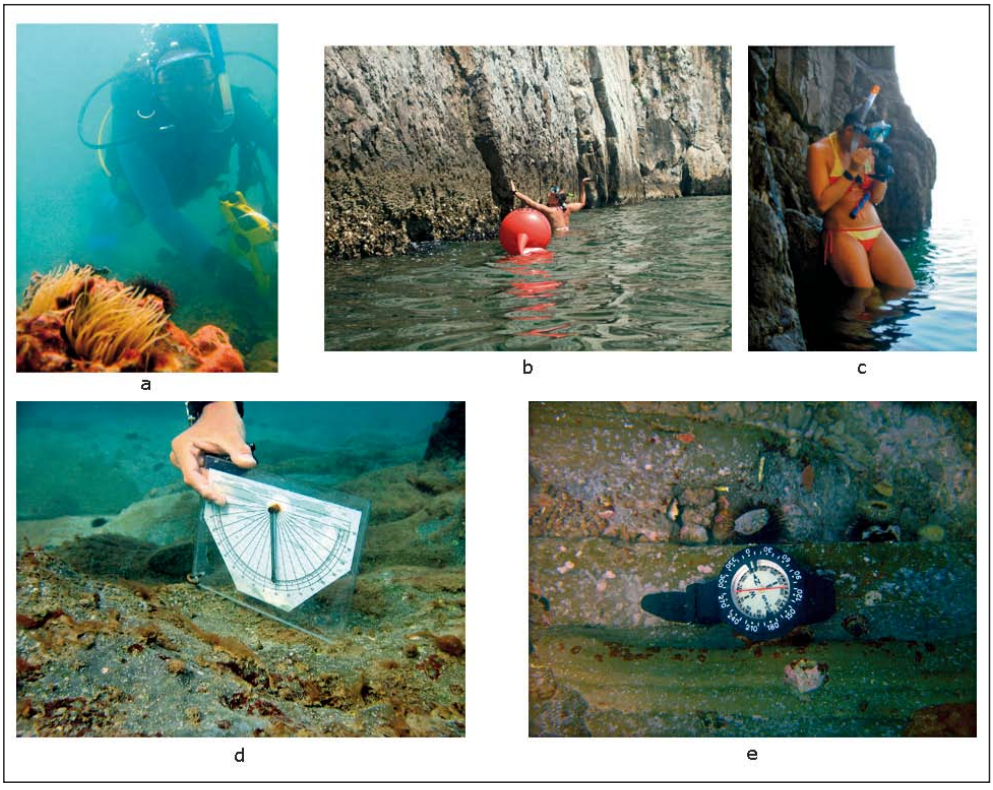

Fig. 2 - a) scuba diver next to the mushroom-like sandstone; b), c) geological surveying along the limestone plunging cliff; d) submarine clinometer; e) submarine compass.

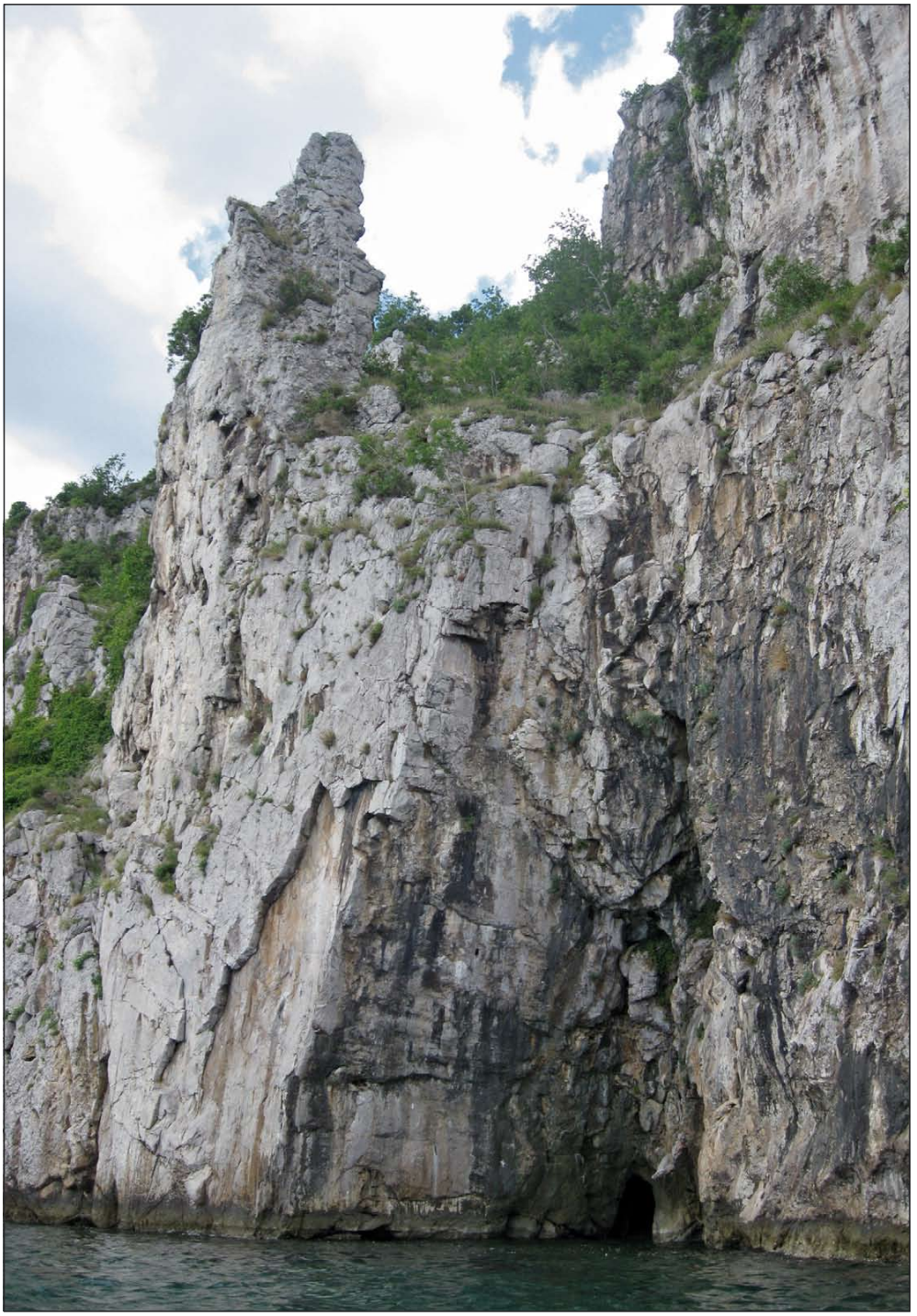

Fig. 3 - The limestone plunging cliffs behind the submerged sandstone outcrop.

The Sistiana-Duino cliffs are cut in cretacic, paleocenic and eocenic limestones. Vertical beds are parallel or sub-parallel to the shoreline and they dip 85° towards S. Cliffs are involved in several strike-slip faults with a dominant N-S direction (fig. 1). Along 170 meters of the cliff, limestone-marls couplets and nodules outcrop. As a matter of fact, only this narrow sector is composed by the top of the eocenic unit (fig. 3). At its base, a flysch outcrop occurs and it represents the only one in the coastal sector between Sistiana and Duino. The analysis of nannoplankton associations in the silty-marls terms suggested that samples belong to the NP16 biozone, upper Lutetian in age. The same biozone has been determined at the bottom of the turbiditic succession in other sites of the Trieste area (GeoCGT Project; Burelli *et al*, 2008a, 2008b).

The outcrop is located in a small embayment, about 200 m northward from the Sistiana Harbour. It is about 170 m long and 45 m wide. Its depth ranges from -1.5 m to -5.0 m. At the base of the cliff, 5 m wide area is covered by collapsed limestone blocks, metric in size, which partially hide the underlying flysch outcrop.

The outcrop is mainly composed by sandstones with millimetric or centimetric interbedded marlstones (T1 *sensu* Onofri, 1982). Sub-vertical sandstone beds range in thickness from 0.10 m (fig. 4a, 4b) to 0.8 m (fig. 4c). Sandstone layers are sometimes cut by joints, fractures and faults and sometimes they displace both the limestone cliff and the underlying flysch outcrop.

30 m offshore we observed a 1 m thick sandstone bed (fig. 4c). Its wide is 50 m. It is characterized by several mushroom-like morphologies (fig. 4d, 4e) and collapsed blocks (fig. 4f).

Discussion and conclusions

The shoreline of the northern part of the Gulf of Trieste is characterised by high resistant limestone plunging cliffs (Fig. 5). The cliff foot is covered by collapsed blocks and marine sediments and whereas the upper terms of the carbonate sequence outcrop, notably in correspondence to the nodular structures previously described, the contact occurs. The presence of the nodules, the marls age (upper Thanetian) and beds dipping suggest that the contact is a paraconformity.

Small vertical fractures both in the limestone cliffs and in the underlying flysch platform have been surveyed, suggesting that tectonic structures that involve the limestone cliffs persist inside the underwater sandstone beds. The surveyed faults and fractures belong to the N-S system that was already recognized both in the carbonate sequence and inside some caves in the Classical Karst (Zini, 2002).

In this sector of the Gulf of Trieste, the Karst Thrust is supposed to be buried and to involve the Flysch.

From a geomorphological point of view, the flysch outcrop represents a shore platform Type B *sensu* Sunamura (1992). Its width (45 m) is relatively short because subvertical bedding prevents platform widening for long time steps (Trenhaile, 1987). Moreover, the presence of limestone cliffs at the back, much more resistant than flysch, brakes cliff recession. In the southern part of the Gulf of Trieste recent and relict platforms are wider because sandstone layers are sub-horizontal and cliffs are cut in flysch (Furlani, 2003a). Even the rapid late-Holocene relative sea level rise (Antonioli *et al.,* 2004, 2007) has influenced the widening of the platform, in fact, since these morphologies develop in the intertidal zone, the submerged platform can be considered a relict one.

The platform is mainly constituted by decimetric sandstone beds and interbedded centimetric marlstones, the latter are partially covered by marine sediments. The overall morphology shows sandstone beds relieved from the marlstones due to differential erosion. Actually,

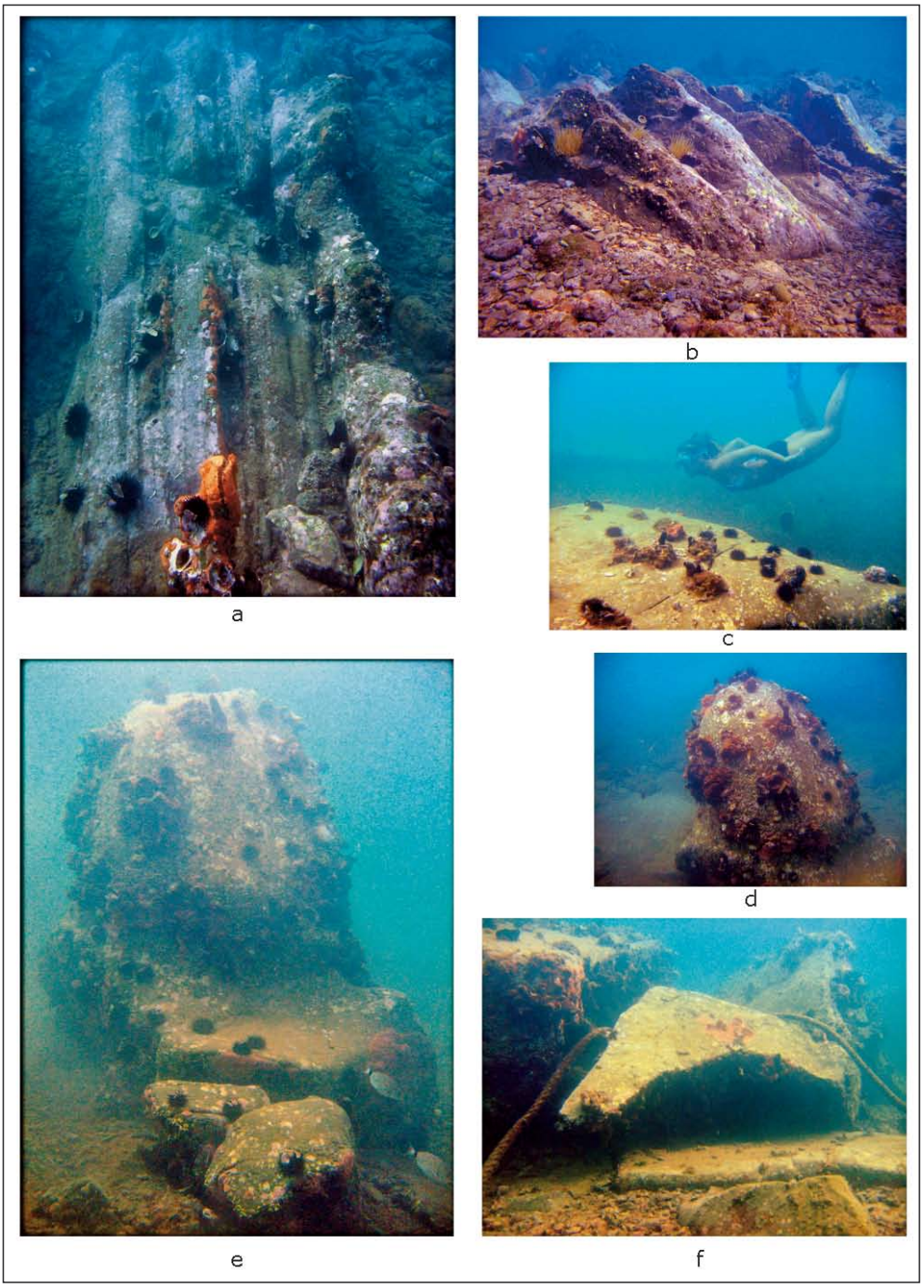

Fig. 4 - Flysch beds on the submerged platform: a), b) underwater sandstones and marlstones; c) sandstone beds on the submerged platform; d), e) mushroom-like sandstone blocks; f) sandstone blocks on the platform.

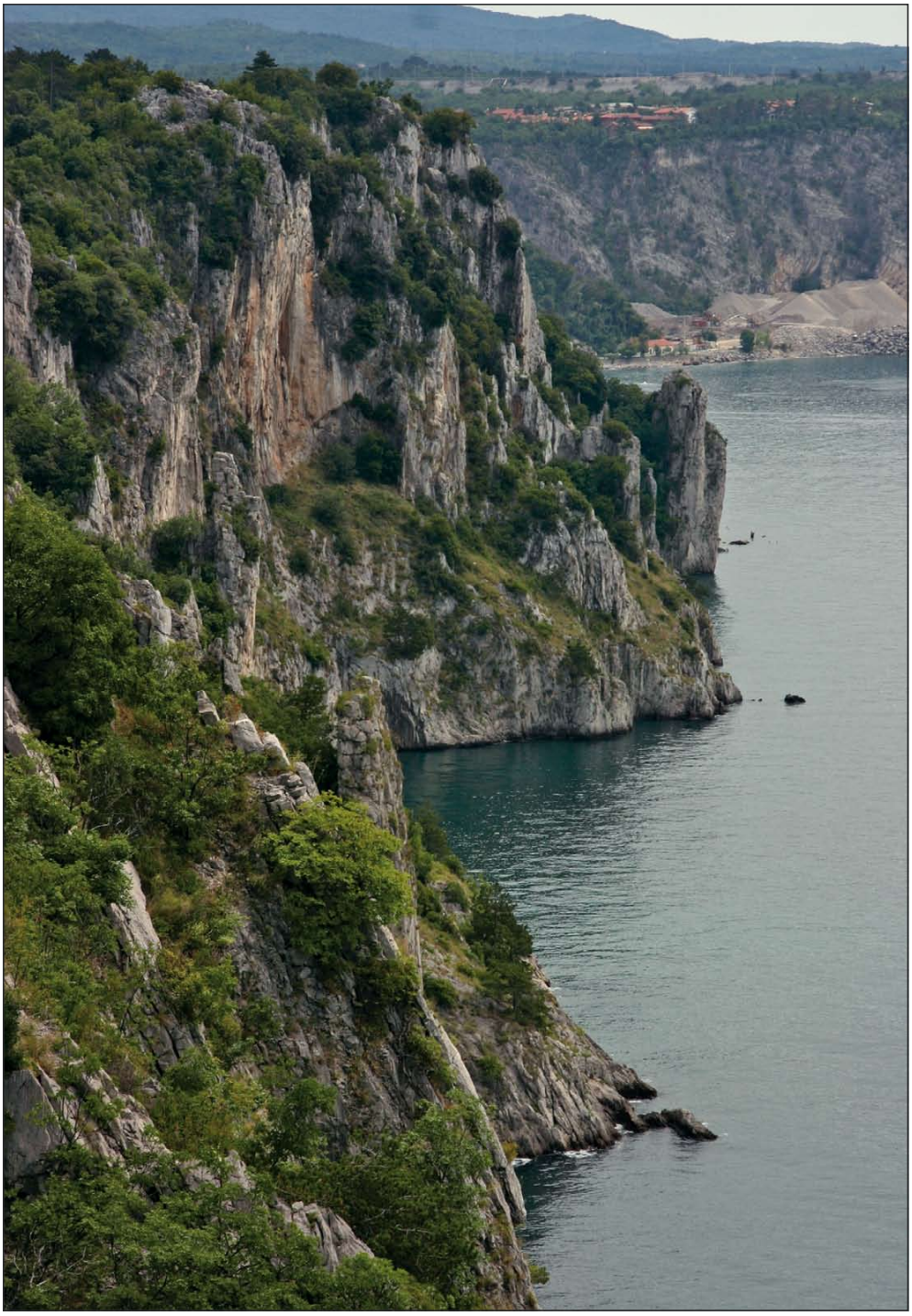

Fig. 5 - The small embayment in which the submerged flysch outcrops.

the assessed predominance of sandstones rather than marlstones provides further resistance to overall denudation. 30 m offshore a large sandstone bed, 0.5 m higher from the platform, forms a wall-like morphology (fig. 4c-f). Its genesis probably comes from differential sandstone weathering at the level of former platform horizons. Sandstones, as previously suggested, are more resistant to weathering and form reliefs (fig. 4c-e).

Further detailed subaerial and underwater measurements, perhaps well-supported by geophysical surveyings, are requested.

Acknowledgements

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